Geologos, 2011, 17 (2): 71–96
doi: 10.2478/v10118-011-0005-6

Gierałtów versus Śnieżnik gneisses – what is the real difference?

Aleksandra Redlińska-Marczyńska

Institute of Geology, Adam Mickiewicz University, Maków Polnych 16, 61-606 Poznań, Poland;
e-mail: agrzesko@amu.edu.pl

Abstract

Structural and petrographic study applied to the gneisses from the eastern part of the Orlica-Śnieżnik Dome, indicate that two different types of gneiss are present. The Śnieżnik gneisses are porphyrithic granites, constricted and sheared into L-S tectonites, most commonly with augens; the Gierałtów gneisses are sheared migmatites, porphyroblastic gneisses and banded gneisses, with two sets of metamorphic foliation, intrafolial folds and lensoid leucosome aggregates or metamorphic porphyroblasts. Both lithologies were later zonally sheared and transformed into more or less deformationally advanced mylonites, difficult to be distinguished from one of the two types. Identification of the Śnieżnik and Gierałtów gneisses is possible only between zones of the late (Variscan) shearing, in which the original, pre-kinematic structures are preserved.

Keywords: Śnieżnik gneisses, Gierałtów gneisses, structural analysis, petrography, West Sudetes, Poland

1. Introduction

The Orlica-Śnieżnik Dome is a tectonometamorphic unit in between the West and East Sudetes of Poland (NE Bohemian Massif). The dome is built of various metasediments (Młynowiec-Stronie Formation) and gneisses, divided into the Śnieżnik and Gierałtów types (Fig.1). The shearing style and NE-SW orientation of the Moldanubian Fault and Thrust Zone, located at the eastern end of the Orlica-Śnieżnik Dome (Fig. 1), is found in rocks of the crystalline basement of the dome (Don et al., 1990; Lange et al., 2002). This tectonic overprint, which is related to a late stage of Variscan orogenesis (Schulmann & Gayer, 2000), caused unification of the gneisses in the region. All lithologies can now be recognised as L-S/S-L tectonites that are more or less advanced in deformation. They macroscopically vary with respect to the grain size, the colour of the rocks and the presence of shear structures (Teisseyre, 1957; Borkowska, et al.,1990; Sawicki, 1995; Don et al., 2003). However, such features are in themselves no reason to distinguish two groups of gneisses.

Both types of gneiss have a similar mineralogical composition; the geochemical and isotopic characteristics give the impression of being identical (see the review in Lange et al., 2005). Radiometric datings of zircons (Turniak et al., 2000; Lange al., 2005) yielded two ages, interpreted as the time of intrusion of a common gneissic protolith (~500 Ma ago), and metamorphism which overprinted the older rocks exclusively during the Variscan orogeny (~340 Ma ago). Geochemical and isotopic convergence, as demonstrated recently (Turniak et al., 2000;

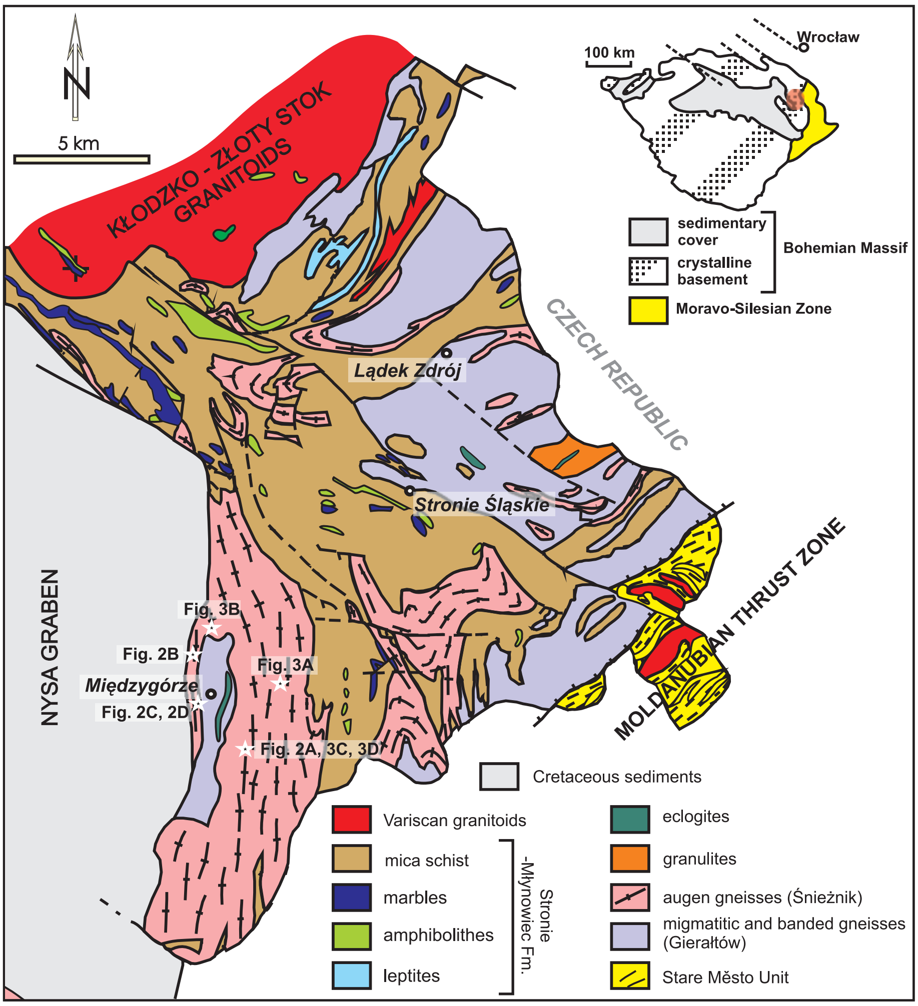


Fig. 1. Geological map of the eastern part of the Orlica-Śnieżnik Dome (modified after Don, 2001).

Lange et al., 2002, 2005), implies a similar provenance and structural history of the Śnieżnik and Gierałtów gneisses (Schulmann & Gayer, 2000; Aleksandrowski & Mazur, 2002; Don et al., 2003). The original distinction between the gneisses in the Orlica-Śnieżnik Dome became even more complicated and was finally abandoned (Gawlikowska & Opletal, 1997). This tectonometamorphic model, which seems coherent at first sight, cannot be proven in the field, and is even more difficult to prove in the Międzygórze 'transitional zone' (Teisseyre, 1957), in which the Śnieżnik and Gierałtów gneisses alternate. Near the village of Międzygórze, Dumicz (1989) discovered that some Gierałtów gneisses are older whereas other occurrences are younger than the Śnieżnik gneisses. Furthermore, the Gierałtów gneisses form isolated enclosures within the Śnieżnik gneisses from this location (Teisseyre, 1957, 1964, 1980; Grześkowiak & Żelaźniewicz, 2002; Grześkowiak, 2004).

The gneisses occuring in the eastern part of the Orlica-Śnieżnik Dome really differ from each other with respect to their types and sequence of deformation (recognizable at a macro-scale) as well as regarding their petrographical characteristics (recognizable at a micro-scale), so that these features can be used as criteria to distinguish between them. The structural and petrographical characteristics of the gneissic suite in the Międzygórze area are presented here with the objective to demonstrate that the gneisses that form the core of the Orlica-Śnieżnik Dome have a different genesis and a more complex tectonothermal evolution than in the commonly accepted, simple Variscan model.

2. Previous studies

The gneisses of the Międzygórze Antiform have been studied ever since Fischer (1936) introduced the first lithostratigraphical scheme. He proposed an Early Proterozoic age for the granite intrusion, which was contaminated with material from the Archaean metasediments (Młynowiec Formation) in which it intruded, and became transformed into the present-day Gierałtów gneisses. Another granite protolith of the Śnieżnik gneisses intruded during the Caledonian orogenesis, subsequently metamorphosing the sediments of the Early Palaeozoic Stronie Formation. Many authors followed Fischer's terminology but often with meanings that differed from the original one, and they placed the various rock units in different stratigraphic orders, following their own interpretation of origin and tectonometamorphic evolution. While a similar age (Early Cambrian – Early Ordovician) and genesis (back-arc basin) for the metasediments in the Orlica-Śnieżnik Dome is commonly accepted (Gunia, 1996; Koszela, 1997; Kröner et al., 2001; Jastrzębski, 2005; Murtezi, 2006; Jastrzębski et al., 2010), the geological interpretations of the gneisses are controversial and differ widely.

Neither Smulikowski (1960, 1979) nor Kozłowska-Koch (1973) has found a genetic or stratigraphic argument to distinguish between the Gierałtów and Śnieżnik gneisses; they considered the latter as an only more mature product of the metasomatic granitisation of mica schists and paragneisses (Stronie and Młynowiec Series). Mapping of the Polish (Don, 1964; Don et al., 2003) and Czech (Opletal et al., 1980; Gawlikowska & Opletal, 1997) parts of the Orlica-Śnieżnik Dome resulted in a complete reversal of the stratigraphic order. The Śnieżnik gneisses became considered as "gneissification product of the granite intruding into already deformed supracrustal Stronie Series" (Don, 1964). Subsequent deformation and migmatisation of both the Śnieżnik gneisses and the Stronie Series resulted in the development of the youngest, migmatitic Gierałtów gneisses, which synkinematically intruded both the Stronie Formation and the Śnieżnik gneisses in the form of diapirs (Don, 2001). A younger origin of the Gierałtów gneisses is supported by the existence of 'transitional zones' (smaller grain-size and lighter colours) between the Śnieżnik and the Gierałtów gneisses.

Based on field observations, Oberc (1957, 1972) and Dumicz (1988, 1989) demonstrated that two types of the Gierałtów gneisses differ in age: one is older and one is younger than the Śnieżnik gneisses. The younger type has been interpreted as zonally, dynamically deformed and then recrystallised Śnieżnik gneiss. According to the fold classification of Dumicz (1988), the two oldest group of folds have a N-S orientation, while the overprinted folds (F3) have a NW-SE direction. Further strain overprinting occurred under a more brittle regime. All these processes were assigned to the Variscan deformational event, which occurred under conditions of amphibolite-facies metamorphism and local migmatisation (Borkowska, 1996). The complicated structural relationship between the rocks of the Orlica-Śnieżnik Dome was also pointed out by Teisseyre (1957, 1964, 1980), who reported the existence of isolated enclosures of Gierałtów gneisses within the Śnieżnik gneisses. A petrological study proved the existence of several types of enclaves within the Śnieżnik host rock (Grześkowiak & Żelaźniewicz, 2002).

This complex relationship seems to be ignored by most recent authors, who tend to base their conclusions on geochemical and isotope data. Kröner et al. (2001) and Lange et al. (2002, 2005) found only exceptional differences in the geochemical composition of the gneisses. They propose that the two groups of gneisses derived from the same protolith, i.e. one large batholith, and that the differences between them are due to later deformation and migmatisation. However, earlier geochemical analyses (Borkowska et al., 1990) demonstrated remarkable differences in the amount of both major and trace elements (Si, Al, Mg, Na and Ba, Sr). These data imply that either two separate protoliths (Borkowska et al., 1990) or one protolith that was chemically diversified by intrusive processes (Borkowska, 1996).

Not only the genesis of the gneissic rocks stands controversial. Also the time and character of their tectogenesis has raised confusion. Some researchers held exclusively or predominantly Variscan events responsible (Dumicz, 1988; Smulikowski 1979; Teisseyre, 1964, 1980; Matte et al., 1990; Turniak et al., 2000, Schulmann & Gayer, 2000; Aleksandrowski et al., 2000; Aleksandrowski & Mazur, 2002), whereas others argue for some contribution of pre-Variscan deformation, not everywhere and not completely overprinted by the Variscan (Visean) event (Opletal et al., 1980; Don et al., 1990; Oliver et al., 1993; Přikryl et al., 1996; Franke & Żelaźniewicz, 2000; Don, 2001; Kröner et al., 2001; Grześkowiak & Żelaźniewicz, 2002; Lange et al., 2002, 2005; Grześkowiak et al., 2005; Murtezi, 2006; Żelaźniewicz et al., 2006). Neither the traditional methods (Rb-Sr, U-Pb, Pb-Pb applied to the whole rock or individual minerals) nor U-Pb SHRIMP dating of zonal zircons from the Orlica-Śnieżnik Dome gneisses allow, however, to conclude the controversy, because they provide evidence for events both approx. 500 Ma and approx. 340 Ma ago (see Turniak et al., 2000; Lange et al., 2005; Bröcker et al., 2009). A Late Cambrian – Early Ordovician intrusion, originated from one large and chemically homogeneous batholith, and diversified during the Variscan metamorphism and deformation seems now the common interprepation. In fact, the Variscan overprint is believed to be responsible for all tectonometamorphic processes in the Orlica-Śnieżnik Dome, such as migmatisation, mylonitisation and tectonic emplacement of eclogites into the gneissic environment (e.g. Schulmann & Gayer, 2000; Lange et al., 2002; Bröcker et al., 2009).

3. Analytical techniques

In order to establish diagnostic differences between the Gierałtów and the Śnieżnik gneisses, field and laboratory studies were carried out, dealing with the structure, mineralogy and petrography of the gneisses in the eastern part of the Orlica-Śnieżnik Dome. Particular emphasis was put on the 'transitional zone' around Międzygórze (Fig. 1), in which the two types of gneisses alternate with each other. Field observations were focused on the minerals' relationships and the kinematics of deformation. The array and orientation of the mesostructures were examined in order to reconstruct the chronology and direction of successive deformation events. The regime was established on the basis of mesostructural characteristics, such as the asymmetry of folds, porphyroclasts and porphyroblasts, SC′ structures, shear and fault-plane kinematic indicators (see Passchier & Trouw, 1996; Ramsay & Huber, 1987). The metamorphic terms used in this contribution follow the IUGS (Brodie et al., 2007).

