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Permo-Carboniferous volcanism of the Kraków region

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VENTS 4

Permo-Carboniferous volcanism of the Kraków region

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Ar-Ar and SHRIMP constraints on the age of Late Palaeozoic intermediate and silicic dykes and sills in the Sudetes

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The widespread late Palaeozoic volcanic and subvolcanic rocks of the Sudetes, in the eastern part of the Variscan Belt of Europe, have been very sparsely dated using isotopic methods. The sequence and timing of the Carboniferous-Permian volcanic events are, therefore, based largely on geological evidence. Recently, a dating programme has been initiated, and selected results are summarized in Table 1. Ar-Ar dating was carried out at Universität Potsdam, Germany, and SHRIMP dating at VSEGEI, St. Petersburg, Russia.

Table 1. Selected results of Ar-Ar and SHRIMP dating of late Palaeozoic subvolcanic rocks of the Sudetes.

SAMPLE		METHOD	AGE, Ma
Location	Rock dated		
Karkonosze Massif, Bukowiec; dykes in granites	micromonzodiorite	SHRIMP; Zrn	318±3[a]
	richterite minette	Ar-Ar; Phl	299±0.5[b]
Intra-Sudetic Basin, Stare Bogaczowice; sill in conglomerates	rhyodacite	SHRIMP; Zrn	306.1±2.8[c]
Orlica-Śnieżnik Massif, Gniewoszów; dykes in gneisses	richterite minette	Ar-Ar; Phl	329±0.6[b]
	richterite minette	Ar-Ar; Am	329±0.7[b]

Am – amphibole, Phl – phlogopite, Zrn – zircon. Age: for SHRIMP – ^{206}Pb-^{238}U age of the main zircon population; for Ar-Ar – plateau age. Sources of data: a – Awdankiewicz et al. (2009): Geological Magazine, in press; b – Awdankiewicz and Timmerman, unpublished; c – Kryza and Awdankiewicz, unpublished.

Dating of the richterite minette and micromonzodiorite dykes suggest that mafic hypabyssal magmatism in the Sudetes occurred in the Carboniferous. Samples from the Orlica-Śnieżnik Massif yield significantly older ages than those from the Karkonosze Massif. The difference between SHRIMP and Ar-Ar results from the Karkonosze Massif reflects either a prolonged period of the mafic magmatism or different stages of cooling of the dykes. The rhyodacite from the Intra-Sudetic Basin has so far been interpreted as an Early Carboniferous lava. The SHRIMP results force a re-interpretation of this rhyodacite sheet as a Late Carbonifeorus intrusion, which suggests that volcanic activity in the Intra-Sudetic Basin started later than previously believed.

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Structure, textures, petrography and mineral chemistry of the Wielisławka rhyolites (Permian), the North-Sudetic Basin

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The Wielisławka Rhyolites represent a part of the Permian volcanic sequence of the North-Sudetic Basin (e.g. Zimmermann, Kühn 1918; Awdankiewicz 2006). The NE-aligned outcrop of the rhyolites, ca. 0.4 x 1.2 km in size, is largely set within crystalline basement rocks of the Świerzawa Horst, but to the west interdigitates with Permian sedimentary rocks of the Świerzawa Graben. An old quarry (protected as a nature reserve due to perfectly developed joints and known as the "Organy Wielisławskie") exposes a ca. 35 m high section through the rhyolites. In the quarry, flow foliation defines a concentric structure ca. 100 m wide, with the axis dipping gently (0-35º) to the NE-E. Small flow folds and lineation show a similar but locally variable alignment. The columnar joints are perpendicular or oblique relative to the flow foliation planes. Southerly dipping, moderately inclined columns (30-65º) predominate but a fan-like pattern converging towards the axis of the structure is recognized. The inner part of the structure is more chaotic, with less clear relationships between flow foliation and joints.

The rhyolites from the quarry typically contain up to ca 35% phenocrysts (< 4 mm in size) of quartz, Na-K feldspar (Or_{72} at cores to Or_{99} at rims), albite pseudomorphs after plagioclase, and biotite (Mg/Mg+Fe ≈ 0.4) strongly replaced by chlorite (close to diabantite in composition). Quartz phenocrysts are rounded and embayed, with small apatite inclusions. The laminated, felsitic and haematite-rich groundmass is mainly composed of anhedral quartz and alkali feldspars. Two types of laminae are distinguished: the predominant set is lighter and contains aligned quartz streaks, the subordinate set is haematite-rich without distinctive quartz. Indistinct spheroidal textures are developed locally. Nearly aphanitic rhyolites occur near the top of Wielisławka Hill.

The described section of the rhyolites may represent a gently inclined plug or an inner part of a lava dome. Consistent with this, the groundmass textures of the rhyolites suggest rather slow cooling and crystallization of the rhyolite magma. Flow banding and variable phenocryst contents may suggest extrusion and mingling of compositionally heterogeneous magma batches. However, the structure characterized above is a relatively small part of a larger, poorly recognized outcrop which remains to be studied in more detail.

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New data on the structure, emplacement mode and post-magmatic alteration of the Grzędy trachyandesites (Lower Permian), the Intra-Sudetic Basin

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The Permian trachyandesite sheet exposed at Grzędy quarry in the central part of the Intra-Sudetic Basin is interpreted as a lava flow erupted from a multi-vent volcanic centre and emplaced into an adjacent basin filled with lacustrine-alluvial sediments (Awdankiewicz 1999). A hydrothermal explosion crater and numerous clastic dykes transecting the sheet originated due to lava-wet sediment interactions at the base of the 70 m thick flow and were exceptionally well exposed in the big quarry. Continuous quarrying of the trachyandesites over the last 10 years destroyed many of the previously exposed structures, but has also revealed new features. Subvertical clastic dykes grade downwards into a few metres thick, gently inclined sediment zones separating lensoid trachyandesite masses. The top contact of the trachyandesites with the overlying fine-grained clastic rocks is conformable, the trachyandesites are non-brecciated apart from small peperitic domains and the overlying rocks are partly silicified; these features are indicative of an intrusive emplacement of the trachyandesite sheet. The previous and new observations suggest that the trachyandesite was erupted as a lava flow but, during emplacement, graded into an invasive flow which burrowed into the underlying clastic sediments in the form of a few lensoidal sheets.

The Grzędy trachyandesites show strong post-magmatic alteration. Albitisation of plagioclase and replacement of mafic minerals by chlorite and secondary amphiboles were reported in earlier studies, whereas Awdankiewicz (1999) considered albite, chlorite, carbonates and quartz to be the dominant alteration-related minerals Post-magmatic mineralization is best developed in the upper, flow-banded section of the trachyandesite sheet. There, alternating massive and amygdaloidal bands are locally cut by various veins. The amygdales are up to ca. 15 cm in size. Within amygdales and veins the post-magmatic minerals form massive or drusy fillings. Haematite-coated carbonate crystals attain 1 cm in size. Quartz and amethyst are also common. Citrine, quartz pseudomorphs after calcite, barite crystals and barite "roses" have also been reported (Lis, Sylwestrzak, 1986; Janusz Zajdel, pers. comm.). The origin and conditions of formation of this mineralization (e.g., strictly post-magmatic or partly diagenetic?) are poorly constrained.

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Geometric modeling of intermediate subvolcanic bodies in the Late Paleozoic Halle Volcanic Complex, Germany

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We have used data from ca 1200 coal and uranium exploration wells (up to 1000 m depth) for the geometric modelling of intermediate subvolcanic bodies that form part of the Halle Volcanic Complex (HVC) in eastern Germany. The HVC is located in the northeastern Saale Basin, a NE-SW-trending Late Variscan intermontane basin controlled by transtension.

In this part of the Saale Basin, the transition from the Stefanian (Gzhelian) Wettin Subformation, dominated by fluvial to lacustrine sandy to pelitic sediments with coal seams, to the Rotliegend (Asselian) volcanosedimentary Halle Formation is marked by a prominent conglomerate. The so-called "Kieselschiefer-Quarzit-Konglomerat" (KQK), which interfingers with sandy beds, is characterized by gravel- to pebble-sized clasts of lydite, vein quartz, quartzite and palustrine to pedogenic carbonate. In the area under investigation, the KQK has a thickness of 20 to 70 m.

The HVC evolved during the deposition of the uppermost Wettin Subformation and of the Halle Formation (Breitkreuz, Ehling, in press). The HVC formed from hybrid magmas with a subduction fingerprint (Romer et al. 2001). It comprises a voluminous (ca 200 km^2) porphyritic rhyolitic complex ('Halle-type laccolith complex'; Breitkreuz, Mock 2004, Mock et al. 2005) and a smaller intermediate subvolcanic complex (ISC) precursory to the former. Both complexes display a dominance of subvolcanic units over extrusive lava and pyroclastic deposits.

Siegert (1967) carefully combined well data with petrographic, geochemical and geophysical log information to delineate the extension (up to 10 km) and thickness (up to 250 m) of four ISC bodies in the area north of Halle. Romer et al. (2001) classified these rocks, which often show signs of magma mingling, as trachybasalts, trachyandesites and trachydacites. The aspect ratio (height / length) ranges between 0.02 and 0.15. In contrast to Siegert (1967) the following points suggest an intrusive nature for most ISC units: i) Although brecciated domains are known, a systematic zonation with base and top breccia and with a clastic apron around the bodies is lacking; ii) several wells exposed sedimentary rafts (pelitic, sandy and conglomeratic) within homogeneous subvolcanic bodies, iii) more than 20 wells show magmatic bodies with KQK conglomerates at the base and the top suggesting an intrusion into the then unconsolidated coarse clastic unit; iv) host sedimentary rocks near the intrusions have been severely deformed and tilted in places.

In the geometric modelling we aimed at a visualization of the vertical and horizontal relations between the ISC bodies and in particular their spatial relation to the KQK, which apparently functioned as a preferred emplacement level for the intermediate magmas.

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Volcanic infilling of S part of the Altenberg-Teplice Caldera; ~700 m deep vertical profile through ignimbrites

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Upper Carboniferous acid volcanic rocks in S part of the large (35x18 km) Altenberg-Teplice Caldera (Westphalian C/D) are hidden beneath Tertiary (± Upper Cretaceous) sedimentary rocks. This study presents the major petrographical features and vertical chemical zoning in volcanic rocks from a deep borehole B (Le 127) S of Duchcov.

The great majority of samples are crystal-rich rhyolite to trachydacite ignimbrites that are strongly welded and completely devitrified. Their ignimbritic character is clear from the abundance of broken phenocrysts (quartz, K-feldspar, and plagioclase) and in most samples also, the presence of plastically deformed fiamme that are typically more coarsely devitrified than the surrounding matrix (Holub 1980). Compositional variations in the profile define four "units", each with SiO_2 contents systematically decreasing upwards.

The lower "unit" is extremely thick (almost 400 m without reaching the base) and may consist of numerous cooling units that are, however, unrecognizable in the profile. Silica contents in raw analyses decrease from about 72 wt.% in the lowermost sample to about 66 wt.% at the top of the "unit". The upper 200 m of the lower-unit ignimbrites are trachydacitic and contain pyroxenes; the uppermost 90 m have metaluminous composition (all other fresh acid ignimbrites are weakly peraluminous). Two co-existing clinopyroxenes were identified: ferropigeonite and ferroaugite. Phenocrysts in metaluminous ignimbrites are dominated by fresh plagioclase and K-feldspar whereas quartz phenocrysts are subordinate. Present are also pyroxene-plag ioclase glomerocrysts, ilmenite, titanomagnetite, apatite, and zircon microphenocrysts.

Ignimbrites of the whole profile are rich in relatively large (up to 6 mm) crystalloclasts whereas the sparse, several cm-sized silica-rich lava fragments are significantly lower in phenocrysts. Besides the common effect of partial loss of fine particles during eruptions, we have to consider mixing of material from the compositionally zoned active magma chamber with nearly crystalline granites from voluminous crystallization fronts. Although no mafic lava has been found in the caldera infilling, the eruptions could be triggered by invasion into the chamber of a hot, significantly more mafic magma.

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The geochemistry of volcaniclastic rocks associated with basaltic trachyandesites in the Nieporaz-Brodła graben near Kraków, Southern Poland

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The Late-Carboniferous/Early-Permian volcanic rocks of the Kraków area are found in the border zone of the Małopolska Block against the Upper Silesian Block. The rocks form a bimodal suite (basaltic trachyandesites and rhyodacites) and have high potassium contents (Czerny, Muszyński 1997). The mafic rocks form both small subvolcanic intrusions (Niedźwiedzia Góra, Wielkie Drogi, Zagacie) and lava flows (Rudno, Regulice, Alwernia, Mirów). The rocks are basaltic trachyandesites and high-K basaltic andesites, and represent a transitional calc-alkaline to alkaline suite. These geochemical features hold also for newly analysed samples of diabase from the Zagacie and Wielkie Drogi boreholes, which suggests they and Niedźwiedzia Góra are the feeder dykes of the Nieporaz-Brodła volcanic edifices. Thick basaltic trachyandesite aa lava flows are interbedded with volcaniclastic rocks of high silica content in the rhyodacite range. This difference in composition has been explained so far as a result either of the addition of terrigenous quartz-rich material to the mafic tephra (Siedlecki, Żabiński 1953) or of simultaneous volcanic activity of different composition leading to intercalated deposits of sialic (explosive) and mafic (effusive) volcanic rocks (Chocyk 1989; 1990). A characteristic feature of effusives is the common occurrence of interstitial glass. The glass fills spaces between the groundmass crystals indicating that it represents residual melt. Where preserved, the glass has high-K rhyolitic composition. Interestingly, its major element composition resembles that of the high-K rhyolitic tuff forming clastic dykes, the matrix of the conglomerates and intercalating lava flows suggesting an origin by magmatic differentiation. However, high incompatible element and low compatible element contents of the glass stays are opposite to their content in the volcaniclastics, which are in the range of basaltic trachyandesites and lamprophyres. This indicates a close genetic relationship between the basaltic trachyandesitic lava flows and volcaniclastics. The high-K and high-Si composition of the volcaniclastics results from a significant admixture of terrigenous minerals (white and dark mica, K-feldspar, alkali plagioclase and quartz). The composition of the tuff may be a result of a phreatomagmatic event, presumably initiating the scoria flows. The fine-grained material could then be incorporated into autoclastic breccias by the caterpillaring effect of the advancing aa lava flow.

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Permian hydrothermal karst in the Kraków region, Southern Poland

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The Dębnik Anticline in the Kraków region, Southern Poland, built of Middle Devonian to Early Carboniferous carbonates, hosts abundant and spacious karst forms filled with various sediments (Paszkowski, Wieczorek 1982). Karst development postdated the Permian (ca. 300 Ma) volcanic activity in the region. The major transcontinental strike and slip Hamburg-Kraków fault zone induced a series of minor, en echelon, extensional faults, which served as magma conduits and guided karst formation.

The karst forms in the Dębnik Anticline reach several to tens of meters in size. They are filled with: i) massive, subaqueous, coarse crystalline calcite spar; ii) crystalloclastic, bedded limestones; iii) jasper lenses; and iv) kaolinitised tuffs. The sediments show a red coloration caused by iron compounds, underwent synsedimentary deformation, which resulted in brecciation, and plastic deformation.

The presently exposed karst forms are fragments of an extensive circulation system, fed by waters of elevated temperature, rich in CO_2, which is proved by fluid inclusion analysis and stable isotope investigations. The origin of this system was related to volcanic activity. The roots of the system represented fissures filled with coarsely crystalline, red calcites common in the Dębnik Anticline. Water issuing on the surface caused precipitation of red travertines. These travertines are only preserved as clasts in the Lower Permian conglomerates deposited in the local tectonic depressions.

