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Gneisses in the Orlica-Śnieżnik Dome, West Sudetes: a single batholitic protolith or a more complex origin?

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ABSTRACT:

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Detailed structural and petrographic studies confirmed the presence of two major units of ca. 515–480 Ma gneisses in the Orlica-Śnieżnik Dome (NE Bohemian Massif) and enabled the distinction of two formations which differ in their mineral composition (modal and chemical) and structural records. An intrusive contact between rocks of the two formations was observed. The Gierałtów Gneiss Formation is composed of rocks having at least two sets of folded metamorphic foliations, with relics of compositional banding and records of early shearing prior to migmatization and metablastesis which produced quartzofeldspathic segregations (D1–D2 events). Such aggregates, even if isometric and shared (D3) may, but must not be mistaken for original augens (porphyroclasts in the original granite). Modal contents of the feldspars differ widely (20–40% of plagioclase feldspar, 16–40% of alkali feldspar) as well as their composition (Ab_{0-90}, An_{6-38}); the biotites can be either poor or enormously enriched in Al (0.26–1.07 Al^{VI}). Such heterogeneities are consistent with the inferred metamorphic transformations of originally diversified sedimentary-volcanogenic protoliths. In contrast, the Śnieżnik Gneiss Formation is composed of metagranites, dynamically metamorphosed into the augen gneisses. They possess only one set of mylonitic foliation and one rodding lineation, both developed during a regional shear event (D3). Nearly equal modes of feldspars and quartz, uniform composition of plagioclase feldspar (An_{6-23}) and a rather stable amount of Al (0.3–08 Al^{VI}) in the biotites are indicative of homogenization of a granitic protolith. Anatectic provenance of the gneisses is evidenced by enclaves. Felsic microgranular enclaves are chilled fragments of the parental intrusion, while xenoliths and surmicaceous enclaves are akin to rocks of the Gierałtów Formation, thus the latter or equivalent rocks formed a migmatic envelope of the Śnieżnik granite pluton.

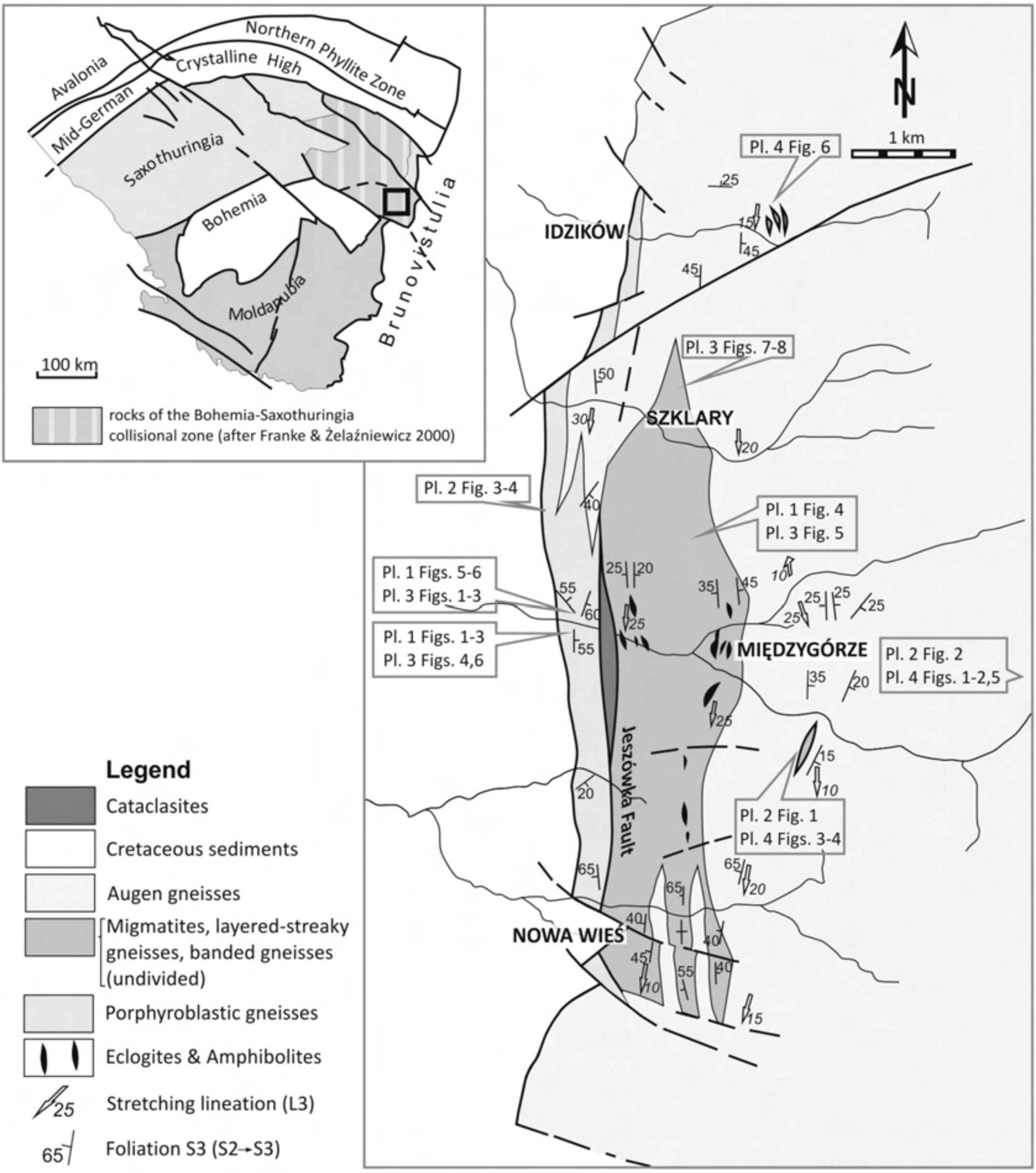
Key words: Orlica-Śnieżnik Dome; Śnieżnik; Gierałtów; Augen gneiss; Migmatite; Enclave; Deformation.

INTRODUCTION

In the West Sudetes, the Orlica-Śnieżnik Dome (OSD) is one of a few tectonic units in which ca. 500 Ma gneisses (see review in Franke and Żelaźniewicz 2000, Żelaźniewicz *et al*. 2002, Lange *et al*. 2005) occur together with metasedimentary rocks whose protolith was deposited in Early/Middle Cambrian–Early Ordovician times (Jastrzębski *et al.* 2010). There are several varieties of the gneisses (Text-fig.1) which were originally considered to have developed in different orogenic events and assigned to the Archaean and Lower Palaeozoic. Those gneisses that were considered older and had a partly migmatitic appearance were named "Gierałtów gneisses"[1] whereas the other gneisses with characteristic augen textures were given

[1] Equivalent former German names: Młynowiec = Mühlbach, Stronie = Seitenberg, Gierałtów = Gersdorf, Śnieżnik = Glatzer Schneeberg.

the name "Śnieżnik gneisses" (Fischer 1936). Later detailed mapping led Don (1964, 2001) and Don *et al.* (2003) to conclude that the migmatitic gneisses developed at the expense of the augen gneisses. However, the exact opposite conclusion was presented by Dumicz (1989) and the divergent views were reviewed by Don *et al.* (1990). Before the advent of radiometric dating, a growing number of field, microscopic and geochemical observations gave rise to a plethora of other options, including the one which assumed that all the gneisses originated by metasomatic feldspathization of adjacent mica schists and thus were essentially of the same protolith age (Smulikowski 1957, 1960, 1979). Teisseyre (1957, 1960, 1968, 1973) distinguished and mapped a transition zone in the Międzygórze area where he observed that the two types of gneisses interfinger and alternate in a complex manner. Different genetic interpretations greatly affected the definitions of lithological units distinguished by various authors for mapping purposes and eventually resulted in misidentification of the units, in particular by those who never mapped in the region. The first isotopic data (Rb-Sr, U-Pb) apparently corroborated the notion concerning similar ages of the gneisses, but not their ori-



Text-fig. 1. Geologic sketch-map of the Międzygórze Antiform with location of structures shown on plates 1–4. Inset shows location of the study area in the Bohemian Massif gin (van Breemen *et al.* 1982; Oliver *et al*. 1993; Kröner *et al.* 2001). However, Borkowska *et al*. (1990) were able to show that the two main gneiss types had different protoliths which, to a noticeable extent, differed in their geochemistry and Rb-Sr systematics (Borkowska 1994, 1996). All further analyses of U-Pb or Pb-Pb systems in zircons retrieved from the gneisses demonstrated the presence of a dominant cluster of 515–480 Ma ages, accompanied by some inherited xenocrysts dated at ca. 560 Ma and metamorphic outgrowths of ca. 340 Ma age, which confirmed the earlier conclusion of Borkowska *et al*. (1990), based on biotite Rb-Sr data, that metamorphism took place at 335 Ma (review in Lange *et al*. 2005). Geochemical data accompanying some of those studies were considered to record no significant differences between the dated samples (Turniak *et al.* 2000, Kröner *et al*. 2001, Lange *et al.* 2002) and the gneisses were proposed to have come from different magma batches supplying the same, ca. 500 Ma old batholith. Although obvious differences in mineral grain-size, colour, metamorphic textures and deformation histories were commonly mentioned to occur between the gneisses, they attracted no particular attention and were tacitly assumed, with no sound argument offered, to be products of subsequent Variscan deformation and migmatization. Such an approach failed, however, to satisfactorily explain the field data and thus was doubted by Grześkowiak and Żelaźniewicz (2002), Grześkowiak *et al*. (2005) and Redlińska-Marczyńska (2011), who observed enclaves of the Gierałtów-type migmatitic gneisses within the augen Śnieżnik gneisses and a distinctly simpler tectonic history of the latter. This paper further explores those observations which have been made throughout the whole OSD, with particular reference to the area of the Międzygórze Antiform, and points to a number of compositional and structural dissimilarities that are interpreted in terms of genetic differences and disparate derivation of the gneisses. One of our aims is to provide a comprehensive account of criteria that should be considered whenever gneisses in the region are to be identified and assigned to either the "Śnieżnik" or the "Gierałtów" category.

GEOLOGICAL SETTING

The Orlica-Śnieżnik Dome (OSD) represents the easternmost tectonic unit of the West Sudetes (Lugicum *sensu* Suess 1912) in the Bohemian Massif (Text-fig.1). Within the European Variscides, the Polish part of the West Sudetes has been assigned either to the Saxothuringian (Franke *et al.* 1993; Franke and Żelaźniewicz 2000) or Moldanubian (Matte 1990; Aleksandrowski and Mazur 2002) zones. The West Sudetes were brought into contact with the Moravosilesian Zone of the East Sudetes (Jeseníky Mountains) along the Staré Město Belt which comprises abundant metabasites interpreted as relicts of Ordovician oceanic crust (Floyd *et al*. 2000; Hegner and Kröner 2000).

A first lithostratigraphic subdivision of rocks in the eastern part of the OSD was proposed by Fischer (1936) who distinguished, from the base to the top: the Młynowiec paragneisses (Archaean), the migmatitic Gierałtów gneisses (Proterozoic), unconformably overlain by metasediments of the Stronie series (Late Proterozoic) and intruded by the Śnieżnik porphyritic granite in the Caledonian cycle (review in Don *et al*. 1990, Żelaźniewicz *et al*. 2002). Based on U-Pb SHRIMP ages of detrital zircons from the Młynowiec and Stronie metasedimentary rocks, Jastrzębski at al. (2010) proved that their protoliths were sourced from the Cadomian basement and did not differ significantly in age of deposition. In a revised lithostratigraphic column, they established the Młynowiec Formation and the overlying Stronie Formation, both developed in Early Cambrian–Early Ordovician times (530–470 Ma). These two formations are in tectonic, secondary contacts with the "Gierałtów gneisses" and the "Śnieżnik gneisses" so that the primary relationships can hardly be observed. The protoliths of the gneisses were isotopically (Rb-Sr, U-Pb, Pb-Pb) dated at ~500 Ma, with inherited components from the ~560–530 Ma Cadomian basement (Borkowska *et al*. 1990; Turniak *et al.* 2000; Grześkowiak *et al*. 2005; Lange *et al.* 2005).

ANALYTICAL METHODS

In view of the apparent compositional and isotopic similarities but different textural properties emphasized in the literature, as well as the different approaches used by previous authors who studied gneisses in the Orlica-Śnieżnik Dome (Oberc 1957, 1977; Ansilewski 1966; Smulikowski 1979; Żelaźniewicz 1984; Don *et al*. 1990), we decided to re-examine the mutual relationships of the gneisses by combining field and laboratory data on both structural as well as mineralogical and petrographic features of these rocks. The Międzygórze Antiform was selected as a key area and a test ground owing to its excellent outcrops where the gneisses occur in numerous variants which alternate in a "transitional zone" (Teisseyre 1973; Don *et al.* 2003) and embrace more or less amphibolitized eclogite bodies (Text-fig.1). Classic structural methods (Ramsay and Huber 1983; Ramsay and Huber 1987; Passchier and Trouw 1996) were used to identify and distinguish different sets of small-scale structures, to establish their relative chronology and kinematics, to assess the deformational regime and to determine the mineralogical characteristics (mineral assemblages) of the consecutive mesostructural sets.

