The Lądek-Śnieżnik Metamorphic Unit – Recent State of Knowledge

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Introduction

The Lądek-Śnieżnik Metamorphic Unit (LSMU) forms eastern part of the Orlica-Śnieżnik Dome (OSD) is the easternmost unit of the Sudetes (Lugicum). The OSD occurs in the hanging wall of the generally W-dipping Moldanubian Thrust Zone, the footwall of which is composed of the Moravo-Silesian units (MS) (Fig. 1). This zone is recently interpreted as an accretionary wedge developed by an oblique collision between the OSD domain of the Sudetes and the Brunnian domain of the MS (Schulmann and Gayer, 2000) in Visean to Namurian times. Another Visean collision took place in the West Sudetes, the record of which occurs in the East Karkonosze and the Kaczawa units, terminating the generally E-directed subduction (Franke and Żelaźniewicz, 2000; Mazur and Aleksandrowski, 2001). Accordingly, during Carboniferous collisions the Sudetes were subjected to roughly W-E shortening. The final architecture of the OSD likely developed due to this shortening. In the OSD core, a variety of (ortho)gneisses (Śnieżnik and Gierałtów) are refolded with a varied series (Stronie[-Młynowiec] Fm.) of mica schists, paragneisses, marbles and bimodal volcanogenic rocks metamorphosed under the middle and lower amphibolite facies conditions. In the LSMU, there are tectonic slices of (U)HP eclogites and granulites set in the gneisses. On the west the OSD is mantled by greenschist facies metapelites and metabasites (Nové Město Fm.); they are beyond the scope of the excursion which focuses on the LSMU.

Lithology, stratigraphy and age of the core units

Varied series

A crude stratigraphic column for protolith of the c. 4–5 km thick Stronie (-Młynowiec) fm. was dominated by pelitic to psammitic deposits, with calcareous and bimodal volcanogenic rocks more abundant toward the top. Earlier data assigned metabasites to a volcanic arc (Wojciechowska, 1986). Later geochemical reevaluation of these rocks pointed, however, to an ensialic rift setting and very limited crustal attenuation that never reached true oceanic stage (Floyd et al., 1996, 2000). Metabasites of WPB type are found to pass laterally to the Stronie deposits with which they have been tightly folded, whereas those of MORB-like signature form more massive and sharply delineated bodies (Nowak and Żelaźniewicz, this volume). Acid metavolcanogenic rocks traditionally referred to as leptites are mostly rhyolitic tuffs and tuffites geochemically akin to the Gierałtów and Śnieżnik gneisses (Wojciechowska et al., 2000). The leptites share tectonometamorphic history with the Stronie mica schists (Murtezi, this volume; STOP 1). Crystalline limestones and dolomites also underwent similar deformational story as the host mica schists (Jastrzębski, this volume; STOP 4). Unpublished results of Pb-Pb datings of two zircon samples from acid metavolcanic rocks yielded the age of 521 Ma (Kröner et al., 1997), which points to (bimodal) volcanic activity at the early/middle Cambrian turn. Palaeontologic data for marbles, quartzites and paragneisses (Gunia, 1997 and references therein), although controversial, suggest Late Proterozoic-Early Cambrian age of the Stronie Fm. The Stronie Fm. clearly represents infilling of an ensialic basin most likely deposited on the Cadomian basement.

Gneisses

Gneisses of the LSMU are traditionally subdivided into two types referred to as the Śnieżnik and Gierałtów gneisses (Fischer, 1936; Don, 2001a,b). Genetic relationships of the two types and their age relations are unclear and still debated (Smulikowski, 1979; Borkowska et al., 1990; Don, 1977; Don et al., 1990; Don, 2001a,b; Turniak et al., 2000; Kröner et al., 2001). They form a wide variety of rocks ranging from relatively fine-grained biotite, streaky or homogeneous, often migmatitic gneisses to coarse-grained rodding, flaser to mylonitically layered augen orthogneisses. With the criteria used so far, clear assignments of these variants to either the Gierałtów or Śnieżnik type often appear difficult, thus subdivision into two types may prove arbitrary, hence ambiguous and misleading (Dumicz, 1988). Field evidence points to intrusion of the porphyritic granite into the already deformed and metamorphosed Stronie Fm. rocks (Don, 2001a,b) and also into other gneiss variants (STOP 2). Moreover, the augen orthogneiss which developed by mylonitization of a porphyrtic granite, contains isolated enclosures of other gneisses and migmatites trapped into a porphyrytic granite magma (Grześkowiak and Żelaźniewicz, this volume). On the other hand, Don (1977, 1982a, 2001a) reports cases of apparently younger migmatites which developed at the expense of mylonitic augen orthogneisses and intruded into them. These observations suggest two generations of migmatites (Franke and Żelaźniewicz, 2000). Such relationships make stratigraphy within the gneissic complex unclear.

Isotopic datings of gneisses have not cleared the issue yet. Rb-Sr whole rock datings yielded the age of c. 464 Ma for a fine-grained homogenous gneiss (assigned to the Gierałtów type) and the age of c. 380 Ma for a coarse-grained augen gneiss (assigned to the Śnieżnik type) carrying distinct metamorphic overprint at c. 335 Ma (Borkowska et al., 1990). However, another augen gneiss (also described as Śnieżnik type) yielded a Rb-Sr whole rock isochrone age of c. 487 Ma (van Breemen et al., 1982). U-Pb conventional and Pb-Pb evaporation datings of single zircon grains have failed to distinguish such age groups and only indicate that all the gneisses dated so far with these methods show ages between c. 522 and c. 488 Ma (Oliver et al., 1993; Borkowska and Dörr, 1998; Kröner et al., 1997, 2001). SHRIMP analysis of zircons yielded far more precise data recording exclusively c. 500 Ma grains, but some with c. 540–530 Ma cores, and many with 342±6 Ma thin rims (Turniak et al., 2000). Interpretations of the results depended on the method used. Oliver et al. (1993) and Kröner et al. (2001) neglected differences between gneisses and link them all with the Ordovician magma-