The petrology of 53 (oriented) polished thin sections was studied in order to establish how mineral assemblages changed with successive tectonic structures. The textures of the minerals were studied with particular focus on deformation mechanisms (dynamic recrystallisation versus static recrystallisation, twinning and recovery processes; see Passchier & Trouw, 1996). The chemical composition and compositional zonation of minerals (over 7000 spots) were analysed using an Electron Probe Microanalyser CAMECA SX–100 with 4 spectrometers (Institute of Geochemistry and Petrology of Warsaw University). Beam conditions for the analysed feldspars and micas were set on a 10 nA current and an acceleration voltage of 15 kV. The analyses of garnets, allanites, epidotes and titanites were performed under an acceleration voltage of 15 kV and a beam current of 20nA. A focused beam was used for most analyses, except for Na-feldspars and white micas (defocused beam of 2–5 μm) to avoid element diffusion during electron bombardment.

In the following, the feldspars are subdivided into plagioclases (Ab-An), alkali feldspars (Or-Ab) and secondary albites (composed of Ab>90%) developed in a form of rims over more calcic grains.

4. Petrography and structural record

In the Międzygórze Antiform, four types of gneisses can be distinguished among the gneissic rocks mapped as belonging to the Śnieżnik and Gierałtów gneisses or complexes (Don et al., 2003). Their characteristics are presented below.

4.1. The Śnieżnik (augen) gneisses

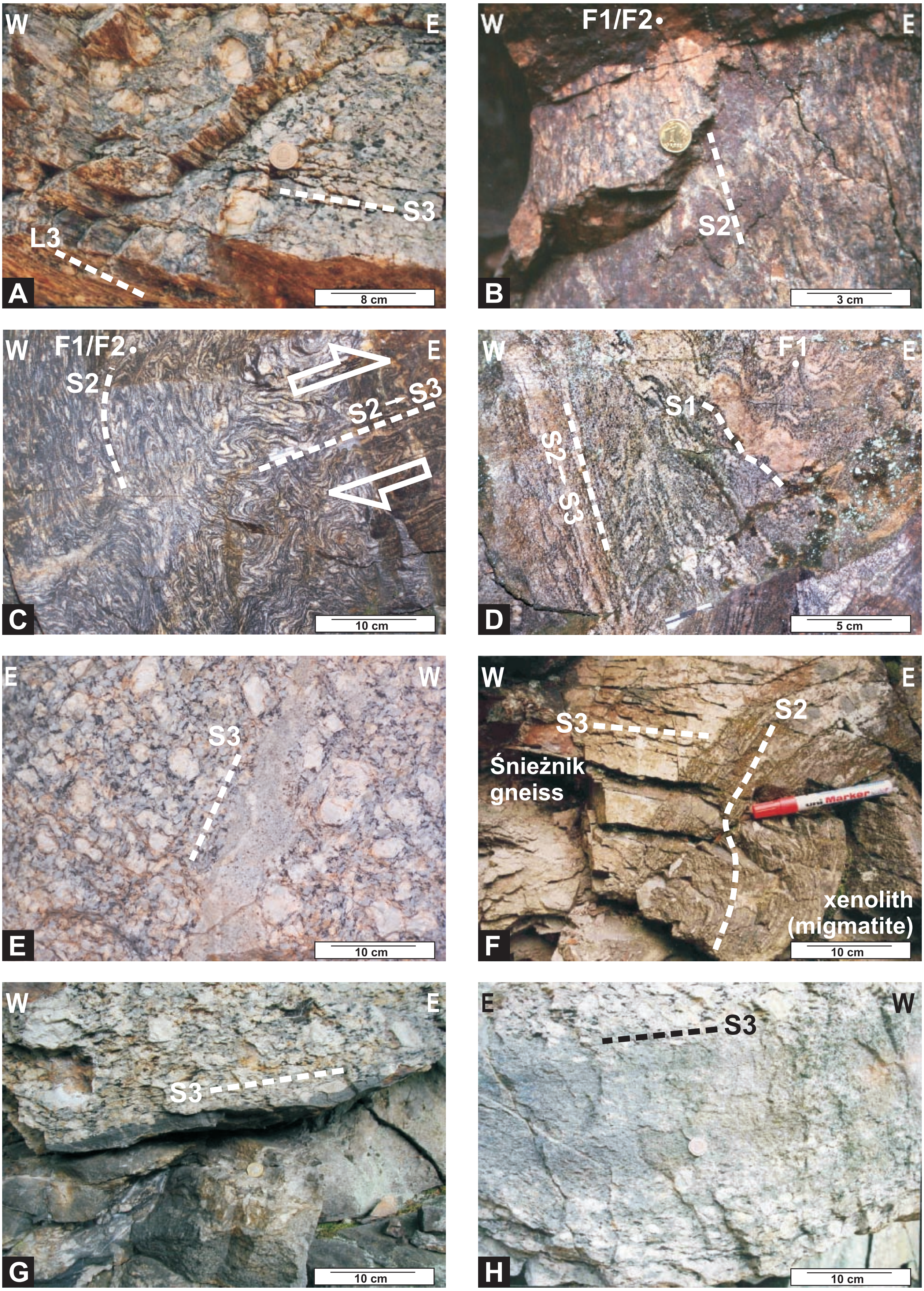
Rocks composed of quartz, alkali feldspar, plagioclase [$An_{6–23}$], biotite, white mica, secondary albite and garnet, apatite, titanite, titanomagnetite and allanite as accessories, can be identified as coarse- to medium-grained, porphyrytic to even-grained L>S, L-S, L< S tectonites, with characteristic rodding lineation and one single mylonitic foliation (separate layers of alkali feldspar, quartz and plagioclase + mica). The foliation anastomoses the alkali-feldspar megacrysts of clearly porphyroclastic origin (Fig. 2A). Microstructural features such as hypauthomorphic shape and growth zonation support a magmatic origin of the megacrysts and consequently the host rocks. Along with an increase of shearing, the size of the grains becomes smaller and the porphyroclasts taper off. No signs of any deformation and/or metamorphism prior to the one ascribed are present. Thus, the constriction followed by the apparent flattening, under high-temperature and low-pressure (HT/LP) conditions, should be regarded as the first recognisable stage of deformation (and metamorphism) in the rocks under study. It is proposed to use the term 'Śnieżnik augen gneisses' (or 'Śnieżnik gneisses') exclusively for rocks with:

- a subhorizontal, N(E)-S(W) trending, penetrative stretching lineation of rodding type, defined by monomineral rods of quartz or potassium feldspar stretched in a ductile state, and plagioclase + mica streaks (Fig. 2A); in the XZ section of the local-strain ellipsoid, asymmetric tails indicate both 'top-to-the-N' and 'top-to-the-S' shear, but most commonly the tails are symmetrical;
- a single, subhorizontal mylonitic foliation formed by separate layers of high-temperature (HT) recrystallised quartz, alkali-feldspar and plagioclase with mica (Fig. 2A); locally S-C′ bands overprint the main foliation with a greenschist-facies mineral assemblage (retrograded biotite, muscovite, albite);
- monomineral augens which are sigma-clasts composed of (hyp)authomorphic megacrysts of potassium feldspar or quartz, characteristically elongated, flattened and surrounded by pressure shadows (quartz, alkali feldspar and minor mica), with both 'top-to-the-N' and 'top-to-the-S' strain markers; such augens are more or less flattened porphyroclasts derived from porphyrocrysts occurring in the original granite (Żelaźniewicz, 1988);
- zonal grain-size reduction, flattening of the porphyroclasts and final transformation into typical (ultra)mylonite; shear zones form rather thin (up to 10 m), N(W)-S(E) trending bands which can be accompanied with medium- to small-scale E(NE)-verging shearing folds, or local crenulation cleavage; triangle-shaped dilatant sites of such folds can be filled up by late, metasomatic quartz segregations;
- large-scale, E-vergent buckling folds, which developed under more brittle conditions; this late event is observed in the whole region, and is responsible for the present-day brachyanticlinal structure of the eastern part of the Orlica-Śnieżnik Dome; both quartz segregations in the axial-plane shear zones and garnet-biotite-plagioclase disequilibrium and mica recrystallisation at the limb's plane point at greenschist-facies metamorphic conditions.

4.2. Porphyroblastic gneisses

Coarse-grained rocks of similar mineralogical composition to the Śnieżnik gneisses (quartz, alkali feldspar, plagioclase [$An_{6–36}$], biotite, white mica, secondary albite, and garnet, apatite, zircon, titanite, allanite, ilmenite, rutile as accessories) often contain felsic porphyroblasts and/or augen-like lenses (Fig. 2B), because of which these rocks are commonly but incorrectly ascribed to the Śnieżnik gneisses (see Don 1964, 1991; Teisseyre, 1957; Smulikowski, 1960, 1979; Sawicki, 1995; Gawlikowska & Opletal, 1997). Such porphyroblastic gneisses show:

- two distinct sets of mylonitic foliation, the first of which is expressed as small-scale double folding (with 'top-to-the-W' and then 'top-to-the-E' kinematics), and the second one is axial planar to these folds (S2 in Fig. 2B);


W
E
S3
L3
A
8 cm
W
F1/F2•
E
S2
B
3 cm
W
F1/F2•
E
S2
S2 – S3
C
10 cm
W
F1
E
S1
S2 – S3
D
5 cm
E
W
S3
E
10 cm
W
E
S3
S2
Śnieżnik gneiss
xenolith (migmatite)
F
10 cm
W
E
S3
G
10 cm
E
W
S3
H
10 cm

- blasts/porphyroblasts (alkali feldspar, quartz or plagioclase) of 0.1–15 cm, polymineral lenses (quartz + alkali feldspar) or leucosome segregations (quartz + alkali feldspar ± plagioclase) of some dozens of centimetres long, which mimage triangle-shaped dilatant sites of the two sets of folds, and which grow in compliance to the axial-plane foliation (S2) or completely disorderly over the existing fabric (Fig. 2B);
- an elongation lineation overprinting the metamorphic fabric; the axial-plane foliation was rejuvenated during subsequent flattening and locally transposed to a subhorizontal position; consequent shearing resulted in the development of a second mylonitic foliation, which does not deflect around metamorphic blasts/lenses, suggesting rigid behaviour of the large blasts and lenses during deformation (Fig. 2B);
- intrafolial folds with porphyroblasts, preserved as flattened and elongated felsic lenses, at first sight similar to the augens in the Śnieżnik gneisses in spite of a completely different genesis;
- signs of an overprint by strong but local shearing; the axial-plane foliation became flattened, the grain size became smaller, porphyroblasts tapered off, and the whole rock transformed into a typical (ultra)mylonite; local HT recrystallisation erased the earlier fabric, leaving only relics of the earlier, oblique cleavage and leftovers of small-scale folds ('ghost structures' recognisable at a microscale); the porphyroblastic gneisses thus became similar to the surrounding Śnieżnik gneisses;
- late, large-scale, E-vergent folds developed under more brittle conditions (greenschist-facies conditions inferred from mica recrystallisation at the limbs' plane).

4.3. Migmatites

Stromatites, metatexites, phlebites (a term after Wimmenauer & Bryhni, 2007) and embrechites are composed of quartz, plagioclase [$An_{6–37}$], alkali feldspar, biotite, white mica, secondary albite and, as accessories, garnet, apatite, zircon, epidote, allanite, titanite, titanomagnetite, ilmenite, rutile and prehnite. Both the palimpsest structures and well developed migmatitic structures were erased by the N(E)-S(W) shear deformation. Within the migmatites, discordant amphibolitised eclogite, amphibolite and granulite bodies occur as enclosures. All types of migmatites reveal the following common features:

- early, non-mylonitic foliation (enhanced by SE-NW elongation lineation) evolved into double folding in a small-scale (F1 folds

Fig. 2. Various gneiss types distinguished in the eastern part of the Orlica-Śnieżnik Dome, and enclaves in the Śnieżnik gneisses (for location: see Fig. 1). Discontinuous lines represent either planar structures (S = foliation) or linear structures (L = lineation); points correspond to folds (F) and arrows show the kinematics of deformation.
A – Śnieżnik (augen) gneiss (L>S tectonite) with K-feldspar porphyroclasts originated from the porphyrithic granite. Constriction produced a rodding-type lineation (L3), and subsequent flattening resulted in the development of mylonitic foliation (S3); **B** – Porphyroblastic gneiss with K-feldspar, quartz and plagioclase porphyroblasts originated from the metablastesis that occurred syn- and post-kinematically with respect to the small-scale folds (F1/F2). A new axial plane foliation (S2) was developed; **C** – Migmatite (stromatite) with early foliation evolved into small-scale folds (F1/F2) and a second foliation developed parallel to their axial planes (S2), with signs of synkinematic migmatisation. Subsequent shearing towards the NE caused transposition of earlier structures (S2→S3) and consequent mylonitisation; B – Layered gneiss with relics of compositional banding S1 (S0?) and small-scale folds (F1). The oblique planar structure S2 as the axial-plane foliation, and was rejuvenated during subsequent shearing (S2→S3); **E** – Felsic microgranular enclave with sharp boundaries within the Śnieżnik gneiss. Note that some K-feldspar porphyroclasts grew in random directions across the enclave's boundary, and that quartz porphyroclasts grew inside the enclave. Th mylonitic foliation of the hosting Śnieżnik gneiss continues across the enclave (S3); **F** – Xenolith with migmatitic fabric (including small-scale ptygmatitic folds). The most prominent axial-plane foliation (S2) is usually at a high angle to the subhorizontally and moderately dipping mylonitic foliation in the surrounding Śnieżnik gneisses (S3); **G** – Enclave of mesocratic gneiss with sharp boundaries with the hosting Śnieżnik gneiss. Note that the K-feldspar and quartz porphyroclasts grew in random directions within the enclave and at the enclave's boundary. The mylonitic foliation of the hosting Śnieżnik gneiss continues across the enclave (S3); **H** – Schlieren with diffuse contacts with the Śnieżnik gneiss, disrupted and transformed by partial melting and assimilation processes. The mylonitic foliation of the hosting Śnieżnik gneiss continues across the enclave (S3).