Petrographic and mineralogical studies were carried out on 143 (oriented) thin sections in order to establish the transformations of mineral assemblages in successive sets of tectonic fabric. The quantitative chemical composition of the minerals and their zonation (over 13000 spots) were analysed using the Electron Probe Microanalyser CAMECA SX-100 with 4 WDS spectrometers (Institute of Geochemistry and Petrology, Warsaw University). Conditions for analyses of feldspars and micas were set on 10 nA probe current and 15 kV acceleration voltage. Analyses of garnets (and allanites, epidotes, titanites) were collected under 15 kV acceleration voltage and a beam current of 20 nA. A focused beam was used for most analyses, except Na-feldspars and white micas (defocused beam of 2–5 μm) to avoid some diffusion of elements during an electron bombardment. In the petrographic study, feldspars were treated as plagioclases ($An_{10\text{-}100}$), alkali feldspars (Or-Ab), K-feldspars (88–100% Or) and albites (90-100% Ab) in order to eliminate the influence of secondary edge albitization.

Modal proportions of feldspars were established on the basis of BSE (Back Scattered Electron) images, generated by the chemical component signal, on which the individual colour phase can be assigned to one particular/individual mineral phase. Each colour phase for each image was repeatedly checked in order to confirm the composition of the feldspars. The BSE images were digitally reworked using the ANALYSIS 2.0 software via separating 256 shades of grey and measuring the engaged area in percentages calculated from the established scale. Additional photomicrographs (magnification ×2.5 and ×4) of thin sections from the coarser-grained gneisses (especially the augen types) were used for appropriate correction of the obtained results. The entire documentation for the study, including oriented rock samples, thin sections and results of the chemical analyses, is stored in the Adam Mickiewicz University, Institute of Geology, Maków Polnych 16, 61-606 Poznań, Poland.

CHARACTERISTICS OF THE GNEISS UNITS

Lithology

The distinction between the "Śnieżnik gneisses" and "Gierałtów gneisses" introduced by Fischer (1936) was in common usage during later mapping campaigns and other fieldwork particularly in the eastern limb of the OSD. On the series of overview maps edited and issued by the Geological Survey (Sawicki 1968, 1995, 1997) and in numerous other publications, all gneisses containing augens or augen-like textures were identified as the Śnieżnik type whereas all fine-grained "augen-free" gneisses were ascribed to the Gierałtów type. On the most recent map (Don *et al*. 2003), coarse augen and flaser gneisses along with aplite and thin-laminated gneisses have been distinguished as the "Śnieżnik complex". In contrast, fine-grained gneisses and migmatites that locally embrace relics of the "Śnieżnik gneisses" have been assigned to the "Gierałtów complex". Such descriptions imply different ages of the two gneiss types and determine their mutual genetic relationships, which produces a view that is not generally accepted. In trying to verify these disputable interrelationships, it can be observed that in some rocks which have been mapped as the coarse-grained "Śnieżnik gneisses", the augens actually do not represent former feldspar phenocrysts, now deformed, but represent instead polymineral augen-like features derived from porphyroblasts or polymineral felsic aggregates. These observations suggest that "Śnieżnik gneisses" distinguished to date may have developed from different protoliths: granites and gneisses. The ubiquitous, zonally more intense, ductile shearing that was experienced by the "Śnieżnik gneisses" strongly controlled the grain size of the minerals, varying from coarse-grained in flaser variants, down to very fine-grained in thinly laminated (ultra)mylonites. The latter, however, were always mapped as "Gierałtów gneisses". For such reasons, especially when no additional information is supplied (characteristics of augens, metamorphic fabric, etc.), controversies arise when it comes to identification and classification of the gneisses during mapping or any other type of fieldwork (Redlińska-Marczyńska 2011). Having combined field relationships, structural observations and petrographic characteristics, we attempt to revise the subdivision of the quartzofeldspathic gneisses incorporated in the Orlica-Śnieżnik Dome. The following subdivision of the gneiss units is based on observations made in the Międzygórze Antiform (Redlińska-Marczyńska 2011), checked and modified in accordance with observations in the rest of the OSD.

Out of the rocks assigned by Don *et al*. (2003) to the "Gierałtów complex" we have been able to discern four different lithological units (Text-fig.1): [1] migmatites, [2] layered and streaky gneisses, [3] banded gneisses and [4] mylonites to ultramylonites.

[1] Migmatites are represented mainly by folded stromatic and phlebitic metatexites which locally contain small, isolated leucosome lenses set in a mesosome matrix with diatexitic nests with a granitic appearance (Pl. 1, Figs 1–3). They are composed of a mineral assemblage of Qtz+Pl+Kfs+Bt+Phg±Grt±

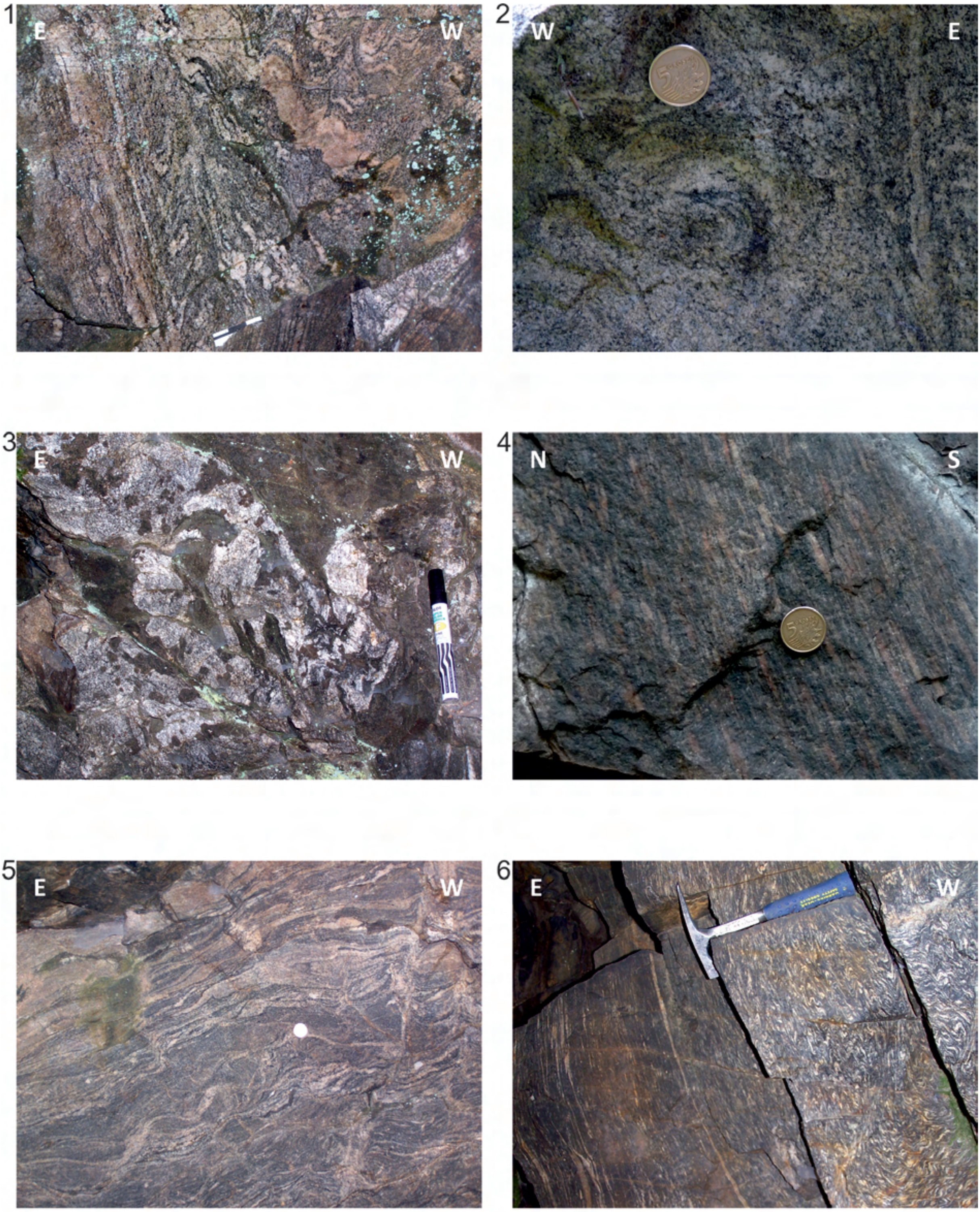


Plate 1. Types of rocks usually classified as the "Gierałtów gneisses/complex". 1 – stromatic migmatite; 2 – metatexitic to diatexitic migmatite; 3 – phlebitic migmatite with enclosures of amphibolite (retrogressed eclogite); 4 – layered to streaky gneiss; 5 – banded gneiss; 6 – (ultra)mylonite; see Text-fig. 1 for geographic location

Plate 2. Types of rocks usually classified as the "Śnieżnik gneisses/complex". 1 – augen gneiss with dominant linear fabric (L-tectonite), section perpendicular to the lineation; 2 – augen gneiss with distinct planar fabric (S-tectonite); 3 – porphyroblastic gneiss; 4 – mylonite zone (right) in the porphyroblastic gneiss; see Text-fig. 1 for geographic location

Ep±Ap±Aln±Ttn[2]. The stromatites are characterized by alternation of leucocratic and mesocratic layers. In the phlebites, numerous disrupted leucosome veins cross-cut mesosome as well as enclosures of high grade rocks (metabasites/eclogites, felsic granulites) occasionally present within the latter. Contacts with such enclosures are either diffuse or sharp and the leucosome material tends to form nests within both the host migmatites and high grade rocks.

[2] Layered and streaky gneisses are composed of Qtz+Pl+Kfs+Bt+Phg±Aln±Ttn±Grt±Ilm and possess well developed foliation marked by continuous (in the layered gneisses) or discontinuous (in the streaky gneisses) quartzofeldspathic layers (Pl. 1, Fig. 4).

[3] Banded gneisses ("homogenous" gneisses of Borkowska *et al*. 1990) are fine-grained, equi-granular rocks with discontinuous gneissic mineral banding marked by parallel alignment of mica flakes and specific compositional alternation (Bt-rich and Bt-poor diffuse banding). The gneisses are composed of an assemblage of Qtz+Pl+Kfs+Bt+Phg±Ap±Ttn±Grt±Ep±Aln±Ilm. In bands richer in biotite leucosome segregations can be conspicuous (Pl. 1, Fig. 5).

[4] Mylonites represent sheared and mylonitized derivatives of the three former gneiss units (Pl. 1, Fig. 6). They are compositionally poorer (Qtz+Pl+Kfs+Bt+Phg±Aln±Grt) than the gneisses and display typical mylonitic lamination accompanied by grain-size reduction. Ductile shearing to various extent obliterated signs of earlier deformational and metamorphic fabrics.

Three lithological units can be distinguished within the "Śnieżnik complex" of Don *et al*. (2003). These are: [1] augen gneisses (with different enclaves), [2] porphyroblastic gneisses and [3] mylonites.

[1] Augen gneisses are coarse- to even-grained metaigneous rocks that grade from porphyritic

[2] Abbreviations of names of minerals follow recommendations by the IUGS (Siivola & Schmid 2007).

(meta)granite to flaser gneisses with genuine augen fabric (K-feldspar porphyroclasts) and mylonitic segregation (Pl. 2, Figs 1–2). Their mineral composition embraces the assemblage Qtz+Kfs+Pl+Bt+Phg±Ap±Ttn±Grt. Within the augen gneisses, many different types of isolated enclaves occur. They range petrographically from felsic (Qtz+Kfs+Pl+Bt+Phg±Ttn±Ap±Ep) to mesocratic microgranular gneisses (Qtz+Pl+Bt±Kfs±Ttn±Aln±Ep) and stromatitic migmatites (Qtz+Kfs+Pl+Bt+Phg±Ttn±Ap±Grt±Aln). The enclaves are rather small (a few centimetres to a few metres in diameter) and have either sharp or diffuse contacts with their host.

[2] Porphyroblastic gneisses have a mineral composition Qtz+Kfs+Pl+Bt+Phg±Ap±Ttn±Grt±Ilm±Aln similar to that of the augen gneisses. As compared to the latter, a major difference between them is tectonometamorphic and not the compositional one. These rocks are characterized by the presence of lensoid, a few cm in diameter, polymineral aggregates (Qtz+Kfs, Qtz+Kfs+Pl) and felsic porphyroblasts (Pl and Kfs overgrowing Qtz, Fsp, Bt, Phg, Grt from the matrix) which often appear in the hinge zones of intrafolial folds. Felsic aggregates impart the general appearance of these gneisses (Pl. 2, Fig. 3).

[3] Mylonites are intensely ductilely sheared variants of the two above-mentioned gneiss types. The shearing is matched by a mineralogically simpler composition (Qtz+Kfs+Pl+Bt+Phg±Ap±Grt), mylonitic segregation and grain-size reduction (Pl. 2, Fig. 4).