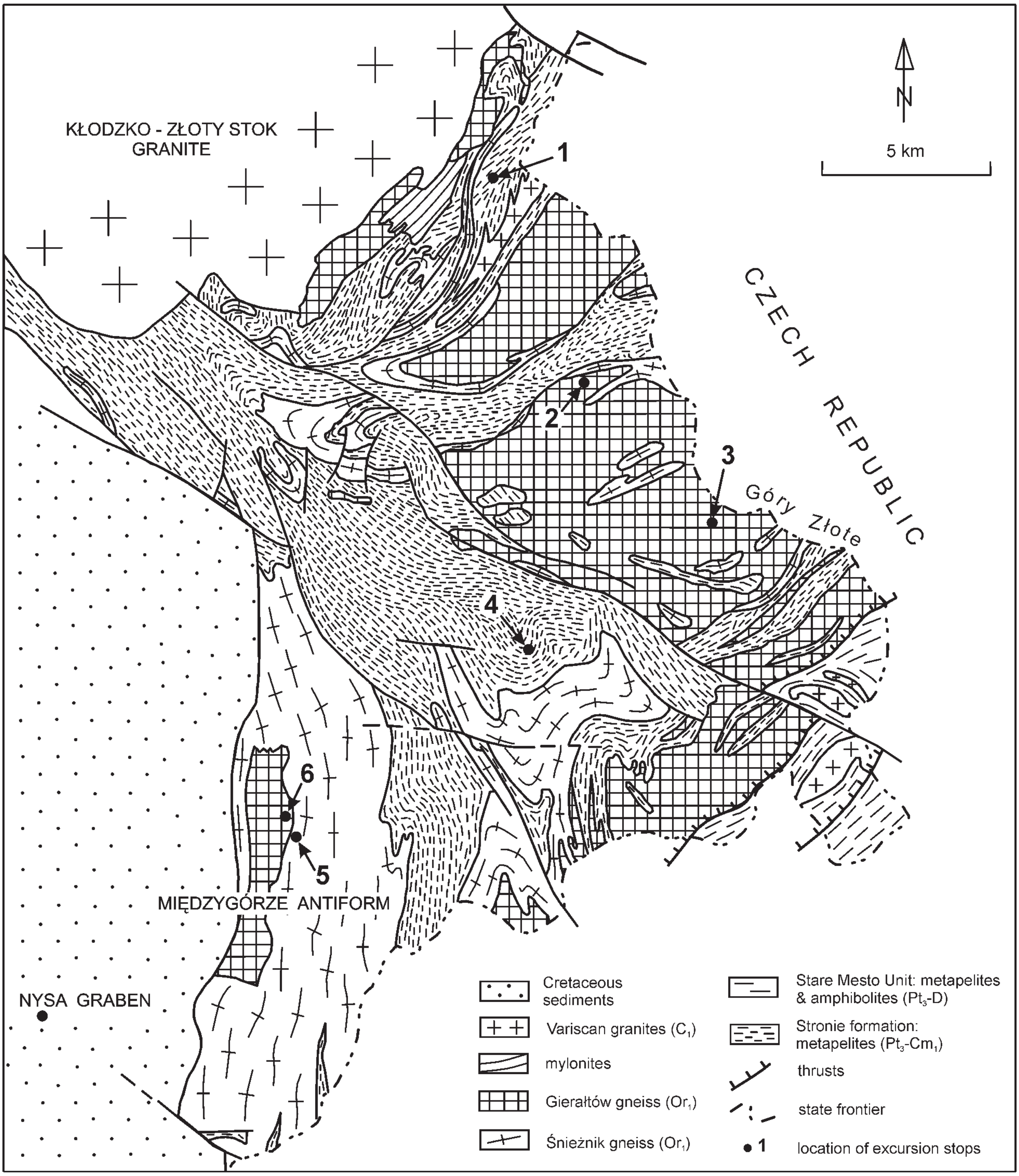

Fig. 1. Outline geology of the Lądek-Śnieżnik Metamorphic Unit after Don (1964) to show location of excursion stops (1–6).

tic arc and Caledonian orogeny involving collision of Avalonia and Baltica. Turniak et al. (2000) also assumed that all gneisses were derived from the same or similar c. 500 Ma granites, which however became differentiated by mylonitisation and consecutive HT-LP migmatisation around 342 Ma during overthrusting of the OSD units over the Moravo-Silesian ones.

Geochemical and mineralogical studies show that although most gneissic variants distinguished by mesoscopic textures are broadly similar meta-aluminous rocks, there are systematic differences between them in element contents and ratios of characteristic elements (Borkowska et al., 1990; Borkowska and Dörr, 1998). Compositions of rock-forming and accessory minerals also vary systematically. Such differences are also found within gneisses arbitrarily assigned to one of the two principal types (whether Gierałtów or Śnieżnik). Enclaves in the augen orthogneisses, either different or nearly identical chemically with the host rock, differ in compositions of feldspars, micas, and sparse garnets (Grześkowiak, this volume; STOP 5), and the differences broadly match those recognized by Borkowska (Borkowska et al., 1990; Borkowska and Dörr, 1998; Borkowska and Orłowski, 2001). Close chemical affinities and apparent syn-collision/post-collision setting signature are explained by inheritance of geochemical features by the c. 500 Ma granitic magma from its parent rocks.

Eclogites and granulites

In the OSD core, some gneiss variants contain lenses/boudins of (U)HP eclogites and HP granulites passing into garnetiferous gneisses (Smulikowski, 1967; Bakun-Czubarow, 1991, 1998; Bröcker and Klemd, 1996; Kryza et al., 1996; STOP 3). Eclogite bodies have sheared and amphibolitized margins (Dumicz, 1993; Stawikowski, 2001, this volume; Żelaźniewicz and Bakun-Czubarow, this volume) testifying to tectonic insertion into the present-day setting (STOP 6).