with 's'-asymmetry followed by F2 folds with 'z'-asymmetry); in many places, both generations of folds interfere and transpose each other (Fig. 2C);
– signs of migmatisation, syn- to post-kinematic in accordance with F1 and F2 folds; neosomes (quartz + feldspars) can form irregular nests, layers and curved/banded lenses or spindles, suspended within very fine-grained, strongly biotitic mesosomes (mica + titanite palaeosomes). In stromatites, the leucosome (neosome) extracts in the hinge zones of folds, parallel to their axial panes (S2 in Fig. 2C), and within discrete axial-plane shear zones (also in the eclogites and amphibolites, if present); subsequent recrystallisation produced individual leucocratic aggregates (up to 10 cm in diameter);
– overprinted N-S trending rodding lineation (quartz + feldspars rods and mica streaks) and subsequent shearing; mylonitic flattening affected all leucocratic aggregates turning them into porphyroclasts; along with the local increase of flattening, transposition of earlier foliations towards a subhorizontal position took place (S2→S3 in Fig. 2C); the grain size became smaller, porphyroblasts tapered off, and the whole rock became transformed into a typical (ultra)mylonite; this HT recrystallisation subsequently erased the earlier fabric, leaving only relics of the earlier cleavage and intrafolial folds in the form of bended leucosome patches/nests, disrupted into boudins;
– frequent shear zones/faults and few metre-scale, E-vergent folds, developed under more brittle conditions (greenschist-facies conditions as inferred from mica recrystallisation at the limbs' planes), which are evidence of the last deformation event.

4.4. Banded gneisses

Fine-grained, aplite-looking, banded gneisses (the 'homogeneous gneisses' of Borkowska et al., 1990 and the 'aplite gneisses' of Don et al., 2003) are composed of quartz, plagioclase [$An_{6–28}$], alkali feldspar, biotite, white mica and secondary albite, and the accessory minerals garnet, apatite, titanite, zircon, rutile, titanomagnetite, ilmenite, epidote, allanite, xenothyme and thorite. Micas do not form separate bands but their fine flakes are uniformly dispersed in the quartz/feldspar mass, so that within a layer they appear to be homogeneous. Alternating bands of leucocratic (biotite-poor) and melanocratic (biotite-rich) compositions form regular layers 0.05–10 m thick, which must have been inherited from the parent rock (Fig. 2D). Within the banded gneisses, eclogites occur as enclosures. The banded gneisses show:
– relics of early, oblique foliation, expressed by compositional banding (S1) resembling the primary alternation S0 (Fig. 2D), which at a micro-scale can be recognised as quartz (± feldspars) (sub)grain elongation; this banding must have evolved into tight to isoclinal folding, presently transformed into the 'ghost' structures; biotite recrystallised parallel to the folds' axial planes, forming a second, subhorizontal foliation S2 (Fig. 2D), slightly oblique to the quartz-feldspathic layers; intrafolial folds are commonly no longer visible, and only indistinct non-mylonitic biotite foliation exists (S2 on Fig. 2D);
– leucosomes locally extracting in the form of nests/layers/lenses and individual leucocratic aggregates, which developed independently on foliations; the amount and size of neosomes (quartz ± feldspars) seems to increase with diminishing distance to the (retro)eclogite boudins (leucosome veins are also present in eclogites themselves);
– no special structures formed during the late NE trending shearing, except for signs of rejuvenation of earlier planes S2→S3 (dynamic recrystallisation at a micro-scale).

4.5. Enclaves within the Śnieżnik gneisses

The Śnieżnik gneisses outcropping in the eastern part of the Orlica-Śnieżnik Dome contain numerous and diverse enclaves, composed of generally lensoid, isolated bodies of metagranites and migmatites (stromatites).

4.5.1. Felsic microgranular felsic and mesocratic gneisses

The most numerous are small (from one to a few decimetres), ellipsoidal to lensoid, felsic bodies, heterogeneously arranged within the host gneisses (Fig. 2E). They have identical composition as their host rock (quartz, alkali feldspar, plagioclase [An_{6-23}], biotite, white mica and secondary albite, and garnet, apatite, titanite, titanomagnetite, epidote and allanite as accessory minerals). Such enclosures can be classified as felsic microgranular enclaves, with typically:

– a metamorphic fabric formed by an alignment of minerals, which is concordant with the mylonitic foliation (if present) in the surrounding Śnieżnik gneisses (Fig. 2E);
– features characteristic of fine-grained igneous rock (general enrichment in apatite, quartz poikilitically enclosing plagioclase and apatite, plagioclases with relict, irregular oscillatory zoning), suggesting a granitic origin of the enclaves, with very limited overprint of recrystallisation;
– sharp boundaries with the host (Fig. 2E), across which xenomorphic to hypauthomorphic porphyroclasts of alkali feldspar or quartz (up to 5 cm) did grow; porphyroclasts display magmatic microstructural features (microcline grid or simple twinning) without strain tails; the mylonitic foliation of the Śnieżnik gneisses anastomoses around the megacrysts, emulating their shape and continuing across the enclaves themselves; ductile deformation of feldspars and quartz suggests a high temperature during recrystallisation;
– an array of longer axes in an (S)E-(N)W direction, considered as the direction of the flow of the primary magma (L0) of the granite protolith.

4.5.2. Migmatitic gneisses

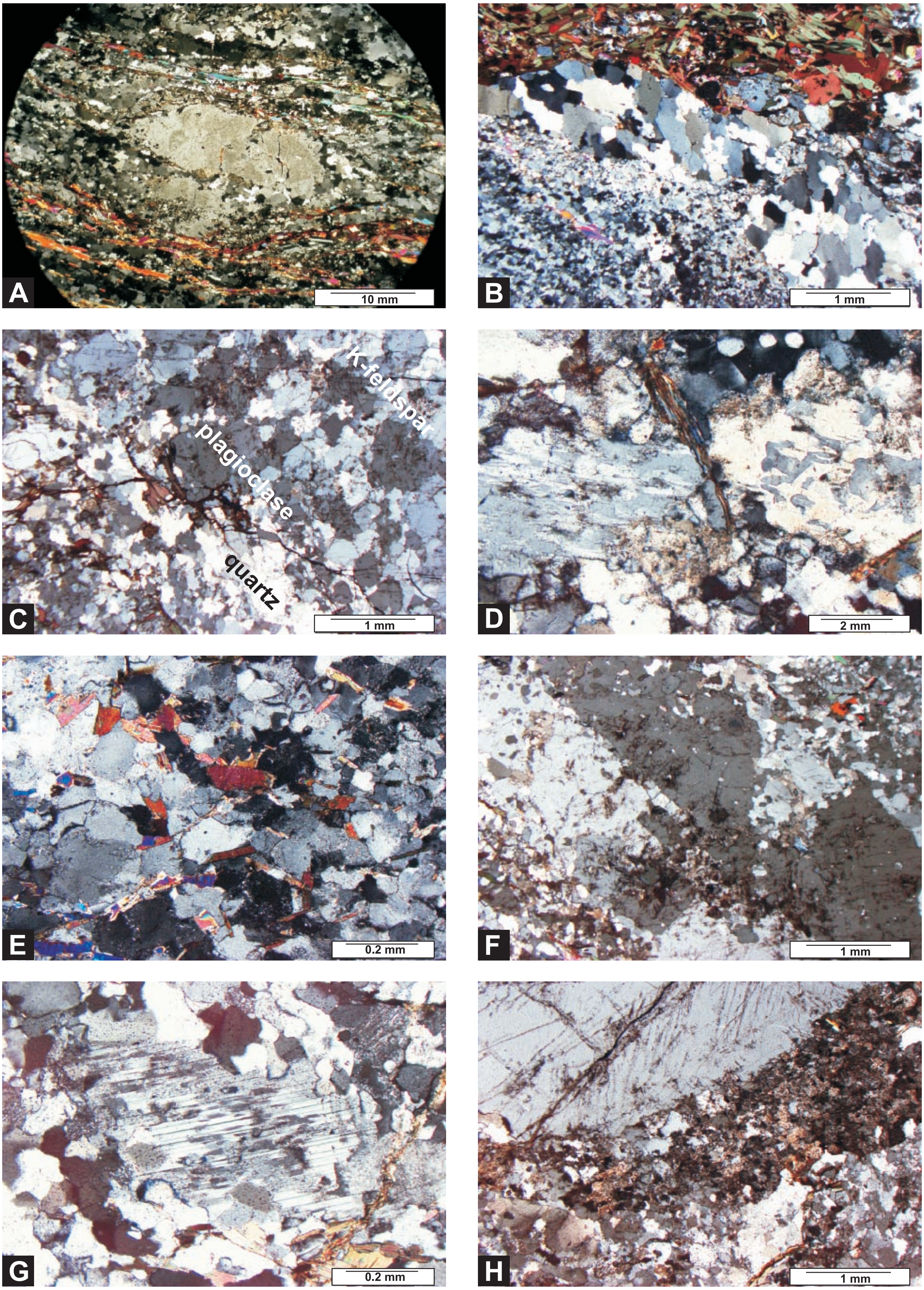
Coarse-grained migmatitic gneisses (~stromatites), with their own, rich internal structure form rare lensoid to boudin-like bodies of a few metres. These enclaves are composed of quartz, alkali feldspar, plagioclase [An_{6-36}], biotite, white mica and secondary albite, and of the accessory minerals garnet, apatite, titanite, zircon, epidote, allanite, titanomagnetite, ilmenite and xenothyme; the characteristic migmatitic structure and sharp, irregular boundaries make them easy to recognize within the gneissic surroundings as xenoliths (Fig. 2F), with characteristic:

– complex metamorphic fabric, including two conspicuous foliations: the older one is strongly disharmonically folded (small-scale folds, often ptygmatitic) and overprinted by a later, axial-plane foliation, which shows usually a high angle with respect to the subhorizontally and moderately dipping, mylonitic foliation in the surrounding gneisses (Fig. 2F);
– leucosome nests/lenses extracted in the hinges of small-scale folds, parallel to the axial-plane foliation and randomly occurring over the existing fabric; additionally, individual, xenomorphic alkali feldspar and quartz porphyroblasts developed over the migmatitic fabric; in some places, strong recrystallisation and metablastesis completely erased the primary, migmatitic fabric, giving the rocks a granitic outlook;
– deflection of the subhorizontal mylonitic foliation in the surrounding Śnieżnik gneisses around more rigid bodies of xenoliths (Fig. 2F).

4.5.3. Mesocratic gneisses

Small (several dozens of centimetres), ellipsoidal to lensoid, mesocratic enclaves consist of fine-grained mesocratic gneisses (quartz, plagioclase [An_{6-36}], biotite, alkali feldspar and secondary albite, with garnet, apatite, zircon, allanite, epidote, titanite, titanomagnetite, ilmenite and rutile as accessories). The mineral composition and the sharp boundaries of the enclaves make them similar to the xenoliths (Fig. 2G). A few enclosures were transformed into disrupted schlieren with extremely diffuse boundaries (Fig. 2H). The mesocratic enclaves should be considered as partially melted xenoliths, disrupted and transformed by partial melting and assimilation into restites (see Montel & Cheilletz, 1989). They show:

– microscopical relics of an early foliation, occasionally evolved into small-scale 'ghost' folds, pronounced by leucocratic segrega-


A
10 mm
B
1 mm
K-feldspar
plagioclase
quartz
C
1 mm
D
2 mm
E
0.2 mm
F
1 mm
G
0.2 mm
H
1 mm

tions (leucosomes?) in the hinge zones, all strongly reworked by dynamic recrystallisation; the mylonitic foliation in the surrounding Śnieżnik gneisses tends to continue across the enclaves (Fig. 2G, H);

- porphyroclasts of poikilitic plagioclase [An_{12-23}] and alkali feldspar (hypauthomorphic/xenomorphic, with relics of primary growth zonation), which pass the enclave boundaries;
- megablasts of quartz or aggregates of quartz and feldspars, grown in random positions inside the enclave (Fig. 3G); they occasionally show a special ocellar structure (K-feldspar or quartz in a core surrounded by a biotite rim);
- longer axes orientated in an E-W direction, which is considered as the flow direction of the primary magma (L0) of the granite protolith of the Śnieżnik gneiss.

5. Mineral texture and chemistry

Gneisses of the Orlica-Śnieżnik Dome differ distinctly in metamorphic and pre-metamorphic (if present) texture, confirming structural differences between the Śnieżnik gneisses and the three other types of gneisses (porphyroblastic gneisses, migmatites and banded gneisses). Moreover, the various types of gneisses and the gneisses from the enclaves differ in their mineral chemistries. While the composition of the minerals from the xenoliths and mesocratic enclaves resembles that of the migmatites and porphyroblastic gneisses, the minerals from the felsic microgranular enclaves resemble the minerals of the Śnieżnik gneiss. Particular attention has been paid to the description of feldspar textures, with regard to their significance for the reconstruction of deformational developments.