The Sivas region in central Turkey may serve as an atonalistic geotectonic counterpart of the Polish fossil system. There fissure-ridge travertines are associated with tectonic deformations resulting from NE–SW extension associated with a NW–SE compressional regime related to the Central Anatolian Thrust Belt (Mesci et al. 2008).

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Amphibole phenocrysts and their alteration in rhyodacitic porphyries from Zalas near Kraków

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Rhyodacitic porphyries of the Zalas laccolith have varied colours and degrees of consolidation, resulting from complex postmagmatic alteration. The alteration of hornblende phenocrysts, one of the main mafic minerals of the rhyodacite, has been studied since 2006. Samples from four basic varieties of porphyries, grey, green, red and whitish, were collected and supplemented by archive samples of the black variety, currently not exposed.

Analyses included optical and scanning electron microscopy (SEM) and energy and wave dispersive spectrometry (EDS, WDS) of the collected samples, and X-ray powder diffraction (XRPD) of the separated amphibole phenocrysts and the whole rocks.

In all porphyry varieties, euhedral prisms of amphiboles (up to 3-4 mm) are more or less altered, even fully pseudomorphed. They contain relicts of primary hornblende: edenite, edenitic-hornblende, ferroan pargasitic-hornblende, and inclusions of primary magmatic minerals: biotite, magnetite, ilmenite and apatite. Secondary minerals include: secondary amphiboles (at the margins of the primary hornblende), i.e., actinolite, actinolitic hornblende and magnesio-hornblende; aggregates of fine-crystalline orthopyroxene corresponding to enstatite (only in the black variety of the porphyries); small flakes of dark mica close to phlogopite developed at the margins of the phenocrysts (in all porphyry varieties); fine flakes of chlorites of the diabantite composition; and clay minerals, mainly mixed-layer Fe-smectite/celadonite, rarely pure celadonite. Calcite, quartz, Na-feldspar (albite, rarely oligoclase or andesine) and fine-crystalline magnetite and ilmenite complete the list of secondary minerals.

The alteration of the hornblende phenocrysts started at the magmatic stage from biotitization proceeding from the grain margins, and the development of orthopyroxenes (the latter in the black porphyries only; this process seems to be younger than biotitization). The post-magmatic processes are the second stage of alteration resulting in autometasomatic chloritization, which reaches its maximum development in the green porphyries. Smectitization, observed in both the red and mainly the whitish rock varieties, was associated with enrichment in potassium and adularization of the porphyries (Marszałek, Czerny 2009).

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Pulses of volcanic activity at Wołek Hill, Kaczawa Mountains – an example of multiphase volcanic events associated with an old tectonic dislocation

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Wołek Hill is an example of multiphase Permian and Neogene volcanic activity in a small area (less than 2 km^2). It is located in the Kaczawa Mountains, at the boundary between the Permo-Mesozoic Leszczyna Depression and the Paleozoic Różana Melange, which belongs to the Variscan basement of the North-Sudetic Basin. There are two second order dislocations in the close neighbourhood of Wołek Hill: the northern Świerzawa fault (SW) and the Muchów fault (NE). It is possible that there is one more hypothetic small fault in the Wołek Hill basement (Cymerman 2002).

Wołek Hill consists of three different types of volcanic rock associated with volcanic tuffs and breccias. The succession starts with three incomplete units of a Lower Permian lava flow. All these units occur only in an abandoned quarry on the south-eastern hill slopes. The rocks are basaltic andesites or trachyandesites (Jankowiak 2007). The second type are Permian acid rocks and tuffs which form a lava dome and pyroclastic flow deposits. Those rocks occupy more than 90% of the analyzed area, but there are only three outcrops where fresh material can be found. The acid rocks are rhyolites or rhyodacites (Nawrocka 2007). The third type is a small Neogene volcanic body, which occurs in the old quarry and its near neighborhood. Those youngest volcanic rocks are basanites (Napieralska 2007) and occupy less than 3% of the studied area (Jankowiak 2007; Nawrocka, 2007). All volcanic activity should be connected to the same tectonic activity in the Kaczawa Montains.

The main result of our work is a new geological map of Wołek Hill and adjacent area.

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Eruptive styles of monogenetic volcanism in the Levín Volcanic Complex – central part of the Krknoše Piedmont Basin (Rotliegend / Autunian)

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Various products of mafic monogenetic volcanism occur in the Levín Volcanic Complex (LVC) in the Permian intermontane Krkonoše Piedmont Basin. The total thickness of the Krkonoše Piedmont Basin fill reaches 1800 m. The LVC is located in its central part, whereas most of the other volcanic bodies are concentrated in the western part. Prouza and Tásler (2001) determined the stratigraphic position of the LVC to be at the boundary between the Vrchlabí and Prosečné Formations. Two quarries offer excellent study profiles in an area with scarce outcrops. The quarries are situated on the opposite margins of the volcanic complex. The Hvězda quarry is located on the SW margin of the LVC and preliminary observations on the pyroclastic sequences were presented by Rapprich (2008 a, b). The non-coherent volcanic products from Studenec quarry on the NE margin of the LVC were first noted by Stárková (2008). Research in both quarries continued in 2008 and in the spirit of VENTS, the research team became international.

The sequence exposed in the upper part of the Hvězda quarry consists of a basaltic andesite lava flow with a brecciated surface (up to 3 m thick). The lava is covered by deposits of a phreatomagmatic eruption (base-surge, accretionary lapilli-rich fall-out) and the entire sequence is capped by up to five units of pyroclastic scoria flow deposits. Six clastic units occur beneath the lava flow: 1. a layer dominated by a mica-rich matrix with scoria fragments 0.5 - 5 cm; 2. a lens of matrix-supported deposit with scoria fragments 1 - 5 mm; 3. a matrix-supported layer, with scarce mica and scoria fragments 2 - 10 mm concentrated in lenses; 4. bedded to laminated layer with lenses rich in carbonatized glass fragments, upper part contain angular fragments of sedimentary rocks; 5. massive layer with fine matrix, scarce lithics and no glass fragments; 6. massive layer dominated by matrix, rich in fragments of scoria and altered glass, lithics up to 25 cm in the lowermost and upper parts, the uppermost part consists of fall-out deposit rich in accretionary lapilli.

The story in the Studenec quarry is somewhat different. This area is dominated by a coherent facies of lavas and sills, but some volcaniclastic deposits can also be found here. An accumulation of welded, weakly vesiculated lava shreds (spatter cone) was observed in the southern part of the quarry. A similar rock can be found at the base of the NW part of the quarry. Pillow lavas with hyaloclastic breccias represent another spectacular facies. The rim of individual pillows and larger hyaloclasts consists of argillized glass. A sequence of sub-horizontal layered volcaniclastic deposits was found near to the pillow lavas in the northern part of the quarry. The total thickness of layered volcaniclastic deposits reaches 4 m. These deposits show both normal and inverse grading, generally becoming finer-grained upwards. It contains abundant fragments of quartz, scoria, volcanic rocks and volcaniclastics. Volcaniclastic deposits of reddish-brown colour rich in large clasts (up to 30 cm - including spindle-form bombs) follow. The matrix of the uppermost deposits is rich in fragments of altered mafic glass. This volcanoclastic succession has been intruded by a basaltic-andesite sill.

Lavas and deposits of Strombolian and phreatomagmatic eruptions are interbedded in the Hvězda quarry.

Studenec quarry is dominated by lava emitted from a Hawaiian spatter cone. The Hawaiian volcanism may temporarily have dammed a stream, forming a temporal lake in which the pillow lava and breccias formed. The overlying pyroclastic deposits are the subject of ongoing research.

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Fate of organic matter during contact metamorphism induced by Permian magmatic activity in the Dębnik Anticline, Southern Poland

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The Dębnik anticline, situated northwest of Kraków, is built of Devonian carbonates and marls, often containing organic matter, and underlain by a late Palaeozoic rhyodacite intrusion. Emplacement of the intrusion caused thermal metamorphism of dolomites resulting in the formation of ca. 300 m thick contact aureole (Lewandowska 1998), and organic matter catagenesis accompanied by hydrocarbon generation. This metamorphism is marked by distinct rock colour changes caused by variations in organic matter maturation/oxidation. Far from the contact, rocks are grey or brown and organic matter maturation is within the oil window $R_r \sim 0.8$ % (e.g. Racławka). Nearer the contact dolomites are black, and vitrinite reflectance reaches $R_r \sim 1.4$ % in Dębnik and 3.15 % in Dubie (Rospondek et al. 2007). At the contact, the rocks are composed of dolomite decomposition products: calcite and brucite (predazzites) and become white (Lewandowska 1998) attesting to complete oxidation of organic matter. The wide transition zone between this black and white coloured rocks consists of layered rocks having the appearance of stockwerk or breccias. This study aims to explain the co-existence of black dolomite and white calcite-brucite marble (predazzite) at the same distance from the igneous rock and presumably formed at the same temperatures. The formation of the black rock neighbouring the white variety can be explained in terms of the internal and external buffering of metamorphic fluid composition, resulting in different alteration of organic matter during metamorphism. The fate of the organic matter was controlled by the thermal decomposition of dolomite and brucite formation and by fluid/rocks mass ratios. Metamorphism led to the formation of calcite-brucite marble (predazzite) and carbon dioxide (Lewandowska 2000).

$$\underset{\text{dolomite}}{CaMg(CO_3)_2} + H_2O \rightarrow \underset{\text{brucite}}{Mg(OH)_2} + \underset{\text{calcite}}{CaCO_3} + CO_2$$

In turn, fluid-brucite equilibria controlled pH according to the reaction:

$$Mg^{2+} + 2H_2O \rightarrow Mg(OH)_2 + 2H^+$$

The differences in composition of the white and black rocks can be explained by the influence of these reactions on the composition of the metamorphic fluids vigorously circulating along fissures and layering surfaces. In the white zones, often formed along layering surfaces and cracks, the fluid composition was externally buffered by oxidising fluids, and CO_2 derived in the reaction could be removed. Dolomite decomposition was completed, and predazzite formed. At this stage the presence of brucite $Mg(OH)_2$ buffered the pore fluid composition enhancing removal of organic matter *via* acid catalysed oxidation reactions e.g. involving SO_4^{2-}. The presence of relatively strong oxidants like SO_4^{2-} is indicated by the occurrence of thaumasite, a mineral containing sulfate moieties (Lewandowska, Rospondek, 2002). On average the rocks contain 0.1-0.2 wt. % TOC, and this small amount of organic matter makes them susceptible to the influence of external oxidation. At high fluid/rock mass ratios, where the oxidation capacity of dissolved oxidants exceeds the reduction capacity of sedimentary organic carbon and ferrous iron, organic matter can be easily removed. This led to whitening of the rocks.

On the other hand, the efficiency of external buffering decreased away from the fissures. In the black zones, organic matter and reaction of dolomite decomposition internally buffered the composition of the metamorphic fluids. This process increased XCO_2, and dolomite decomposition was restricted. Thus, this mineral is still the most important component of the rock. At generally low fluid/rock mass ratios in the absence of external oxidants, sedimentary organic carbon and ferrous iron present in rocks react with the limited amount of fluid to create reducing conditions. Organic matter is preserved, though in strongly coalified form. Pyrolysis (Py(610°C)-GC-MS analysis) of such a rock after extraction did not generate significant amounts of products. This must be attributed to the fact that organic compounds had already been generated during thermal metamorphism. The natural pyrolisates were expelled from the source rock, and some of them were trapped in the late generation black calcite veins. Nonetheless, the extractable organic matter reveals strong oxidation. The amounts of apolar fractions are minor with *n*-alkanes in the range C_{13}-C_{36} having CPI ~1, and extracts are rich in aromatic fractions. The aromatic fractions are composed of naphthalene, phenanthrene and their alkyl derivatives, anthracene, pyrene, dibenzo[*b*]furan, and often predominating dibenzo[*b*]thiophene. Interestingly, these fractions contain also some phenylphenanthrenes (Rospondek et al. 2009), polyphenyls and minor amounts of phenyldibenzo[*b*]thiophenes (Rospondek et al. 2007). Phenylnaphthalenes and terphenyls show a reversed distribution presumably caused by overmaturation, with dominance of 1- and *o*-isomers, respectively.

Processes of external and internal buffering leading to the formation of predazzite and restricting dolomite decomposition, respectively, at the same metamorphic temperatures, are able to explain satisfactorily differences in the fate of organic matter in these coexisting zones.

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Self-organized complexity of crystal growth from heterogeneous magmas

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Growth textures and the trace element composition of alkali feldspars from two igneous bodies of mixed magma origin have been investigated. Each crystal was analyzed (Ba, Rb, Sr) along several transects from margin to margin. 3D visualization combined with fractal statistics allow us to gain an insight into the mechanism of crystal growth in a system showing non-linear dynamics. A self-similarity parameter, the Hurst exponent, was used to show the long-range dependence of element behaviour during the growth process. The expected values of H lie between 0 and 1. For $H = 0.5$, element behaviour shows a random walk and the process produces uncorrelated white noise. For values either greater or less than 0.5, the system shows non-linear dynamics. $H < 0.5$ represents anti-persistent (more chaotic) behaviour, whereas $H > 0.5$ corresponds to increasing persistence (less chaotic). The magmatic systems responsible for the formation of the investigated feldspars shows different, non-linear dynamics. The crystals grew from mixed magmas characterized by different degree of homogenization. 3D visualization of trace element distribution shows that in some of them the crystallization process is also followed by interaction with fluids. Feldspars grown in active regions of mingled magmas are strongly zoned. The Hurst exponent ranges from $H=0.06$ to $H=0.47$ reflecting intensive chemical mixing and underlying strong non-linear dynamics of the system. Feldspars grown from mixed and homogenized magmas are almost homogeneous. Relatively small and irregular variation in trace element contents makes their growth morphology patchy. Despite homogenization the fractal statistics reveal that trace elements were incorporated chaotically into the growing crystals. The anti-persistent, chaotic behaviour of elements during growth of these feldspars is progressively changed into persistent behaviour within domains, where exchange reaction with fluids took place. This interaction changed the trace element patterns. Fractal statistics points to different element behaviour during two different processes e.g. can distinguish the two processes. 3D visualization does similarly. It appears that fractal statistics combined with 3D visualization is an ideal tool for the identification of the growth mechanism and any subsequent changes.

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Westphalian volcanic activity south of The Teplice-Altenberg caldera, Central and Western Bohemian Basins

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Variscan volcanism in Central Bohemia started before sedimentation in the Carboniferous basins. Rhyolitic dykes (NW-SE, SW-NE) are well known from the basement of the southern part of the Central Bohemian Basins (Kladno Coal mine, borehole Lu 1) and near the southern limit of the Central and Western Bohemian Basins (CWB) (locality Lubná). The most intense volcanic activity started shortly after the opening of the CWB in the Bolsovian.