Eclogites and plagioclase-omphacite granulites have protoliths derived from (1) MORB-type rocks, (2) calc-alkaline rocks as well as (3) ferrogabbroic and bimodal volcanic rocks (Bakun-Czubarow, 1998). This diversity excludes single source of primary mafic rocks which might be of different protolith ages and/or come from originally different lithotectonic units, now tectonically juxtaposed. Eclogites derived from bimodal volcanic rocks occur as dispersed bodies within quartzo-feldspathic granulites (STOP 3). Isotopic ages of eclogites differ. Sm-Nd clinopyroxene-whole rock-garnet isochron ages spread between 352±4 and 329±6 Ma, which are not interpreted as timing of eclogite-facies event but the times the eclogites were removed from their HP crustal locations and cooled to temperatures preventing omphacite to grow (Brueckner et al., 1991). This agrees with a U-Pb single SHRIMP datings of oscillatory zoned zircons that yielded the age of c. 350 Ma for rims and of 525 Ma for grain cores, which is assumed to match the protolith age (D. Gebauer, unpublished data). Accordingly, first arrivals of eclogites to crustal depths occurred at c. 350 Ma, but the duration of their residence at (U)HP conditions and the onset of exhumation of the eclogites from a depth of c. 120 km remain unknown. Migmatitic gneisses immediately adjacent to eclogites in Miedzygórze yielded a U-Pb lower intercept zircon age of 372±7 Ma and a Rb-Sr thin slab whole rock isochron age of 396±17 Ma (Bröcker et al., 1997), which suggests Devonian events. Further work is clearly necessary.

P-T paths of the core units

Varied series

Tectonic juxtapositions of rocks within the LSMU are mostly evident form contrasting P-T paths of neighbouring units, although particular tectonic boundaries are difficult to locate. Recent estimates show that acid and basic metavolcanic rocks, marbles and mica schists of the varied Stronie fm., occurring in a c. 5 km wide belt between Ołdrzychowice and Śnieżnik, or in the Skrzynka-Złoty Stok belt, underwent progressive metamorphism with similar peak conditions at 560–620 °C and 7–8 kbar (Jastrzębski, this volume; Józefiak, 2000; Murtezi, this volume; Nowak and Żelaźniewicz, this volume; Romanová and Štipska, 2001). Lithologic components of the Stronie Fm. in these belts were likely uniformly submerged to c. 23–25 km depth and then uplifted without developing major tectonic breaks of dip-slip type. However, metapelite and associated amphibolite from the Bielice area depart from this coherent picture, yielding temperatures of 740±40 °C and 845±130 °C, and pressures of 9.3±1.4 and 9.1±2.5 kbar, respectively (Szczepański and Anczkiewicz, 2000), which may suggest the presence of unrecognized ductile fault.

Gneisses

Earlier P-T estimations for gneisses of the Gierałtów unit yielded T=580–670 °C and P=4–6 kbar (Smulikowski, 1979), or T=520–555° and P=4.5–8.5 kbar (Borkowska, 1996). In the Międzygórze area, the streaky migmatitic gneisses underwent progressive metamorphism as shown by changes in core-to-rim compositions of zoned Ca-rich garnets. However, the high grossular content in the garnets invalidates usage of grt-bt geothermometry. The Si-geobarometer applied to the migmatites yields the peak pressure of 10–11 kbar, while various temperature estimates give values between 510 and 550 °C (Borkowska, 1996; Grześkowiak, this volume; STOP 5). These temperatures, if correct, do not reflect migmatisation but re-equilibration during later metamorphism under conditions similar to those experienced by the Stronie Fm. rocks. However, differences in pressures estimates may confirm the notion that the Gierałtów and Międzygórze units represent different crustal sements.

Eclogites and granulites

Eclogites bodies which occur within either gneissses (mostly migmatitic variants) or granulites underwent much more severe metamorphism (Bakun-Czubarow, 1991, 1998; Bröcker and Klemd, 1996; Klemd and Bröcker, 1999). The eclogites from the Międzygórze, Śnieżnik and Radochów areas reached peak at T = 660–780°C and P * 30 kbar followed by decompression down to pressures of *10(−12) kbar and then isothermal retrogression to amphibolite facies assemblage at 9–5 kbar and c. 600 °C. They form a group of relatively lower-T and higher-P eclogites as compared to those occurring within granulites of the Gierałtów area characterized by higher-T and lower-P and different P-T trajectories. The latter underwent metamorphism with peak conditions between c. 21 to 28 kbar at 800 to 1000 °C (Bakun-Czubarow, 1998; Klemd and Bröcker, 1999). They correspond to peak meatmorphic conditions of the surrounding granulites (Kryza et al., 1996), amidst which the eclogites resided for some time (Bakun-Czubarow, 1998). This suggests that the two eclogitic groups and consequently their country rocks may have belonged to different lithospheric segments, which corroborates different provenance of mafic protoliths with different P-T paths, and possibly also with different tectonic histories.

The Międzygórze migmatitic gneisses have no contacts with the Stronie Fm., but they contain eclogite boudins thrice metamorphosed under the eclogite facies conditions; first at 770 °C and 33 kbar, then at 750–680° and 20–15 kbar, and again at 650 °C and 11 kbar (Bakun-Czubarow, 1998; Żelaźniewicz and Bakun, this volume). The adjacent gneiss reached peak between 650–700 °C and 9 kbar. The two rocks are separated by ductile shear zones, which although extremely narrow, must represent parts of a thrust system which ensured a stepwise exhumation of the UHP elements from a depth of c. 120 km at first to a depth of 65–55 km and then to a depth of 30–25 km where the eclogites became retrograded to amphibolites under conditions similar to those bringing about progressive metamorphism of the gneisses and the Stronie Fm. rocks. The problem whether and which other rocks of the OSD have undergone high-P history similar to that of eclogites and granulites has not been solved yet.