5.1. Feldspars

Elongated and flattened K-feldspar porphyroclasts (up to 10 cm) with tails of strain shadows, occurring in a polymineral (plagioclase + quartz + subordinate mica) matrix, are the most characteristic feature of the Śnieżnik augen gneisses. Hypauthomorphic orthoclase megacrysts (with Carlsbad twinning) are often affected by dynamic recrystallisation (inferred from the presence of subgrains with undulose extinction) and grain-boundary migration recrystallisation (inferred from the lobate shape of the grains: Passchier & Trouw, 1996). Additionally, granulation at the edges and tensile fractures, filled by the recrystallised ma-

Fig. 3. Some microstructural relationships between the feldspars in various gneiss types that are distinguished in the eastern part of the Orlica-Śnieżnik Dome.
A – Śnieżnik augen gneiss. Elongated and flattened orthoclase porphyroclast with tails of strain shadows (quartz ± K-feldspar ± micas), tapering gradually off towards the mylonitic layer. Foliation anastomoses the porphyroclast, which has been dynamically recrystallised (subgrains with undulose extinction), is granulated at the edges and possesses tensile fractures, filled by recrystallised matrix; **B** – Śnieżnik augen gneiss. The mylonitic layering is emphasized by the bimodal grain size. The lobate grain boundaries and subgrains with undulose extinction indicate dynamic recrystallisation; **C** – Porphyroblastic gneiss. A xenomorphic porphyroblast formed in the core of K-feldspar and is surrounded by a plagioclase mantle and quartz rim; **D** – Migmatite. Fragment of a neosome (leucosome) domain consisting of antiperthitic blasts, quartz, K-feldspar and subordinate (chloritised) biotite. The lobate grain boundaries, subgrains with undulose extinction indicate dynamic recrystallisation; **E** – Banded gneiss. Fine flakes of biotite are uniformly dispersed in the quartz-feldspar mass, giving the rock a homogeneous appearance. The primary foliation in the layered gneiss is formed by fine-grained, elongated, poikiloblastic quartz, plagioclase and K-feldspar, showing evidence of dynamic recrystallisation, grain-boundary migration recrystallisation (lobate-amoeboid shape, subgrains with undulose extinction) and static recrystallisation (isometric polygonal shape); **F** – Felsic microgranular enclave. A K-feldspar porhyroclast crystallised at the enclave's border. The hypauthomorphic orthoclase with Carlsbad twinning and edge granulation shows signs of dynamic recrystallisation and grain-boundary migration recrystallisation (subgrains with undulose extinction, lobate shape of surrounding minerals and 'left over grains' of quartz); **G** – Xenolith. Fragment of neosome (leucosome) segregation consisting of xenomorphic antiperthite with relics of polysynthetic twinning (in the centre). All grains display evidence of dynamic recrystallisation (lobate-amoeboid subgrains with undulose extinction) and static recrystallisation (tendency to polygonal shape); **H** – Mesocratic enclave. Fragment of a xenomorphic K-feldspar porphyroclast (without strain shadows) growing inside the matrix of the enclave.

trix (quartz, K-feldspar, plagioclase [An_{0-5}]) occur (Fig. 3A). The bimodal grain size also indicates dynamic recrystallisation (Fig. 3B). Although scarce, myrmekites occur that set the minimum temperature conditions during deformation at 500ºC (cf. Vernon et al., 1983). In more flattened and mylonitised varieties of the Śnieżnik gneisses, the K-feldspars were deformed largely in a ductile manner into long, foliation-parallel ribbons. If still present, the parent grains occur in the central part of the lamella, and smaller, dynamically recrystallised subgrains (with undulose extinction) stick out of it. The ductile behaviour of quartz and feldspars indicates even higher temperature conditions during deformation (~600ºC according to Passchier & Trouw, 1996).

The mylonitic layers consist of statically recrystallised plagioclase [An_{6-15}] (inferred from the isometric shape of the grains) and minor potassium feldspar (not twinned). Larger (>1 mm) and xenomorphic grains of plagioclase [An_{15-23}] are often poikiloblastic (mica intergrowths), antiperthitic, strongly affected by dynamic recrystallisation (subgrains with undulose extinction) and bulging ('left-over' grains of quartz). All these features are evidence of the blastesis of plagioclases over the earlier fabric (cf. Passchier & Trouw, 1996). Edge albitisation commonly affects all feldspars in the mylonitic layers.

The characteristic porphyroblasts in the porphyroblastic gneisses consist of xenomorphic K-feldspar with minor quartz and plagioclase, showing occasionally a core-and-mantle texture (Fig. 3C). The core parts are occupied by K-feldspar (not twinned or cross-hatch-twinned microcline), surrounded by a mantle of poikiloblastic plagioclase [An_{6-36}] with albite twinning and then a quartz rim, gradually passing into matrix. All grains have been dynamically recrystallised (lobate shape, subgrains with undulose extinction) and are poikiloblastic (mica, quartz intergrowths).

The mylonitic layers are composed of isometric grains of poikilitic plagioclase [An_{6-26}], polysynthetically twinned, and only scarce xenomorphic K-feldspar. The polygonal shape of the grains indicates static recrystallisation as the last visible process of rock transformation. Secondary edge albitisation affected all grains. In some cases, plagioclase was completely replaced by myrmekites or forms intergrowths with quartz, giving rise to a diablastic texture. The ductile behaviour of quartz and feldspars (mylonitic separation) and the common myrmekite texture indicate high-grade conditions during deformation (500–600ºC according to Passchier & Trouw, 1996).

The migmatitic lenses growing in random over the planar fabric are composed of xenomorphic quartz, K-feldspar (orthoclase without twinning) and plagioclase [An_{6-36}] (including antiperthite). All grains have been dynamically recrystallised (subgrains with undulose extinction and/or traces of subgrain rotation recrystallisation) and grew over the deformed matrix (deformed mica intergrowths).

The palimpsest structures of the migmatites are composed of plagioclase [An_{6-28}] with polysynthetic twinning of albite type and potassium feldspar (orthoclase without twinning and cross-hatch-twinned microcline). They are all poikiloblastic, lobate grains developing subgrains with undulose extinction, indicative of grain-boundary migration recrystallisation and dynamic recrystallisation, respectively. Antiperthitic intergrowths are common. Secondary albite developed especially in the albitic parts of the myrmekites as well as along cleavage and twining planes of feldspars. The presence of myrmekite in combination with the ductile behaviour of the quartz and feldspars indicates high-grade conditions during deformation (500–600ºC according to Passchier & Trouw, 1996).

The migmatitic domains are built of quartz, plagioclase [An_{6-36}] with polysynthetic twinning or antiperthite and microcline (cross-hatch-twinning). All grains have dynamically recrystallised, with lobate grain boundaries, subgrains with evidence of subgrain rotation recrystallisation and undulose extinction (Fig. 3D). Individual porphyroblasts are either xenomorphic and antiperthitic plagioclases [An_{6-36}], overgrowing deformed minerals from the matrix (e.g. mica, titanite) or xenomorphic K-feldspars (without twinning or cross-hatch-twinned).

The primary foliation in the banded gneisses is built of fine-grained, elongated, poikiloblastic plagioclase [An_{6-28}] and K-feldspar (orthoclase without twinning), showing evidence of dynamic recrystallisation (lobate-amoeboid-shaped subgrains with undulose extinction) and static recrystallisation (isometrical polygonal shape in Fig. 3E). Potassium-feldspar grains occasionally form lenses 1–3 mm long, HT recrystallised in very-fine grained aggregates. Antiperthitic intergrowths are scarce, myrmekites hardly ever occur. Secondary edge albitisation is pervasive. The ductile behaviour of the quartz and feldspars indicate high-grade conditions during deformation (500–600°C according to Passchier & Trouw, 1996).

The mylonitic foliation in the felsic microgranular enclaves is composed of quartz, poikiloblastic plagioclase [An_{6-23}] with albite twinning and orthoclase without twinning. All grains are xenomorphic and show signs of dynamic recrystallisation (lobate-amoeboid shape, subgrains with undulose extinction) and subsequent static recrystallisation (tendency to polygonal shape). Quartz actively bulging into feldspars indicates grain-boundary migration recrystallisation. The common occurrence of myrmekite in combination with the mylonitic separation indicates high-grade conditions during deformation (500–600°C according to Passchier & Trouw, 1996).

The individual K-feldspar megacrysts (2–5 cm long) that crystallised inside the enclaves and at the enclaves' boundaries, are hypauthomorphic orthoclase (Carlsbad twinning) without a mantle or strain tails (Fig. 3F). Tensile fractures are occasionally filled by very fine-grained quartz and plagioclase. Edge granulation and subgrains (with undulose extinction) developed only at the crystals' edges. Adjacent plagioclases may form myrmekites convex towards K-megacrysts.

The palimpsest structure in the xenoliths is composed of fine-grained feldspars, quartz and micas, arranged in a mylonitic way. Plagioclase [An_{6-30}] and K-feldspar (orthoclase without twinning and cross-hatch-twinned microcline) are both xenomorphic and dynamically recrystallised grains (lobate subgrains with undulose extinction). The poikiloblastic texture (quartz ± mica intergrowths) indicates strong grain-boundary migration recrystallisation. The common occurrence of myrmekite sets the minimum temperature conditions during recrystallisation at 500°C (according to Passchier & Trouw, 1996).

The leucosome aggregates (Fig. 3G) are composed of quartz, xenomorphic and poikiloblastic plagioclase [An_{6-36}] and potassium feldspar (without twinning). All grains have been dynamically recrystallised (lobate-amoeboid-shaped subgrains with undulose extinction). Feldspars are often antiperthitically intergrown and plagioclase is polysynthetically twinned. Intergrowths of plagioclase and mica suggest that feldspar blasts overgrew deformed minerals from the matrix. Rim myrmekites (even inside antiperthites) are common.

The fine-grained matrix of mesocratic enclaves consists of quartz, plagioclase [An_{6-28}] and mica with minor K-feldspar (twinning), arranged in a mylonitic structure. All components show signs of dynamic recrystallisation and grain-boundary migration recrystallisation (lobate subgrains with undulose extinction, 'left-over' quartz) with a conspicuous overprint of the static recrystallisation (polygonal shape of feldspars). Plagioclase is often polysynthetically twinned and subsequently replaced by muscovite. Myrmekites with tiny quartz vermicules occur.

The polymineral lenses considered as relics of the migmatitic fabric are composed of K-feldspar ± plagioclase [An_{15-36}] (in their core) and plagioclase ± quartz ± K-feldspar (in tails), separated from the matrix by anastomosing mica layers. Porphyrocrysts crystallised inside the enclaves consist of xenomorphic quartz or hypidiomorphic orthoclase without mantles or stress shadows (Fig. 3H). The only sign of recrystallisation is granulation at the crystals' edges. Megacrysts show occasionally a special ocellar structure, formed by a felsic core (K-feldspar or quartz) surrounded by a mafic (biotite) rim.

5.2. Micas

The dark micas from the studied gneisses are classified generally as annites (Al^{VI} in the range of 0.33–1.0) with #mg ratio [=Mg/

(Mg+Fe)] in the range of 0.11-0.42. Siderophyllite (Al^{VI} up to 1.31) occurs exclusively in migmatites bordering amphibolite boudins. In all studied types of rocks, two groups of biotite can be identified (Tables 1 and 2). The first group is characterised by an increasing Ti content from the core towards the rims of the flakes, and in the second group the pattern is the reverse (decrease of the Ti contents from the core towards the rims of the flakes). The biotites from the Śnieżnik gneisses as well as the felsic microgranular enclaves and mesocratic enclaves are mostly aligned in accordance with the mylonitic foliation and register a decrease of the TiO_2 content from the cores (max. 3.7 wt%) toward the rims of the flakes. Sparse biotites, chaotically suspended within the rock mass, show an indistinct increase of the TiO_2 contents within the flakes. Within the migmatites, porphyroblastic gneisses, banded gneisses and xenoliths (within the Śnieżnik gneisses), biotite flakes with increasing Ti toward the rims (max. 4.84 wt% of TiO_2) are arranged in accordance with the intrafolial folds and axial-plane foliation (S2), and the flakes with decreasing Ti toward the rims are arranged parallel to the relic/transposed foliation.

The white micas within all analysed gneisses are commonly enriched in Si (phengites). The phengites in the Śnieżnik gneisses as well as the felsic microgranular enclaves, mesocratic enclaves are mostly arranged in accordance with the mylonitic foliation and contain intermediate values of Si between 3.10 and 3.25 (pfu). Flakes with a higher amount of Si (max. 3.37 pfu) are scarce (Table 3). Within the migmatites, porphyroblastic gneisses and layered gneisses, the phengites with the highest amount of Si (up to 3.43 pfu) define the intrafolial folds F1/F2 and their axial-plane foliation (S2). In the xenoliths, the flakes with the highest amount of Si (max. 3.39 pfu) are in the same way arranged in accordance with the ptygmatitic folds. Flakes with lower amounts of Si occur only in the form of recrystallised aggregates (more or less parallel to relic and transposed foliations). The white micas in leucosome extractions are muscovite (Si ~ 3.0 pfu); they are chaotically between feldspars.

5.3. Garnets

The scarce garnets in the Śnieżnik gneisses and the felsic microgranular enclaves are atoll to irregular in shape and are adjacent to biotite, quartz and secondary albite or phengite. They have a characteristic, calcium-rich composition (30–53% of andradite + grossular, 47–67% of almandine, 0–17% spessartine, and 0–6% of pyrope) and simple compositional zoning (high-Ca cores versus lower-Ca rims: Table 4). The outermost parts of the grains are always Ca-depleted, indicating alteration at the edges (Fig. 4A). The cores of the plagioclase blasts [An_{6-15}] can be intergrown with small garnets, which show a reverse zoning (high-Ca rims versus lower-Ca cores), but the proportion of the end-members is comparable with the composition of the garnets from the matrix.