The above subdivision of gneiss units is one more proposal how to differentiate the gneisses in the study area (see Redlińska-Marczyńska 2011). As compared with earlier proposals, it shows that the detailed distinction and assignment of gneisses to one of the two major (Śnieżnik and Gierałtów) types or "complexes" can be difficult and even confusing. Therefore, some oversimplifications made for mapping purposes (coarse-grained gneisses with augen or augen-like features = "Śnieżnik gneisses", all others = "Gierałtów gneisses") apparently resulted in cartographic misrepresentation of different gneiss units. An example of such misrepresentations is the erroneous mapping of the porphyroblastic gneisses as the "Śnieżnik augen gneisses" because augen-like porphyroblasts have been mistaken for true augens. Geochemical similarities, considered without paying attention to the distinct structural and textural diversification and to systematic differences in the petrographic composition and modal proportions of the minerals in the gneisses, further contribute to an oversimplified genetic interpretation of the OSD gneisses and their tectonometamorphic evolution in the dome.

Structural and petrographic features

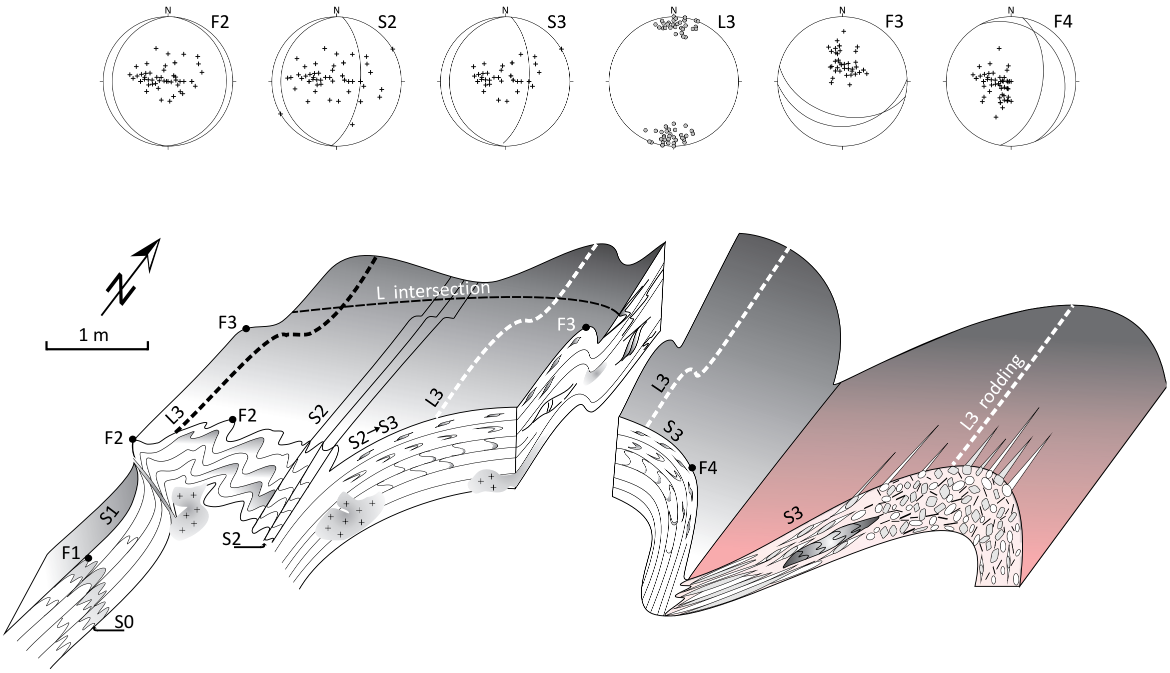
Metamorphic rocks of the Orlica-Śnieżnik Dome have been the subject of structural investigations since the 1960s. The descriptions and interpretations of deformation sequences observed in various fragments of the Orlica-Śnieżnik Dome which were published by several authors (Dumicz 1964, 1998; Teisseyre 1973; Don *et al*. 1990; Żelaźniewicz 1976, 1978; Opletal 1980; Cymerman 1997; Mazur *et al*. 2005; Jastrzębski 2005; Murtezi 2006) are summarized in Table 1 and juxtaposed with our scheme. Although the structural studies provided meaningful lines of evidence for different deformation paths recorded by the "Gierałtów" and "Śnieżnik" gneisses, it was only Dumicz (1998) who paid attention to the significance of these differences. In the systematic description which follows, the gneiss types distinguished above are presented, utilizing a combination of structural (meso- and micro-) features with petrographic data to provide criteria that enable the different types to be discriminated.

Sequence of deformation

Based on structural observations made in the Międzygórze area (Redlińska-Marczyńska 2011) and all over the Orlica-Śnieżnik Dome, a sequence of deformational events was established (Table 1, Text-fig. 2). In the Międzygórze Antiform, like in the adjacent mica schist throughout the dome, the earliest foliation which mimetically followed sedimentary bedding/banding (S0) was involved in small-scale, isoclinal and intrafolial folds (F1) and transformed into metamorphic foliation S1, parallel or slightly oblique to S0 in the fold limbs, which enhanced the compositional banding (Pl. 3 Figs 1–2). The F1 folds had originally roughly W–E to NW–SE axial directions which now vary greatly (Text-fig. 2). The D1 structures observed in the banded gneisses, layered-streaky gneisses, migmatites and porphyroblastic gneisses, apparently with N- to NE vergence, were refolded on roughly N–S axes by F2 folds (Pl. 1, Fig. 1; Pl. 2, Fig. 3; Pl. 3, Figs 2–3) having tight to open asymmetric geometry and accompanied by the formation of a new, axial planar foliation (S2). The D2 deformations proceeded mainly in a "top-to-the W" kinematic regime and were accompanied by zonally intense shearing which additionally gave rise to small-scale shear folds F2, some of fault-bend type (Pl. 3 Fig. 3, Text-fig. 2). However, the most prominent feature of the D2 event was a high temperature metamorphic episode which terminated with migmatization and metablastesis that continued late- to post-kinematically (with respect to D2). The effects of the D2 metablaste-

Proposed in this paper	**Żelaźniewicz (1976, 1978)**	**Opletal et al. (1980)**	**Don (in Don et al., 1990)**	**Dumicz (1998)**	**Mazur et al. (2005)**
D1. Compositional banding transformed into gneissic mineral banding (S0 =S1). D2. Formation of F1 - small-scale, tight folds (changeable kinematics) and F2 – small-scale shear zones (roughly "top-to-W" oriented) and same fault-band folds. In the axial plane position the S2 – axial planar foliation is formed, with the F1 and F2 as intrafolial structures. Inter- to post-D2 pervasive, 2-stage migmatization.	D1 and D2. Formation of intrafolial F1 and tight to isoclinal folds F2, with generally N–S (NW–SE to NE–SW) trending axes, under metamorphism progressing from greenschist (D1 event) to lower amphibolite facies (D2 event). The main foliation and lineation developed during D2. Formation of E-vergent F2 folds and D2 thrusting. Local NE-vergent F3 folds of open geometry and axes parallel to F2. Pre-D4 granitoid emplacement.		*(D1. Exclusively within the Stronie-Młynowiec Formation development of early foliation (S1) folded into F1 tight folds.)*	D1. Early foliation within the Gierałtów gneisses *(and the Stronie Formation).* D2. Tight folding F2, with development of S2 axial planar foliation (with intrafolial relics). Incorporation of eclogites within the gneisses.	D1. Top-to-the SE oblique-slip ductile thrusting of Nove Mesto Unit over Orlica-Śnieżnik Dome. Foliation S1 and NW-plunging lineation L1 together with intrafolial folds F1 develop, to be later almost totally obliterated in Orlica-Śnieżnik Dome by deformation D2.
E-W oriented intrusion of the augen gneisses protolith (Śnieżnik granite).			Intrusion of the Śnieżnik gneisses protolith.		
D3. Formation of gneisossity S3 within the Śnieżnik granite (development of the augen gneisses) and rejuvenation of the S1-S2 surfaces via flattening and shearing ("top-to-N" kinematics) S1-S2→S3. Formation of L3 stretching (rodding) lineation (N-S direction). N-vergent F3 folds deforming lineation L3 and locally accompanied by H-MT blastesis in the hinge zones.		Formation of folds with N–S trending axes in Orlica-Śnieżnik Dome and N–S to NNW–SSE (also NE–SW) axes near the contact zone in Nove Mesto Unit.	D2. Gneissification of the protolith of the Śnieżnik gneisses (S2) and formation of large-scale E-vergent F2 thrusts. D3. Recrystallization and migmatization of the Stronie series together with the Śnieżnik gneisses resulted in development of the Gierałtów gneisses. Migmatization of the Gierałtów gneisses and incorporation of eclogites.	D3. Transposition of S1 and S2 foliations and development of foliation S3. Formation of NE–SW to NW–SE rodding lineation L3 and local folds F3. Development of „younger Gierałtów gneisses".	D2. Ductile dextral shearing along the contact zone of Nove Mesto Unit and Orlica-Śnieżnik Dome; pervasive deformation in resulting in formation of S2 foliation and NNW–SSE to N–S trending lineation L2 and tight, E vergent folds F2. Granitoid emplacement and uplift of Orlica-Śnieżnik Dome during final stages of D2 deformation.
D4. Late, large-scale bending folds F4 (E-vergent in the Międzygórze Antiform).	D4. Formation of E–W trending N- or NE-vergent folds F4 under waning stages of metamorphism.	Formation of younger folds with axes trending E–W to NW–SE.	Formation of tight laying folds F3.	D4. Formation of open, banding folds F4 of E–W axial trend.	D3. Folding due to N–S compression under conditions of waning metamorphism. Open to tight S- or N-vergent folds F3 of E–W-trending axes.
	Two systems of contractional kink structures: F5 striking NE–SW and F6 striking NW–SE.			D5. Oblique-slip, normal sinistral displacement in transtensional, semi-brittle regime.	D4. Localized normal-slip displacements along ductile–brittle shear zones throwing to SW.

Table 1. Deformation events recognized in the Orlica-Śnieżnik Dome by various authors and correlation with the sequence established in this paper (kinematics considered in the present-day coordinates)



Text-fig. 2. Blockdiagram to show relationships of the successive mesostructures in the Międzygórze Antiform (augen gneisses marked in pink, all other gneiss units are in white). S – planar structures; L – linear structures; F – folds; white – quartz, gray – K-feldspar, tonal filling – quartzo-feldspathic segregations. Equal area stereographic projection on the lower hemisphere. See text for further explanations

sis are particularly conspicuous in the hinge areas of F2 folds where new porphyroblasts grew and random recrystallization led to obliteration of earlier fabrics, giving a granitic appearance to the rock (Pl. 2 Fig. 3, Pl. 3 Fig. 3). This process also swapped felsic blast or leucocratic segregations (leucosome) nucleated earlier in the hinge zones of F1folds. Structural control exerted by F2 folds over leucosome extracted in situ (nests) and/or injected (phlebites) also point to migmatization occurring syn-to post-kinematically with respect to the D2 event (Text-fig. 2, Pl. 1 Fig. 3). Small pods/nests of leucosome occur in the banded gneisses as well.

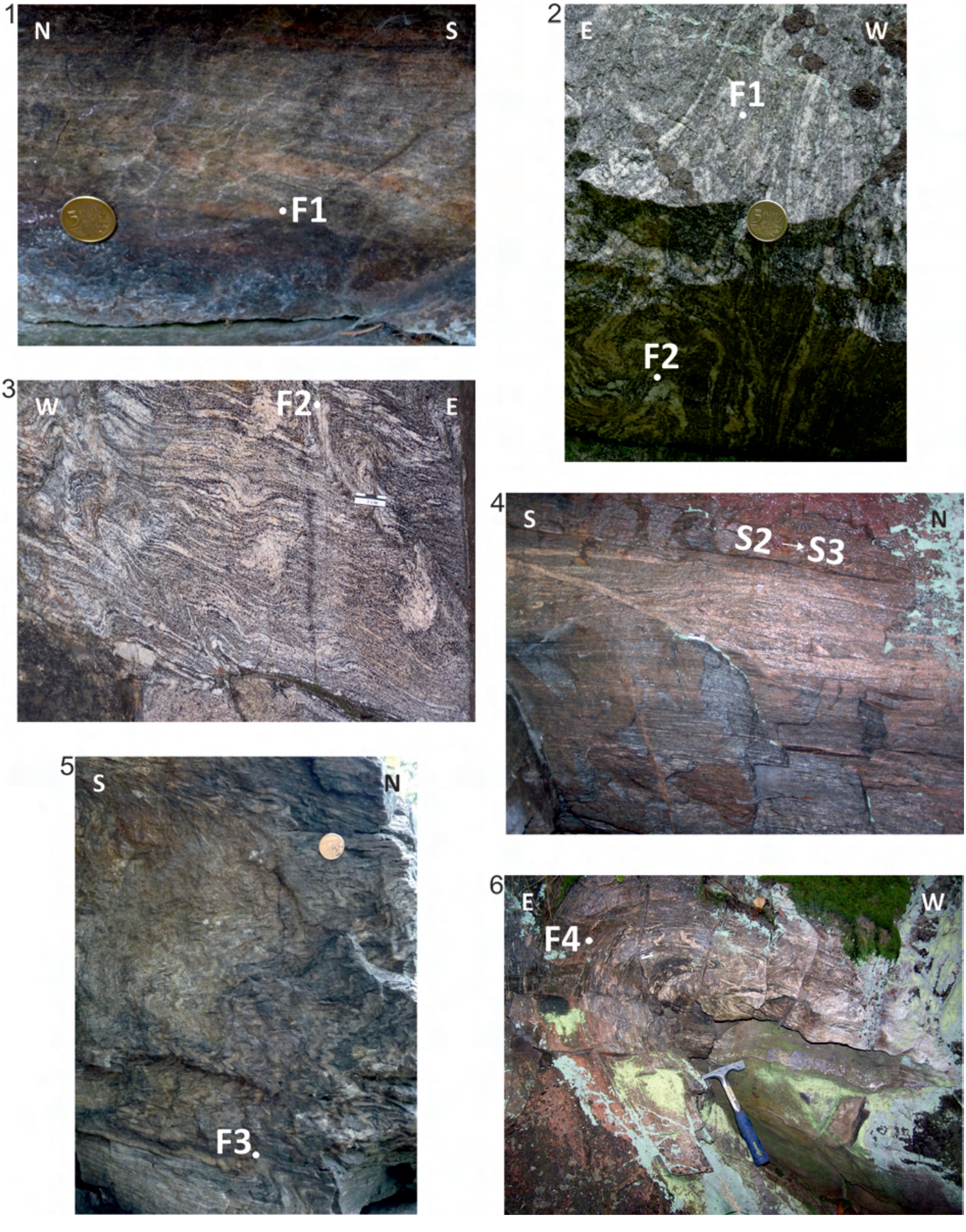
A further deformational stage (D3) brought about an overprint of the stretching lineation (L3) and reactivation of the S1-S2 surfaces by shearing (S1-S2→S3) with roughly “top-to-the N” (locally “top-to-the-S”) kinematics (Pl. 3 Fig. 4, Text-fig. 2). The rejuvenation of S2 planes resulted in the transformation of earlier porphyroblasts into porphyroclasts (both delta and sigma types), which is particularly common in the porphyroblastic gneisses (Pl. 2 Fig. 3).