Deformation of the core units

The presence of c. 342 Ma thin rims on zircons was interpreted by Turniak et al. (2000) as a record of migmatisation following mylonitisation. The new Rb-Sr ages of phengites and biotites from ductile shear zones indicating that mylonitisation is older than 340 Ma (Lange et al., in press) correspond with this interpretation. The most recent Ar-Ar mica ages from mylonitized gneisses show that the minimum age of the mylonitisation is 334 ±3 Ma (Marheine et al., 2002). However, Kröner et al. (2001) found a microgranite dyke dated at 492 Ma that crosscuts already mylonitized granite, which suggests that the c. 500 Ma granites underwent at least two mylonitic deformations. This exemplifies a need for better resolution of the deformation story of the OSD rocks.

The early structural template of the Stronie fm. rocks consists of F_1 and F_2 folds. F_1 folds, accompanied by early intersection lineation, are recognizable in hand specimens or beneath microscope as intrafolial structures, or folded inclusions in plagioclase blasts, etc. (Teisseyre, 1973; Wojciechowska, 1972; Żelaźniewicz, 1976; Szczepański, 2001; Romanová and Štipska, 2001), more rarely in outcrop pattern (Don, 1976; Don and Gotowała, 1980). The F_1 minor fold axes and associated lineation have wide orientation scatter due to later refoldings and passive rotation in shear zones. F_2 fold overprint, with axial trends ranging from NE through to NW directions, often co-axial with F_1 folds but with different plunge angles, produced main large-scale and small-scale structures in the OSD.

The S_2 axial planes are shallowly or moderately to steeply dipping to various directions but mostly roughly W-ward in the western part of the OSD and E-ward in its eastern part, with many departures because of further large-scale refoldings. Such an attitude of the S_2 planes and often the subvertical folding mirror of F_2 folds suggests that F_1 folds in the Stronie fm. rocks were dominantly upright to inclined with subvertical S_1 foliation, while F_2 ones were commonly overturned to recumbent. These structural relationships suggest that the early W-E subhorizontal shortening of D_1 was generally replaced by subvertical shortening during D_2 (Dumicz, 1979). S_2 foliation in the varied Stronie rocks is heterogeneous, invariably expressed by progressive mineral assemblages and varies from spaced crenulation cleavage to dense schistosity. The latter developed in high strain zones connected with ductile thrust to strike-slip faultings that represent either further stages of progressive D_2 deformation, or later reactivation of the S_2 surfaces. In mica schists, such zones are often overlooked, but they can be located along the lines of abrupt changes in orientation of F_2/L_2 structures (e.g. Żelaźniewicz, 1978) or around rheologically harder lithologies, such as marbles or metavolcanic rocks (Jastrzebski, this volume; Murtezi, this volume). Passive rotations of earlier linear features in the reactivated foliations (S_1 and S_2) due to N-S to NE-SW transport are often observed. The earliest D1 shearing remains unconstrained.

Mappable and mesoscopic field evidence suggests that F_1 and F_2 foldings were separated by a roughly concordant intrusion of the c. 500 Ma porphyrytic Śnieżnik granite locally truncating S_1 planes (Don et al., 1990; Don, 2001a). Subhorizontal primary lineation marked by parallel alignment of feldspar phenocrysts likely caused by magmatic flow during syn- to late-tectonic (with respect to D_1) intrusions was enhanced by ensuing subsolidus deformation in similar constrictional regime. The granite turned then into augen orthogneisses ranging from rodding (L-tectonite) to layered and laminated (S-tectonite) variants (Żelaźniewicz, 1988). Subvertical shortening D_2 also introduced roughly subhorizontal foliation into the Śnieżnik granite which was transformed into the augen gneiss, with top-to-the-N/NW/NE and top-to-the-S/SW kinematics. This shearing occurred during progressive deformation of the regional D_2 event and continued during later reactivations of the gneissosity planes.

Despite recognition of relative sequences of small-scale structures, the overall architecture of the OSD is still unclear and no unified model exists. Several cross sections for the Międzygórze-Śnieżnik or Kletno areas show a complex generally upright fanned structure with W and E-vergent folds and thrusts, the important details of which vary greatly (Teisseyre, 1973; Don, 1982b); other accounts point to controversial identifications of anticlinorial and synclinorial elements (Oberc, 1972) and dominance of the E-verging features in the northern part of the LSMU. The latter are customarily explained by E/NE-directed thrusting of the LSMU over the Moravo-Silesian units during Variscan collision of the Bohemian Massif and the Bruno-Vistulian terrane. The detailed structural observations made so far are not satisfactorily coupled with major structures, which is a task still to be done.

The presence of rocks units with apparently different P-T-d histories implies their separations by ductile fault, which are however difficult to trace. Nevertheless, their proper identification and mapping is necessary to reconsider the gross structure and evolution of the OSD. This also applies to the subsequent deformation of the core units, labelled F_3 (Teisseyre, 1973; Wojciechowska, 1972, 1975; Don, 1982a,b, 2001a,b), which is seen only in the LSMU (lacking in other parts of the OSD), mostly in the NW-SE transversal Ołdrzychoice-Śnieżnik belt of the Stronie fm. The NW-trending folds F_3 are accompanied by mineral biotite lineation. In migmatitic gneisses, the latter is seen to overprint the earlier stretching lineation and taken to prove the operation of a migmatitic front within the gneiss complex, which brought about migmatisation of mylonitic orthogneisses (Don, 1982 a, 2001 a,b).

Ubiquitous brittle overprints brought about a rich realm of kink folds connected with the conjugate sets of kink planes, of which the NW-striking system is older than the NE-trending one. NE-SW shortening responsible for the older system brought the OSD rocks into a large-scale antiform in the western part of the OSD and a synform in the eastern part.

Stop 1

Heterogeneous D2 shearing and mylonitization in leptites of the Stronie Formation.
Leader: Mentor Murtezi
Topics: Polyphase structural evolution of rocks from the Złoty Stok-Skrzynka Shear Zone
Location: Złote Mts, the E slope of the Jawornik Mt., along the road between Złoty Stok and Lądek Zdrój.