This volcanic activity was dominated by many thin and widespread silicic tuffs (fine grained tonsteins mostly with a clay matrix) in the basal Radnice member of Carboniferous fluviolacustrine sedimentation. Chondrite-normalized REE patterns of these tuffs are similar to those of Precarboniferous rhyolitic rocks, including large negative europium anomalies. The tuffs are preserved mostly together with finely graded sediments of swamps and mires in depressions where the presence of humic acids from degradation of organic matter promoted alteration of volcanic ash. The Bělka-Whetstone sequence is stratigraphically the most important volcanic layer of the Radnice Member. Its age was determined by the Ar/Ar method as 309±3.7 Ma (Hess et al. 1985). It consists of fall-out tuff at the base and reworked volcanoclastic material above. The pyroclastic deposit consists of quartz and sanidine crystal fragments in a kaolinized matrix. The extent of this horizon is quite enormous; it spread from the western to eastern margin of the CWB and was also preserved in relics of Carboniferous sediments in Central Bohemia, south of the CWB. Rare outcrops can be found in the southern part of the CWB and also in small Carboniferous relics outside the CWB. Thickness variations and drillcore data from the southern rim of the CWB (Lu 1, Řv 1, Řv 3, Ru 1) re-introduced the hypothesis of Mašek (1978) dealing with the presence of a hypothetical conduit for Bolsovian volcanism at . the southern margin of the CWB. The bottom of drillcore Ru 1 consists of white devitrified rhyolite and breccia with angular hydroclastic fragments (mostly rhyolite, Neoproterozoic basement and pumice). These rocks are overlain by 80 m of pyroclastic deposits with large fragments of altered pumice, lithics and kaolinized matrix. The platy pumice and lithic clasts display a preferred orientation, suggesting an inclination of the deposit of about 20°. The similar pyroclastic deposits are preserved at the base of the drillcore of deep borehole Zl 1, 30 km NE of Ru 1. The succession there begins with fine-grained surge deposits. The overlying pyroclastic deposits are nearly white, finer-grained with small fragments of pumice. The total thickness of pyroclastic deposits reaches 45 m. Pyroclastic deposits from both Zl 1 and Ru 1 boreholes are crystal-poor

The other boreholes (Ln 1, Ko 1, Tř 1, Pu 1) drilled Westphalian paleodepression north of the CWB. The composition of pyroclastic deposits at the bottoms of the drillcores is

rather different. The altered or glassy matrix contains abundant crystals of quartz, plagioclase and K-feldspar. Tuffs with both accretionary and armoured lapilli (cores of crystal fragments) were found in the upper part of pyroclastic and volcanoclastic deposits (50 m of total thickness in Ln 1). These drill cores are situated close to the southern margin of the Teplice-Altenberg caldera, which is covered by Cretaceous and Tertiary sediments.
It is presumed that these drilled pyroclastic rocks and also pyroclastic deposits described from a small Brandov occurence (W of the Teplice rhyolite) are connected with the oldest volcanic phase of the Teplice-Altenberg Caldera.

Only the first preliminary results are presented in this contribution. Our ongoing research aims to answer several questions: Did paleotopography (the Bílichov elevation, after Opluštil, 2003) prevent the Teplice ignimbrite from spreading further south? Does another smaller volcanic centre apart from the Teplice-Altenberg Caldera really exist, and did it influence Westphalian sedimentation in the CWB?

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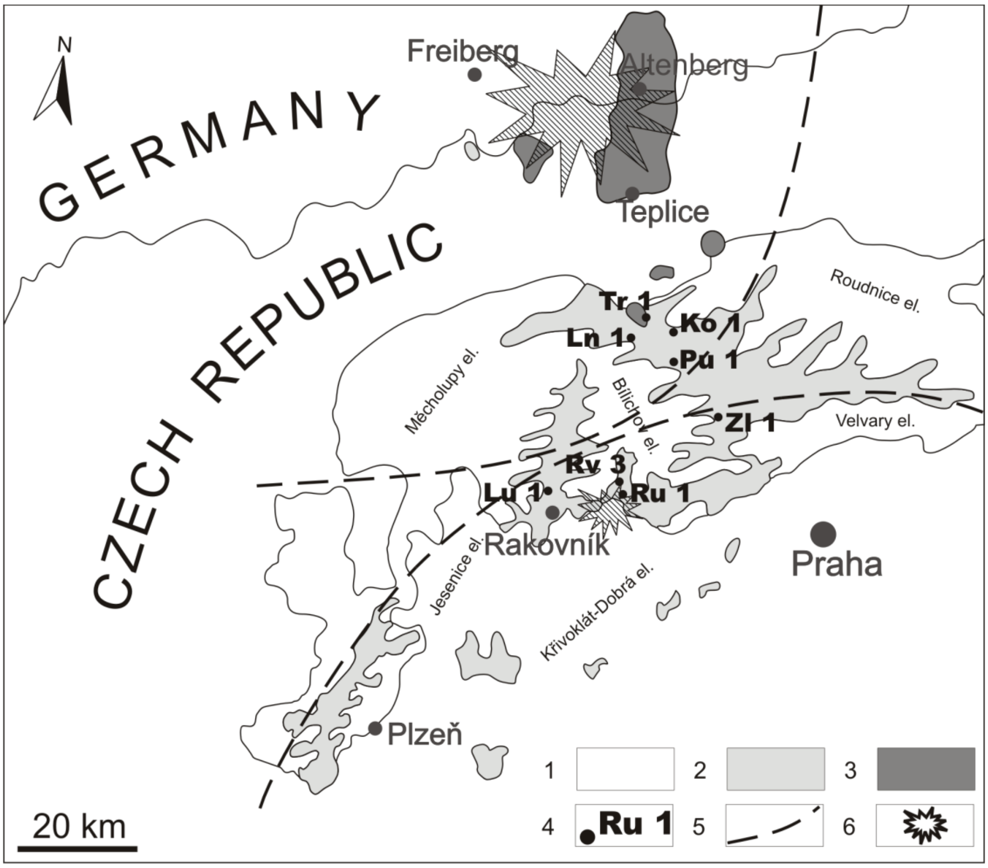

Fig. 1. Central and Western Bohemian Basins and Carboniferous relics with hypothetical Westphalian volcanic centers (modified after Opluštil 2005).
1 – Morphological elevations during Bolsovian; 2 – depocenters in the beginning of Bolsovian sedimentation; 3 – Teplice Rhyolite; 4 – studied drillcores; 5 – limit of distribution of pyroclastic deposits; 6 – volcanic centres.

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Petrological and sedimentological analysis of volcaniclastic Permian rocks with reference to volcanic series, Western Wielkopolska

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Rocks of the Rotliegend succession occur in Western Wielkopolska at an average depth of 2550 meters. There are two main kinds of rocks in this complex: volcanic and volcaniclastic. The clastic part of the sequence is found as volcaniclastic sedimentary rocks which come mainly from the disintegration of a Permian volcanic edifice, with interbedded pyroclastic deposits (Maliszewska et al. 2003). Sedimentary rocks were formed in arid and semiarid climates during periods of intense tectonic activity (Karnkowski 1991), where water had a major influence on erosion and deposition (Kiersnowski et al. 1999).

The lower part of the Rotliegend clastic sediments was formed in a humid climate (fluvial deposits and lacustrine sediments), whereas the upper part was drier (eolianite deposits). There are formations characteristic of facies of alluvial fans, sheet floods and debris flows in the whole sediment profile.

Over the whole area, before the development of the sedimentary complex, acid explosive volcanism dominated, shown by analysis of cores. In the upper part of the Lower Rotliegend there is an acid volcanic edifice and ignimbrites, mainly of rhyolitic composition with lesser amounts of rhyodacite and dacite. Beneath, there are intermediate rocks with andesitic composition (Maliszewska et al. 2003).

The remaining volcanic edifice attained a thickness not greater than a few hundred meters; because of pr- and post-volcanic erosion, they have been preserved only fragmentarily. The intense tectonic activity and resistance to weathering both influenced the preservation of the volcanic edifice (Geiβler et al. 2008).

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The origin of selected volcanic deposits from Grotta dei Pisani, Vulcano, the Aeolian Islands

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The so-called Brown Tuffs are weakly characterized, but intensely studied volcaniclastic deposits found on several islands in the Aeolian Arc in Southern Italy (Gianfilippo De Astis, pers. comm. 2005; Lucchi et al. 2008). In the Grotta dei Pisani region on the western slope of Vulcano, the 70 ka to 9 ka Formations of Lower and Intermediate Brown Tuffs (BT), Spiaggia Lunga (SL) and Tufi di Grotte dei Rossi Inferiori (TGRI; correlated with the Upper Brown Tuffs by Lucchi et al. 2008) are well exposed. Recent studies (Szczepara 2008) have provided new information on the origin of these deposits.

The BT at Grotta dei Pisani are 10 m thick and mainly massive and unstratified, with only local, subtle, subhorizontal bedding and a cross-stratified channel in the middle-upper part. The deposits are grey and brown and range from monolithological and well-sorted ash to more variable lapilli ashes, with lithic clasts, scoria, lapilli and pyrogenic augites set in a finer matrix. A blanket of strongly welded SL scoria, 4 m thick, overlies the BT. The TGRI, which crop out as isolated "caps" up to 4 m in high, ca. 80 m above the BT and SL exposures, are unstratified to weakly stratified, fine-grained, brown, beige and black ashes.

The BT are basaltic or basaltic andesitic, the SL deposits are trachybasaltic and the TGRI are trachyandesitic, all showing shoshonitic affinity. The main components of all deposits are glass shards: dark to opaque tachylite or light sideromelane. Phenocrysts are dominated by euhedral and subhedral clinopyroxenes (augite or diopside) and sieve-textured plagioclase. Subordinate minerals are olivine (often with iddingsite rim), alkali feldspars and titanomagnetite. Many crystals have envelopes of volcanic glass. Scoria from SL has hypocrystalline-porphyrytric, vesicular, sometimes spongy texture. Yellowish palagonite was found in some specimens.

The unstratified BT are pyroclastic fall and/or surge deposits. The sub-horizontally bedded BT could have been deposited from pyroclastic surges. The channel-bedded BT were redeposited by water eroding the slopes of Vulcano. The welded scoria blanket formed as the result of fissure eruption from a source located ca. 1 km NE from the studied outcrops. The TGRI were deposited from hydromagmatic eruptions sourced in a shallow sea. Changing vent locations and distinctive magma compositions at successive eruptive episodes reflect tapping of various parts of the evolving magmatic system of Vulcano.

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Thermal action of Pilica granodiorite intrusion on sedimentary cover rocks, Southern Poland

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Granodiorite intrusions connected with Variscan magmatism of Upper Carboniferous age are located in the Paleozoic basement of the Silesian-Kraków region and represent the apical parts of larger batholiths occurring in deeper (abyssal) zone in the basement (Żaba 1999). In four areas the intrusions have been detected in several boreholes: Myszków-Mrzygłód, Zawiercie, Pilica and Będkowska Valley. Pilica granodiorite intrusion is situated within the marginal zone of the Małopolska block, in a Lower Paleozoic sedimentary complex. The top of this intrusion was reached by boreholes (WB 115, KH1, KH2 and KH3) at depths 605.5m, 670.8m, 419.0m and 1215.8m, respectively (Harańczyk 1994).

The granodiorites have a grey colour, are medium grained and show a holocrystalline, sometimes "porphyritic" texture. They consist of zoned plagioclase (andesine-oligoclase), quartz, orthoclase microperthite, hornblende, biotite and accessory: titanite, apatite, zircon and magnetite. They are calc-alkaline rocks, have meta/peraluminous character and have VAG affinity.

Some parts of the granodiorite body are strongly hydrothermally altered, related to the mineralization of porphyry copper deposit type (Wolska 2001).

The thermal action of the large Pilica granodiorite intrusion on the surrounding country rocks resulted in the formation of a contact aureole, up to 300-400 m wide. A similar contact aureole of the Będkowska Valley granodiorite intrusion, was described by Koszowska and Wolska (2000).

In borehole KH-3 the Lower Paleozoic sedimentary complex begin at a depth of 305 m. The rocks are cut by hydrothermal quartz-feldspar and quartz-chlorite veinlets, locally including ore minerals. Thermally altered rocks are represented by fine-grained cordierite hornfelses, metamudstones and metasandstones. Cordierite hornfelses occur as intercalations in other rocks and do not differ macroscopically from them. Their presence was identified by PXRD investigations. These rocks are black-brown in colour, massive and hard. A spotted texture is visible only in thin section. Light-coloured spots (0.5 mm in size) consist of cordierite, covered by numerous submicroscopic inclusions of opaque minerals and brown biotite flakes (less then 0.01 mm in size). Consequently, the rock shows the sieve texture characteristic of hornfelses.

Cordierite crystals often exhibit sectoral twinnig and are Fe-Mg cordierite (mg*= 0.44-0.41, Fe/Mg ratio=1.2-1.5 with MnO up to 1.5 wt.%). In hydrothermally altered zones, cordierite was altered to a mixture of light mica and chlorite. Brown biotite flakes (up 0.1 mm in size), K-feldspar and plagioclase also occur. Quartz is absent or very rare. Biotite flakes show strong pleochroism (α=yellow, γ=dark reddish-brown) and are Fe rich (mg=0.27-0.32, Fe/Mg ratio=2.2-2.7 with TiO_2=3.5-4.0 wt. %). K-feldspar ($Or_{90}Ab_9An_1$) occurs in the matrix and in cordierite spots as submicroscopic inclusions.

In comparison to Będkowska Valley cordierite hornfelses, the rocks studied are finer-grained and minerals such as cordierite and biotite have higher iron contents.

The mineral paragenesis of cordierite, biotite, and K-feldspar in the contact altered country rocks, indicate the orthoclase-cordierite-hornfels facies of thermal metamorphism and conditions of formation corresponding to temperatures from 580 to 630° C and pressure 1-2 kbar.

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Enclaves in granodiorite intrusions from the Paleozoic basement of the Silesian-Kraków area, Southern Poland

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Granodiorite intrusions occur in the Lower Paleozoic basements of the Silesian-Kraków area. These plutonic rocks have the character of "stitching intrusions" and are located in a broad tectonic zone between the Upper Silesia and Małopolska blocks (Unrug et al. 1999). The granodiorite intrusions were found in boreholes in four areas: Myszków-Mrzygłód, Pilica, Zawiercie and Będkowska Valley.

The granodiorite intrusion from Będkowska Valley was drilled in the boreholes DB5 and WB102A, whereas the Pilica granodiorite body was found in the boreholes WB115, KH1, KH2 and KH3. The age of the intrusions has been debated by numerous authors. Some consider them to be related to Variscan magmatisim of Upper Carboniferous age (Żaba 1999). Their age was determined using the K-Ar isochrone method as 312Ma (Jarmołowicz-Szulc 1985).

Granodiorites are grey, medium-grained, holocrystalline rocks, sometimes showing porphyritic texture They consist of zoned plagioclases (andesine-oligoclase), quartz, microperthitic orthoclase, biotite, hornblende and accessory titanite, zircon, apatite, allanite and opaque minerals (Harańczyk et al. 1995; Płonczyńska 2000; Wolska 2000; 2001).

Geochemically they are calc-alkaline rocks of meta/peraluminous character and have VAG geotectonic affinity. Granodiorite intrusions were altered to various degrees during ore-bearing hydrothermal mineralization of copper porphyry type (Wolska 2000; 2001).

Granodiorite intrusions contain enclaves of various petrographic types. Enclaves of hornfels xenoliths (1-4 cm in size) are oval or ellipsoidal and represented by dark brown, very fine-grained rocks with characteristic hornfels structure visible in thin section (the size of rock-forming minerals varies from 0.01mm to 0.06 mm). These xenoliths consist of: plagioclase (andesine $Ab_{69-56}An_{43-29}Or_{6-1}$, rare oligoclase $Ab_{85-70}An_{29-10}Or_{8-1}$), K-feldspar ($Or_{95-93}Ab_{6-5}An_{2-1}$), strong pleochroic, reddish brown biotite (mg=0.44-0.35, Fe/Mg ratio=1.9-1.3, TiO_2 5.0-3.5 wt.%., MnO 0.7 wt.% and V_2O_5 0.2 wt.%) and opaque minerals (magnetite and ilmenite). Quartz is absent or very rare.

Dark micaceous enclaves (restite) are more or less elongated and discoidal, 3-6 cm in size, fine-grained and dark green in colour. Crystalloblasts of rock-forming minerals are 0.2-0.5 mm in size. The enclave consists of: olive-brown Fe-biotite (mg=0.40-0.35, Fe/Mg ratio=1.7-1.4 with admixture of TiO_2 3.2-2.4 wt.% and MnO 0.7-0.4 wt.%), plagioclase (labradorite $Ab_{47-44}An_{56-52}Or_1$, andesine $Ab_{63-52}An_{45-36}$ Or_{2-1}, and rare oligoclase $Ab_{75-72}An_{26-23}Or_2$), magnetite, corundum and sericitic pseudomorphs after cordierite. Quartz and K-feldspar are absent (Wolska 2004).