In the migmatites, porphyroblastic gneisses and layered gneisses garnets commonly occur as atoll to irregular crystals, which border plagioclase [An_{6-28}], alkali feldspar, quartz or chlorite and rarely enclose quartz, chlorite or alkali feldspar. Their composition can be recalculated to 30–55% of andradite + grossular, 45–70% of almandine, 0–8% of spessartine, and 0–8% of pyrope. A characteristic irregular, oscillatory zoning is well visible on back-scattered electron images (Fig. 4B). Exclusively within the porphyroblastic gneisses, isometric garnets are found in the matrix (30–35% andradite + grossular). Within plagioclase porphyroblasts [An_{6-36}], two types of garnet that are different in composition occur as intergrowths. In the cores of plagioclases, garnets of similar composition as those occurring in the matrix (~ 40% andradite + grossular) are found. The external parts of plagioclase blasts are intergrown with more ferrous garnets (up to 73% almandine + spessartine).

Garnets from xenoliths and mesocratic enclaves and schlieren are roughly similar to garnets in the porphyroblastic gneisses and migmatites, both regarding their shape (Fig. 4C) and their compositional zoning (35–55% of andradite + grossular, 44–64% of almandine, 0–10% of spessartine, and 0–8% of pyrope). Furthermore, isometric garnets with a homogeneous composition (Fig. 4D) are found in

Table 1. Representative microprobe analyses of biotite from the distinguished gneiss types of the eastern part of the Orlica-Śnieżnik Dome.

rock type:	Śnieżnik gneiss				porphyroblastic gneiss				migmatite				banded gneiss			
Ti zonation:	Ti-progressive[1]		Ti-regressive[1]		Ti-progressive[1]		Ti-regressive[1]		Ti-progressive[1]		Ti-regressive[1]		Ti-progressive[1]		Ti-regressive[1]	
spot:	core	rim	core	rim	core	rim	core	rim	core	rim	core	rim	core	rim	core	rim
SiO_2	34.70	34.52	35.60	35.95	34.59	35.08	35.19	35.01	35.48	35.89	34.64	34.49	36.53	35.05	35.44	34.94
TiO_2	2.87	3.21	3.70	3.28	3.06	3.12	4.85	3.14	3.26	4.78	3.05	2.96	2.18	2.52	3.68	3.38
Al_2O_3	17.36	17.10	17.02	17.01	17.64	17.40	17.70	17.20	16.90	18.07	17.66	17.24	17.38	17.75	17.87	17.05
Cr_2O_3	0.01	0.00	0.00	0.03	0.00	0.04	0.04	0.02	0.02	0.05	0.00	0.01	0.02	0.01	0.07	0.00
MgO	6.30	6.04	6.22	6.47	6.12	6.27	4.67	6.43	7.49	6.58	6.68	6.64	7.03	6.25	5.47	5.54
MnO	0.20	0.16	0.26	0.22	0.26	0.33	0.27	0.20	0.35	0.31	0.37	0.45	0.19	0.33	0.32	0.30
FeO	23.83	24.30	23.28	23.45	24.62	23.88	23.36	24.46	21.42	20.32	22.82	22.83	22.20	23.97	23.60	25.03
Na_2O	0.05	0.03	0.09	0.09	0.10	0.08	0.52	0.08	0.09	0.07	0.08	0.08	0.06	0.08	0.08	0.04
K_2O	9.42	9.57	9.75	9.45	8.27	9.21	8.64	9.15	9.44	9.65	9.85	9.73	9.71	9.52	9.62	9.32
H_2O	3.62	3.75	3.78	3.71	3.83	3.85	3.86	3.85	3.85	3.93	3.84	3.81	3.62	3.66	3.72	3.69
total	98.38	98.66	99.71	99.67	98.50	99.26	99.09	99.53	98.30	99.65	98.98	98.24	98.91	99.14	99.86	99.28
recalculated to 22 O																
Si	5.45	5.44	5.51	5.55	5.42	5.46	5.46	5.45	5.53	5.47	5.41	5.44	5.64	5.47	5.47	5.47
Ti	0.34	0.38	0.43	0.38	0.36	0.37	0.56	0.37	0.38	0.55	0.36	0.35	0.25	0.30	0.43	0.40
Al	3.22	3.18	3.11	3.10	3.26	3.19	3.24	3.16	3.10	3.25	3.25	3.20	3.16	3.26	3.25	3.15
Cr	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00
Mg	1.48	1.42	1.44	1.49	1.43	1.46	1.08	1.49	1.74	1.50	1.56	1.56	1.62	1.45	1.26	1.29
Mn	0.03	0.02	0.03	0.03	0.04	0.04	0.04	0.03	0.05	0.04	0.05	0.06	0.03	0.04	0.04	0.04
Fe	3.13	3.20	3.01	3.03	3.23	3.11	3.03	3.19	2.79	2.59	2.98	3.01	2.87	3.13	3.05	3.28
Na	0.02	0.01	0.03	0.03	0.03	0.02	0.16	0.02	0.03	0.02	0.02	0.03	0.02	0.02	0.02	0.01
K	1.89	1.92	1.93	1.86	1.65	1.83	1.71	1.82	1.88	1.88	1.96	1.96	1.91	1.90	1.90	1.86
total	15.55	15.56	15.48	15.46	15.42	15.49	15.28	15.52	15.49	15.30	15.60	15.60	15.49	15.57	15.43	15.49
#mg =[Mg/(Mg+Fe)]	0.32	0.31	0.32	0.33	0.31	0.32	0.26	0.32	0.38	0.37	0.34	0.34	0.36	0.32	0.29	0.28

[1] progressive = increasing Ti-content from core to rim; regressive = decreasing Ti-content from core to rim.

Table 2. Representative microprobe analyses of biotite from the enclaves within the Śnieżnik gneisses (eastern part of the Orlica-Śnieżnik Dome).

rock type:	felsic microgranular enclave				xenolith				mesocratic enclave			
Ti zonation:	Ti-progressive[1]		Ti-regressive[1]		Ti-progressive[1]		Ti-regressive[1]		Ti-progressive[1]		Ti-regressive[1]	
Spot :	core	rim	core	rim	core	rim	core	rim	core	rim	core	rim
SiO_2	35.32	35.33	35.22	34.77	34.82	34.98	35.27	35.14	35.41	34.92	35.07	34.93
TiO_2	2.52	2.57	3.26	2.68	2.65	2.87	3.95	3.70	3.06	2.83	3.04	2.70
Al_2O_3	15.67	15.49	17.32	16.94	17.48	16.70	16.92	17.30	17.41	17.73	17.29	17.63
Cr_2O_3	0.00	0.04	0.00	0.01	0.04	0.07	0.04	0.03	0.00	0.02	0.00	0.03
MgO	5.54	5.63	4.95	5.29	7.56	7.59	6.88	6.95	5.59	5.69	5.54	5.54
MnO	0.30	0.24	0.29	0.29	0.29	0.25	0.18	0.23	0.15	0.26	0.25	0.33
FeO	26.19	26.24	25.81	25.80	23.29	22.92	22.14	21.86	24.58	24.44	25.20	25.22
Na_2O	0.04	0.05	0.08	0.07	0.11	0.08	0.09	0.12	0.06	0.10	0.08	0.06
K_2O	9.38	9.45	9.45	9.70	9.41	8.97	9.58	9.34	9.55	9.64	9.63	9.46
H_2O	3.78	3.78	3.85	3.80	3.86	3.83	3.86	3.85	3.85	3.84	3.84	3.84
total	98.74	98.80	100.23	99.34	99.49	98.26	98.91	98.50	99.66	99.45	99.93	99.74
recalculated to 22 O												
Si	5.61	5.61	5.48	5.48	5.41	5.48	5.48	5.47	5.51	5.46	5.47	5.46
Ti	0.30	0.31	0.38	0.32	0.31	0.34	0.46	0.43	0.36	0.33	0.36	0.32
Al	2.93	2.90	3.18	3.15	3.20	3.09	3.10	3.17	3.19	3.26	3.18	3.25
Cr	0.00	0.01	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00
Mg	1.31	1.33	1.15	1.24	1.75	1.77	1.60	1.61	1.30	1.33	1.29	1.29
Mn	0.04	0.03	0.04	0.04	0.04	0.03	0.02	0.03	0.02	0.03	0.03	0.04
Fe	3.48	3.48	3.36	3.40	3.03	3.00	2.88	2.85	3.20	3.19	3.29	3.29
Na	0.01	0.01	0.03	0.02	0.03	0.02	0.03	0.04	0.02	0.03	0.03	0.02
K	1.90	1.91	1.88	1.95	1.86	1.79	1.90	1.85	1.90	1.92	1.92	1.89
total	15.58	15.60	15.50	15.61	15.63	15.54	15.47	15.46	15.49	15.56	15.55	15.55
#mg = [Mg/(Mg+Fe)]	0.27	0.28	0.25	0.27	0.37	0.37	0.36	0.36	0.29	0.29	0.28	0.28

[1] progressive = increasing Ti-content from core to rim; regressive = decreasing Ti-content from core to rim.

the matrix (60–72% of almandine, 0–20% of spessartine). The composition of the garnets from the mesocratic enclaves depends on the location of the host rock. Whenever the host Śnieżnik gneisses are in direct contact with the metasediments of the Młynowiec-Stronie Formation, the enclaves contain irregular and compositionally zoned garnets that are relatively Ca-poor (19–35% of andradite + grossular, 68–80% of almandine, 10–17% of spessartine). In enclaves of the same type from the areas where the host Śnieżnik gneisses are in contact with the migmatites, the grossular content in the garnets reaches values identical to that in the xenoliths (up to 56% of grossular + andradite).

Table 3. Representative microprobe analyses of white mica from the distinguished gneiss types of the eastern part of the Orlica-Śnieżnik Dome.

rock type:	Śnieżnik gneiss			porphyroblastic gneiss		migmatite			banded gneiss		felsic microgranular enclave		xenolith		mesocratic enclave	
Spot:	core	core	core	core	core	core	core	core	core	core	core	core	core	core	core	core
SiO_2	49.55	47.95	46.87	49.93	47.98	52.56	47.47	49.07	49.39	46.87	47.27	47.12	50.20	47.13	50.21	47.72
TiO_2	0.23	0.41	0.6	1.13	0.48	0.20	0.75	0.72	0.17	0.60	0.58	0.61	0.32	0.92	0.29	0.39
Al_2O_3	27.81	29.71	31.58	27.76	29.49	27.93	32.62	31.00	27.92	31.58	30.41	30.45	28.38	32.91	27.86	31.24
MgO	2.03	1.97	1.41	2.19	1.82	2.06	1.82	1.78	2.22	1.41	1.50	1.44	2.07	1.06	2.21	1.56
MnO	0.05	0	0.01	0.04	0.01	0.00	0.00	0.07	0.00	0.01	0.04	0.12	0.01	0.00	0.00	0.00
FeO	3.73	3.79	3.71	3.16	3.47	3.22	3.29	3.33	4.10	3.71	3.46	3.43	3.52	2.65	3.34	3.31
Na_2O	0.16	0.18	0.22	0.20	0.17	0.15	0.18	0.21	0.21	0.22	0.16	0.16	0.12	0.14	0.17	0.24
K_2O	10.77	10.98	10.5	10.40	10.66	10.48	9.95	10.72	10.85	10.50	10.79	11.11	10.84	10.68	10.52	11.28
H_2O	4.41	4.42	4.43	4.45	4.40	4.59	4.52	4.51	4.42	4.43	4.40	4.40	4.47	4.49	4.45	4.46
total	98.74	99.41	99.33	99.27	98.49	101.12	100.59	101.43	99.28	99.34	98.59	98.83	99.93	99.97	99.04	100.20
recalculated to 22 O																
Si	6.74	6.5	6.34	6.72	6.54	6.87	6.30	6.45	6.70	6.34	6.45	6.43	6.73	6.30	6.77	6.41
Ti	0.02	0.04	0.06	0.12	0.05	0.02	0.08	0.07	0.02	0.06	0.06	0.06	0.03	0.09	0.03	0.04
Al	4.46	4.75	5.04	4.41	4.74	4.30	5.10	4.84	4.46	5.04	4.89	4.89	4.48	5.19	4.43	4.95
Mg	0.41	0.4	0.29	0.44	0.37	0.51	0.36	0.35	0.45	0.29	0.30	0.29	0.42	0.21	0.45	0.31
Mn	0.01	0	0	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
Fe	0.42	0.43	0.42	0.36	0.40	0.35	0.37	0.36	0.47	0.42	0.39	0.39	0.40	0.30	0.38	0.37
Na	0.04	0.05	0.06	0.05	0.05	0.04	0.05	0.06	0.05	0.06	0.04	0.04	0.03	0.04	0.04	0.06
K	1.87	1.9	1.81	1.79	1.85	1.76	1.69	1.82	1.88	1.81	1.88	1.93	1.85	1.82	1.81	1.93
total	13.97	14.06	14.02	13.88	13.99	13.85	13.94	13.98	14.03	14.02	14.01	14.05	13.94	13.94	13.91	14.07
#mg = [Mg/(Mg+Fe)]	0.49	0.48	0.4	0.55	0.48	0.59	0.50	0.49	0.49	0.40	0.44	0.43	0.51	0.42	0.54	0.46

Table 4. Representative microprobe analyses of garnet from the distinguished gneiss types of the eastern part of the Orlica-Śnieżnik Dome.