The D3 shearing was the first deformational event experienced by the porphyritic granite and it gave rise to the formation of the stretching lineation (rodding type) and the mylonitic foliation which enveloped anastomosingly the Kfs porphyrocrysts – turned into porphyroclasts (Pl. 2 Figs. 2, Text-fig. 2). The D3 deformation, which proceeded under amphibolite facies metamorphic conditions (HT recrystallization of Qtz and Fsp), was connected with mainly “top-to-the N” shearing and produced generally N-vergent folds (local F3 on the Pl. 3 Fig. 5).

The next (D4) event refolded earlier structures on the N–S trending axes which coincided with the earlier stretching lineation L3 and produced E-vergent folds (Z-type F4) with flat-lying longer limbs, steep to overturned short limbs with weak to no axial plane growth (Pl. 3 Fig. 6). The F4 folds hinges are places where the disequilibration of Grt+Bt+Pl was accompanied by Mca recrystallization, both testifying to the greenschist facies condition overprint.

Significant structural records

Our structural observations revealed that the migmatites, layered-streaky gneisses and banded gneisses traditionally assigned to the “Gierałtów complex” have structural records similar to that recognized in the porphyroblastic gneisses (see Redlińska-Marczyńska 2011). The latter are, however, commonly included into the “Śnieżnik complex” albeit they differ from other rocks included in this “complex” in having evidence for two more deformation episodes (foliation formation and foldings) which is missing in the genuine augen gneisses. In the porphyroblastic gneisses, it is the F1 and F2 folding that controlled both syn- to post-kinematic (with respect to F2) metablastesis of new anhedral to rarely euhedral feldspar grains and the common growth of polymineral felsic lenses or more or less regular aggregates (Pl. 2 Fig. 3). They overgrew and obliterated the original alternations of compositional bands/layers (Qtz+Fsp±Bt±Phg±Chl and Bt±Grt±Aln±Ep, respectively). When subjected to shearing, such new felsic aggregates were changed to augen-like objects during the same event that produced the augen gneisses at the expense of the originally porphyritic granites. This hitherto unrecognized convergence is re-



sponsible for serious misidentifications of the gneiss units in the Międzygórze Antiform and throughout the Orlica-Śnieżnik Dome. The most misleading feature is the presence of the deformed felsic lenses, aggregates or porphyroblasts, which are often mistaken for phenocryst derivatives (Redlińska-Marczyńska 2011). An unfortunate consequence of such a mistake is an erroneous classification and wrong interpretation of the origin and evolution of the porphyroblastic gneisses which are unjustifiably treated as derived from the porphyritic granite. The ductile shearing (D3) actually turned the porphyritic granite into augen gneisses but in the porphyroblastic gneisses only overprinted early features (D1 and D2), which enhanced their planar fabrics and transformed the porphyroblasts and polymineral aggregates in migmatites into the augen-like structures.

In the migmatites, layered to streaky gneisses, banded gneisses and porphyroblastic gneisses, new polymineral aggregates and porphyroblasts (overgrowing some minerals from the matrix) nucleated in the hinges of the F2 folds (Redlińska-Marczyńska 2011). Progressive metamorphic recrystallization which promoted this process also enhanced quartzofeldspathic layers in the layered and streaky gneisses that graded to metatexites and eventually produced local diatexitic textures of migmatites. Metablastesis of mono- and poly-mineral aggregates (Qtz /Qtz+Kfs / Kfs±Qtz±Pl / Qtz+Kfs+Pl, Qtz+Fsp±Mca) together with leucosome/neososme extraction (Qtz+Kfs+Pl±Mca) may be considered as inter- to syn-kinematic processes with respect to the F1 and F2 episodes (Text-fig. 2). The neosome composed of Qtz+Kfs+Pl±Mca, which alternates with the mesosome (Pl+Bt+Grt), also occurs in the form of irregular veins and nests in phlebitic migmatites, and additionally cross-cut or developed inside isolated bodies of amphibolites (and retrograded eclogites) which occur within the gneisses (Pl. 1, Fig. 3). Different shapes, composition and deformational disruptions suggest that the described migmatization and melt extraction possibly did not occur simultaneously, but instead occurred successively, in two separate stages.

The banded gneisses represent rocks in which compositional banding can be identified as primary, sedimentary structure S0, mimetically followed by later metamorphic recrystallization (S0→S1).

These are very fine-grained, massive ("homogenous" of Borkowska *et al*. 1990) rocks with aplite appearance that reveal some similarities with the three groups mentioned above (Pl. 1, Fig. 5; Pl. 3, Fig. 1). They are enriched in accessories (Ttn±Grs±Ep±Aln) and often possess characteristic regular alternations of Bt-rich and Bt-poor bands/layers of widely different thickness (0.05–10 m). Such alternating bands remain slightly oblique (~5º) to the foliation expressed by the parallel arrangement of biotite flakes and felsic grain shapes observed under the hand lens or microscope. In the Międzygórze Antiform, such banded gneisses occur as intercalations within the migmatites, layered gneisses

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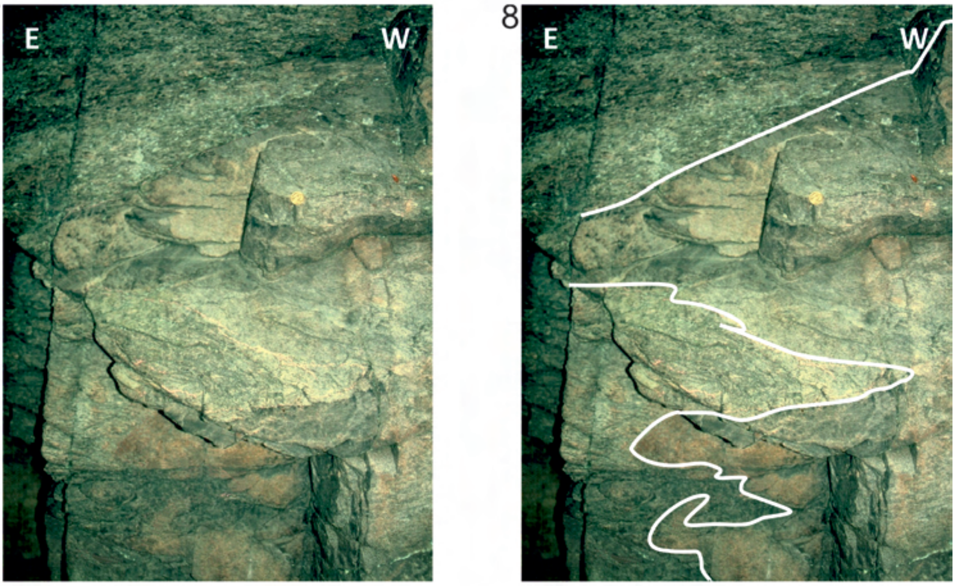


Plate 3. Significant structures developed in rocks of the Międzygórze Antiform (see Text-fig. 1 for geographic location). 1 – compositional banding (S0) involved into F1 folding (banded gneiss); 2 – folds F1 involved in disharmonic folds F2, migmatite; 3 – metablastesis of quartzofeldspathic segregations, often in the F2 hinge zones, migmatite; 4 – rejuvenation of S1 and S2 surfaces as the S3 foliation, sheared migmatite; 5 – a closure of the N-vergent fold F3 in the earlier sheared layered gneiss, some Kfs+Qtz recrstallization in the hinge zone; 6 – E-vergent F4 fold (migmatite), 7-8 – discordant, folded contact between the augen gneiss (at the left) and the banded gneiss (at the right), record of intrusion of the Śnieżnik granite in the "Gierałtów gneiss"

and porphyroblastic gneisses (Redlińska-Marczyńska 2011). The boundaries of such intercalations are always sharp, concordant with the S2→S3 surfaces, which suggests that all these gneiss units represent primary compositional differences, probably of sedimentary (and/or pyroclastic) nature (Pl. 1, Fig. 5) reworked by subsequent shearing and superimposed migmatization. Borkowska et al. (1990) interpreted these rocks as the most "typical" brand of the Gierałtów gneisses and Don *et al*. (2003) ascribed them to the "fine-grained group" of the Gierałtów gneisses.

The augen gneisses are coarse-grained, porphyritic to even-grained metagranites (see Redlińska-Marczyńska 2011). Some of the augen gneisses have the distinct constrictional fabric of L>S tectonites marked by a conspicuous rodding lineation defined by the elongated felsic, monomineral (Qtz or Fsp) rods and intervening streaks of parallel-oriented mica flakes (Pl. 2, Fig. 1). Such rodding lineation is the first linear structure that developed in the augen gneisses (metagranites), albeit in the layered to streaky gneisses, porphyroblastic gneisses, banded gneisses and migmatites it is the third deformational structure (L3). The lineation developed under amphibolite facies conditions as indicated by the equilibrium of the Grt+Pl+Bt assemblage.

In most cases, a planar fabric of S-L tectonites is observed to have overprinted the rodding lineation and metagranites grade to S-tectonites in zonally developed mylonites to ultramylonites. In such highly deformed rocks, only one set of the penetrative foliation is formed by monomineral ribbons or layers of the dynamically recrystallized quartz and K-feldspars, and polymineral ones composed of plagioclase and micas (Pl. 2, Fig. 2). The mylonitic foliation resulted from shearing along the shallowly dipping planes with mainly "top-to-the N/NE" kinematics. In the other rocks (migmatites, layered to streaky gneisses, banded gneisses and porphyroblastic gneisses) the deformation reactivated the S1-S2 surfaces as S3 ones, and caused flattening and superposition of the stretching lineation L3 (Text-fig. 2).

In the XZ section of the strain ellipsoid, pinch-and-swell structures along with monomineral feldspar augens accompanied by Qtz±Kfs±Mca pressure shadows are in evidence and testify to the porphyroclastic origin of the augens derived from original porphyrocrysts of a magmatic protolith (Żelaźniewicz 1988; Redlińska-Marczyńska 2011). The pressure shadows are mainly asymmetric and indicate a "top-to-the N" and "top-to-the S" tectonic transport. Along with the increasing intensity of shearing, the grain sizes of the minerals become smaller, the porphyroclasts taper off, and the rock grades to typical mylonite. As the augen gneisses do not possess signs of any earlier deformation and/or metamorphism, the early constriction and subsequently superimposed shearing under amphibolite facies conditions (HT recrystallization of Qtz, Fsp, Mca plus relics of Grt+Bt+Pl equilibrium) are inferred to record the first tectonometamorphic events to have affected these rocks. Locally, N-vergent folds (F3) in the gneissic and mylonitic foliation developed during progressive shearing, sometimes accompanied by axial planar crenulation cleavage. Occasionally observed S-C' structures show similar kinematics but are apparently later as the C' bands are marked by retrogressed biotite and albite, which suggests a greenschist facies overprint. The latter is expressed by the Grt-Bt-Pl disequilibrium and Mca recrystallization.

Analogously to in the augen gneisses, the L3 lineation in the migmatites, layered-streaky gneisses, banded gneisses and porphyroblastic gneisses developed as a result of syntectonic, ductile recrystallization of Qtz, Fsp, Mca with dominantly "top-to-the N" kinematics under amphibolite facies conditions which retained equilibrium of the Grt+Bt+Pl assemblage. The N-vergent, small- to medium-scale shear folds (F3 on Pl. 3, Fig. 5) in S3 planes either involved the elongation lineation (L3) or the lineation overwrapped the folds, which suggests that the two structures developed simultaneously (Text-fig. 2). Locally, in the hinge parts of the F3 folds, limited blastesis of small-scale Qtz+Fsp aggregates (0.02-0.2 m size) can be observed, which also indicates amphibolite facies conditions.