Microgranitoid enclaves (mafic microgranular enclaves, oval or ellipsoidal in shape) are dark grey rocks, showing a fine-grained structure (0.1- 0.4 mm in size) with megacryst

(0.4 cm in size). In thin section they show a doleritic texture with zoned plagioclase megacrysts (labradorite $Ab_{44-40}An_{53-51}Or_{3-2}$, andesine $Ab_{58-50}An_{47-43}Or_{3-1}$) altered in various degree. In the matrix there occur zoned plagioclase laths (andesine $Ab_{67-50}An_{48-37}Or_{5-2}$, oligoclase $Ab_{80-71}An_{25-19}Or_{4-1}$), hornblende (mg=0.45-0.32, Fe/Mg ratio from 2.1 to 1.8) with secondary brown biotite (mg=0.33-0.31 Fe/Mg ratio=2.3-2.1), titanite and epidote. Quartz and K-feldspar ($Or_{98-96}Ab_{3-1}An_1$) are rare and occur in interstices. Accessory minerals are represented by zircon, apatite and magnetite (with V_2O_5 0.9wt.%).

The occurrence of hornfels xenoliths indicates that granodiorites of the Silesia-Kraków region crystallized in the middle or upper crust and are high-level plutons.

The dark micaceous enclaves are the residues of partial melting of metamorphic rocks in the lower crust and indicate the origin of the host granitoid magma.

Microgranitoid enclaves (MME) are probably hybrid blobs. A mantle-derived mafic magma was injected into the lower crust and induced the melting of lower crustal metamorphic rocks forming the basement of the Małopolska block. The MME formed by mixing of the two mafic and anatectic silicic magmas.

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Introduction to field trip

Paleozoic successions along the Upper Silesia – Małopolska Terranes border

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The Paleozoic basement of the Kraków region (the Kraków-Silesia Laramide monocline) can be divided into two distinct tectonic domains: Brno-Upper Silesian and Małopolska Terranes, divided by the Hamburg-Kraków-Dobrogea transcontinental strike-slip tectonic line. In the western domain Devonian and Carboniferous rocks form the less deformed Variscan structural stage, penacordantly lying on the Cambrian or older Cadomian metamorphic basement of the Brno-Upper Silesian Terrane. The Lower Paleozoic sedimentary cover of the Cadomian basement, comprising Cambrian conglomerates, marine shales, and nearshore facies of red quarzite with Scolithos. There is some evidence near Lubliniec of a local, very restricted occurrence of marine Ordovician strata.

In the Małopolska Terrane, on the north-east part of the region, a deformed Cadomian epimetamorphic siliciclastic basement and an almost complete Paleozoic succession are known. The Cambrian is represented by thick marine siliciclastic rocks: polymictic and arkosic sandstones, conglomerates and shales with limited paleontological age control. The Ordovician was developed as a variety of facies, predominantly fine-grained siliciclastic rocks, arenites and carbonates, well documented by conodonts and acritarchs. A Silurian coarsening-upward sequence is known from the Zawiercie area: hemipelagic shales of starved basin pass upwards into synorogenic, coarser-grained graywacke volcanoclastic turbidites and debris flows from the Scandian fore-magmatic arc basin and is capped by wildflysch containing huge blocks of plastically deformed shales, eroded from slightly older Silurian strata.

During the Devonian and Carboniferous, Moravia and Małopolska were a segment of an extensive shelf bordering the Fennosarmatian part of the Laurussian craton. The shelf developed on the marginal parts of the Early Precambrian craton and over the terranes, which were accreted to it in the Early Paleozoic. The Moravia-Malopolska shelf was bounded to the south by a hypothetical Pre-Carpathian Land (e.g., Narkiewicz 1988; Paszkowski, Szulczewski, 1995) or East Silesia Terrane (Ziegler 1989). The existence of this land is inferred from a general southward thinning of the sedimentary cover, shallowing of the reconstructed depositional environments, increasing hiatus ranges, and influxes of terrigenous admixtures in the carbonates. For example, widespread quartz arenites occur in the Lower Famennian and Upper Visean carbonate succession. The shelf was largely occupied by Moravia-Małpolska carbonate depositional systems. Carbonate shelf deposits are underlain by a Devonian terrigenous complex. Over major parts of the area, terrigenous deposits unconformably onlap their Cadomian and Caledonian basements, and are relatively thin and uniform on both sides of the Brno-Upper Silesia/Małopolska Masiffs border. Local bodies of coarse-grained red bed-type conglomerates occur as post-Caledonian graben fill, in the Zawiercie area only. Usually, they belong mostly to the Emsian, but towards the west (the Ostrava-Bielsko-Biała block), and probably also to the south, they are much younger and reach up to the lower Givetian, according to Czech geologists.

The depositional environments of the terrigenous succession were largely continental, lacustrine and fluvial. Skeletal fossils are scarce, except for placoderm fish remains. Mature quartz arenites, shales and pyroclastics are heavily bioturbated. Lower Devonian siliciclastic rocks are inaccessible at the surface in the Kraków region, but clasts of that age are common constituents of younger clastic rocks, e.g., in the tectonic fissure conglomerate fill in Dębnik quarry and the Lower Triassic conglomerate alluvial fan, south-east of Dąbrowa Górnicza.

During a significant rise in sea-level close to the Early/Middle Devonian boundary, terrigenous deposition ceased diachronously over the external part of the shelf. Still in the late Eifelian, an originally fairly variable, transgressive facies pattern was replaced by a far more uniform deposition of shallow marine carbonates. The resulting carbonate platform was established over a substantial part of the shelf (Paszkowski, Szulczewski, 1995).

During the Variscan cycle, the basement of the wide Brno-Upper Silesian Terrane was dismembered into several fault-bounded blocks, e.g. the Kraków block. Particular blocks showed different subsidence rates, horizontal and vertical synsedimentary movements, rotation, and tilting (Paszkowski 1988). On the Kraków block, less deformed Dinantian carbonates directly cover the Famennian succession without stratigraphic gaps (Gromczakiewicz-Łomnicka 1979), except for the southernmost part of the block. The thickness of the Dinantian sequence ranges up to 1200 m (near Krzeszowice). Since the Early Carboniferous, this block was synsedimentarily tilted towards the north, and finally, clinoform, northward-thickening Carboniferous limestone lithosome, formed a typical attached carbonate platform. Facies belts of shelf crest and platform slope occurred along the northern edge of this platform. Within the slope facies, organic build-ups with cryptobial frameworks appeared locally. The whole section of Dinantian carbonates shows distinct similarities to the Dinantian sequences in other segments of the southern shelf of the Laurussian continent, especially in South Wales and Belgium. These similarities are generally a result of uniform climatic conditions and/or eustatic fluctuations of sea-level during the Dinantian. Similarly, in the cyclically deposited Strunian carbonates, we can observe analogies with uppermost Fammenian carbonate sequences from other areas, such as the Moscow and Dnepr-Donets Basins.

The main body of platform carbonates thinned towards the north, west and north-east and passed laterally into radially arranged fans of allodapic limestones (Bełka 1985; Paszkowski 1988). Outside the platforms, these fans interfinger with stratigraphically condensed claystones, radiolarites, and spiculites with pyroclastic intercalations of the classical Culm magnafacies. This lithological suite represents typical starved basin deposits. Individual basin-scale correlatable lithological complexes of the Moravo-Silesian Culm section can easily be compared with classical lithostratigraphic subdivisions of the Rheno-Hercynian Culm.

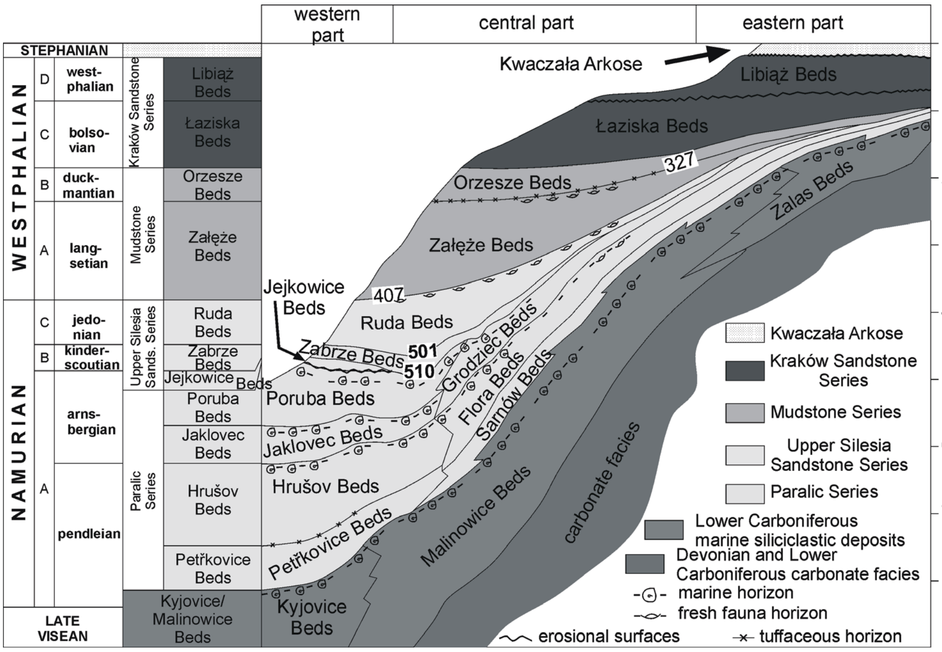

Fig. 1. Composite, synthetic cross-section/lithostratigraphic subdivisions of the Carboniferous of the Upper Silesian Coal Basin (modified from Kotas 1977).

During the Late Carboniferous, the Kraków area formed a part of the wider sedimentary basin representing the Moravo-Silesian foredeep (Bogacz 1980). During the latest Visean and earliest Namurian, a depositional area of synorogenic graywacke flysch spread eastwards over the whole foredeep. During this time, the Upper Silesian Coal Basin (USCB) was formed, ranging eastward to the western part of the Kraków area. Rapid subsidence of the USCB basement formed the space for deposition of a paralic (Namurian A) and limnic (Westphalian A-D) coal-bearing molasse with numerous workable coal seams (Kotas 1977). Provenance of this siliciclastic sequence was generally from the Bohemian Terrane segment of the Variscian Orogen. Numerous pyroclastic horizons occur as kaolinised tonstein beds up 2 m thick, but fine-grained, and are especially common in the Namurian A Poruba beds and Westphalian B Kraków Sandstone Series. These tonstein beds, easily correlatable on the Laurussia scale, were most probably derived from contemporaneous subaerial volcanic centers in the Central European Variscan magmatic arc. The Stephanian Kwaczała Arkose is the youngest Carboniferous deposit known from the Kraków area, and represents a coal-free red-bed facies with numerous silicified araucarite stems. The precise spatial and stratigraphic relationships between the arkose and underlying coal-bearing strata are still not clear.

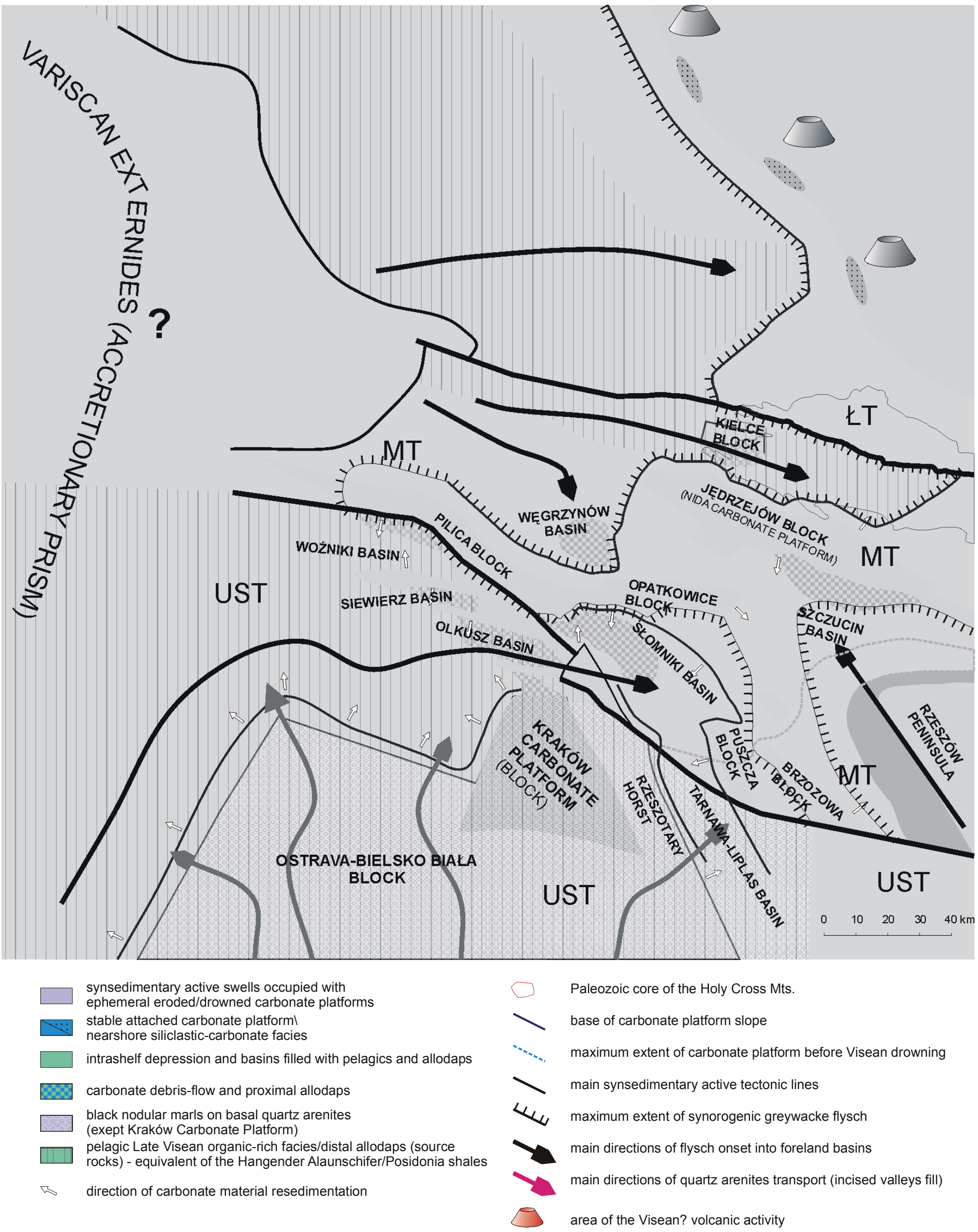

Fig. 2. Main elements of the Visean/Namurian A paleogeography of Southern-Central Poland: MT – Małopolska Terrane; UST – Upper Silesian Terrane; MT – Łysogóry Terrane.

The Caledonian and Variscan deformation belt occurs in the basement of the eastern part of the Kraków area. It is called the "Cracovides" (Harańczyk 1982). From late Devonian to Permian times, the deformation belt belonged to a segment of the transcontinental Kraków-Hamburg strike-slip zone (Żaba 1999).

Recognition of the nature of the TESZ-parallel, NW-SE trending, epi-Variscan/Permo-Triassic fault system is important for geotectonic and paleogeographic reconstructions of

Europe and Asia Minor. The most crucial structure in the above-metioned group is the large-scale Hamburg-Kraków-Dobrogea/Scythian-Turanian trans-Eurasia strike slip zone, with the related peri-Baltica basement terrane collage/cover basin family. The Buła-Żaba line (formerly known as the Kraków-Lubliniec line), the southern Poland segment of the Hamburg-Kraków-Dobrogea zone, separates the two above-mentioned crustal terranes: the Gondwana-derived Brno-Upper Silesia and the Malopolska Terranes with Baltican lower crust. The recent exciting discovery of a hidden, huge Permo-Triassic megaorogen, the "Silk Road Arc", 6600 km long, crossing longitudinally the whole of Eurasia from Strandja and fore-Dobrogea to Manchuria, allows us to advance a totally new explanation. All features of the kinematics of the fault family, the related Permian and Triassic volcanic center activity, and terrane collage pattern are joint effects of continental-scale, lateral escape tectonics at the western end of the oblique Silk Road /Scythides collisional orogen.