rock type:	Śnieżnik gneiss		porphyroblastic gneiss			migmatite			banded gneiss			felsic microgranular enclave		xenolith		mesocratic enclave	
Spot:	core	rim	core	mantle	rim	core	mantle	rim	core	mantle	rim	core	rim	core	rim	core	rim
SiO_2	37.63	37.45	37.08	36.90	37.42	37.76	37.70	38.03	37.54	37.76	37.60	37.47	37.30	37.75	37.73	36.91	36.27
TiO_2	0.00	0.02	0.07	0.06	0.06	0.07	0.23	0.09	0.15	0.18	0.09	0.11	0.04	0.15	0.15	0.01	0.02
Al_2O_3	21.58	21.38	20.86	20.94	21.34	20.76	20.59	20.86	21.30	21.37	21.20	21.23	21.12	21.30	21.29	20.74	20.78
Cr_2O_3	0.01	0.00	0.00	0.02	0.01	0.01	0.01	0.00	0.01	0.00	0.01	0.00	0.00	0.01	0.03	0.00	0.00
Fe_2O_3	0.00	0.00	0.32	0.26	0.00	0.80	0.85	0.70	0.00	0.18	0.00	0.15	0.12	0.22	0.00	0.24	0.00
MgO	0.85	0.72	0.64	0.55	0.64	0.97	0.95	0.56	0.51	0.30	0.63	0.36	0.69	0.52	0.46	0.37	0.35
CaO	11.47	10.63	14.34	12.72	15.55	13.66	13.27	17.36	14.66	15.99	13.22	17.10	11.42	14.86	15.11	7.33	5.47
MnO	2.45	5.06	3.18	3.92	2.37	1.09	1.18	1.53	1.27	0.86	0.98	2.15	3.46	1.26	1.29	6.60	8.94
FeO	26.32	25.25	22.06	23.95	22.15	24.68	25.01	20.08	24.60	24.29	25.60	20.95	25.77	24.67	23.83	27.43	27.16
total	100.31	100.50	98.61	99.37	99.54	99.79	99.77	99.20	100.05	100.94	99.33	99.52	99.91	100.73	99.88	99.68	99.05
recalculated to 24 O																	
Si	5.98	5.97	5.97	5.94	5.95	6.01	6.01	6.03	5.96	5.95	6.01	5.96	5.97	5.96	5.99	5.99	5.96
Ti	0.00	0.00	0.01	0.01	0.01	0.01	0.03	0.01	0.02	0.02	0.01	0.01	0.00	0.02	0.02	0.00	0.00
Al	4.04	4.02	3.96	3.97	4.00	3.89	3.87	3.90	3.99	3.97	3.99	3.98	3.99	3.96	3.98	3.97	4.03
Cr	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mg	0.20	0.17	0.15	0.13	0.15	0.23	0.23	0.13	0.12	0.07	0.15	0.08	0.17	0.12	0.11	0.09	0.09
Ca	1.95	1.82	2.48	2.19	2.65	2.33	2.27	2.95	2.50	2.70	2.26	2.91	1.96	2.51	2.57	1.28	0.96
Mn	0.33	0.68	0.43	0.53	0.32	0.15	0.16	0.21	0.17	0.12	0.13	0.29	0.47	0.17	0.17	0.91	1.24
Fe_{tot}	3.50	3.37	3.10	3.25	2.95	3.38	3.43	2.74	3.27	3.22	3.42	2.80	3.47	3.29	3.16	3.76	3.73
total	16.00	16.02	16.03	16.06	16.04	15.99	15.98	15.97	16.03	16.04	15.98	16.03	16.02	16.03	16.00	16.01	16.03
almandine	58.49	55.77	49.24	53.01	48.57	54.84	55.70	44.77	53.96	52.59	57.33	45.87	57.10	53.72	52.59	62.10	61.94
pyrope	3.35	2.84	2.55	2.16	2.50	3.83	3.77	2.21	2.00	1.17	2.52	1.39	2.73	2.03	1.79	1.51	1.42
spessartine	5.51	11.31	7.19	8.78	5.26	2.45	2.65	3.45	2.83	1.89	2.22	4.77	7.75	2.79	2.89	15.13	20.64
andradite	0.00	0.00	0.98	0.78	0.00	2.39	2.57	2.09	0.00	0.54	0.00	0.45	0.36	0.63	0.00	0.75	0.00
grossular	32.62	30.09	40.03	35.22	43.66	36.44	35.29	47.48	41.16	43.82	37.89	47.52	32.05	40.80	42.62	20.51	16.00

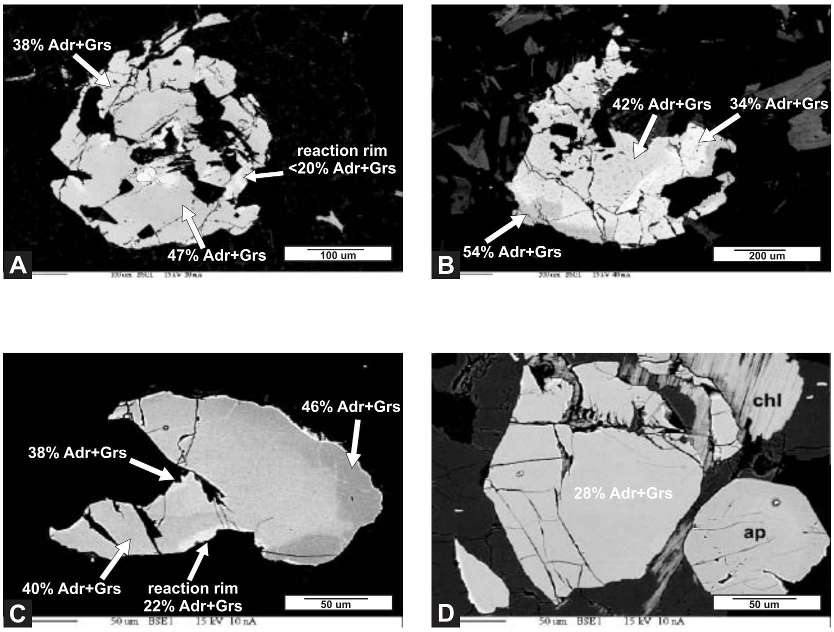


Fig. 4. Back-scattered electron images of garnets from some types of gneiss distinguished in the eastern part of the Orlica-Śnieżnik Dome. The reaction rims are always Ca-depleted.
A – Śnieżnik augen gneiss. Simple pattern of compositional zoning in garnet from a high-Ca core toward a lower-Ca rim; **B** – Migmatite. Oscillatory pattern of compositional zoning in garnet from the medium-Ca core toward the low-Ca mantle and the high-Ca rim; **C** – Xenolith. Reverse pattern of compositional zoning in a garnet from a low-Ca core toward a medium-Ca mantle and a high-Ca rim; **D** – Xenolith. an isometric and compositionally homogeneous garnet from the matrix, adjacent to apatite (ap) and chlorite (chl).

6. Discussion

6.1. A new subdivision for the gneisses based on tectonics and petrography

The gneisses of the eastern part of the Orlica-Śnieżnik Dome show different tectonic evolutions. The common feature of migmatites, porphyroblastic gneisses and banded gneisses is the presence of deformation (primary foliation folded at a small scale) and (ultra) metamorphism (migmatisation/metablastesis) prior to the constriction and shear (connected with the Moldanubian Thrust Zone). The N-S rodding lineation and subhorizontal flattening (mylonitisation) are in turn first recognisable deformational structures in the Śnieżnik gneisses, which were not affected by any deformation and/or metamorphism prior to the Variscan thrusting. Overprinted shear deformation caused unification of all the gneisses in the eastern part of the Orlica-Śnieżnik Dome, thus obscuring in particular the difference between the Śnieżnik gneisses and porphyroblastic gneisses. The presence of porphyroblasts and polymineral lenses, developed during metablastesis and migmatisation, is the most misleading feature. These metamorphic structures affected by flattening, subsequently changed into the porphyroclasts. Because of the presence of such augen-like structures, the porphyroblastic gneisses have been commonly but incorrectly ascribed to the Śnieżnik group/complex of augen gneisses (e.g. the gneisses outcropping near Lądek Zdrój). Such 'augens' are in fact large blasts (lenses), however, with hardly ever strain shadows around them, pointing at relatively rigid behaviour during the final deformation. While the porphyroblastic gneisses happen to be erroneously assigned to the Śnieżnik group/complex, the migmatites and banded gneisses have always been considered as part of the Gierałtów group/complex.

The zonal shear deformation is superimposed, enabling local preservation of the pre-deformation (pre-Variscan) metamorphic fabric. Wherever this occurs, the primary fabric can be treated as an important indicator of the genesis and provenance of the gneissic rocks of the Międzygórze Antiform. On the basis of these structural and petrographical analyses, a new subdivision of the gneisses is proposed here.

The name 'Gierałtów gneisses' should be retained, but exclusively for the migmatites, porphyroblastic gneisses and banded gneisses that show common features such as (1) early foliation evolved into intrafolial folds, (2) porphyroblasts and/or polymineral lenses, and (3) superimposed axial-plane foliation (S2), which is (4) sheared or transposed into subhorizontal position (S3).

The name 'Śnieżnik (augen) gneisses' should be exclusively used for the gneisses of clearly magmatic provenance (porphyroclasts developed at the expense of porphyrocrysts), with only a single mylonitic foliation and/for an elongation lineation.

6.2. Sequence of deformations

The Gierałtów gneisses record a sequence, from D1: early foliation (S1), D2: small-scale folding (F1, F2) accompanied by the development of axial-plane foliation (S2) and synkinematic migmatisation, toward D3: N-S constriction (L3) and subsequent flattening (S3) (Table 5). The last event (D3) took place under amphibolite-facies conditions. A similar deformation path can be reconstructed for the xenoliths in the Śnieżnik gneisses. The Śnieżnik gneisses registered only D3 structures (and primary fluidal structures, D0). The magmatic lineation L0 was interpreted on the basis of the E-W alignment of small enclaves and the same orientation of slightly deformed K-feldspar megacrysts, which avoided flattening. The latest deformation in the gneisses (and metasediments) of the eastern part of the Orlica-Śnieżnik Dome is large-scale buckling (E- and W-vergent F4 folds), developed under greenschist-facies conditions.

Both the Śnieżnik granites and the Gierałtów gneisses were affected by Variscan shearing (D3), changing all the rocks into more or less advanced (L, L-S, S-L) tectonites and (ultra) mylonites. This shear deformation, present in the gneisses and adjacent metasediments (Jastrzębski, 2005; Murtezi, 2006), can, however, in no way be responsible for the migmatisation, as it was suggested by Turniak et al. (2000), Don (2001), Lange et al. (2002, 2005) and Don et al. (2003), as these processes correspond to contradictory P-T conditions and strain fields: mylonitisation requires high pressure, whereas migmatisation is commonly connected with some degree of decompression and partial melt extraction. The high-T structures that occur exclusively in the Gierałtów gneisses (migmatites, porphyroblastic gneisses and banded gneisses) should consequently be regarded as inherited from pre-Variscan times.

6.3. Origin of the gneisses

Although the geochemical composition and geochronological record of the Śnieżnik and Gierałtów gneisses are beyond the scope of the present contribution, some remarks concerning the origin of the gneisses should be made here. The magmatic provenance of the Śnieżnik gneisses, suggested by earlier authors on the basis of geochemical data and structural observations (Borkowska et al., 1990; Don et al., 1990, 2003; Don, 2001; Lange et al., 2002, 2005) is confirmed by structural and textural features and also by the presence of several types of enclaves. A single magmatic origin of the Gierałtów gneisses (Turniak et al., 2000; Don 2001; Lange et al., 2002, 2005) is, however, unacceptable. An argument against this hypothesis is that the reconstruction of the original source for the migmatites and porphyroblastic gneisses is problematic because of the advanced melt extraction and strong recrystallisation. For the same reason, discrimination of the tectonic settings of the metamorphic rocks from their geochemistry (Turniak et al. 2000; Lange et al., 2002, 2005) should be considered with extreme caution. Ambiguous is the genesis of the banded gneisses. Borkowska et al. (1990) interpreted these rocks as the most typical types of Gierałtów gneisses, and Don et al. (2003) attributed them to the fine-grained group of the Gierałtów complex. The structural and petrographic outline of the banded gneisses is similar to the Gierałtów group, but their compositional layering is well developed and most likely indicative of a sedimentary/pyroclastic origin of the protolith.