Of particular importance is the fact that the deformation history of the augen gneisses was shorter than that of the migmatites, layered-streaky gneisses, banded gneisses and porphyroblastic gneisses. Common deformation of all the gneiss types started from the D3 event (Redlińska-Marczyńska 2011). This relationship is due to the fact that the granite protolith of the augen gneisses intruded the other gneissic rocks when they had already been deformed and migmatized.

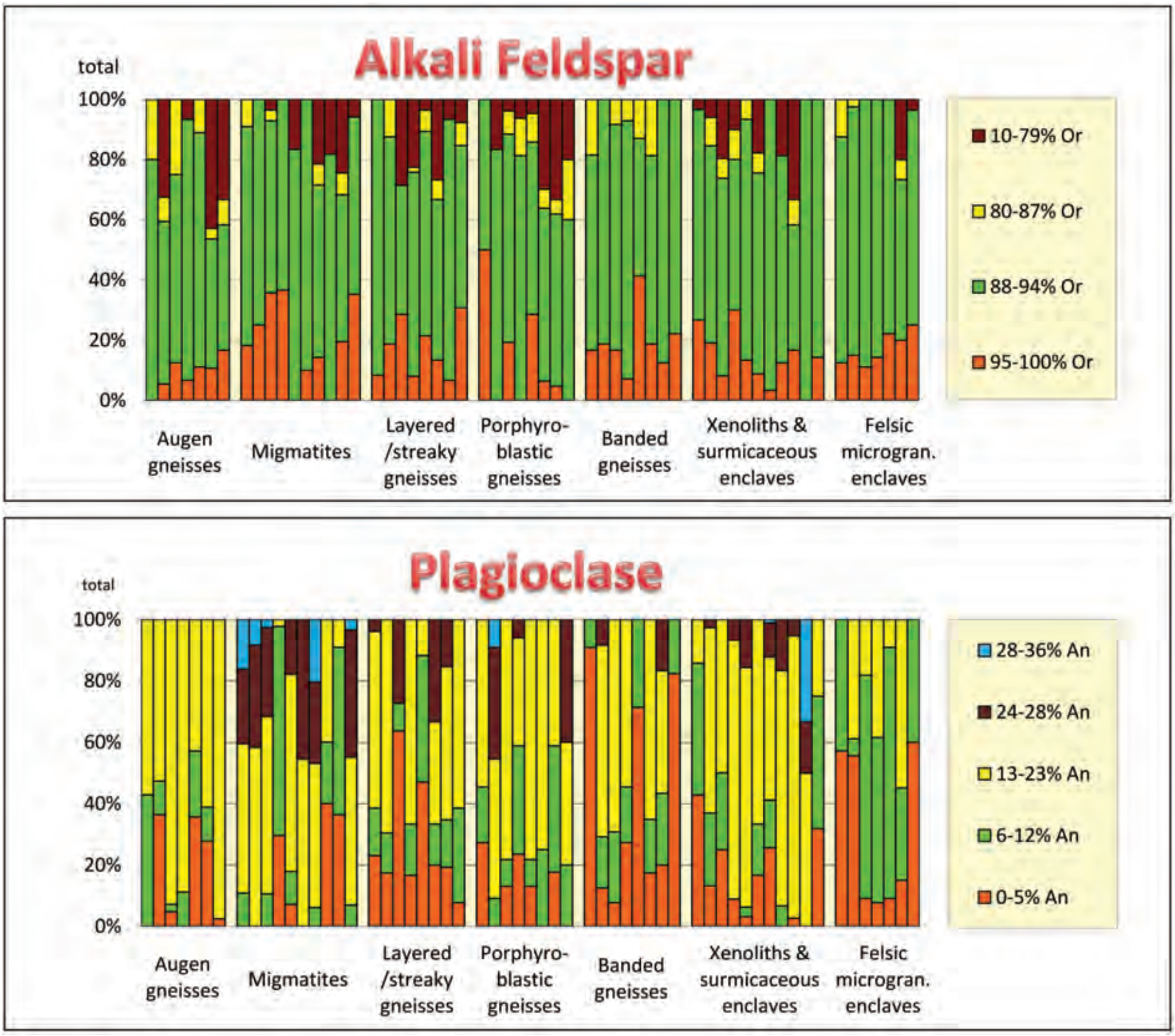
Although rare, discordant contacts between the present augen gneisses and the other gneisses can be observed (Pl. 3, Figs 7–8). We interpret such contacts as relics of the primary intrusive interface between the porphyritic granite and the gneissic/migmatitic surrounding into which it must have intruded inter-tectonically between the D2 and D3 stages or toward the end of the D2 event. The granite intruded across the earlier S-surfaces; the contact itself is only rarely observed because the superimposed shearing rotated all the planar features and made them parallel.

The enclaves embraced by the augen gneisses (derived from the porphyritic granite) have longer dimensions aligned mainly in an E–W direction, parallel to the alignment of Kfs porphyrocrysts observed in poorly deformed domains of the augen gneisses (Pl. 4, Fig. 1). Both features are interpreted to have recorded the direction of magma flow, which would be consistent with a "top-to-the W" kinematics of F2 folding and shearing.

Mylonites and ultramylonites developed at the expense of all types of the gneisses, which gave them mineralogically similar yet simpler compositions. They acquired typically mylonitic segregations of monomineral Qtz and Kfs layers which alternate with polymineral Pl+Mca layers. Kinematic indicators (δ-clasts, S-C, S-C', "mica fishes") show both a "top-to-the-(N)NE" and "top-to-the-(S)SW" sense of movements. Such a structural feature may have resulted from (1) pure shear acting on originally differently oriented objects, or (2) superimposed deformation. Strain partitioning into non-coaxial and coaxial components in mylonites of the Międzygórze area is suggested, but this topic is beyond the scope of this paper. All the mylonites have a N–S oriented stretching lineation expressed by elongated quartz and feldspar grains paralleled by the intervening arrays of mica flakes. Bulk mylonitization occurred under amphibolite facies metamorphic conditions, as implied by relics of Grt+Bt+Pl equilibrium. (Ultra)mylonites are indistinguishable from each other despite different derivations and only field relationships can reveal the protoliths (compare Pl. 1, Fig. 6 and Pl. 2, Fig. 4).

Mineralogical features

Further features prompting the distinction between the gneiss units are based on some significant differences in the detailed composition of the rock-forming minerals.



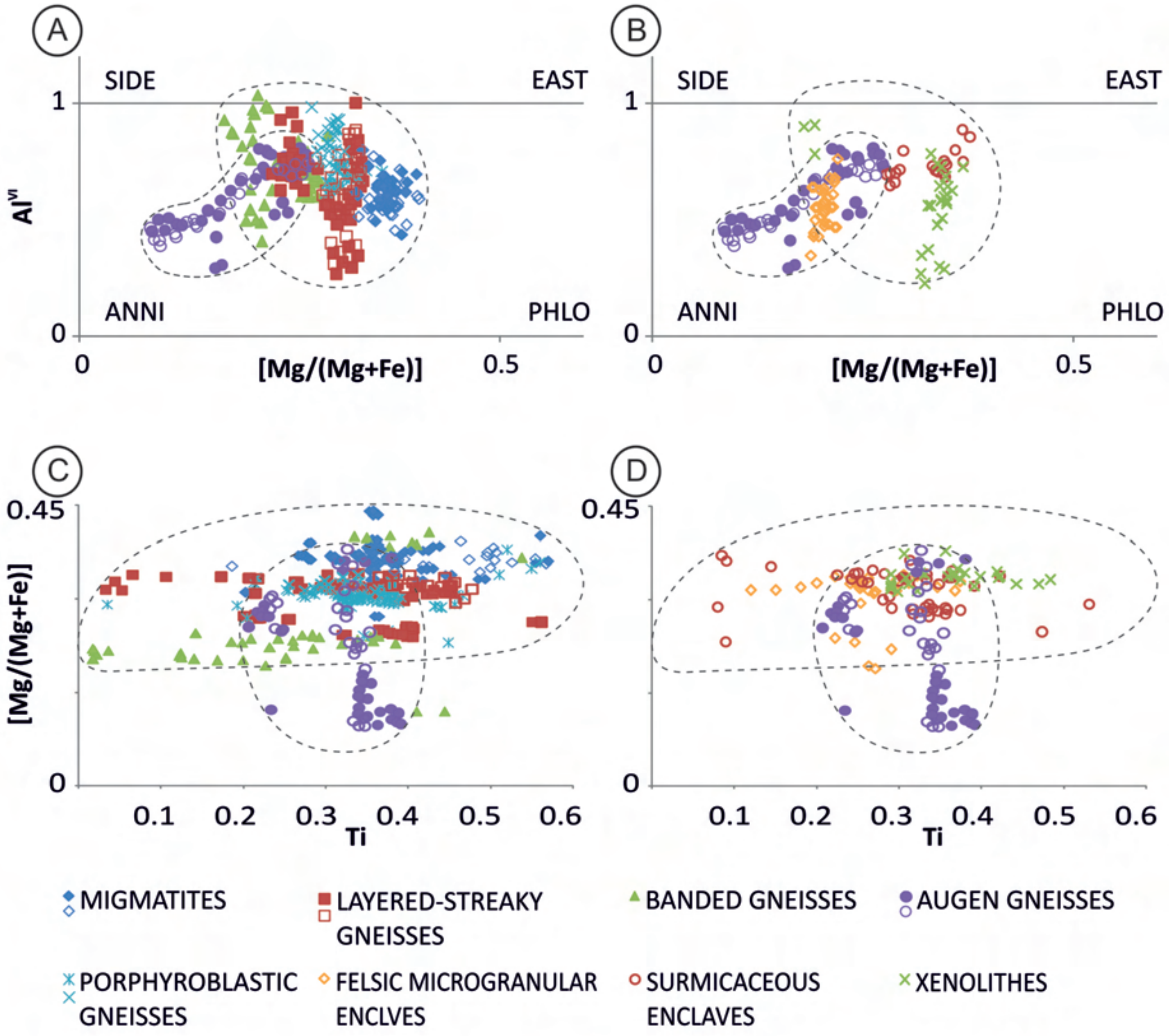
Text-fig. 3. Cumulative histogram illustrating chemical composition of feldspars from the discerned gneiss units (feldspars recalculated to 100% within the individual thin sections)

Feldspars

Feldspars from the gneiss units were studied in terms of their end-member components. The results are presented in histograms on Text-fig. 3. The percentages of feldspars are recalculated to 100% within an individual thin section. Detailed descriptions of the textural properties of feldspars were given elswhere (Redlińska-Marczyńska 2011).

In the augen gneisses, the proportion of the anorthite end-member of the plagioclase feldspar is always less than 23% (An_{6-23}). Oligoclase represents 42–96% of the total plagioclase population and in half of the studied samples is the only feldspar, while pure albite (An_{0-5}) does not exceed 38% of the total plagioclase feldspar. The feldspathic porphyroclasts are microcline (Ab_{6-12}). The matrix is composed of minerals of similar end-member proportions, except antiperthites in which the alkali feldspar may contain 20–90% of Ab.

The compositions of plagioclase feldspars from the migmatites, layered-streaky gneisses and porphyroblastic gneisses are generally more diversified compared with those from the augen gneisses. No more than 30% of the population is composed of oligoclase, with the proportion of An in excess of 23%. Feldspars with the highest content of An (up to 36%) form up to 20% of the total plagioclase population. Andesine is often associated with the mesosome of the migmatites and with fragments adjacent to the metabasitic bodies. The alkali feldspars can be classified as microcline (Ab_{0-20}).



Text-fig. 4. Composition of dark micas expressed in quadrilateral classification diagram ([Mg/(Mg+Fe^{2+})] vs. Al^{VI}) after Guidotti (1984) and [Ti vs. Mg/(Mg+Fe^{2+})] diagram (diagram A and B – composition of main types of gneissic units, diagram C and D – enclaves with hosting gneisses). Fields of range for the augen gneisses and the rest of gneissic units are marked in doted lines. Filled symbols represent rock samples from the Międzygórze Antiform, open symbols mark rock samples from the Orlica-Śnieżnik Dome collected outside the antiform

In widespread exsolution microstructures mainly orthoclase and anorthoclase (Ab_{20-90}) occur. Anorthoclase from the migmatites and porphyroblastic gneisses usually contains up to 15% of the An end-member. The porphyroblasts and leucosome aggregates are composed of feldspars with compositions Ab_{6-12} (~ 75%) and Ab_{13-20} (~25%).

Plagioclase feldspars in the banded gneisses have a bimodal composition. In the Bt-rich bands oligoclase with 13–38% of An occurs, while in the Bt-poor bands the plagioclase feldspar is mainly albite (70–90% of the population). The alkali feldspars are orthoclase and microcline with the proportion of the Ab end-member mainly in a range of 6–12%. A unique feature of the banded gneisses is the lack of antiperthites, thus the alkali feldspar composition is simpler (with the Or amount always exceeding 88%).