The pattern of the Variscan and epi-Variscan structural elements of the Kraków segment of this zone, more recently covered with Mesozoic rocks, is clearly recognizable on gravimetric maps. The dense network of transtensional longitudinal horsts, brachyanticlines, grabens, and halfgrabens was finally formed during the Late Carboniferous-Early Permian. The Upper Paleozoic sedimentary sequence was removed from some blocks by continental erosion during this time. Along the Kraków-Lubliniec border zone between the Upper Silesia and the Małopolska Terranes (Buła 1995; Żaba 1999), an Early Permian succession of continental deposits up to 600 m thick unconformably covers the erosion surfaces of the Devonian or Carboniferous. The Permian deposits, mostly conglomerates, filled the narrow, 5–15 km wide and 80 km long, transtensional Sławków Graben. Limestone-dominated detrital material of the Myślachowice conglomerates consisted of different Upper Paleozoic carbonate rocks. Traces of Permian paleokarstic phenomena are also very common here, for example the pyroclastic paleocave fill in Czatkowice Quarry or in some blocks of the Lower Triassic cyclopean collapse breccia with terra rossa matrix in Paczółtowice. Different volcanogenic rocks are most characteristic of the Permian complex in the area. Basaltoid and rhyolitic lava flows and related hypabyssal intrusions occurred along the edges of the fault-bounded Sławków Graben. Pyroclastic lithosomes (Filipowice Tuffs) are also known as two or more intercalations within the whole Permian sequence.

Volcanic activity was connected with hydrothermal events, which caused development of a system of calcite-hematite veins cutting Devonian and Dinantian carbonates of the Dębnik Anticline. Chemotrophic, cryptobial hematite endostromatolites occurred locally within the near-surface parts of some veins. Similar cryptobial structures are known from clasts of Permian travertine (Kamiowice Travertine) found in the Myślachowice Conglomerates; they probably represent fragments of proximal, near-spring parts of the travertine cover.

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Early Permian paleoenvironments

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Post-Hercynian tectonic and magmatic activity continued into Early Permian times. Strike-slip movements following the Hamburg-Kraków-Dobrogea master fault, at the NE margin of the Upper Silesian block resulted in the development of a narrow (< 15 km) but deep trough structure called the Sławkow Graben. The fault block mountains bounding the rift reached some 1000 meters (or more) in relative altitude.

Considering the subtropical paleoposition of Central Europe in Early Permian time, the Kraków region was dominated by semi-arid paleoclimatic conditions (Fig. 1). This inference is supported by the sedimentological and geochemical evidence presented below. High mountain topography favoured coarse alluvial deposition, with olistolites typical of piedmont fanglomerates. The fanglomerates are the major component of the molasse assemblage and comprise Devonian and Lower Carboniferous carbonate clasts, Upper Carboniferous siliciclastic and Permian volcaniclastic material. Open-work fabrics and faint sorting of the conglomerates are evidence of episodic, pulsatory gravel input, probably triggered by seismic and/or volcanic events. Some caliche crusts with root molds occurring within the conglomerates mark periodic stabilisation of the fans and periods of nondeposition. The coarse alluvia pass distally into sandflat/mudflat redbed facies with playa evaporites in the central part of the graben.

The Sławkow Graben was filled with a continental molasse assemblage (up to 700 m thick) comprising, besides the fanglomerates, igneous rocks, playa mudflat deposits with evaporates and freshwater carbonates. All the components of the basin fill interfinger with one another, indicating a concurrent origin on one hand and vigorous tectonic, volcanic and sedimentary processes on the other.

Carbonate deposits, often referred to as Karniowice Travertine, are especially interesting among the other Lower Permian rocks of the Kraków region. Based on a very rich plant assemblage Lipiarski (1971) described their habitat as topogenous fen. The vascular plant assemblage includes both Carboniferous and Permian components (Raciborski 1891). The ultimate criterion for classifying the travertine as Lower Permian was the high proportion of new components, which were absent from Carboniferous assemblages (Lipiarski 1971). The swamp facies harbored a rich malacofauna which is rare in other facies of the Karniowice travertine. This gastropod assemblage forms one of the oldest-known land snail assemblages.

The survival of Carboniferous tropical flora in the generally semi-arid climate of the Early Permian was possible only due to the presence of a vast system of karstic springs, which fed an extensive paleo-oasis. These carbonate-depositing springs surfaced along the fault scarp.

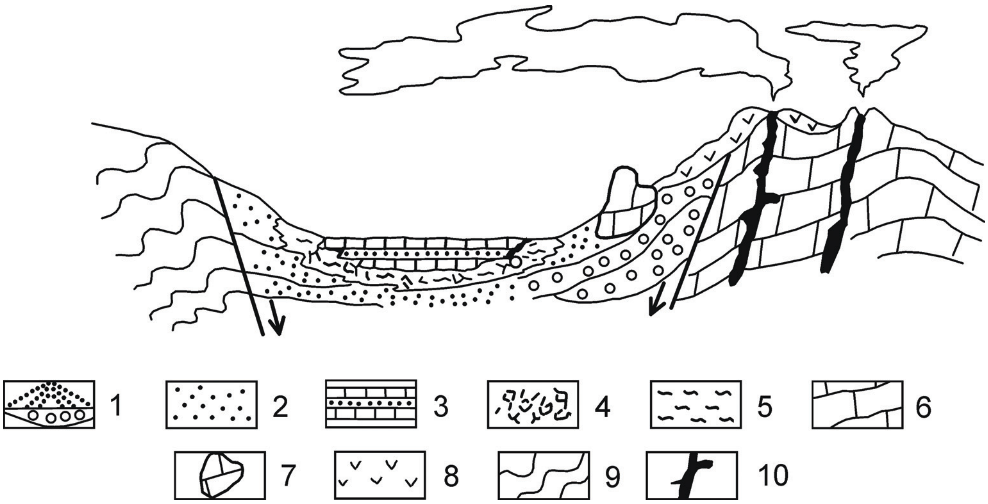

Fig. 1. Schematic section of molasses sediments of the Sławków Graben. 1. Conglomerates with caliche cap and karst cavities; 2. sandstones; 3. fine-grained clastics with evaporates; 4. fine-grained clastics, evaporates and gypsum veins; 5. mudstones; 6. Pre-Permian carbonate bedrock; 7. Olistolites; 8. tuffs and volcanic rocks; 9. Pre-Permian siliciclastic bedrock; 10. volcanic vents.

Sedimentological and geochemical studies (Szulc, Ćwiżewicz 1989) of the carbonate deposits show that their facies context is much wider than travertine *s.s.* and include calcareous deposits formed in small, stagnant water bodies (semi-limnic), or in streams feeding these water bodies, and calcareous deposits of swamp facies, with numerous, calcified remains of vascular plants.

Most important for paleoenvironmental reconstructions is the appearance of annually-varved limnic limestones formed on microbial mats. These varved sediments revealed a very prominent seasonal gradient in ^{18}O signals (between 1-3 ‰ vs. PDB) that correlates with the mean annual temperature amplitude reaching some 10-15°C (Szulc, Ćwiżewicz 1989). The obtained $\delta^{18}O$ gradient and the computed mean annual temperature amplitude correspond well with the seasonal variation measured in limnic carbonates from the present-day in subtropical zones. Beside the seasonal rhythm, the $\delta^{18}O$ curve displays also longer, 4-7 year cycles with $\delta^{18}O$ excursions reaching 4 ‰. This cycle is interpreted as the effect of rainfall fluctuations affected by the Permian counterpart of recent ENSO phenomena. This, in turn, depends essentially on the 4 to 9-year slackening periodicity in trade wind circulation, typical of subtropical zones.

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Late Carboniferous – Early Permian magmatic rocks of the Kraków region

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Extensive Late Carboniferous-Early Permian magmatism took place within both the Variscan orogenic belt and its northern foreland (Wilson et al. 2004). In the Sudetes, part of the eastern Variscides, three major Permo-Carboniferous intramontane troughs, the North-Sudetic Basin, the Intra-Sudetic Basin and the Sub-Krkonoše Trough, contain thick volcano-sedimentary sequences (Awdankiewicz 1999a,b). The most complete succession formed in the Intra-Sudetic Basin and provides a record of three distinct volcanic stages (Viséan, Late Carboniferous and Early Permian). In the eastern foreland of the Variscan orogen, in the Kraków region (Fig. 1), counterparts of each stage can be traced. However, the Viséan stage, comprising rhyolite tuffs, is poorly documented (Bukowy, Cebulak 1964).

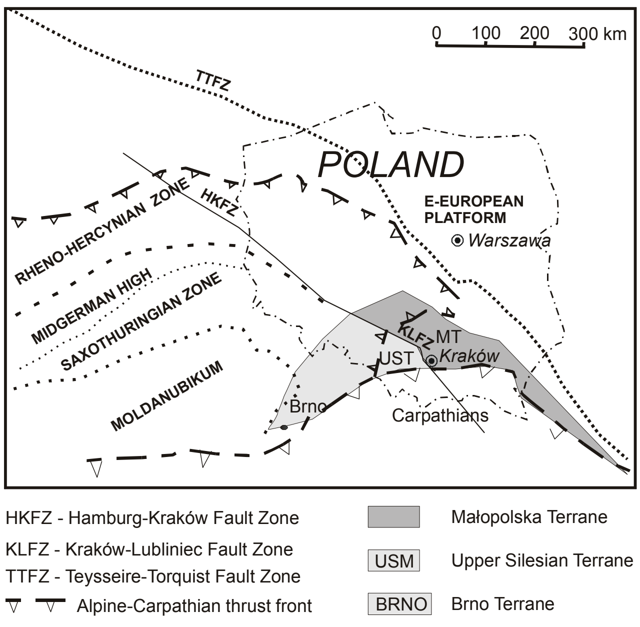

Fig. 1. Variscan structures in Poland (based on Pożaryski et al. 1992; Unrug et al. 1999; Winchester et al. 2002).

The second stage, of Late Carboniferous age, is represented by pyroclastic rocks interbedded with a coal-bearing terrigenous (Westphalian) sequence of the Upper Silesian Basin (e.g. Bukowy, Cebulak 1964). The volcanic centres have not been firmly located yet.

Rocks representing the second stage are located along a deep fault system, the Kraków-Lubliniec Fault Zone, marking the contact between the Małopolska Terrane in the east and Brno-Upper Silesian Terrane in the west. This fault zone is part of the transcontinental master dislocation – the Hamburg-Kraków Fault Zone (Żaba 2000) (HKFZ in Fig. 1). The Carboniferous/Permian boundary yielded large granodiorite intrusions and extensive volcanic activity (Jarmołowicz-Szulc 1984, 1985; Harańczyk 1989; Podemski 2001, Markiewicz 2001; Nawrocki et al. 2008).

The plutonic rocks are granodiorite and granite plutons from the Będkowska Valley, Pilica, Zawiercie and Myszków (Fig. 2). Of these, micas from the Myszków granodiorite yielded $^{40}Ar/^{39}Ar$ ages of 300-296 Ma for biotites, 297.5±0.5 Ma for a white mica and K-feldspars 290-292 Ma (Markowiak et al. 2001), which ages are within an error of $^{40}Ar/^{39}Ar$ biotite ages from the Będkowska Valley granodirite pluton (293±10 Ma; Oliver *vide* Harańczyk 1989). Smaller diabases like Mrzygłód (Ryka 1974) and gabbroid intrusions, like Sułoszowa, Kwaśniów (Karwowski 1988) have not been dated, except for a biotite from a diabase in the Myszków area, dated by $^{40}Ar/^{39}Ar$ at 305 Ma (Podemski 2001).

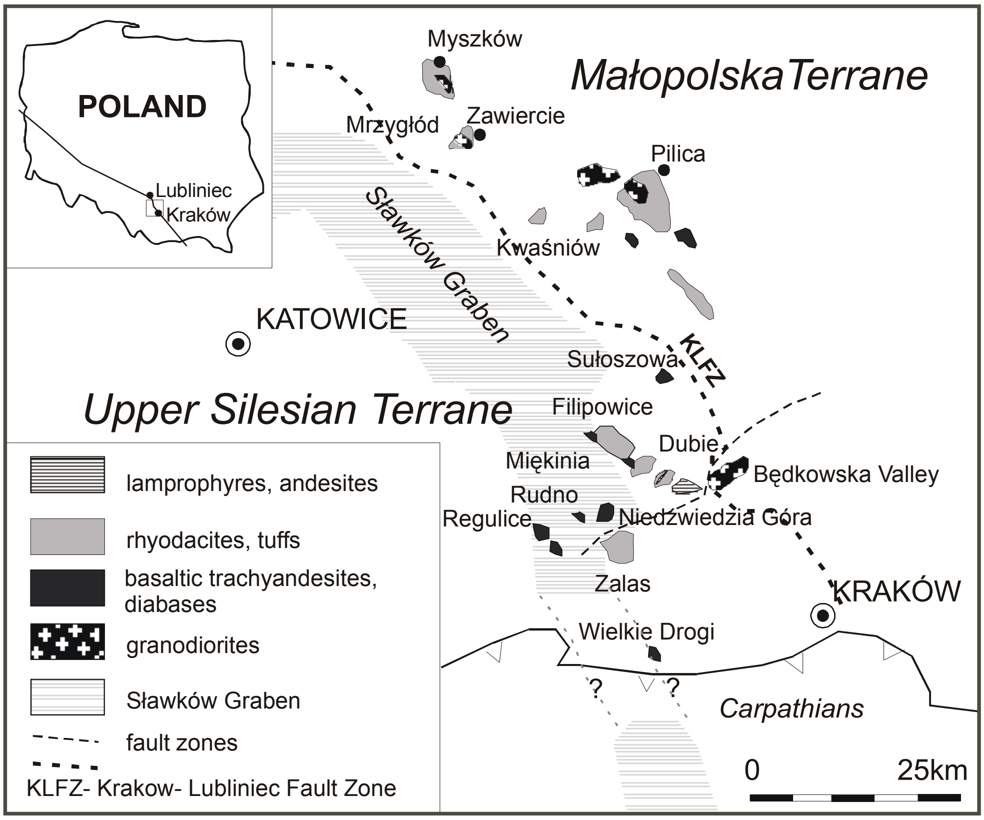

Fig. 2. Major magmatic rocks at Upper Silesian – Małopolska Terranes boundary (based on Żaba 1999; Szulc, Ćwiżewicz 1989; Kiersnowski 2001).

Numerous dykes cut the granodiorite plutons, suggesting that magma generation and influx continued after solidification and the uplifting of the plutons. This scenario is further confirmed by finds of granodiorite enclaves in rhyodacites (Muszyński, Czerny 1999; Lewandowska, Bochenek 2001).

Intense volcanic activity was contemporaneous with the accumulation of thick molasse sequences in extensional basins located along the Kraków-Lubliniec Fault Zone (Fig. 1). The most complete Carboniferous/Permian molasse succession is found in the Sławków Graben and its southeastern extension, the Nieporaz-Brodła Graben (Siedlecka 1964; Kiersnowski 1991) near Krzeszowice (Fig. 2, 3).