6.4. Interpretation of the chemical diversification of the minerals

The mineral composition of the Śnieżnik and Gierałtów gneisses is similar, but the chemical composition of the minerals show meaningful differences. The most noticeable differ-

Table 5. Summary of the mesostructural analysis of the eastern part of the Orlica-Śnieżnik Dome gneisses. Qtz = quartz, Kfs = potassium feldspar, Pl = plagioclase, Bt = biotite.

deformation events:	deformation related to the pre-Variscan activity			deformation related to the Variscan activity (Moldanubian Thrust Zone)		
	D0	D1	D2	D3-1	D3-2	D4
Śnieżnik (augen) gneisses	L0 = primary magma lineation presently subhorizontal (W-E)	none	none	L3 = elongation lineation defined by HT recrystallized rods of Qtz, Kfs, Pl and mica streaks	S3 = mylonitic foliation defined by HT recrystallized layers of separate Qtz, Kfs, Pl and mica S3 anastomoses around porphyroclasts with strain shadows indicating 'top-to-the-N' and 'top-to-the-S' kinematics C3 = local crenulation cleavage	F4 = large-scale E-vergent folds accompanied by mica recrystallisation over the fold's limbs
Gierałtów gneisses – porphyroblastic gneisses	none	S1 = mylonitic foliation	F1 = small-scale W-vergent folds interfering with F2 = small-scale E-vergent folds syn-kinematic metablastesis of Kfs and Qtz or recrystallisation of polymineral lenses (Kfs±Qtz±Pl or Qtz) falling within folding and local extraction of leucosome (Qtz+Kfs±Pl) S2 = new axial-plane foliation (F1 and F2 presently intrafolial) post-kinematic growth of Kfs and Qtz porhyroblasts (chaotically over the S2) without strain-shadows	L3 = elongation lineation defined by HT recrystallised rods of Qtz, Kfs, Pl and mica streaks	S2→S3 = flattening at the 'top-to-NE' direction consequently driving to transposition of the S2 foliation towards subhorizontal position; transposed S2→S3 foliation anastomoses around porphyroblasts and leucosome segregations without strain shadows	F4 = large-scale E-vergent folds accompanied by mica recrystallisation over the fold's limbs
Gierałtów gneisses – migmatites	none	S1 = non-mylonitic foliation	disharmonic, migmatitic folds, locally displaying the sequence: F1 = small-scale 's'-asymmetric folds interfering with F2 = small-scale 'z'-asymmetric folds syn-kinematic extraction of leucosome (Qtz+Kfs±Pl) within triangle dilatant sites of F1 and F2 and small ductile shear zones (with the 'top-to-the-E' kinematics) S2 = new axial-plane foliation (F1 and F2 presently intrafolial) post-kinematic growth of Kfs and Qtz porhyroblasts (chaotically over the S2) without strain shadows	L3 = elongation lineation defined by HT recrystallised rods of Qtz, Kfs, Pl and mica streaks	S2→S3 = flattening at the 'top-to-NE/SW' direction consequently driving to flattening and transposition of the S2 foliation towards subhorizontal position; transposed S2→S3 foliation anastomoses around porphyroblasts and leucosome segregations (and eclogites, amphibolites if present) with or without strain shadows	F4 = large-scale E-vergent fold accompanied by mica recrystallisation over the fold's limbs

Table 5. cont.

deformation events:		deformation related to the pre-Variscan activity			deformation related to the Variscan activity (Moldanubian Thrust Zone)		
		D0	D1	D2	D3-1	D3-2	D4
Gierałtów gneisses	banded gneisses	S0 = relics of primary sedimentary layering in protolith (Bt-rich versus Bt-poor layers)	S1 = compositional foliation, mimetic to S0	F1 = relics of small-scale folds S2 = axial plane foliation ('ghost' folds F1 presently intrafolial); the S2 foliation is presently subhorizontal, oblique to the S1	L3 = elongation lineation defined by HT recrystallized rods of Qtz, Kfs, Pl and mica streaks	S2→S3 or S3 = rejuvenation of earlier structures or scarce mylonitic foliation (sub)mimetic to S2	F4 = large-scale E-vergent fold accompanied by mica recrystallization over the fold's limbs
enclaves within the Śnieżnik gneisses	felsic micro-granular enclaves	none	none	none	L3 = elongation lineation defined by HT recrystallized rods of Qtz, Kfs, Pl and mica streaks at the enclave borders	S3 = mylonitic foliation defined by HT recrystallized layers of separate Qtz, Kfs, Pl and mica	mica recrystallization points at retrogression without deformation record
	xenoliths	none	S1 = non-mylonitic foliation	F1 = small-scale folds, often ptygmatitic syn-kinematic extraction of leucosome (Qtz+Kfs±Pl) within triangle dilatant sites of F1 S2 = new axial plane foliation (F1 presently intrafolial) post-kinematic growth of Kfs and Qtz porphyroblasts (chaotically over S2)	L3 = at the enclave borders elongation lineation defined by HT recrystallized rods of Qtz, Kfs, Pl and mica streaks at the enclave borders	S3 = subhorizontal HT recrystallization of minerals (in a microscale)	mica recrystallization points at retrogression without deformation record
	mesocratic enclaves	none	S1 = relics of non-mylonitic foliation	F1 = relics of small-scale folds syn-kinematic segregations of Qtz+Kfs (leucosome?) within triangle dilatant sites of F1	L3 = at the enclave borders elongation lineation defined by HT recrystallized rods of Qtz, Kfs, Pl and mica streaks at the enclave borders	S3 = subhorizontal HT recrystallization of minerals (in a microscale)	mica recrystallization points at retrogression without deformation record

ence regards the chemical composition of the feldspars. The plagioclase from the Gierałtów gneisses is albite to andesine ([An_{6-36}]), while the plagioclase from the Śnieżnik gneisses is albite and oligoclase ([An_{6-23}]). The plagioclases within the enclaves are either comparable with the Śnieżnik gneisses (felsic microgranular enclaves have [An_{6-23}] plagioclase) or resembling the migmatites (the xenoliths and mesocratic enclaves have [An_{6-36}] plagioclases). Exsolution textures (antiperthites) are common in all types of the rocks, except in the banded gneisses. The plagioclases from all types of gneiss show a normal zonation (Ca-decrease from the core to the rim of the grains), subsequently overprinted by (sub)grain-edge albitisation. These differences can be interpreted as an effect of primary variations in the source material (granitic provenance of the Śnieżnik gneisses versus multi-source genesis of the Gierałtów gneisses) and/or the effect of metamorphic recrystallisation (metablastesis and migmatisation). The latter would require external contamination and enrichment of the Gierałtów gneisses during metamorphism. The ductile behaviour of the quartz and feldspars sets the minimum temperature conditions during recrystallisation at 500–600ºC (see Passchier & Trouw, 1996), which corresponds to amphibolite-facies metamorphism.

The structural dependence of the TiO_2 concentration in the dark micas suggests differences in temperature conditions between the Gierałtów gneisses and Śnieżnik gneisses, as the Ti content increases with increasing temperature (see Forbes & Flower, 1974; Arima & Edgar, 1981; Tronnes et al., 1985). The higher temperature conditions that affected the Gierałtów gneisses possibly originated from migmatisation/metablastesis.

The white micas in the gneisses of the eastern part of the Orlica-Śnieżnik Dome are mostly phengites (sporadically muscovites). Both the amount of white mica and their Si-content increase from the muscovite-out boundary at low pressures towards higher pressures and lower temperatures (cf. Spear, 1993). The experimentally determined (Massonne & Schreyer, 1987) increase in phengitic white mica and the decrease in biotite and K-feldspar with pressure, according to the simplified reaction formula: phlogopite + K-feldspar + quartz + H_2O = phengite, can be used as a geobarometer. The stable or decreasing Si (pfu) content from the cores of the mica flakes towards their rims, which is found in all gneisses, indicates retrogressive way metamorphism. The highest value of Si pfu (3.43), which complies with P = 1.1–1.6 GPa (in the assumed range of T = 400–800ºC) was obtained from the Gierałtów migmatites and the partially melted xenoliths (mesocratic enclaves) enclosed in the Śnieżnik gneisses. The highest Si content depends on the structural context of the phengites in accordance with the D2 deformation structures. The phengites in the Śnieżnik gneisses themselves indicate a pressure range of 0.6–1.3 GPa (in the assumed range of T = 400–800ºC). Identical results have been obtained from the felsic microgranitoid enclaves. The phengites from the porphyroblastic gneisses and the banded gneisses indicate a pressure of 0.8–1.4 GPa (T = 400–800ºC). As the phengite geobarometer has been applied to rocks in which the minerals are not in equilibrium and do not correspond to the actual KMASH system (lack of Al_2O_3 phase), the results should be considered with caution (see Massonne & Schreyer, 1987).

The garnets from the Śnieżnik and Gierałtów gneisses are exceptionally Ca-rich, and the implications have been dealt with earlier (Borkowska et al., 1990, and references therein). Grossular enrichment in garnets is related to high-grade metamorphism and/or the bulk composition of the protolith. The oscillatory compositional zoning is due to uninhibited diffusion of Ca, Fe, and Mg ions during metamorphism (Spear, 1993). The garnet intergrowths within the porphyroblasts in the Gierałtów gneisses and the xenoliths are characterised by a distinct increase of the almandine end-member if compared with the garnets from the matrix. The Fe-garnets record a considerable change in the ion admittance during blastesis, and suggest a more complex/longer (P)T metamorphic path of the Gierałtów gneisses (and the xenoliths) than holds for the Śnieżnik gneisses themselves. Moreover, the garnets from the Śnieżnik gneisses have a higher amount of the spessartine end-member (up to 17%) than those in the Gierałtów gneisses (max. 8%), confirming different metamorphic conditions for the two groups of rock, as the spessartine content increases with decreasing temperature (see Spear, 1993). The higher temperature conditions must have occurred during the migmatisation (and metablastesis) of the Gierałtów gneisses. Unfortunately, all thermometers requiring biotites and garnets being in equilibrium (Ferry & Spear, 1978; Bhattacharya et al., 1982; Ganguly & Saxena, 1984; Hoinkes, 1986; Berman, 1990; Dasgupta et al., 1991) cannot be reliably applied, due to the large amount of the grossular end-member or the disequilibrium between garnet and biotite. All results are thus underestimated and yield ~500–550 °C (assuming P = 0.6–1.4 GPa).

Acknowledgements

I would like to thank Prof. Andrzej Żelaźniewicz for his assistance during all stages of this research. I am deeply indebted to the reviewers, Prof. Teresa Oberc-Dziedzic and Prof. Witold Smulikowski for their critical and stimulating reviews and valuable improvement of this contribution. My thanks go to Dr. Julita Biernacka for helpful comments on the work. I wish to thank Dr. Piotr Dierżanowski and M.Sc. Lidia Jeżak (Warsaw University) for help with microprobe analyses. This study was financially supported by the State Committee for Scientific Research through grant KBN 3P04D 062 24.

References

Aleksandrowski, P., Kryza, R., Mazur, S., Pin, C. & Zalasiewicz, J.A., 2000. The Polish Sudetes: Caledonian or Variscan? *Transactions of the Royal Society of Edinburgh: Earth Sciences* 90, 127–146.

Aleksandrowski, P. & Mazur, S., 2002. Collage tectonics in the northeasternmost part of the Variscan Belt: the Sudetes, Bohemian Massif. [In:] J.A. Winchester, T.C. Pharaoh & J. Verniers (Eds): *Palaeozoic amalgamation of central Europe.* Geological Society of London Special Publications 201, 237–277.

Arima, M. & Edgar, A.D., 1983. A high pressure experimental study on a magnesian-rich leucite-lamproite from the West Kimberley area, Australia: petrogenetic implications. *Contributions to Mineralogy and Petrology* 84, 228–234.

Barbarin, B. & Didier, J., 1991. Macroscopic features of mafic microgranular enclaves. [In:] J. Didier & B. Barbarin (Eds): Enclaves and granite petrology. *Developments in Petrology* (Elsevier, Amsterdam) 13, 253–263..

Berman, R.G., 1990. Mixing properties of Ca-Mg-Fe-Mn garnets. *American Mineralogist* 75, 328–344.

Bhattacharya, A., Mohanty, L., Maji, A., Sen, S.K. & Raith, M., 1982. Non-ideal mixing in the phlogopite-annite binary: constrains from experimental data on Mg-Fe partitioning and reformulation of the biotite-garnet geothermometer. *Contributions to Mineralogy and Petrology* 111, 87–93.

Borkowska, M., 1996. P-T conditions of metamorphism in gneisses of the Śnieżnik region – Sudetes, Poland. *Terra Nostra* 96, 26–30.

Borkowska, M., Choukroune, P., Hameurt, J. & Martineau, F., 1990. A geochemical investigation of age, significance and structural evolution of the Caledonian-Variscan granite-gneisses of the Śnieżnik metamorphic area (central Sudetes, Poland). *Geologia Sudetica* 25, 1–27.

Brodie, K., Fetted, D. & Harte, B., 2007. Structural terms including fault rocks terms. [In:] D. Fettes, & J. Desmons (Eds): *Metamorphic rocks – a classification and glossary of terms – recommendations of the International Union of Geological Sciences Subcommission on the Systematics of Metamorphic Rocks*. Cambridge University Press, Cambridge U.K., 24–31.

Bröcker, M., Klemd, R., Cosca, M., Brock, W., Larionov, A.N. & Rodionov, N., 2009. The timing of eclogite facies metamorphism and migmatization in the Orlica-Śnieżnik complex, Bohemian Massif: constraints from a multimethod geochronological study. *Journal of Metamorphic Petrology* 27, 385–403.

Dasgupta, S., Sengupta, P., Guha, D. & Fukuoka, M., 1991. A refined garnet-biotite Fe-Mg exchange geothermometer and its application in amphibolites and granulites. *Contributions to Mineralogy and Petrology* 109, 130–137.

Didier, J., 1991. The various types of enclaves in the Hercynian granitoids of the Massif Central, France. [In:] J. Didier & B. Barbarin (Eds): Enclaves and granite petrology. *Developments in Petrology* (Elsevier. Amsterdam) 13, 47–63.

Don, J., 1964. Góry Złote i Krowiarki jako elementy składowe metamorfiku Śnieżnika [The Złote and Krowiarki Mts. as structural elements of the Śnieżnik metamorphic massif]. *Geologia Sudetica* 1, 79–117.

Don, J., 1991. Seria Młynowca oraz problem następstwa gnejsów w świetle tektoniki fałdowej metamorfiku Śnieżnika [The Młynowiec Series and the problem of superposition of the gneisses in the light of fold tectonics of the Śnieżnik Metamorphic Unit]. [In:] M. Dumicz (Ed.): Następstwo serii skalnych masywu Śnieżnika w świetle kartografii geologicznej, analizy strukturalnej i badań radiometrycznych [Superposition of rock series from the Śnieżnik Massif in the light of geological mapping, structural analysis and radiometric investigations]. Materiały konferencji terenowej, Wydawnictwa Uniwersytetu Wrocławskiego, 42–53.