Plagioclases from all types of the gneisses display normal zonation (Ca-decrease from core to rim) that was, however, disturbed by subsequent secondary edge albitization, which produced ca. 20–40% of albite within the augen gneisses, porphyroblastic gneisses and migmatites, and up to 60% of albite within the layered-streaky gneisses and banded gneisses. The albitization, involving gain of Na and loss of Ca, was accompanied with the loss of K in the alkali feldspars – up to 40% of the alkali feldspars from the rocks studied contain more than 20% of Ab (Text-fig. 3).

Dark micas

Dark micas occurring in the gneisses classify mainly as annite, and their chemical composition is structurally controlled (see Redlińska-Marczyńska 2011). Those from the augen gneisses usually have a lower #mg ratio ([=$Mg/(Mg+Fe^{2+})$] in a range of 0.23 to 0.39) as compared with those in the migmatites, layered-streaky and porphyroblastic gneisses (#mg up to 0.44). The Al^{VI} content in dark micas from the augen gneisses is rather stable, independent of the Mg and Fe amounts (note smoothly curved positive trend on Text-fig. 4A and B). Similarly, the titanium content is stable and independent of the Mg and Fe amounts (note vertical trend on Text-fig. 4C). Variability of titanium content in the biotites was also considered in relation to their structural position in the rocks (Text-fig. 4C). Most of the biotites aligned parallel to the mylonitic foliation (S3) show a decrease in Ti content (Ti-regressive flakes) from the cores to the rims ranging from 0.18 to 0.39 (cations per formula unit [pfu]). Parallel to the longer edges of such flakes some serious loss of titanium (less than 0.1) and silica (Si< 2.3 [pfu]) can be observed. Sparse and chaotically distributed biotites reveal an increase in Ti content (Ti-progressive flakes) from the cores to the rims of the flakes ranging from 0.19 to 0.39 [pfu]).

Dark micas in the migmatites, layered-streaky gneisses and the porphyroblastic gneisses are more diverse and classify as annite and siderophyllite (Text-fig. 4A). Each gneiss unit is characterized by a wide range of the Al^{VI} amounts and a small degree of variability of #mg (vertical trends on Text-fig. 4A). In contrast, the titanium content in the biotites varies over a wide range (note horizontal trends on Text-fig. 4C). The other common feature is the arrangement of Ti- progressive flakes, which is controlled by the geometry of the intrafolial folds (F1, F2) and the axial plane foliation (S2). Ti content [pfu] in such flakes increases from the cores of the flakes (0.2–0.4) towards their rims, reaching the maximum recorded value of 0.56 (Text-fig. 4C). The Ti-regressive flakes are bound to planar structures of the relic foliation S1 and/or the reactivated foliation (S2→S3). The total amount of Ti is astonishingly high in cores (up to 0.56 of Ti [pfu]) and rims as compared with the augen gneisses. Quite often the Ti amount decreases at the shorter edges, which are more prone to retrogressive reactions consistent with a lattice preferred orientation.

In the banded gneisses, the dark micas are depleted in Mg ions (Text-fig. 4A and C) in comparison with the already described gneisses (#mg = 0.11–0.23). Independently of their structural position, the micas may show some Ti progress as the Ti content increases from cores to rims over a wide range of 0.03 to 0.56 [pfu] (Text-fig. 4C). The highest measured amount of titanium (0.56) [pfu] is accompanied by a relatively low #mg ratio (0.21). Scarce, Ti-regressive biotite flakes became even more depleted in magnesium (< 0.01 wt%).

As shown by the diagrams in Text-fig. 4, the composition of the dark micas from the augen gneisses only partly overlaps with the compositions of the dark micas in the other types of rocks studied; it is distinctly more uniform and shows a strikingly different trend from the remainder.

White micas

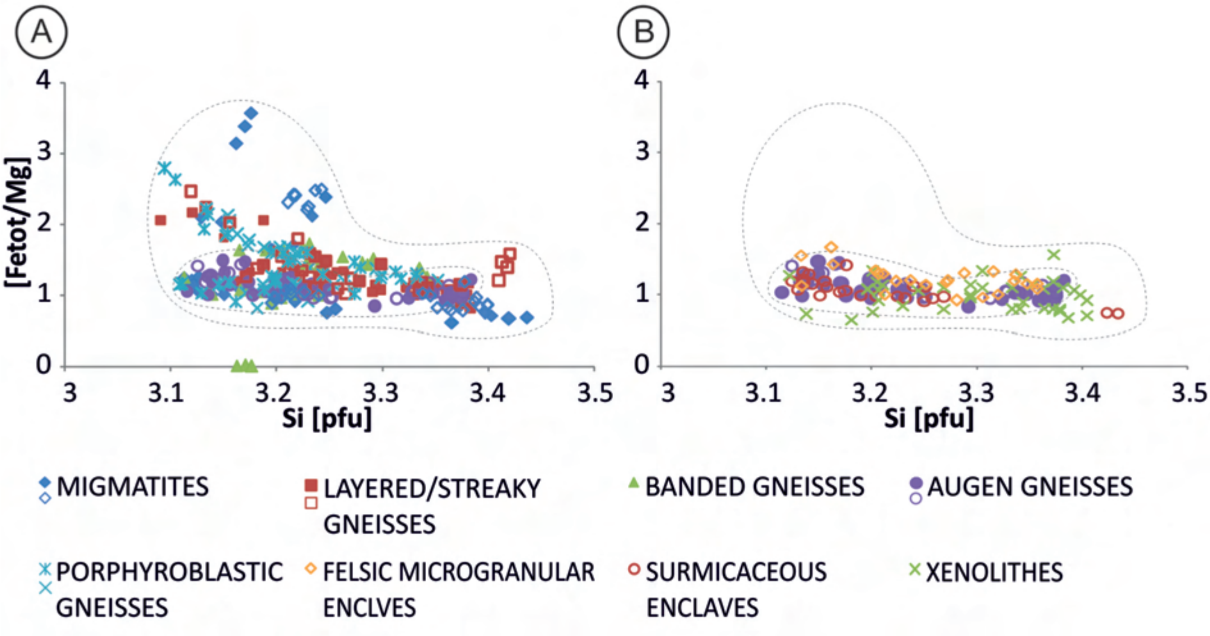
White micas occurring within the gneisses are Mg-Fe micas (Text-fig. 5A) with relatively high values of Si [pfu] (Redlińska-Marczyńska 2011). The augen gneisses contain micas which can be subdivided into three groups, based on the Si content (~ 3.1, ~ 3.2 and ~ 3.4 [pfu]) and structural position occupied. The two groups with a relatively high silica content (3.20–3.37 [pfu]) are more difficult to trace and scarcer than the common group of low-Si flakes (3.11–3.17) [pfu] which are arranged parallel to or just define the S3 foliation, and hence similar to the biotites with Ti-regression. A general trend of Si decrease (matched by Al increase) from the cores of flakes to their rims is accompanied by rather stable amounts of Mg and Fe_{tot} (note horizontal trend on Text-fig. 5A and B).

White micas in the migmatites, layered to streaky gneisses and porphyroblastic gneisses can likewise be subdivided into three groups (based on Si content), controlled by their structural position. Micas of the group characterised by the highest (and quite stable) amount of silica (up to 3.43 [pfu]) and #mg ratio, follow the outlines of the intrafolial folds (F1, F2) and the axial plane foliation (S2). The other two groups of flakes reveal lower amounts of Si [pfu] (3.12–3.26), which additionally decrease toward the rims and occur only as recrystallized aggregates, more or less parallel to the S1 and S3 foliations. The general Fe (also Mg) content remains constant within the flakes, except for some parts of the migmatites, in which the Fe content often reveals a noticeable increase from the cores to the rims of the flakes even in low-Si groups (note vertical and smoothly curved negative trends on Text-fig. 5A). In contrast, a different composition is shown by micas from the leucosomes (Si = 3.0–3.2 [pfu]; [Na/(Na+K)]= 0.02-0.04; #mg= 0.35–0.45), which grew as small flakes, chaotically distributed between the feldspars.

White micas from the banded gneisses are markedly depleted in Mg (towards 0 on Text-fig.5A), tending compositionally to muscovites (with [Na/Na+K]> 0.01 and Si< 3.2 [pfu]). However, they can be subdivided into three (Si-dependent groups), in which some decrease in Si content from the cores to the rims of the flakes can be persistently noticed (Text-fig. 5A). However, they do not reveal any particular dependence on structural position. The high silica flakes (up to 3.34 [pfu]) are the most abundant, and the lowest silica contents are characteristic of those micas that wrap around rare, larger (up to 1 mm) alkali feldspar blasts.

Garnets

The garnets in the gneisses are highly enriched in calcium and iron (XGrs≤ 0.52; XAlm≤ 0.7; XAdr≤ 0.03), while other elements are only minor components (XPrp≤ 0.07, XSps≤ 0.15; XUvt≤ 0.009) (see Redlińska-Marczyńska 2011). In the augen gneisses (Text-fig. 6A and B), scarce garnets border the biotites and commonly enclose Qtz, secondary Ab and Phg. They have an atoll to irregular shape and characteristic compositional zoning. In the cores, the Grs and Alm end-members (35–50% Adr+Grs, 47–67% Alm, 0–10% Sps) dominate, whereas in the rims Alm and Sps particles (30-34% Adr+Grs, 0–20% Sps, 52–70% Alm) prevail. Small intergrowths within scarce plagioclase blasts display similar Grs-Alm proportions (40–52% Adr+Grs, 50-62% Alm) albeit different Sps contents (<1% Sps).

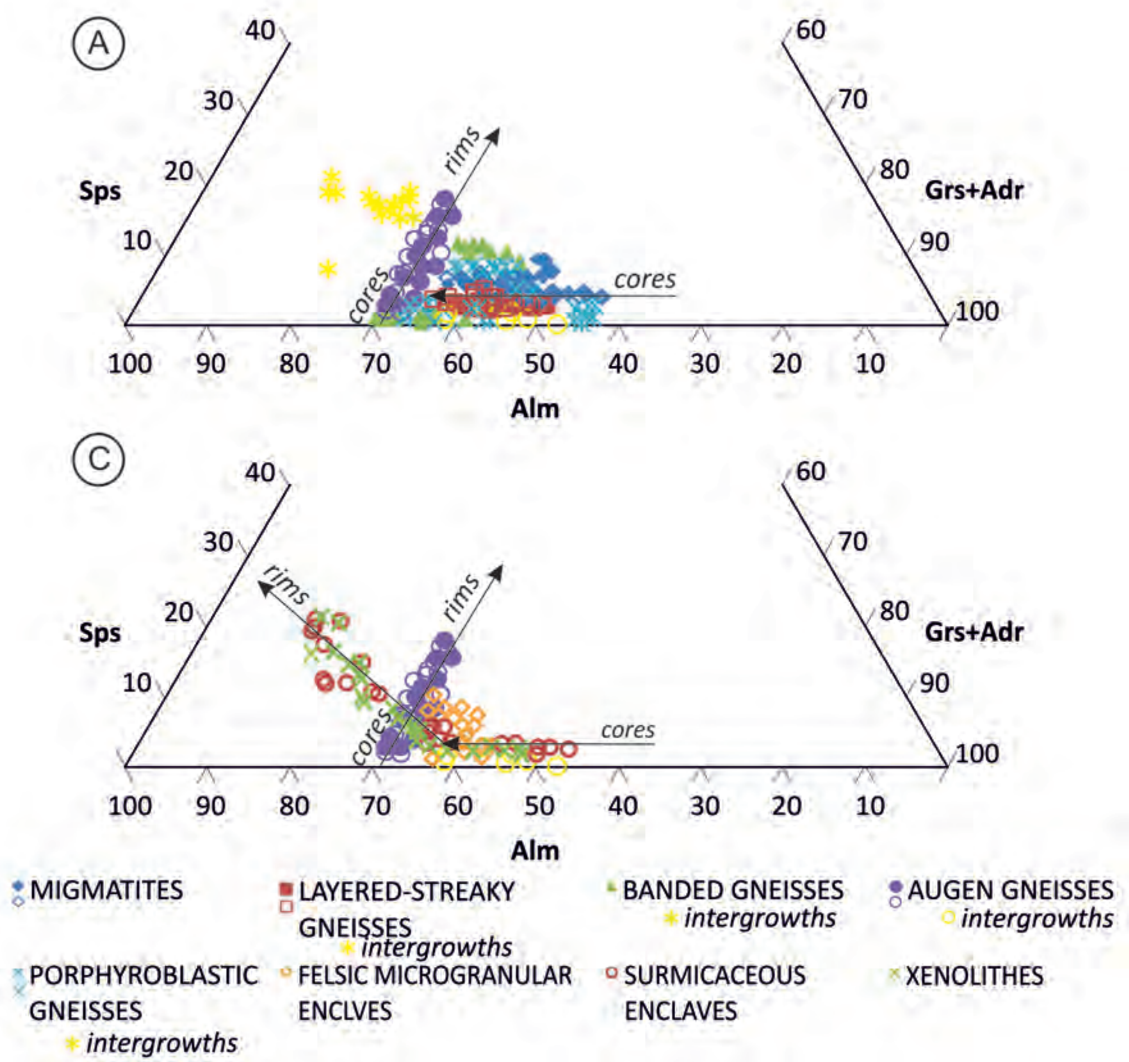


Text-fig. 5. Composition of white micas expressed in the Si pfu vs. $[Fe_{tot}/Mg)]$ diagrams (A – composition of main types of gneissic units, diagram B – enclaves with hosting gneisses). Fields of range for the augen gneisses and the rest of gneissic units are marked in doted lines. Filled symbols represent rock samples from the Międzygórze Antiform, open symbols mark rock samples from the Orlica–Śnieżnik Dome collected outside the antiform

In the migmatites and layered-streaky gneisses, the garnets are larger and far more common. They are irregular, porous or atoll-shaped, enclose Qtz, Chl and Kfs, and border on Pl, Kfs, Qtz or Chl. Complicated compositional zoning is clearly visible in back-scattered electron (BSE) images. Besides the clearly visible core (38–56% Adr+Grs), diffusive mantles (37–52% Adr+Grs) and a rim (33–43% Adr+Grs) can be observed. The reaction fringes are always Ca-depleted. Garnet crystals having regular shape are small and occur in two compositional groups, which contain either 46–49% Adr+Grs or 34–38% Adr+Grs.