Here the remains of volcanic formations are preserved. The major volcanic outcrops are related to a series of faults bordering the graben. Thick series of basaltic trachyandesite lava flows, alternating with volcaniclastic rocks (Fig. 2) occur in Regulice, Alwernia, Rudno and Miękinia. Rhyodacites occur as laccoliths and domes in Zalas, Miękinia and Dębnik. Zircon SHRIMP studies of the Zalas rhyodacite indicate an age of 294.2±2.1 Ma (Nawrocki et al. 2007). The Miękinia rhyodacite is accompanied by felsic Filipowice tuffs and ignimbrites in Kowalska Góra (Parachoniak, Wieser 1985). This suite is accompanied by minor andesite, e.g. Dubie dated at 291.3±6.4 Ma, Lewandowska et al. 2007) and lamprophyre (e.g. Szklary) dykes and a basaltic trachyandesite sill in Niedźwiedzia Góra (Muszyński 1995 and works cited therein; Czerny, Muszyński 1997; Lewandowska, Rospondek 2003).

An important common feature of the bimodal (basaltic trachyandesite/ rhyodacite) volcanic series is the relatively high K content and chemistry transitional between calc-alkaline and alkaline. The high K content and close temporal and spatial association of mafic and felsic volcanic rocks in the Kraków region raises the question of their cogeneticity (Rospondek et al. 2004). However, detailed geochemical analysis and modelling of the residual melts composition in the basaltic trachyandesites shows that fractional crystallization alone is not able to explain the formation of voluminous rhyodacites (Lewandowska et al. 2008). This indicates that genetic relationships in the Kraków magmatic suite are more complex (Słaby et al. this volume).

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The origin and the evolution of magmas of Permo-Carboniferous volcanism of the Kraków region

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Permian volcanic rocks from the Kraków area form a bimodal, high K to shoshonitic, calc-alkaline, basic-intermediate and acid suite. Although clearly related to discontinuity zones, the present tectonic and stratigraphic settings do not provide a clear answer to the source of magmatism. In the literature, there are two parallel evolutionary models that try to embrace the present geological context. Although they differ substantially in the origin of stratigaphic units, both include oceanic crust and multiple collisions in the discussion.

The area investigated area is the contact zone between the Upper Silesian Terrane (UST) and Malopolska Terrane (MT), separated by a deep fault system (KLZ – the Kraków-Lubliniec Zone). This zone underwent repeated reactivation caused by multistage deformation of orogenic origin. The timing of those events remains somewhat unclear but the period from the Silurian to the upper Triassic seems to be the most plausible (Buła et al. 1997; Żaba 1999; 2000). Afterwards this configuration was changed only by vertical displacements dated as Miocene (Żaba 1999). According to this model both terranes and the neighbouring Lysogory Terrane (LT), have been considered, judging from their faunal affinities, to be microplates of Baltica (BLT) origin. Their migration along Baltica in the late Paleozoic to their present location was terminated between the Early Devonian and Carboniferous. The KLZ feature that accommodates the investigated volcanic formations is assumed to be a remnant of the closed Tornquist Sea (Berthelsen 1998).

Another evolutionary model distinguishes independent units in place of the KLZ fault system,which is surrounded by a group of small units. It is interesting to note that unlike KLZ, those terranes have a crystalline basement with affinities to the Gondvana continent (Unrug et al. 1999). This allows us to interpret the KLZ as a fragment of an oceanic plate that was trapped between micro plates during a number of collisions in late Silurian, late Devonian and Carboniferous times. This process played a key role in source formation and subsequent post-collision magmatism that continued till the Lower Permian.

The origin and evolution of the magmas have been the subject of many studies. Rozen (1909) assigned all the volcanic rocks to one differentiation series. Bolewski (1939) related magma origin to two different sources. In his opinion two compositionally different magmas were generated: calc-alkaline and high potassium – alkaline. Słaby (1987) questioned this hypothesis. She recognized intensive, secondary adularization and albitization, which could account for the enrichment in alkalis. Bukowy and Cebulak (1964) related the differences in composition to magma mixing, where the end-member magmas were mafic and felsic. This idea was not supported by Harańczyk (1989), who invoked four different types of magmas reflected in four types of rocks: diabase, rhyodacite, trachyte and lamprophyre. According to Czerny and Muszyński (1997) only three types of magmas (diabasic, lamprophyric and rhyodacitic) were involved in the genesis of all rock types. They explained trace element variation in low silica (intermediate) rocks by variable degrees of mixing between mafic and lamprophyric melts. This model was questioned by Gniazdowska (2004) and Falenty (2004). They modelled magma differentiation in both the more basic and more acidic rocks, using major elements and selected trace element concentrations. They revealed that the magmas had evolved by fractional crystallization. Rospondek et al. (2004) also proposed fractional crystallization as a petrogenetic mechanism, causing intermediate magma to evolve towards acidic. However, Gniazdowska and Falenty (op.cit) did not consider the mafic and felsic rocks comagmatic. According to them, the evolution of intermediate magmas into felsic was not possible.

New trace element analyses and isotopic data have allowed us to performextended geochemical modelling using a full set of data (Słaby et al. 2007). It seems that the magma for all the rockswas generated in two different sources, viz. enriched lithospheric mantle and crust. New data show that the variability in composition of the basalts-trachybasalts-trachyandesites can be related to various degree of partial melting and to compositional heterogeneity of the metasomatized mantle. Dacites-trachydacites-rhyolites were derived from crust-related magma and did not evolve from mafic melt. Crustal amphibolites are considerd to be the source of the acid magmas. Mixing hypothesis suggested by Czerny and Muszyński (1997) and Bukowy and Cebulak (1964) have been not verified positively taking into consideration their assumptions. However, the mixing invoked by the above authors was responsible for some of the magmas forming the Regulice-Alwernia lava flows. All the new contamination models have been developed using intermediate and acid parental magmas. These models explain the origin of some silica-enriched, intermediate magma blobs.

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Field trip - Permo-Carboniferous volcanism of the Kraków region

Volcanic rocks outcrop in the Krzeszowice area, west of Kraków. The outcrops are situated along faults bordering on the east Sławków Graben, its southern prolongation Nieporaz-Brodła Graben and in the Dębnik Anticline. In this region the Sławków Graben is cut by the Alpine Krzeszowice Graben, which resulted in the individualization of the southern part as the Nieporaz–Brodła Graben (Fig. 3).

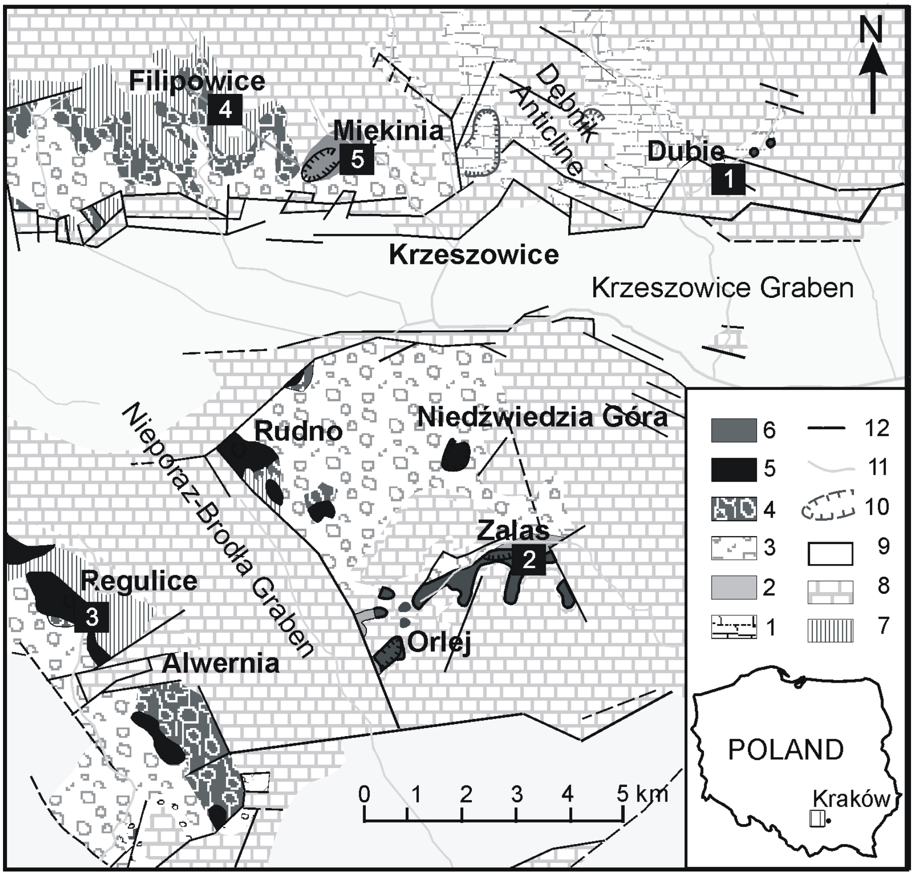

Fig. 3. Distribution of volcanic rocks in the Krzeszowice area (based on Gradziński 1993) with locations of the field trip stops: 1. Devonian and Lower Carboniferous carbonates; 2. Lower Carboniferous mudstones; 3. Upper Carboniferous conglomerates; 4. Permian conglomerates and travertines; 5. Permo-Carboniferous basaltic trachyandesite lavas and sills; 6. Permian rhyodacitic domes and rhyolitic, trachytic and andesitic dykes; 7. Permo-Carboniferous volcanoclastics; 8. Mesozoic sediment; 9. Tertiary mudstones; 10. quarries; 11. rivers; 12. faults, ■ - field trip stops.

STOP 1. Dubie – operating quarry

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Key words: complex dyke, andesite, Dębnik rhyodacite laccolith, contact aureole, predazzite.

Access: From the Kraków-Katowice road (79-E22a) about 15 km west of Kraków, turn right to Rudawa; then follow signs to Dubie. The quarry is located in the northern part of Dubie village.

The operating Dubie quarry exploits black "Zbrza" dolomites of Middle Devonian age. The formation was dated at the base of *Stringocephalus burtini* (Kaźmierczak 1971) and *Amphipora angusta* Lecompte (Baliński 1979) and is thus of Givetian age. The dark finely-crystalline, thick-bedded carbonates often display a fine lamination and fenestral fabrics with abundant brecciation. They were deposited in a shallow marine, highly saline environment (Łaptaś 1982).

The sedimentary sequence is cut by a complex dyke up to 3 m wide (Harańczyk 1980) (Fig. 4), which has been traced for a distance of ca. 400 m. It continues from the quarry to the northeast and outcrops on Zamczysko Hill. A zonation within the igneous rock, perpendicular to the dyke walls, is marked by colour change and was taken as evidence that the magma conduit opened several times (Harańczyk, Wala 1989). Either black andesites and light trachytes (Harańczyk, Wala 1989) or andesites and dacites (Muszyński, Pieczka 1992) were described, based on the geochemical composition of rocks from the different zones.

Fig. 4. Andesite dyke in the Dubie quarry (photo J. Szulc).

Mineralogical observations do not reveal a significant difference between rocks of different colour. All varieties are composed of similar amounts of plagioclase, hornblende and Fe-Ti oxide phenocrysts, set in a plagioclase-rich groundmass. Clay minerals and quartz pseudomorphs after phenocrysts and groundmass are common in the light rock, being products of hydrothermal alteration (Harańczyk, Chłopecka 1989).

Fresh rocks contain plagioclase phenocrysts of two generations: large (0.5-2 mm) labradorite crystals with evidence of a complex history and a smaller type with higher anorthite content (Fig. 5), whereas the groundmass plagioclase is andesine. Labradorite phenocrysts show sieve texture and zonation. The neighboring crystals show either normal or reverse zoning, revealing the evolution of each crystal in drastically different conditions. These features clearly point to magma mixing. Turbulent mixing of hybrid magma on ascent in an open system is thought to be the reason for the mixing of phenocrysts with different zoning patterns (Nixon, Pearce 1987). The likely parental magmas were those, which yielded the igneous rocks of the bimodal suite of the Kraków area – viz. basaltic andesites and rhyodacites. Such a hypothesis is supported by the existence of two generations of plagioclase phenocrysts.

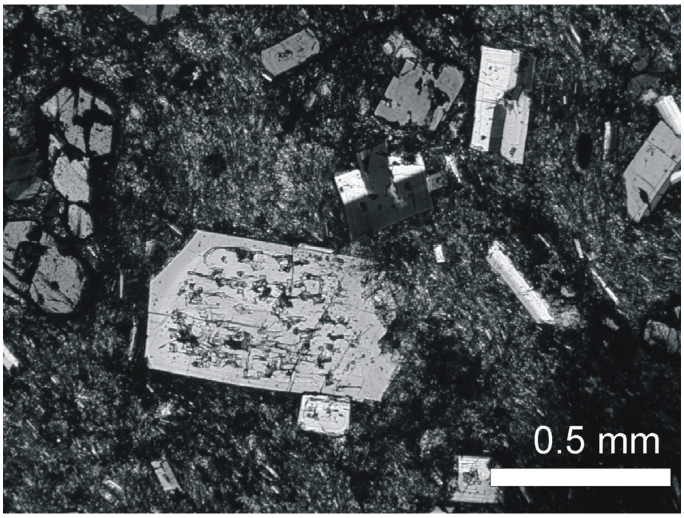

Fig. 5. Two generations of plagioclase phenocrysts: large labradorite with sieve texture and smaller twinned homogeneous labradorite – bytownite.

K-Ar dating of hornblende phenocrysts from the black andesite gave an age of 291.3 ± 6.4 Ma, which corresponds to the Carboniferous-Permian transition (Lewandowska et al. 2007).

The country rocks do not show thermal alteration at the contact with dyke. However, the majority of the rock sequence at a distance from the dyke is surprisingly metamorphosed. This phenomenon is attributed to the thermal influence of the intrusion of a rhyodacite laccolith, which was drilled at a depth of ca. 300 m. The strongest contact metamorphism is observed in the southern part of the quarry. Rhyodacite emplacement induced contact metamorphism of the wall dolomites (Lewandowska 1991), which can be summarized in the reaction:

$$CaMg(CO_3)_2 + H_2O \leftrightarrow Mg(OH)_2 + CaCO_3 + CO_2\uparrow$$

In this process bluish calcite-brucite marbles, called predazzites, formed. The process of thermal carbonate decomposition was accompanied by oxidation and removal of organic matter, causing whitening of the rock (Rospondek et al., this volume). The contact metamorphism of marls intercalated with the dolomites yielded colourful calc-silicate layered rocks – skarns, where additionally serpentines (lizardite) and garnets (grossular) formed (Lewandowska 1991).

STOP 2. Zalas laccolith – rhyodacite quarry

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Key words: laccolith, magma emplacement textures, rhyodacite, alteration processes, alteration zones
Access: From the Kraków-Katowice (79-E22a) road turn left in Krzeszowice to Alwernia, then follow the road signs to Zalas.

The Zalas rhyodacite-dacite was emplaced as a series of pulses and solidified as a laccolith (Dżułyński 1955). The laccolith is exposed at several places at the surface e.g. in Zalas, Głuchówki (Orley quarry), Frywałd, Piekło and Bór. The best outcrop is in the active quarry at Zalas.

The rising magma body migrated here into Carboniferous schists and is covered by Jurassic limestones. The contact between the laccolith and the black and thermally altered schists is visible in the eastern part of the quarry (Fig 6).