Leptites of the Stronie Formation, considered as metamorphosed acid volcanogenic rocks, are exposed in the NE-SW trending belt, along the Złoty Stok-Skrzynka Shear Zone (ZSTSZ). Conspicuous deformation caused by sinistral shearing of the D_2 stage can be observed in a number of small outcrops along the road between Złoty Stok and Lądek Zdrój. Leptites underwent heterogeneous zonal mylonitization, the kinematics of which is

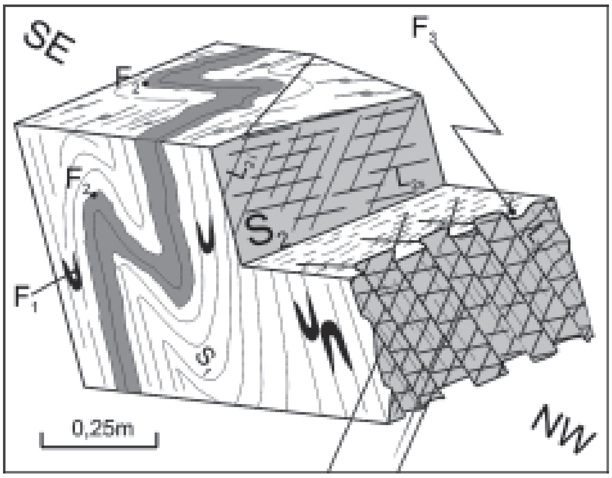

Fig. 2. Schematic sketch showing the sequence of structural features observed within the ZSTSZ leptites.

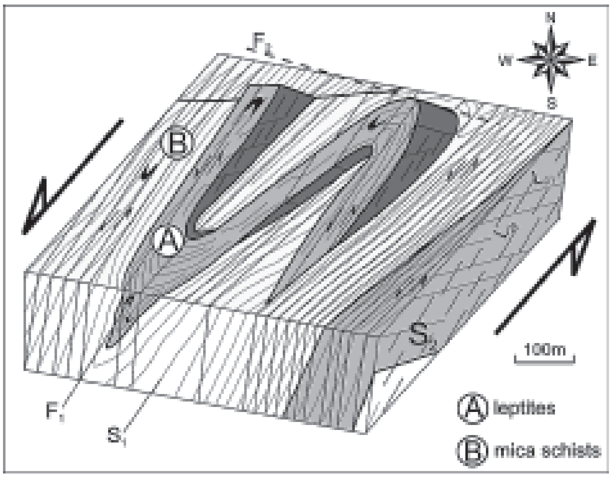

Fig. 3. Block diagram, showing mechanism of the development of the Bzowiec fold during the D2 sinistral shearing.

expressed by asymmetrically elongated and sheared feldspar augens.

During the earliest recognisable stage of deformation (D_1) tight, isoclinal folds F_1 were developed with the penetrative axial plane foliation S_1. Early shearing along these planes remains unconstrained. Orientation of S_1 varies, showing maximum ~320/70. Folds F_1 form now intrafolial relicts. Their axes plunge at a low angle to the NE and NW. Successive stage (D_2) led to folding, shearing and mylonitization in sinistral oblique-slip regime. The axes of tight, non-cylindrical folds F_2 plunge steeply towards NE. Shearing and mylonitization occur in many places parallel to the composite foliation S_2, which has resulted from the transposition of S_1. However hinges of F_2 folds in leptites occur in low strain areas with less intense shear band cleavage (S_2). On the surfaces of steeply dipping to the NW foliation S_2, stretching lineation L_{2S}, plunging under low angle to the SW, is visible (Fig. 2). Locally on the S_2 surfaces can also be seen lineation L_{2i}, developed due to intersection with the S_1 foliation. Another – noticeable at this locality – structural feature of the leptites is the occurrence of kink folds F_3 and NW-SE-trending corrugation lineation L_3, developed parallel to the fold axes.

Rocks of the ZSTSZ underwent polyphase tectono-metamorphic evolution (see Murtezi, this volume). Progressive deformation under sinistral simple shear conditions of stage D_2 controlled the majority of tectonic features observed in this area. According to the observations of shear sense indicators, which show consistent kinematics over the entire area (lack of opposite shear senses on limbs of F_2 folds), development of F_2 folds can be connected with sinistral shearing, recorded by the stretching lineation L_{2S}. It is suggested that prominent macrostructure of the area – situated about 1,5 km to the SW of this locality – the Bzowiec fold (Don, 1964; Don and Gotowała, 1980) was developed under this deformational regime (Fig. 3). The described D_2 folding and shearing were interpreted as one progressive event, although it is possible that the S_2 planes were reactivated during later ductile overprint.

Stop 2

Structural record in the Gierałtów gneiss.
Leaders: Jacek Szczepański and Robert Anczkiewicz
Topic: Deformation sequence in the Gierałtów gneiss
Location: Lądek Zdrój, rock scarp on the right bank of the Biała Lądecka river.

The Gierałtów gneiss is the dominant lithological unit in the eastern part of the Orlica Śnieżnik dome. It is formed by ortho- and paragneisses, which contain smaller bodies of high pressure (HP) and ultra high pressure (UHP) granulites and eclogites. This and the next outcrop compare some of the structural features developed in HP and UHP rocks as well as in the surrounding Gierałtów gneiss.

The exposure in Lądek Zdrój represents thinly laminated, fine grained, at places migmatitic, gneiss of granitic composition. Locally, up to 1 m thick, lenses of metabasites occur. This sequence was intruded by granite dykes, whose example can be seen in the E-part of the outcrop. The dyke is fine grained, and unlike the host rock, shows only weakly developed planar fabric. The main mineral paragenesis in the gneiss is represented by quartz, K-feldspar, plagioclase, muscovite and biotite and was formed under upper amphibolite facies conditions. However, Bröcker and Klemd (1996) found relics of UHP assemblage (garnet + titanite + zoisite) in the gneisses exposed directly at the contact with eclogites in Międzygórze area. Subsequent PT estimates provided by the latter authors established peak metamorphic conditions as P = 31 kbars and T = 790 °C. This result indicates UHP conditions, similar to those obtained for eclogites and granulites in this region (see next stop).