In the layered-streaky gneisses, garnet also occurs as numerous inclusions in the recrystallized plagioclase (An_{10-20}) porphyroblasts. Internal parts (core and mantle) of such porphyroblasts are intergrown with irregularly shaped garnets that reveal compositional zonation, with cores (36–43% Adr+Grs), mantles (38–41 % Adr+Grs) and outer rims (33–37% Adr+Grs). The mantle parts of the Pl porphyroblasts can also be intergrown with garnets that are regular in shape and uniform in composition (32–35% Adr+Grs). Most external parts of the Pl porphyroblasts contain similarly regular and uniformly composed garnet inclusions, though the composition is extraordinary (18–20% Adr+Grs, 77–80% Alm+Sps).

The porphyroblastic gneisses contain irregularly shaped garnets, with similarly high contents of calcium (up to 54% of Adr+Grs) and an almost unzoned structure (cores and rims have similar XGrs). Additionally,



Text-fig. 6. Composition of garnets expressed in tri-diagrams with respect to the Grs+Adr, Alm and Sps end-members (diagram A – composition of main types of gneissic units, diagram B – enclaves with hosting gneisses). Lines of trends from the core parts of grains towards their rims are marked in arrows. Filled symbols are rock samples from the Międzygórze Antiform; open symbols are rock samples from the Orlica-Śnieżnik Dome collected outside the antiform there are small, isometric garnets, reversely zoned from cores (31-35% Adr+Grs) to rims (35–43% Adr+Grs). In plagioclase porphyroblasts, two types of garnets differing in composition occur as intergrowths. The mantle parts of the porphyroblasts can be intergrown with garnets comparable with those occurring in the matrix as they are regular in shape and composition (32–42% Adr+Grs). The external parts of the same porphyroblasts are intergrown by dissimilar, much more ferric garnets (24–25% Adr+Grs, 71–74% Alm+Sps).

In the banded gneisses, the garnets are compositionally similar to those occurring in the migmatites. They form two morphological groups (larger and irregular versus smaller and regular in shape) which are, however, similar in chemical composition. The irregular garnets have oscillatory zoning from cores (34–38% Adr+Grs) to mantles (35–41% Adr+Grs) to rims (30–35% Adr+Grs). The regular and uniform garnets have identical end-member proportions in a range of 37 to 42% Adr+Grs. Inside larger (>1mm) plagioclase blasts ($An_{5\text{-}20}$) small (a few microns only) garnet inclusions arranged in a circular manner may be found. They differ in composition from garnets occurring in the matrix: 20–28% Adr+Grs, 70–78% Alm+Sps.

Garnets from the augen gneisses form their own trend which departs from those displayed by garnets from the other rocks studied. The composition of this significant accessory mineral, as well as the compositions of the rock-forming feldspars and dark micas, point to the distinct difference between the augen gneisses and the remaining rock units.

ENCLAVES

Types of enclaves

In the augen gneisses coming from the dynamically metamorphosed porphyritic granite, there are several different types of enclaves as revealed by detailed field and petrological studies (Grześkowiak and Żelaźniewicz 2002; Grześkowiak *et al*. 2005; Sitarz 2009; Redlińska-Marczyńska 2011). Rocks in the enclaves range from microgranular (meta)granitoids (finer grain-size than the host granite) and mesocratic microgranular gneisses (fine-grained rocks with ~35% of dark minerals) to coarse-crystalline migmatites (stromatites) with their own, rich fabric, discordant to that of the host augen gneisses (Redlińska-Marczyńska 2011). Although such enclaves are numerous in the Międzygórze Antiform (Text-fig. 1) and throughout the eastern part of the Orlica-Śnieżnik Dome, they are almost absent from the western limb of the dome (Orlickie Mts. and Bystrzyckie Mts.).

The most common **felsic microgranular enclaves** (FME) are represented by small (up to a few decimetres across), ellipsoidal to lensoid bodies of microgranular metagranite irregularly distributed (34 objects found in the study area). Their composition (Qtz+Kfs+Pl+Bt+Phg±Ttn±Ap±Ep) is similar to that of the host augen gneisses and also their metamorphic fabric marked by parallel arrangement of Qtz, Fsp and Bt crystals is consistent with the foliation in the country rocks (Pl. 4, Figs 1–2). A granitic provenance of these enclaves is evidenced by such igneous features as: poikilitic quartz enclosing plagioclase and apatite, alkali feldspar enclosing epidote, plagioclases with euhedral but irregular oscillatory zoning, or enrichment in apatite – all characteristic of fine-crystalline magmatic rocks (see Kumar *et al*. 2004).

Boundaries of FME are usually sharp but characteristically decorated with euhedral to subhedral porphyrocrysts of Kfs and Qtz (up to 6 cm in diameter, Pl. 4, Fig. 2). Simple twinning or a microcline grid in the Kfs crystals attest to magmatic conditions during their crystallization. The megacrysts also grew within the enclaves, which proves a similar rheology of the enclaves and surrounding magma (see Vernon 1986; Barbarin and Didier 1991 and references therein). Similar rheological properties of the rocks persisted until the solid state was reached as the primary magmatic foliation in the porphyritic granites, expressed by parallel arrangement of the Kfs crystals, was not forced to anastomose but continued across the enclaves (Pl. 4, Fig. 1). In the Międzygórze Antiform, the enclaves have longer axes oriented in the E-W direction (Redlińska-Marczyńska 2011), consistent with the parallel alignment (L0) of the Kfs porphyrocrysts, which, taken together is interpreted by us as the direction of the primary flow of the magma (Pl. 4, Fig. 1).

Less common are **surmicaceous enclaves** (23 objects found in the study area). They are formed by fine-grained mesocratic gneisses composed of an assemblage of Qtz+Pl+Bt±Kfs±Ttn±Aln±Ep. Their dark shade is due to a high amount of biotite, titanite and grey quartz grains (Pl. 4, Figs 3–4). A pre-intrusive history of the gneisses is marked by relics of an early foliation occasionally involved in small-scale folds of ghost appearance, often with leucocratic segregations in the hinge zones. The longer axes of the surmicaceous enclaves are aligned in the E-W direction, which also confirms the magma flow direction inferred from the FME (Redlińska-Marczyńska 2011).

Subhedral, growth-zoned feldspar megacrysts stemming from the host granite grew across over sharp edges of the enclaves which must have behaved plastically at that time (Pl. 4, Figs 3–4). Inside the enclaves, both Kfs and Pl poikilitic porhyrocrysts and Qtz or Kfs±Qtz±Pl aggregates/porhyroblasts grew in a random manner (Redlińska-Marczyńska 2011). The megacrysts reveal a rare ocelli structure defined by felsic cores (Kfs, Kfs±Qtz±Pl or Qtz) and mafic (Bt) rims. Such reaction aureoles testify to strong ion diffusion in the plastic state as felsic cores more probably came from the host and the rims from the enclave

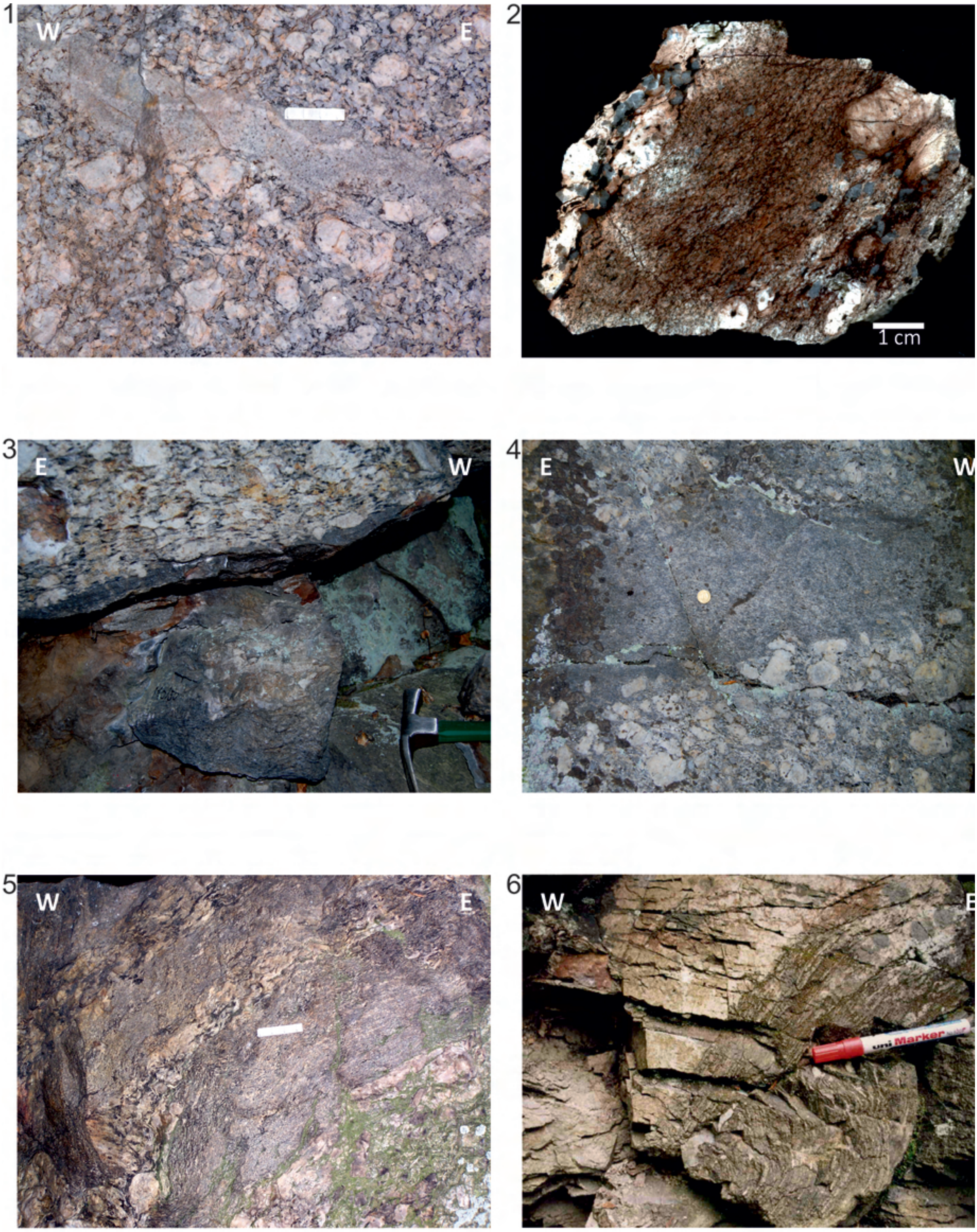


Plate 4. Photographs of various enclaves recognized within the augen gneisses (see Text-fig. 1 for geographic location). 1-2 – felsic microgranular enclaves; 3-4 – surmicaceous enclaves; 5 – schlieren; 6 – xenolith

(see Vernon 1986, Paterson et al. 2004). These features represent various stages of the temperature equilibration of the hot magma and the cool enclaves. Their restitic (sensu Mehnert 1968) origin is also marked by disruptions and transformation into schlieren by gradual melting and assimilation, then with extremely diffuse contacts with their host metagranite (Pl. 4, Fig. 5).

The apparently least common, yet quite important enclaves (4 objects found in the study area) are several metres long lensoid bodies of migmatitic gneisses (~stromatites) composed of Qtz+Kfs+Pl+Bt+Phg±Ttn±Ap±Grt±Aln. The characteristic migmatitic fabric with disharmonic and ptygmatitic folds in the foliation discordant to sharp boundaries classify them readily as **xenoliths** (Pl. 4, Fig. 6) that were incorporated as fragments of solid rocks into the granitic magma (Redlińska-Marczyńska 2011).

The gneissic foliation of the surrounding augen gneisses deflects and anastomoses around such big, rigid bodies (Pl. 4, Fig. 6) and does not continue across their boundaries. In the enclaves, individual Kfs, Qtz or polymineral (Kfs+Qtz±Pl) blasts, nests and pods nucleated at random over the folded and migmatized fabric. Such processes imparted a granitic appearanceto the rock, which thus graded to a porphyritic granite, in places quite similar to the host rock (Redlińska-Marczyńska 2011).