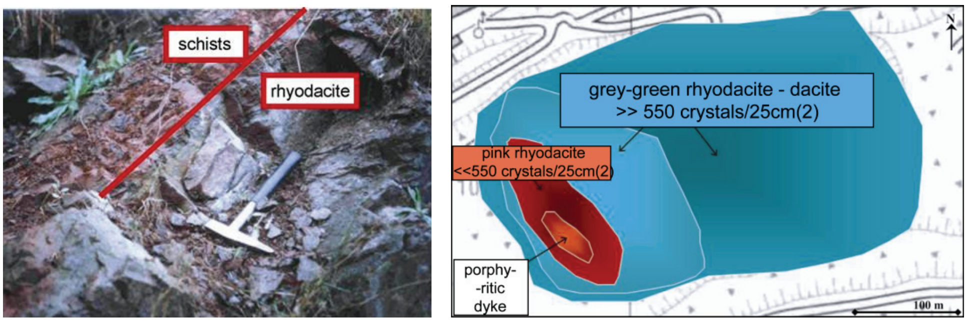

Fig. 6. Zalas quarry. On the left: laccolith contact with Carboniferous schists (white line) (Gniazdowska 2004). On the right: crystal distribution in the rhyodacite quarry points to multiple recharge of the system (Gniazdowska 2004) and to feasible link to a deep-seated magma chamber.

Rhyodacite-dacite rocks are porphyritic with variable amounts of phenocrysts of plagioclase (seldom sanidine) and quartz. In addition, dark patches in the matrix are composed of hornblende and pseudomorphs after hornblende crystals. The matrix is composed of quartz-sanidine intergrowths. Mapping of crystal distribution (Fig. 6) indicates many magma pulses rising to the exposed level in the intrusion. At many places in the quarry it can be that magma was emplaced into semi-brittle, previously emplaced material, which is brecciated due to the new pulse. The rocks appear generally in two varieties of grey-green and pink color. The color change can be related to alteration. The grey-green variety is fresher and pink. Low temperature carbonatitic fluids caused the extensive changes named by Rozen (1909) “kalifikation”. Due to fluid action the primary plagioclases were dissolved and replaced by secondary potassium feldspars (Słaby 1987). The transformation process was accompanied by albitization. The anorthite component was removed and albite preserved as a restitic phase. The excess of alkalis caused free adularia crystallization in voids and veins. The voids and veins are also filled by calcite. Alteration yielded a distinct zoning in the rocks. The zone of most intensive change is adularia-bearing. With falling values of K^+/H^+, it was transformed into an illite-smectite bearing zone.

STOP 3. Regulice – Czarna Góra abandoned quarry

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Key words: basaltic trachyandesite lavas, volcaniclastic rocks.
Access: From the Kraków-Katowice road (79-E22a) in Krzeszowice turn left to Alwernia; then follow the road to Regulice.

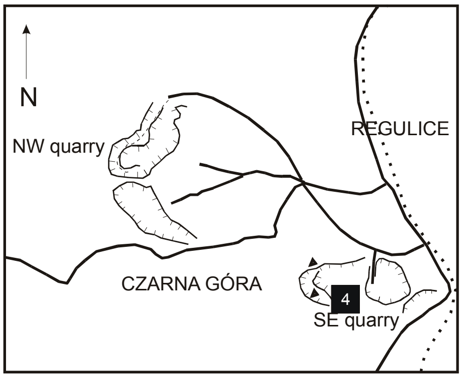

Fig. 7. Abandoned basaltic trachyandesite quarries at Czarna Góra in Regulice.

In the Nieporaz-Brodła Graben (Fig. 3) a thick series of basaltic lava flows, interbedded with volcaniclastic rocks, lie on Stephanian arkosic sandstones containing silicified araucarite stems (Birkenmajer 1952). The volcanic sequence is composed of at the most five lava flows reaching 150 m in thickness, together with associated volcaniclastic rocks (Roszek, Siedlecka 1966; Chocyk 1989, 1990). Occasionally, the sequence overlies the Myślachowice Conglomerates, and in other places is intercalated with red clastic rocks, most probably forming a distal fine-grained facies of the conglomerates. An Early Permian age was proposed, based on the Autunian flora found in intercalations of fresh-water tuffs (the Karniowice travertine) occurring within the Myślachowice conglomerate (Lipiarski 1971).

In the Regulice-Alwernia area, e.g. in the north-western Czarna Góra quarry (Fig. 7), three layers of volcanic rocks are exposed, having altogether about 40 m in thickness (Chocyk 1990). There, the basaltic flows consist of a massive central part with angular scoriaceous rubble at the base and top, forming autoclastic breccias with a tuff matrix. The sequence is comparable to aa lava flows, with a stratification consisting of solid, massive lava sandwiched between layers of fragmented clinker. Usually, the breccias on the tops consist of more scoriaceous fragments and are thicker than those at the bottom. The lava flows contain rare irregular elongated vesicles that are drawn out in response to internal flow. The scoria is usually reddish and has vesicles up to 3 cm. Some vesicles are filled with secondary minerals (Cichoń 1982; Parachoniak, Wieser 1992), and such rocks were omitted in the cited chemical analyses (Fig. 8). The volcanic rocks are basaltic trachyandesites, while the tuffs are dacites\rhyolites. For some rocks, the K_2O/Na_2O ratios are high enough to term them shoshonites.

Some volcaniclastic rocks overlying lava flows were interpreted as a result of sub-aerial fall-out tephra (lapillite). Such volcaniclastic rocks consist of framework-supported breccias with scoriaceous lapilli and blocks (Chocyk 1990) in ash matrix. Additionally, ash tephra forms thin layers intercalated with pulses of lava and clastic dykes. Altered tephra contains abundant, lava clasts, clasts of quartz, K-feldspars, alkaline plagioclases and dark and white mica, suggesting an input of terrigenous material. A high admixture of terrigenous material may suggest the phreatomagmatic nature of some eruptions.

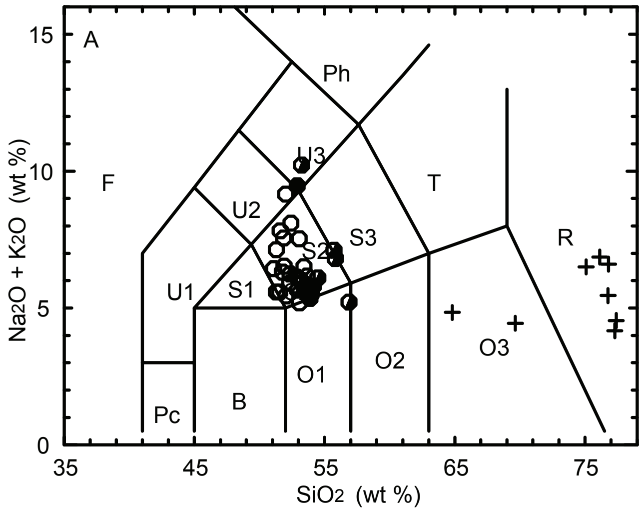

Fig. 8. The composition of mafic and associated volcanclastic rocks from the Nieporaz-Brodła graben: + - volcaniclastic rocks, ○ - massive lava flows, ○ (half filled) - subvolcanic equivalents (O1-basaltic andesite, O2-andesite, O3-dacite, S1-trachybasalt, S2-basaltic trachyandesite, S3-trachyandesite, R-rhyolite, U2-phonotephrite, U3-tephriphonolite) on the TAS and K_2O-SiO_2 (Le Maitre et al., 1989) classification diagrams. Rock analyses by Czerny and Muszyński (1997) and Chocyk (1989) are included.

In the south-eastern Czarna Góra quarry (Fig. 7), however, a thick (>15 m) coarse grained breccia body is exposed as a separate crest rock. The breccias fill a wide channel formed on the top of the lava flow (Fig. 9). The breccias are composed of variable amounts of basaltic ash and unsorted scoriaceous clasts up to 2-3 m in diameter. The presence of levees, steep deposition fronts (Fig. 9) and large angular blocks indicate a high yield strength during rock deposition, features characteristic of topographically-controlled scoria flows. This may suggest that the channel surface dip reflects the dip of the paleoslope of the volcanic edifice.

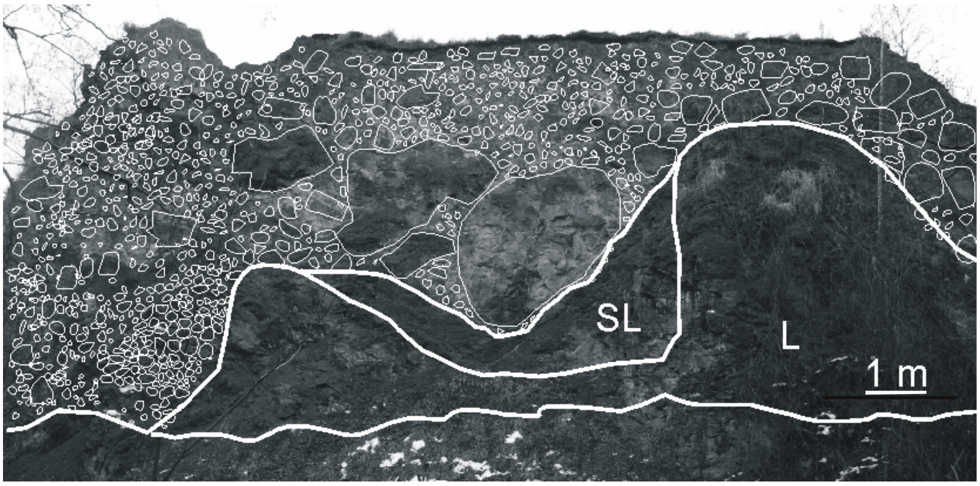

Fig. 9. Scoria flow deposit in Regulice Czarna Góra quarry, filling a wide channel, is an unsorted breccia (ca. 15 m thick) composed of variable amounts of basaltic ash and scoriaceous clasts up to several meters in diameter; L – massive lava, SL - amygdaloidal lava.

STOP 4. Kowalska Góra – abandoned quarry

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Key words: epiclastic deposits, ignimbrites

Access: From the Kraków-Katowice (79-E22a) road, turn right to Krzeszowice centre, then follow the road signs to Czerna and Nawojowa Góra. In Miekinia, turn left in front of the AGH student base, and follow a small road for ca 2 km till the end.

In the Filipowice neighbourhood, Upper Carboniferous sandstones are overlain by a ca 100 m thick sequence of early Permian conglomerates and pyroclastic deposits. This overlying sequence comprises three lithologic units: Myślachowice Conglomerates, epiclastic conglomerates and Filipowice pyroclastics.

The thick unit of Myślachowice conglomerates is built of carbonate pebbles and subordinate chert pebbles set in a reddish matrix. The composition, size and roundness of the pebbles suggest that they formed as episodic debris-flows descending from nearby Variscan carbonate hills, e.g., the Dębnik Anticline, into the Sławków Graben.

The Myślachowice Conglomerates are interfingered by sporadic layers of epiclastic conglomerates ca 1 meter thick (Fig. 10). These epiclastic conglomerates exclusively contain rounded volcanic rock pebbles reaching 40 cm in size that are set in a matrix of similar composition. An abundance of angular feldspar implies that the material was not extensively reworked and that the source was most likely local. The exposures of the volcaniclastic conglomerates show normal gradation. There are no signs of fragile pumice. Fluvial transport and deposition seems most likely. The flow energy must have fluctuated over time but it was clearly an energetic flood that transported and dropped the large boulders.

The Myślachowice conglomerates are covered by pyroclastic deposits traditionally called the Filipowice tuff. The average thickness of the Filipowice tuff is about 20 m, and the total volume about 1.6 km3 (Parachoniak, Wieser 1985). The volcanic grains are sand-sized although lithic fragments reach several centimetres. Crystaloclasts are feldspars, quartz and biotite. Among lithoclasts, rectangular porphyritic volcanic rocks predominate; limestones and mudstones are rare. The rock can be classified as a crystalo-lithoclastic tuff. These deposits were considered by Parachoniak and Wieser (1985) to be ignimbrites. The tuff is strongly altered and the original fabric is hardly visible. Even so, our observations showed that the characteristic directional fabric of Filipowice tuff is due to aligned and stretched ca. 1 cm biotite flakes that are clearly visible only on tectonic surfaces.

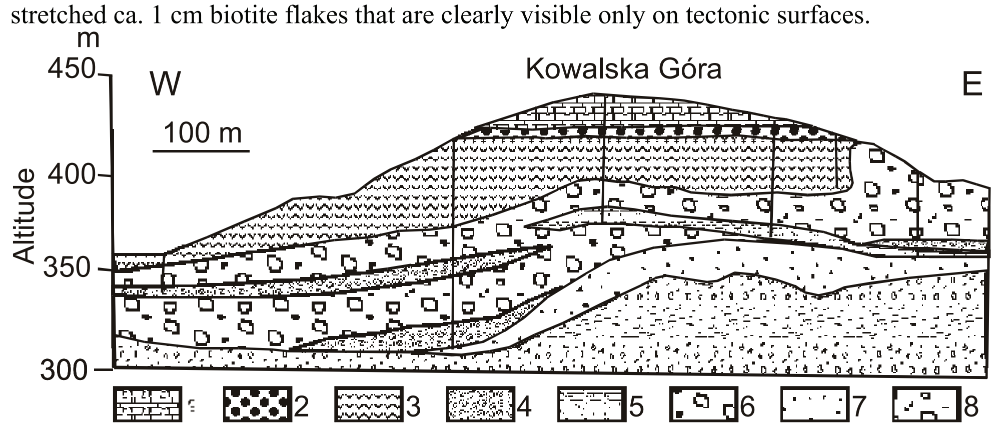

Fig. 10. Cross section of Kowalska Góra near Filipowice. Triassic: 1. dolomitic marls; 2. Bunter sandstone conglomerates. Lower Permian: 3. pyroclastic deposits; 4. epiclastic deposits, 5. Karniowice calcareous travertine; 6. Myślachowice conglomerates. Upper Carboniferous: 7. arkosic arenites. 8. sandstones intercalated with coals (based on Oberc et al. 1952 *vide* Parachoniak, Wieser 1985).

STOP 5. Miękinia - abandoned rhyodacite quarry

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Key words: lava dom, rhyodacite, alteration

Access: From the Kraków-Katowice road (79-E22a) turn right to Krzeszowice centre, then follow the road signs to Czerna and Nawojowa Góra. In Miękinia turn left in front of AGH student base, which is located in the quarry.

The magma body at Miękinia is a rhyodacite lava dome. Crystal distribution measured in the northern wall of the abandoned quarry points to a multistage magma emplacement. Crystal size and habit indicate an extended differentiation history. It is probable that the whole system is linked to a deep-seated magma chamber.

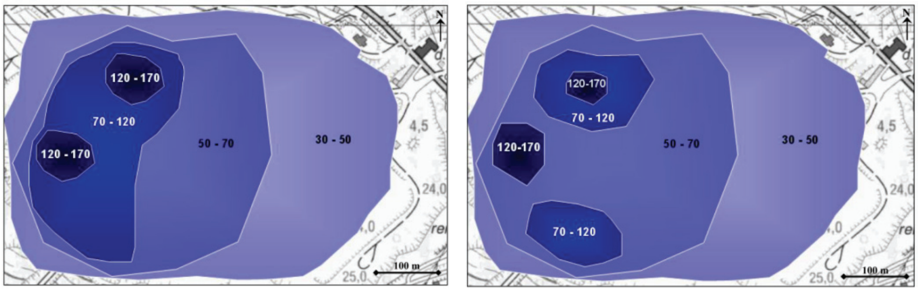

Fig. 11. Crystal distribution in Miękinia quarry show magma impulses at different stage of differentiation (Gniazdowska 2004).

The Miękinia rhyodacite is porphyritic and has a cherry-like color. The phenocrysts are mainly plagioclase, biotite and quartz. Feldspars occur as glomerophyric clusters. Under the microscope, they reveal complex zoning, with many resorption planes reflecting magma contamination processes during crystal growth. The rock is relatively fresh. Careful mapping of the quarry wall reveals however, that its upper part, close to the contact with Triassic dolomite, forms a horizontal zone where alteration significantly changed the primary composition. A mixture of carbonate and clay minerals replaced plagioclase. As at Zalas, alteration processes were governed by K-rich fluids. Through higher K activity in the fluids, plagioclases are replaced by secondary pure-potassium feldspars. Hydrothermal feldspars are water-clear and crystallized in association with carbonates.