The best time estimate for the amphibolite facies metamorphic event recorded in the Gierałtów gneiss is provided by U-Pb SHRIMP zircon dating from orthogneisses near Międzygórze. 342 ± 6 Ma age obtained for zircon rims was interpreted as closely approximating thermal peak (Turniak et al., 2000).

Deformation within the gneisses on the regional scale is quite heterogeneously distributed but the main features can be traced nearly in the whole Śnieżnik area. Gneissic foliation formed under amphibolite facies conditions is deformed by early isoclinal NE-SW and NW-SE oriented folds. The main foliation planes bear stretching lineation, which generally, trends NE-SW and is defined by elongated feldspars and quartz-feldspar aggregates. During the same stage of deformation parallel to the foliation planes, up to tens of cm wide, ductile shear zones developed. Weak, but consistent kinematic indicators show top to the NE sense of shear (Cymerman, 1992). However, Żelaźniewicz (1991) reported kinematic indicators displaying both top to the NE and top to the SW asymmetry. According to Żelaźniewicz, (1991, 1988) opposite shear senses resulted from N-S coaxial extension caused by E-W compression.

Stop 3

Ultra high pressure Gierałtów granulites.
Leaders: Jacek Szczepański and Robert Anczkiewicz
Topic: Comparison of structural evolution of the UHP granulites and the surrounding rocks
Location: Rock scarp on the right bank of the Biała Lądecka river, Stary Gierałtów village, 10 km SE of Stronie Śląskie.

Stary Gierałtów granulites form a large lensoidal shape body up to 2 km wide and 12 km long extending from SW to NE. The predominant lithological type is felsic granulite composed of quartz, plagioclase, K-feldspar, biotite garnet and kyanite. The second, less abundant, mafic type, additionally contains significant amount of clinopyroxene and devoids of K feldspar. Locally, in the granulites small lenses of eclogites occur, which bear quartz pseudomorphs after coesite (Bakun-Czubarow, 1992). The protolith of the granulites was described either as interlayered acid and basic tuffs (Pouba et al., 1985) or as bimodal volcanics with small admixture of sedimentary material (Bakun-Czubarow, 1992). The PT conditions for the UHP event in granulites and eclogites are similar and were determined as minimum c. 27 kbars pressure, whereas estimated range of temperature varies between 800–1000 °C (Pouba et al., 1985; Bakun-Czubarow, 1991; Kryza et al., 1996; Klemd and Bröcker, 1999). However, Štipska et al., (2001) suggested significantly lower PT conditions for the HP event at ~800 °C and 18 kbar. Lower P-T requilibration of the UHP rock complex was assessed as 630 °C at pressure of 11 kbar (Steltenpohl et al., 1993) and ~560 °C at pressures of 6–8 kbar (Bröcker and Klemd, 1996). Sm-Nd dates obtained for garnets from both the granulites and eclogites provide an age range for the UHP episode between 340 and 369 Ma (Brückner et al., 1991; Klemd and Bröcker, 1999). $^{40}Ar/^{39}Ar$ cooling ages obtained on hornblende, muscovite and biotite range between 328–338 Ma implying rapid exhumation of the UHP complex (Steltenpohl et al., 1993).

The granulites are surrounded predominantly by high grade gneisses (described as mainly of Gierałtów type) and by subordinate high grade metasediments of the Młynowiec-Stronie formation (Don et al., 1990). Tectonic position of UHP rocks has been variously interpreted. Finckh and Fischer (1938) and Don (1991; 2001) suggested that granulites occupy the core of an antiform. Conversely, Oberc (1972), Pouba et al. (1985), Dumicz (1993) and Szczepański and Anczkiewicz (2000) argued that granulites form the central part of a synform. Moreover, Don (1990) and Don et al., (1990) considered UHP rocks as exotic blocks tectonically incorporated into gneisses at the final stage of its structural evolution. On the contrary, geobarometric calculations performed by Bröcker and Klemd (1996) lead the latter authors to conclude that the Gierałtów gneiss, shared an ultra-high pressure event with granulites and eclogites (see also stop 2).

The structural evolution of the Gierałtów granulites is difficult to unravel due to only very few in situ exposures. Thus, large amount of structural data has been derived from studying loose boulders. In this exposure foliation of the granulites expressed by differentiation of the rock into dark (biotite) and light (quratzo-feldspathic) lamina is deformed by small scale, approximately upright folds. Stretching lineation is, similarly to gneisses, NE-SW oriented and parallel to the fold axes. Additionally, observations performed on loose blocks show that within UHP rocks, foliation is deformed by small scale isoclinal folds analogous to those observed in the gneisses. The relationship between the fold axes and stretching lineation is always parallel and is very consistent on the regional scale. Strong similarity of the small scale structures observed within the granulites as well as in the surrounding gneisses suggests that both units shared their deformational history since the very early stage (Dumicz, 1993; Szczepański and Anczkiewicz, 2000).

Stop 4

Marble interbeds in mica schists of the Stronie Series.
Leader: Mirosław Jastrzębski
Location: SW slope of Krzyżnik Mt.
Topic: Deformation sequence in the varied series of the Lądek-Śnieżnik Metamorphic Unit.

The quarry “Krzyżnik” is localised within marbles of the eastern limb of the large-scale Krzyżnik fold. The outcrop exposes deformed tremolite marbles surrounded by staurolite-bearing mica schists, the structural relations of which attract geologists’ attention (e.g., Don, 1976). In the Krzyżnik Mt. region structures of 5 deformation episodes are recognisable which developed under ductile medium-grade metamorphic conditions (D_1, D_2) then low-grade to brittle (D_3, D_4, D_5) (see Jastrzębski, this volume). In the quarry, D_2 and D_4 structures can be observed.