Don, J., 2001. The relationship between the Gierałtów migmatites and the Śnieżnik granitogneisses within the Kletno fold. *Prace Specjalne Polskiego Towarzystwa Mineralogicznego* 19, 189–194.

Don, J., Dumicz, M., Wojciechowska, I. & Żelaźniewicz, A., 1990. Lithology and tectonics of the Orlica-Śnieżnik Dome, Sudetes – recent state of knowledge. *Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen* 197, 159–188.

Don, J., Skácel, J. & Gotowała, R., 2003. The boundary zone of the East and West Sudetes on the 1:50 000 scale geological map of the Velké Vrbno, Staré Město and Śnieżnik Metamorphic Units. *Geologia Sudetica* 35, 25–59.

Dumicz, M., 1988. Strefa tektoniczna Złoty Stok-Skrzynka w świetle analizy mezostrukturalnej metamorfiku Lądka-Śnieżnika [The Złoty Stok-Skrzynka structural element in the light of a mesostrucrtural analysis of the Lądek-Śnieżnik metamorphic terrain]. *Geologia Sudetica* 23, 83–106.

Dumicz, M., 1989. Następstwo serii gnejsowych masywu Śnieżnika w świetle analizy mezostrukturalnej wybranych obszarów w jednostkach geologicznych Międzygórza i Gierałtowa [The succession of the Śnieżnik Mountains gneisses in the light of a mesostructural analysis of some areas of the Międzygórze and Gierałtów units]. *Geologia Sudetica* 24, 139–189.

Ferry, J.M. & Spear, F.S., 1978. Experimental calibration of the partitioning of Fe and Mg between biotite and garnet. *Contributions to Mineralogy and Petrology* 66, 113–117.

Fischer, G., 1936. Der Bau des Glatzer Schneegebirges. *Jahrbuch der Preußischen Geologischen Landesanstalt* 56, 712–732.

Forbes, W.C. & Flower, M.F.J., 1974. Phase relations of titan-phlogopite, $K_2Mg_4TiAl_2Si_6O_{20}(OH)_4$: a refractory phase in the upper mantle? *Earth and Planetary Science Letters* 22, 60–66.

Franke, W. & Żelaźniewicz, A., 2000. The eastern termination of the Variscides: terrane correlation and kinematic evolution. [In:] W. Franke, V. Haak, O. Oncken & D. Tanner (Eds): *Orogenic processes: quantification and modelling in the Variscan belt*. Geological Society, London, Special Publications 179, 63–86.

Ganguly, J. & Saxena, S., 1984. Mixing properties of aluminosilicate garnets: constraints from natural and experimental data, and applications to geothermobarometry. *American Mineralogist* 69, 88–97.

Gawlikowska, E. & Opletal, M., 1997. *Mapa geologiczno-turystyczna.* [Králický Sněžník – Masyw Śnieżnika – a geological-touristic map]. Český geologický ústav, Państwowy Instytut Geologiczny.

Gunia, T., 1996. Problem wieku marmurów okolicy Stronia Śląskiego na podstawie mikroskamieniałości (Sudety) [The problem of the age of the marbles from the Stronie Śląskie area on the basis of microfossils]. *Acta Universitatis Wratislaviensis, Prace Geologiczno-Mineralogiczne* 62, 5–48.

Grześkowiak, A., 2004. Genesis of the diversification of the Międzygórze structure gneisses, Śnieżnik Metamorphic Unit. Unpublished Ph.D. thesis, Adam Mickiewicz University, Poznań.

Grześkowiak, A. & Żelaźniewicz, A., 2002. On the significance of gneissic enclaves in the 500 Ma metagranite, the Lądek-Śnieżnik Metamorphic Unit, the West Sudetes. *Geolines* 14, 28–29.

Grześkowiak, A., Żelaźniewicz, A. & Fanning, M., 2005. Early Palaeozoic syntectonic migmatization preceded Variscan metamorphism in the Orlica-Śnieżnik Dome, Sudetes: U-Pb SHRIMP evidence. *Geolines* 19, 46–48.

Hoinkes, G., 1986. Effect of grossular-content in garnet on the partitioning of Fe and Mg between garnet and biotite. *Contributions to Mineralogy and Petrology* 92, 393–399.

Jastrzębski, M., 2005. The tectonometamorphic evolution of the marbles in the Lądek-Śnieżnik Metamorphic Unit, West Sudetes. *Geologia Sudetica* 37, 1–26.

Jastrzębski, M., Żelaźniewicz, A., Nowak, I., Murtezi, M. & Larionov, A., 2010. Protolith age and provenance of metasedimentary rocks in Variscan allochthon units: U-Pb SHRIMP zircon data from the Orlica-Śnieżnik Dome, West Sudetes. *Geological Magazine* 147, 416–433.

Koszela, S., 1997. Petrogeneza marmurów z południowo-wschodniej części metamorfiku Śnieżnika (Sudety) [Petrogenesis of the marbles from the south-eastern part of the Śnieżnik Metamorphic Massif (Sudetes)]. *Geologia Sudetica* 30, 58–115.

Kozłowska-Koch, M., 1973. Polimetamorfity strefy tektonicznej Złoty Stok-Skrzynka w Sudetach [Polymetamorphic rocks of the Złoty Stok – Skrzynka dislocation zone]. *Geologia Sudetica* 8, 121–160.

Kröner, A., Jaeckel, P., Hegner, E. & Opletal, M., 2001. Single zircon ages and whole-rock Nd isotopic systematic of early Paleozoic granitoid gneisses from the Czech and Polish Sudetes (Jizerske hory, Karkonosze Mountains and Orlica-Śnieżnik Complex). *International Journal of Earth Science* 90, 304–324.

Kumar, S., Rino, V. & Pal, A.B., 2004. Field evidence of magma mixing from microgranular enclaves hosted in Palaeoproterozoic Malanjkhand granitoids, central India. *Gondwana Research* 7, 539–548.

Lange, U., Bröcker, M., Mezger, K. & Don, J., 2002. Geochemistry and Rb-Sr geochronology of a ductile shear zone in the Orlica-Śnieżnik dome (West Sudetes, Poland). *International Journal of Earth Science* 91, 1005–1016.

Lange, U., Bröcker, M., Armstrong, R., Żelaźniewicz, A., Trapp, E. & Mezger K., 2005. The gneisses of the Orlica-Śnieżnik complex (West Sudetes, Poland): geochemical characteristics, the importance of pre-Variscan migmatisation and constraints on the cooling history. *Journal of the Geological Society of London* 162, 973–984.

Matte, Ph., Maluski, H., Rajlich, P. & Franke, W., 1990. Terrane boundaries in the Bohemian Massif: result of large-scale Variscan shearing. *Tectonophysics* 177, 151–170.

Maury, R.C. & Didier, J., 1991. Xenoliths and the role of assimilation. [In:] J. Didier & B. Barbarin (Eds): Enclaves and granite petrology. *Developments in Petrology* (Elsevier, Amsterdam) 13, 529–542..

Massonne, H.-J. & Schreyer, W. 1987. Phengite geobarometry based on the limiting assemblage with K-feldspar, phlogopite, and quartz. *Contributions to Mineralogy and Petrology* 96, 212–224.

Mehnert, K.R., 1968. *Migmatites and the origin of granitic rocks*. Elsevier Publishing Company, Amsterdam, 393 pp.

Montel, J.M. & Cheilletz, A., 1989. Nature and composition of restites in the Velay granite (France). *Terra Abstracts* 1, 282.

Murtezi, M., 2006. The acid metavolcanic rocks of the Orlica-Śnieżnik Dome (Sudetes): their origin and tectono-metamorphic evolution. *Geologia Sudetica* 38, 1–38.

Oberc, J., 1957. Zagadnienia geologii metamorfiku zachodniej części Gór Bialskich i obniżenia Stronia Śląskiego [Issues from the geology of the Metamorphic Unit of the Bialskie Mountains and the Stronie Śląskie area]. Przewodnik do XXX Zjazdu PTG w Ziemi Kłodzkiej (Duszniki Zdrój 19–21 maja 1957), 72–89.

Oberc, J., 1972. *Budowa geologiczna Polski. Tektonika. Sudety i obszary przyległe* [Geology of Poland. Tectonics. Sudetes and the adjacent areas]. IV, 2. Wydawnictwa Geologiczne Warszawa, 307 pp.

Oliver, G.J.H., Corfu, F. & Krogh, T.E., 1993. U-Pb ages from SW Poland: evidence for Caledonian suture zone between Baltica and Gondwana. *Journal of the Geological Society of London* 150, 355–369.

Opletal, M., Domečka, K. & Čech, S., 1980. *Geologie Orlických hor* [Geology of the Orlické hory Mts.] (in Czech with extended English summary). Geological Survey, Praha, 202 pp.

Passchier, C. & Trouw, R.A.J., 1996. *Microtectonics*. Springer-Verlag. Berlin, 289 pp.

Paterson, S., Pignotta, G. & Vernon, R., 2004. The significance of microgranitoid enclave shapes and orientations. *Journal of Structural Geology* 26, 1465–1481.

Poli, G. & Tommasini, S., 1991. Model for the origin and significance of microgranular enclaves in calc-alkaline granitoids. *Journal of Petrology* 32, 657–666.

Přikryl, R., Schulmann, K. & Melka, R., 1996. A perpendicular fabrics in the Orlické hory gneisses (western part of the Orlica-Śnieżnik Dome, Bohemian Massif) due to high temperature E-W deformational event and late lower temperature N-S overprint. *Journal of Czech Geological Society* 41, 156–166.

Ramsay, J.G. & Huber, M.I.,1987. *The techniques of modern structural geology 2: Folds and fractures*. Academic Press, London, 391 pp.

Schulmann, K. & Gayer, R., 2000. A model for a continental accretionary wedge developed by oblique collision: the NE Bohemian Massif. *Journal of the Geological Society of London* 157, 401–416.

Sawicki, L., 1995. Geological map of Lower Silesia with adjacent Czech and German territories 1:100 000. Państwowy Instytut Geologiczny, Warszawa.

Smulikowski, K. 1960. Evolution of the granite-gneisses in the Śnieżnik Mountains – East Sudetes. Report of the 21 International Geological Congress (Copenhagen) 14, 120–130.

Smulikowski, K., 1979. Ewolucja polimetamorficzna krystaliniku Śnieżnika Kłodzkiego i Gór Złotych w Sudetach [Polymetamorphic evolution of the crystalline complex of Śnieżnik and Góry Złote Mounains in the Sudetes]. *Geologia Sudetica* 14, 7–76.

Spear, F.S., 1993. *Metamorphic phase equilibria and pressure-temperature-time paths*. Mineralogical Society of America, Washington, D.C., 799 pp.

Teisseyre, H., 1957. Budowa geologiczna okolic Międzygórza [Geology of the Międzygórze area]. [In:] H. Teisseyre (Ed): Przewodnik do XXX Zjazdu Polskiego Towarzystwa Geologicznego w Ziemi Kłodzkiej, Duszniki Zdrój 19–21 maja 1957.

Teisseyre, H., 1964. Uwagi o ewolucji strukturalnej Sudetów [Some remarks on the structural evolution of the Sudetes]. *Acta Geologica Polonica* 14, 459–499.

Teisseyre, H., 1980. Precambrian in south-western Poland. *Geologia Sudetica* 15, 7–40.

Tronnes, R.G., Edgar, A.D. & Arima, M. 1985. A high pressure-high temperature study of TiO_2 solubility in Mg-rich phlogopite: implications to phlogopite chemistry. *Geochimica et Cosmochimica Acta* 49, 2323–2329.

Turniak, K., Mazur, S. & Wysoczański, R., 2000. SHRIMP zircon geochronology and geochemistry of the 'Orlica-Śnieżnik gneisses' (Variscan belt of central Europe) and their tectonic implications. *Geodinamica Acta* 13, 393–312.

Vernon, R.H., 1986. Alkali feldspar megacrysts in granites – phenocrysts, not porphyroblasts. *Earth-Science Reviews* 23, 1–63.

Vernon, R.H., Williams, V.A. & d'Arcy, W.F., 1983. Grainsize reduction and foliation development in a deformed granitoid batholith. *Tectonophysics* 92, 123–145.

Vernon, R.H., 1991. Interpretation of microstructures of microgranitoid enclaves. [In:] J. Didier & B. Barbarin (Eds): Enclaves and granite petrology. *Developments in Petrology* (Elsevier, Amsterdam) 13, 277–293.

Wimmenauer, W. & Bryhni, I., 2007. Migmatites and related rocks. [In:] D. Fettes & J. Desmons (Eds): *Metamorphic rocks. A classification and glossary of terms – recommendations of the International Union of Geological Sciences Subcommission on the Systematics of Metamorphic Rocks*. Cambridge University Press, Cambrige, U.K., 43–45.

Żelaźniewicz, A., 1988. Gneisses due to irrotational extension, a case from the Sudetes, Bohemian Massif. *Geologische Rundschau* 77, 671–682.

Żelaźniewicz, A., Nowak, I., Larionov, A. & Presnyakov, S., 2006. Syntectonic Lower Ordovician migmatite and post-tectonic Upper Visean syenite in the western limb of the Orlica-Śnieżnik Dome, West Sudetes: U-Pb SHRIMP data from zircons. *Geologia Sudetica* 38, 63–80.

Manuscript received 14 July 2010
revision accepted 20 March 2011