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Introduction to field trip

Cretaceous alkaline magmatism from the Polish Outer Western Carpathians

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A classic area of igneous rocks belonging to the teschenite-picrite association is an important feature of the western part of the Outer Carpathians. This province (~ 1500 km^2) is 15-25 km wide and extends in a NE direction for over 100 km from Hranice in Moravia, Czech Republic, to Cieszyn and Bielsko-Biała in Poland (Fig. 1).

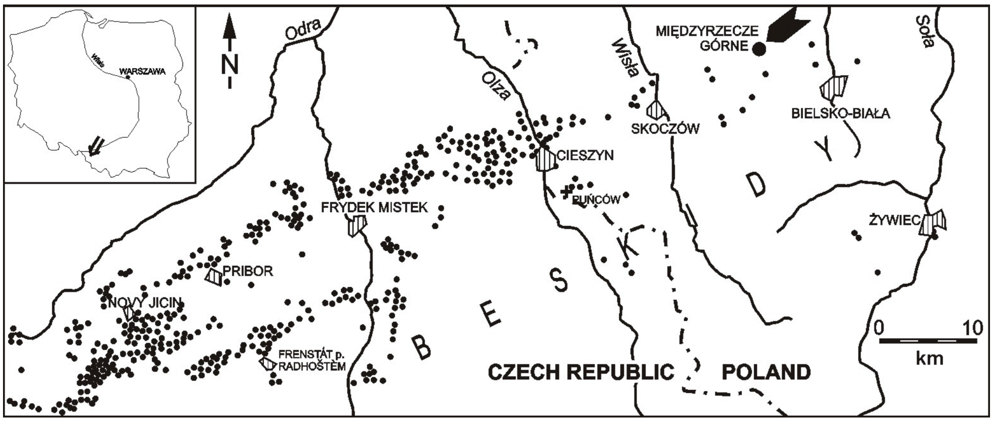

Fig. 1. Location of the picrite-teschenite association in southern Poland and in the Czech Republic (from Smulikowski 1930 and Šmid 1978).

Teschenites and related rocks outcrop in the Silesian Nappe; they are chiefly encountered in Upper Cieszyn Shales (Valanginian-Hauterivian). In Lower Cieszyn Shales (Kimmeridgian-Tithonian) and Cieszyn Limestones (Thithonian-Beriasian), they occur sporadically. Radiometric data (Grabowski et al. 2003; Lucińska-Anczkiewicz et al. 2002) indicate that the period of magmatic activity in the Silesian Basin spanned the interval Valanginian to Barremian-Aptian. The main products of the volcanic activity are shallow, subsurface sills with thicknesses varying from a few centimeters to 40 meters. The teschenite dykes and sills intruded in an extensional regime related to a horst-graben system in the soft sediments of the Silesian Basin. The initial rifting was aborted and was not followed by spreading and oceanization (Nemčok et al. 2001).

Major- and trace-element patterns, and Nd-Sr isotope values, indicate that the parent magma of the differentiated rocks series was likely to have been the product of partial melting in the upper lithospheric mantle. Geochemical modelling shows that they could have been generated by different degrees of partial melting (PM < 5-6%) of garnet-bearing upper mantle at a depth of ca 60-80 km followed by fractional crystallization (Narębski 1990; Dostal, Owen 1998). These Cretaceous alkali volcanic rocks in the External Western Carpathians can be compared to the Late Cenozoic alkali volcanic rocks of Central and Western Europe and to Mesozoic alkali volcanic rocks in various parts of Europe, e.g., the North-Pyrenean rift zone and the Northern Calcareous Alps.

The term "teschenite" was applied for the first time by Hohenegger (1861) to all granular rocks from the Moravskosliezske Beskydy Mts. Tschermak (1866) distinguished melanocratic olivine-rich rocks (picrite), confining the term teschenite to olivine-free granular rocks. The studies of Smulikowski (Cieszyn, Silesia, 1929 and the region as a whole, 1930) and Pacák (Moravia, 1926) provide basic information on the chemistry and petrography of these rocks.

The teschenite-picrite association contains a wide range of rocks with variable textures, structures and mineral abundances (Table 1). The rocks of the hypabyssal intrusions can be classified as picrites, picroteschenites, alkaline- (theralite, essexite) and subalkaline teschenites, and syenites. The mineral composition of the alkali rocks described here is relatively simple; the main phases are olivine (Fo_{90-75}), clinopyroxene, amphibole, dark mica and spinel. Among the pale minerals, feldspar and nepheline are dominant.

Table 1. Classification of the alkaline rocks from the Polish Western Carpathians.

Felsic minerals		Mafic minerals	Range of M	Rocks
feldspars	foid			
–	–	*ol ≥ flog, kaer > di*	*ultramafic*	picrite
or > pl	–	*di ≥ flog, kaer >ol±*	*melanocratic*	picroteschenite
pl > or	–	*di > kaer, bi±*		mafic teschenite
pl > or	–	*di > bi, kaer±*	*mesocratic*	subalkaline teschenite
pl > or	*feld > foid*	*di > kaer*		theralite teschenite
or ≥ pl	*feld > foid*	*di > bi*		essexite teschenite
or >> pl	*feld > foid*	*hed > fe-kaer, ann*	*leucocratic*	syenite

Abbreviations: foid - feldspathoid; feld - feldspars; or - orthoclase; pl -plagioclase; ol - oliwine; flog - flogopite; kaer - kaersutite; di - diopside; hed - hedenbergite; bi - biotite; ann - annite.

Clinopyroxene is the most abundant minerals (up to 70 vol. %) in the rock series. As is typical for alkali rocks, it exhibits hourglass zoning. In teschenite rocks, the pyroxenes vary from Al-Ti diopside to hedenbergite and, in syenite veins, from hedenbergite to aegirine-augite and Ti-aegirine.

Two main compositional trends characterize the amphiboles of the alkaline rocks. In picrites and picroteschenites, amphiboles range in composition from kaersutite and ferrokaersutite through Mg-hastingsite and Mg-katophorite to richterite. In teschenite sills, they range from kaersutite-ferrokaersutite through hasingsite (early magmatic stages) to taramite/katophorite (theralite teschenite) or Fe-richterite and arfvedsonite (subalkaline teschenite, late magmatic stages). Dark mica compositions vary from phlogopite to biotite, annite and siderophyllite.

In general, plagioclase compositions vary from An_{70}-An_{20} and Or contents increase (up to Or_{10}) with increasing Ab. The compositions of K-feldspar grains range from

$Or_{70}Ab_{28}An_2$ - $Or_{48}Ab_{48}An_4$. Some individual grains of alkali feldspar are Ba-rich (<6 wt.% BaO). Nephelines show evolutionary trends from ~$Qz_4Ne_{80}Ks_{16}$ to ~ $Qz_{32}Ne_{62}Ks_6$ (mol.%). A first stage of primary feldspar metasomatism led to the formation of an adularia-albite paragenesis. Zeolitization, post-dating the deuteric formation of feldspar, resulted in the development of the following zeolites: analcime, natrolite mesolite, thomsonite, heulandite, harmotome and ferrierite.

In the picrites, the chemical composition of spinel varies from Al-rich chromite to Al/Cr-rich magnetite whereas the remaining rocks contain titanomagnetite oxidized to titanomaghemite. The occurrence of perovskite in the picrite-teschenite association was recorded for the first time by Włodyka and Karwowski (2000).

In the Polish Western Carpathians, outcrops of the volcanic rocks are rare. Teschenite, the most common rock type in this region, will be presented in Rudów (STOP 1) and Boguszowice village (STOP 2, 3) north of Cieszyn (Fig. 2).

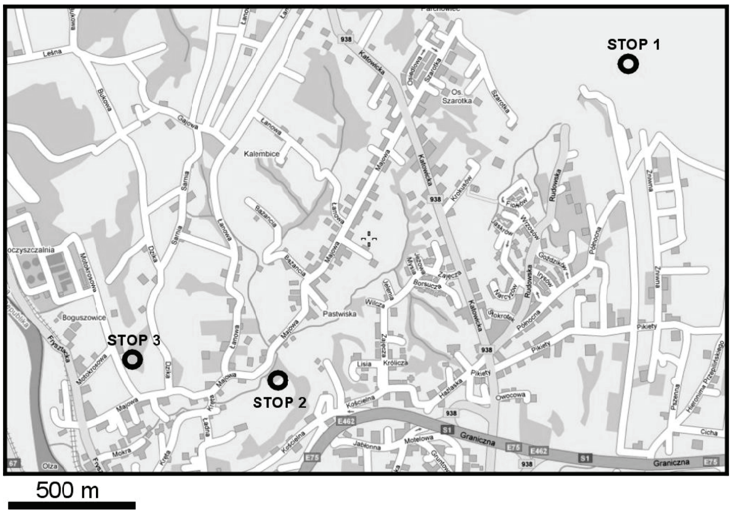

Fig. 2. Map of the Cieszyn area with field stops indicated. STOP 1 – Rudów, STOP 2 and 3 – Boguszowice.

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Field trip - Cretaceous alkaline magmatism from the Polish Outer Western Carpathians

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Key words: alkaline rocks, Cieszyn Magmatic Province, picrite, picroteschenite, teschenite, syenite,

Access: Starting out from Miękinia, travel towards Krzeszowice, ca 6 km away in the south-westerly direction. Before entering the center of Krzeszowice, take the turn (road No 79) via Trzebinia to Chrzanów 17.8 km away. There, turn west and go along road No E40 (E462) in the direction of the Katowice-Wrocław road. Near Mysłowice, which is some 34 km away from Chrzanów, turn to the south and go directly to Tychy. The motorway between Mysłowice and Tychy is called Wschodnia Obwodnica GOP and is marked on general maps as road No E462, E75 or 51. From Tychy, travel to Bielsko Biała 69 km away along the motorway identified as No 1, E75 and E462. In Bielsko Biała turn the west towards Cieszyn 36 km away on E462 (E75, 51) at the S1 crossroad. In Cieszyn, go north on road No 938. After 500 m, turn right and travel straight along Rudowska Street. After 300 m, turn right again and go ca 150 m to STOP 1 (49°46'50.21"N, 18°38'45.01"E).

Afterwards, return to road No 938 and go right for 1.3 km to Katowicka Street. Turn left on Majowa Street towards STOP 2 (49°46'10.73"N, 18°37'30.46"E) located 1.4 km away.

STOP 1. Rudów

The massive central parts of the Rudów sill can be observed in the small, abandoned quarry (Fig. 3) while, in the Piotrkówka stream section, the upper margin and the contact between sill and sediments are visible. The top 0.2-0.3 m of the sill is chilled teschenite containing numerous microphenocrysts of clinopyroxene and olivine (largely pseudomorphed). This very fine-grained chilled upper margin grades, over ca 2-3 m, through fine-grained mafic teschenite to the typical medium-grained theralite teschenite comprising elongate plagioclase laths sub-ophitically intergrown with purplish-red, sector-zoned, subsilicic diopsides. Amphibole, a relative common phase, occurs as single crystals or epitaxial overgrowths on clinopyroxene. This type of teschenite rock is mainly exposed in the closed quarry (Fig. 4a). Syenites (Fig. 4), which may occur as small irregular bodies with sharp boundaries in the upper part of the sill, or as veins cross-cutting the upper or lower chilled margins, are absent in these outcrops.

Fig. 3. Theralite-teschenite sill in the northern part of the Rudów quarry.

The pyroxenes are among the most abundant minerals (<70 vol. %) in all rock types of the sill. They vary from microlites (< 0.35 mm) in chilled margins to prismatic, euhedral crystals about 1.5 mm across and 5 mm long in teschenite. Generally, the teschenite clinopyroxenes are subsilicic diopsides while the clinopyroxene in syenite is hedenbergite. Amphiboles vary in modal abundance from 2 % (syenite) to 30 vol. % (mafic teschenite). They vary from microlites (< 0.3 mm, chilled margins) to prismatic, euhedral crystals (< 6 mm, teschenite) and needle-like crystals (< 10 mm, syenite). The amphibole compositions range from kaersutite (teschenite) to ferro-kaersutite (syenite) with reactionary green rims of hastingsite. The plagioclase grains have homogeneous cores (>> An_{58}) and zoned rims (< An_{23}). Rims of alkali feldspars occur on the lath-shaped plagioclase grains in teschenite rocks whereas separate, bar-shaped grains of K-rich feldspar ($Or_{72-52}Ab_{28-48}An_0$) dominate in syenite rocks.

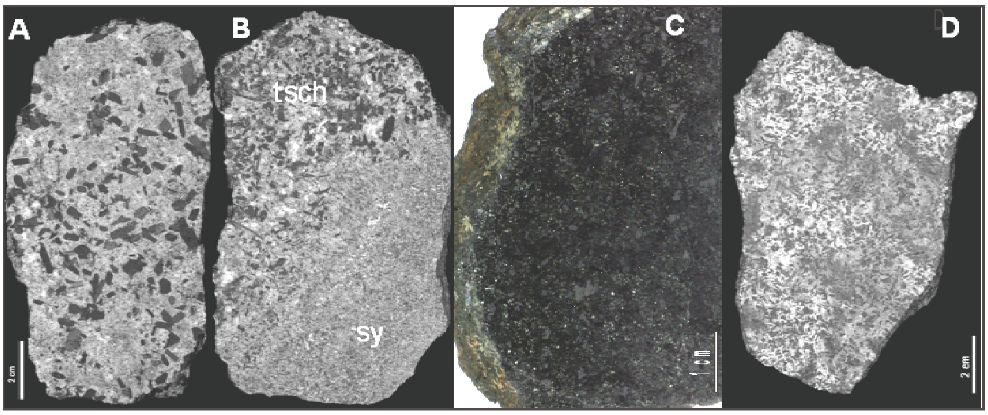

Fig. 4. Microphotographs of magmatic rocks from the Cieszyn area: STOP 1. A – theralite teschenite, B – boundary between syenite (sy) and theralite teschenite (tsch). STOP 2. C – picroteschenite; STOP 3. D – subalkaline teschenite.

STOP 2. Boguszowice

Fig. 5. Picroteschenite in small quarry in Boguszowice near Cieszyn.

In a small closed quarry in Boguszowice, the central parts of a picroteschenite sill are visible (Fig. 5). This is a fine-grained rock of grey-black colour with macroscopically visible phlogopite lamellae (Fig. 4c), which differs from picrite in its lower olivine content (> 10 vol.%) and in the presence of feldspars in the matrix. The phenocrysts (>20 vol.%). are mainly clinopyroxenes, less commonly phlogopite. Green aegirine, locally overgrowing Al-Ti diopsides, is present in accessory amounts. Opaque minerals (> 10 vol.%) are evenly distributed throughout the rock. Diopside and phlogopite are common groundmass minerals and kaersutite less so. These are associated with lesser amounts of titaniferous magnetite. Feldspars replaced by analcime. Phlogopite encloses spicular- or isometric apatite (> 3 vol.%).

STOP 3. Boguszowice, Olza Valley

In this quarry (Fig. 6), teschenite rocks occur which are silica-saturated (< 10% normative quartz). This type is composed mainly of plagioclase (> 55 vol.%) and clinopyroxene (augite < 30 vol.%) with secondary quantities of biotite, ferro-kaersutite (> 5 vol.%) and Fe-Ti oxide (Fig. 4d). The bulk of the rock is composed of plagioclase laths ophitically intergrown with clinopyroxene crystals. Analcime occurs most commonly as wedge-shaped crystals in the interstices between plagioclase laths. In these types of rocks the following compositional trend of NaCa- to Na-amphibole was established: Mg-katophorite $\Rightarrow$ katophorite $\Rightarrow$ Fe-richterite and arfvedsonite.

Fig. 6. Teschenite in abandoned quarry in Boguszowice, Olza Valley.

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