D_2 stage is represented by second-order fold F_2 several meters large in amplitude connected with the major overturned Krzyżnik synform. Z and S-shaped tight, non-cylindrical higher order folds on limbs and M-shaped folds at the hinge areas form a set of parasitic folds, which reflects geometry of that second-order structure (Fig. 4). F2 fold axes plunging shallowly towards N show scattered orientation from 324/5 to 20/25, with maximum at 344/15. In marbles, the axial planar foliation S_2 dipping at low angles toward NE is defined by parallel arrangement of flattened dolomite and needle-shaped tremolite blasts. Parallel to the F_2 fold axes, well preserved lineation L_2, caused by the intersection of S_1 and S_2 foliations, can be observed. Weakly visible stretching lineation L_{2f} perpendicular to L_2 was produced by the flexural slip on the S_1 planes. Regional shear overprint top-to-the-N on reactivated planes S_2 (D_3) recorded in the region cannot be seen in the quarry. The D_4 structures are more frequent within mica schists than within marbles, which were more rigid at the time of D_4 deformation. Several millimetres to several centimetres scale vertical, open, concentric or king folds F_4 and crenulation lineation L_4 dip towards NE under moderate angles. The axial planes of the F_4 folds form to set of complementary surfaces – more frequently 120/70 and 330/60.

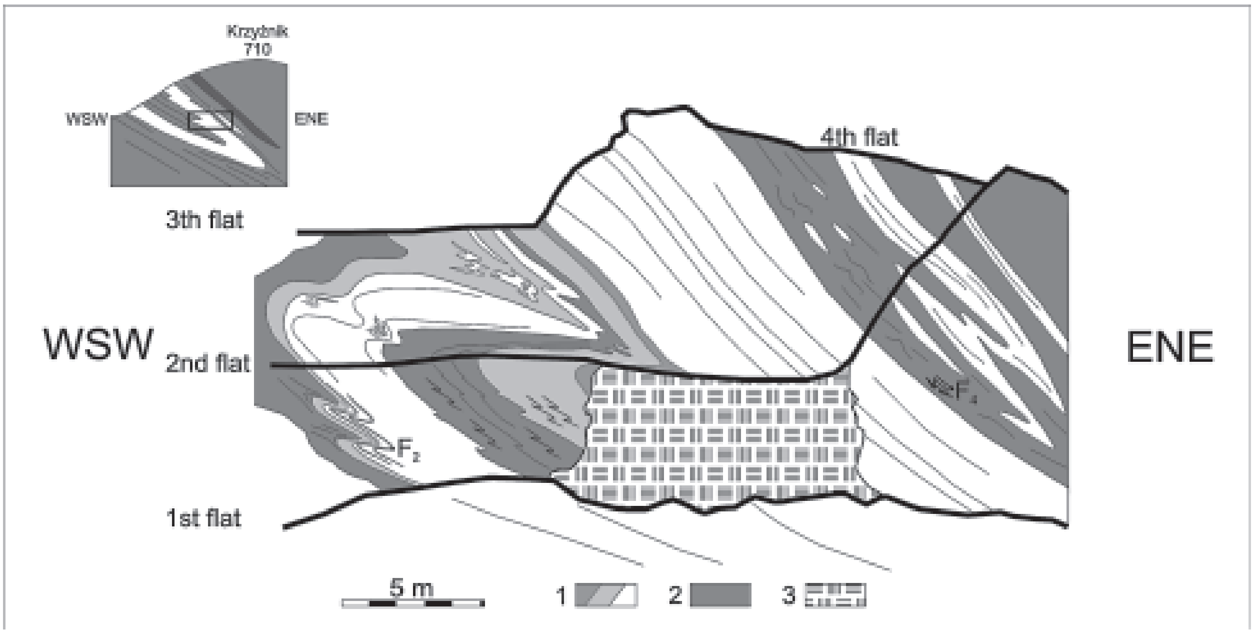

Fig. 4. A sketch of the quarry "Krzyżnik". 1 – carbonate rocks, 2 – mica schists, 3 – heap.

Stop 5

Enclaves in the Śnieznik metagranite.
Leader: Aleksandra Grześkowiak
Location: The right bank of the stream Wilczki, c. 1800 metres from the centre of Międzygórze.
Topics: Significance of gneissic enclaves for the petrogenesis of the porphyrytic Śnieżnik metagranite.

The stop is located in the southern part of the Międzygórze antiform which contains the fine-grained, migmatitic (Gierałtów) gneisses with UHP eclogite bodies in the core and coarse-grained, augen rodding to layered gneisses (Śnieżnik) in the limbs. The augen gneisses developed from the c. 500 Ma porphyritic Śnieżnik granite by heterogeneous deformation (L to LS tectonite) imparting characteristic rodding fabric to the rocks. It brought about roughly N-S to NE-SW oriented subhorizontal stretching lineation associated, wherever present, with flat-lying mylonitic foliation. This contrasts strongly with steeply disposed foliation in outcrop scale enclaves of fine-grained biotite migmatitic gneisses (Gierałtów).

In the easternmost part of the stop, a crag in the wood on the right side of the stream Wilczka, one can observe coarse-grained, characteristically pinkish rodding orthogneiss of L-tectonite type developed from the c. 500 Ma Śnieżnik granite. Constrictional strain due to roughly N-S subhorizontal stretching produced gently plunging strong rodding lineation (160–170/15–20) and subhorizontal faint foliation (20/15–20 to 200/15–20). Note occasional small biotitic pods and enclaves. Mineral composition: K-feldspar, plagioclase (15–22 % An and 0–12 % An), quartz, biotite (#mg 0.32 core–0.39 rim), phengite (3.1 rim–3.54 core Si p.f.u.), and very rare garnet (60 % Alm + Sps, 40 % Adr + Grs).

In the westernmost part of the stop close to the bridge over the stream Wilczki, a pack of gneissic enclaves occur in the augen gneiss (Śnieżnik metagranite). The augen gneiss has mylonitic foliation dipping gently to S or SW (190–220/10) and subhorizontal rodding lineation (190/10). Enclaves differ in their mineral composition and structure. The largest one consists of relatively fine-grained biotite gneisses with two foliations, of which the younger is subvertical (100/85) to moderately dipping and axial planar to small scale disharmonic ptygmatitic folds. Two sets of mineral lineations (dip and strike parallel) are observed on the steep foliation.

Plagioclases of the migmatitic enclave have varying compositions 0 % An, 5–12 % An, 15–22 %. Biotites have #mg of 0.24–0.32 rim. Si content in biotites is 2.54rim-2.82 p.f.u. and Si content in phengites is 3.13 rim–3.39 p.f.u. Garnets have 40–45 % Alm + Sps and 45–55 % Adr + Grs in cores and 58–65 % Alm+Sps, 35–42 % Adr + Grs in rims, which suggests temperature increase. Garnet in the metagranite has composition similar to that of the garnet rims in the migmatite, which may indicate inheritance. The presence of unusual Ca-rich garnets and Si-rich phengites in the Śnieżnik metagranite suggests that its magma developed via melting of a gneissic precursor now preserved in not wholly diffused migmatitic enclaves. It is unlikely that the granite has ever undergone (U)HP metamorphism.

The high grossular content in the garnets invalidates the usage of grt-bt geothermometry. The Si geobarometer (Massonne and Schreyer, 1987) applied to the Międzygórze migmatites yielded the peak pressure of 10–11 kbar at temperature of c. 550 °C obtained from two-feldspar geothermometer used for the suitable mineral assemblages in these rocks (Borkowska, 1996). The same peak pressure was estimated for the enclave. The garnet-biotite-muscovite-plagioclase geothermometer (Bhattacharya et al., 1992) shows temperature of 508–517 °C at a given pressure of 8–12 kbar, while the grt-bt therometer calibrated by Hoinkes (1986) yields temperatures of 530–612 °C for garnet cores and of 799–834 °C for garnet rims at P = 10 kbar. These results, however, are highly uncertain. The chemical zircon geothermometer (Watson and Harrison, 1983) applied for the metagranite shows temperature of 736 °C, which seems to approximate temperature of a crystallising parental magma.

Internal planar fabric in the enclave is conspicuously discordant to foliation in the augen gneiss. Enclaves are disposed roughly parallel to both rodding lineation and mylonitic foliation in the host augen gneiss. They were reoriented toward the parallelism with the stretching direction probably during magma flow. K-feldspar megacrysts growing in random across the boundary between them and original granite document that the enclaves were soft because soaked in a granitic melt from which K-feldspar crystallized. Later solid-state mylonitic foliation bends and wraps around more rigid enclaves and feldspar porphyroclasts.

In view of strong geochemical similarities of gneissic enclaves and augen gneiss all the observed differences in mineral composition and structure testify to anatectic origin of the Śnieżnik granite which at least in part developed at the expense of rocks now preserved in enclaves.

Stop 6

Eclogite lenses inside mylonitic orthogneisses in the Miedzygórze Unit.

Leader: Wojciech Stawikowski

Location: Międzygórze (Parkowa Hill).

Topic: Position of (ultra)high-pressure eclogite bodies within surrounding gneisses of the Śnieżnik Metamorphic Unit.

A position of (ultra)high-pressure eclogite bodies within surrounding gneisses of the Śnieżnik Metamorphic Unit is still unclear. The locally dense alternations of eclogites with high-P quartzofeldspathic/gneissic rocks but without evidence for shearing between them suggest primary contacts (Smulikowski, 1967), thus similar P-T histories of both types of rocks (Bröcker and Klemd, 1996). Such observations, however, do not preclude tectonic contacts between larger high-P rock bodies and their surroundings which have never passed through high-P metamorphism. Tectonic contacts of eclogites are more obvious wherever the adjacent gneisses are mylonitised.

On W slopes of the Parkowa Hill, partly amphibolitized eclogites occur. They outcrop in a narrow, 4 km long belt of migmatic gneisses (Frąckiewicz and Teisseyre, 1973). The visited exposure is one of numerous crags in the belt and allows to show the interrelationship between metabasites and surrounding gneisses. A direct contact of the mylonitised orthogneiss and the partly amphibolitised eclogite body c. 10 m long can be observed.

Mineral composition of the gneiss includes: Kfs-Pl (Olig [An 20])-Qtz-Bt-Ti-Ep-All-Ap-Zr±Grt±Chl±Ms±Mon. Garnet has uncommon composition of Alm40-60-Grs38-52-Sps5--Prp 1.-3.5. Interestingly, similar garnets occur in other gneiss variants nearby, with distinctly different fabrics. The presence of unusual garnets has prompted Borkowska et al. (1990) and Bröcker and Klemd (1996) to infer a high-P metamorphism also for gneisses enclosing the eclogites. The orthogneisses contain mylonitic foliation S1G which dips towards the E/ESE and subhorizontal N-trending stretching lineation l1G. Sometimes the l1G becomes composite because of parallel corrugations. In many places, there is also in evidence the second stretching lineation l2G which weakly overprints the l1G and plunges gently towards the SSE.

The metabasitic lenses have complex and diverse structure. Their inner parts are eclogites composed of Grt-Omp-Qtz-Phe-Rt±Ky±Hbl±Dol±Zo (Bakun-Czubarow, 1998), while their rims have been retrograded to amphibolites composed of Amph+ +Pl+Ti±Qtz±Ep±Bt±Chl±All±Grt±Rt±Phe±Zo±Ilm. The amphibolites distinctly differ from the eclogites in structural record. The eclogites, often laminated, have foliation S0E that dips toward the NW. The amphibolites directly at the contact with gneisses have structural characteristics very similar to them. Their mylonitic foliation S_{1A} and subhorizontal stretching lineation L_{1A} are oriented consistently with the foliation and lineation in the gneisses. Metamorphic conditions in the shear zones were preliminary estimated for the two kinds of rocks. For the gneisses – T = 630 °C (Hoinkes, 1986) and P = 8–9 kbar (Massonne and Schreyer, 1987) for the amphibolites – T = 625 ± 35 °C at a given pressure of 8–9 kbar (Holland and Blundy, 1994). The mylonitic fabrics of both the amphibolites and gneisses developed during the tectonic emplacement of the eclogites into their present-day surroundings.

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