Mineralogy of the enclaves

The mineral composition of the enclaves strongly depends on their types. The chemical composition of the minerals is presented on diagrams against the background of the hosting augen gneisses and the range field of the migmatites, layered-streaky gneisses, banded gneisses and porphyroblastic gneisses (Text-figs 3–6).

In felsic microgranular enclaves, the **feldspars** are compositionally similar to those of their host augen gneisses (Text-fig. 3). The major part of the plagioclase feldspar (up to 90%) contains An_{0-12} and displays normal zonation (Ca decrease from core to rim). The alkali feldspar is microcline and orthoclase; up to 90% of the population is composed of Ab_{6-12} and up to 25% of Or_{95-100}.

Feldspars in surmicaceous enclaves and xenoliths display modal proportions different from those of the host rock of the enclaves (Text-fig. 3). The plagioclase feldspar population ranges from 0 to 85% of albite, 0 to 90% of oligoclase to 37% of andesine (An up to 34%). The alkali feldspar is orthoclase and microcline, yet exsolution microstructures (antiperthites) are common. The major part (40–85%) of the alkali feldspar from the xenoliths is composed of Ab_{6-12} but aniperthititic intergrowths are solid solutions with Ab_{20-80}. The plagioclase feldspar displays normal zonation (Ca decrease from core to rim). All types of feldspars occurring in the matrix are overprinted with subsequent subgrain edge albitization (increase of XAb by few per cent), but the edges of individual Pl grains may contain even 40% Or, which confirms the role of K-feldspathisation, influencing the present day composition of the xenoliths. A detailed description of textural properties and relationships between feldspars was given by Redlińska-Marczyńska (2011).

In FME, **micas** are biotites (annite) and phengites (Mg-Fe mica) comparable in composition with those of the host augen gneisses (Text-fig. 4 B and D, Text-fig. 5B). Like micas from the enclave's host rock, they do not display any noticeable correlation of composition (Ti, #mg) with the structural position occupied (Redlińska-Marczyńska 2011). Nevertheless, biotites in these enclaves can be subdivided into Ti-controlled groups: flakes with progressive amount of Ti [pfu] from cores (0.16–0.27) toward longer rims (up to 0.37) and flakes with regressive amount of Ti [pfu] from cores (0.27–0.35) toward both long and short edges (0.14–0.35). The Ti-regressive flakes are significantly more abundant. Correlation between the biotite chemistry from the FME and host rocks can be observed (Text-fig. 4B and D). White micas have relatively high contents of Si [pfu] and occur in two groups (Text-fig. 5B) which correspond to cores (3.19–3.37) and rims (3.12–3.29) respectively. A lack of the lowest Si group is noticeable (Si < 3.19 [pfu] in cores).

In surmicaceous enclaves, biotites (annite) occur in two Ti-controlled groups and, as in the case of micas from the FME, no correlation between composition and structural position is recognizable (Redlińska-Marczyńska 2011). There are, however, flakes in which some increase in Ti [pfu] from cores (0.27–0.35) to longer rims (up to 0.53) can be observed (Text-fig. 4D). No significant variability of Fe concentration can be noticed (#mg= 0.28–0.35). Significantly more abundant is the group of biotites in which a distinct decrease in Ti [pfu] from cores (0.14–0.34) to both rims (<0.1) can be traced. Some relics of high silicon concentration (Si = 3.35–3.43 [pfu]) occur only in a few phengites (Text-fig. 5B) dispersed chaotically within the matrix of the surmicaceous enclaves. Most of the white micas are arranged parallel to the foliation (S3) of the host augen gneisses (Redlińska-Marczyńska 2011).

In the migmatitic xenoliths, the biotitic flakes display strong compositional correlation with annite from the layered-streaky gneisses and the migmatites, confirming the foreign origin of the xenoliths (Redlińska-Marczyńska 2011). Moreover, the composition of the flakes is related to their structural position and the Ti-contents (Text-fig. 4D). The concentration of Ti [pfu] increases from the cores (0.32–0.39) to the rims (up to 0.48) of these flakes, which are arranged in accordance with the ptygmatic folds and the axial planar foliation. Ti-regressive biotites occur mainly as aggregates of flakes arranged more or less parallel with relicts of the early, pre-migmatitic foliation. The amounts of titanium in this group of flakes are similar to those of the former group, decreasing to a range of 0.29 to 0.39 Ti [pfu] (Text-fig. 4D). Magnesium and iron remain in comparable proportions in both groups of micas (#mg= 0.33–0.38). Phengite flakes (Text-fig. 5B) with the highest amount of Si (up to 3.39 [pfu]) mimic the geometry of small scale ptygmatitic folds and their axial plane foliation. Flakes with a lower concentration of silica (Si ~3.2 [pfu]) are dispersed within the matrix and arranged in groups of mica flakes in the same manner as the biotites. A lack of the lowest Si group (Si < 3.18 [pfu] in cores) is noticeable.

In felsic microgranular enclaves, **garnets** are very similar in composition (Text-fig. 6B) and structure (see Redlińska-Marczyńska 2011) to those from the host metagranite - large, xenomorphic grains, registering a decrease in Ca contents from cores (42–47% Adr+Grs) to rims (37–43% Adr+Grs). Smaller, newly grown crystals are compositionally homogeneous, with the XGrs identical to those in the larger grains (35–45% Adr+Grs). No garnets in the form of inclusions have been found.

Garnet grains from the surmicaceous enclaves are odd in composition and shape compared with those of the host (Text-fig. 6B). Most of them are large, atoll-shaped, and compositionally zoned garnets (37–56% Adr+Grs). Much rarer are small (a few microns), regularly-shaped grains that are significantly more ferric in composition (19–35% Adr+Grs, 63–79% Alm+Sps).

Two types of garnet occur in the migmatic xenoliths (Text-fig. 6B). One type is represented by large, irregular, atoll-shaped crystals with complex compositional zoning and pervasive Ca-loss at wide reaction fringes (32–47% Adr+Grs in cores, 21–42% Adr+Grs in mantles, 15–19% Adr+Grs in rims). The other type is formed by small, isometric, homogeneous grains which can be further subdivided into two groups of different composition (35-42% Adr+Grs versus 14–20% Adr+Grs). In the latter case, the XGrs decrease is accompanied by XSps increase (up to 0.2), while XAlm remains stable (see Redlińska-Marczyńska 2011).

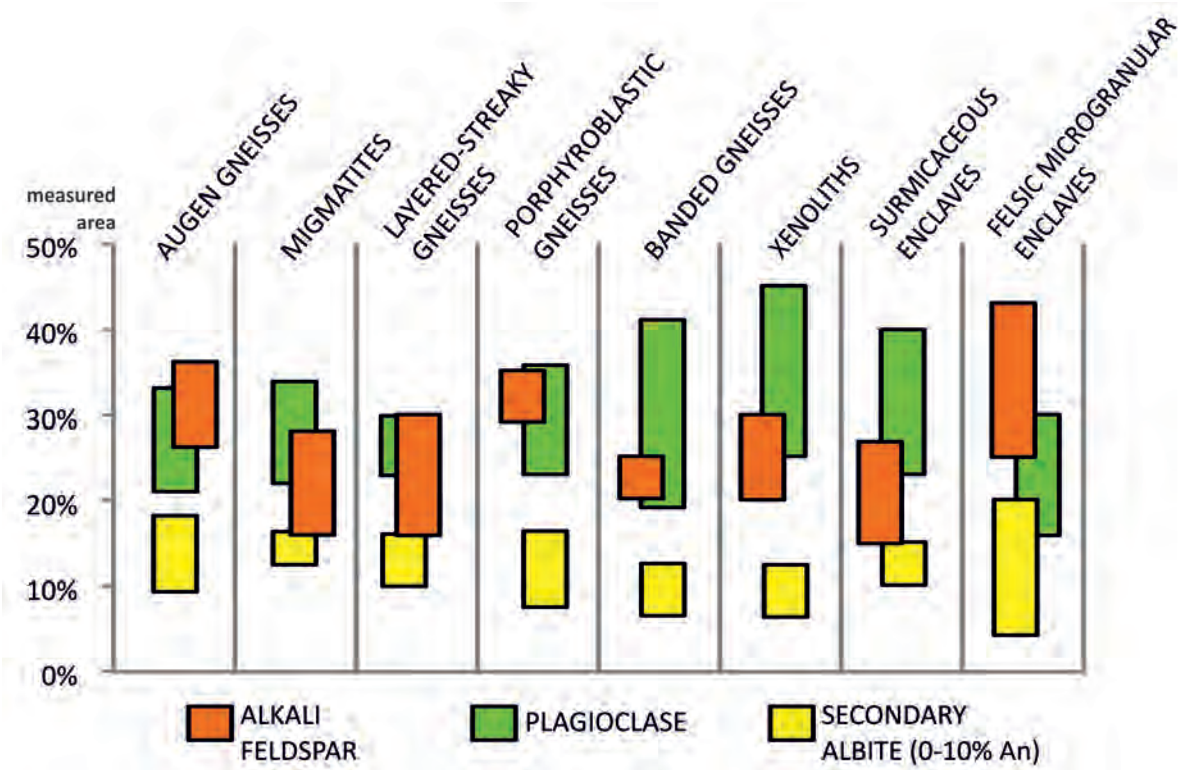
MODAL AND CHEMICAL DIVERSIFICATION OF MINERAL ASSEMBLAGES

Although qualitative mineralogical and bulk chemical compositions of all the analysed gneisses reveal some similarities, we decided to relate the differences between the augen gneisses (together with enclosed enclaves) and the other gneisses inferred from the structural observations to the modal proportions and detailed chemistry of the rock-forming minerals. Such a comparison yielded significant results which are summarized on Text-figs 3–6, 7.

The most uniform modal composition in terms of feldspars is characteristic of the augen gneisses, which distinguishes them from all of the other gneiss units (Text-fig. 7). Planimetric analysis revealed that the augen gneisses contain about 10% more alkali feldspar (26–36% of the measured area) than the migmatites (16–28%), banded gneisses (20–25%) or layered gneisses (16–30%). The banded gneisses are richer in plagioclase feldspar (20–40%) than all of the other rock types (20–30%), which is positively dependent upon the biotite contents in the alternating compositional bands.

An increase in the amount of alkali feldspar in the migmatitic and porphyroblastic gneisses decreases the modal differences between the gneiss units as leucosome and porphyroblasts become more volumetrically important. Plagioclase feldspars from all types of the gneisses were subsequently affected by secondary edge albitization, which produced 5–20% of albite in all the rocks analyzed (Text-fig. 7). Such alteration has strongly influenced the total composition and modal proportion of the feldspars, and has secondarily unified the chemical composition of the minerals. The gain in Na ions together with the loss of Ca and K (within the alkali feldspars) are inferred to have occurred during the latest stages of amphibolite facies regional metamorphism and just after the metamorphic peak (Vernon and Clarke 2008 and references therein). The regional albitization is commonly considered as post-kinematic to the main/last metamorphic event and associated with penetrative tectonic structures (after Vernon and Clarke 2008). In the gneisses of the Orlica-Śnieżnik Dome, such widespread alteration postdates the D3 event, consistent with the accompanying retrograde conditions from amphibolite to greenschist facies metamorphism.

Planimetric measurements applied to enclaves within the augen gneisses revealed that the modal proportions of the felsic microgranular enclaves are modally akin to those of their host. They possess 25–43% of alkali feldspar, 16–30% of plagioclase feldspar and 4–20% of secondary albite. In contrast, the other two types of enclaves display modal proportions that differ from those



Text-fig. 7. Modal compositions of feldspars in different gneiss units (calculated from planimetrically measured area)

of the host rock. The proportions calculated from the surmicaceous enclaves show 15–27% of alkali feldspar, 23–40% of plagioclase feldspar and 10–15% of secondary albite, which is comparable with the modes in the migmatites and layered gneisses. The xenoliths display a distinct enrichment in plagioclase feldspar, up to 45% of the measured area. This extraordinarily high percentage results from strong feldspathization, which occurred at the edges of the grains.

Ti [pfu] compositional zoning within metamorphic mica generally reflects relative temperature changes (Ti-progress with increasing temperature) during metamorphic processes (see Forbes and Flower 1974; Arima and Edgar 1981; Tronnes *et al*. 1985; Henry *et al*. 2005). Despite stipulations regarding Ti substitution controlled by biotite crystal chemistry and coexisting mineral assemblages (see Guidotti 1984; Guidotti *et al*. 1977, 1988; Dymek 1983; Labotka 1983; Tracy and Robinson 1988), the detected differences in Ti contents between mica flakes at different structural position may be linked with differences in thermal conditions during the successive tectonic events that the rocks underwent (Redlińska-Marczyńska 2011). In the migmatites, layered-streaky gneisses, porphyroblastic gneisses and xenoliths (enclosed within the augen gneisses), the Ti-progressive Bt flakes follow the intrafolial folds (F1, F2) and their axial plane foliation (S2), thus indicating that the thermal peak was attained during the D2 event. All the Ti-regressive flakes are arranged in accordance with the subsequent S3 foliation (S1, S2→S3), which suggests that the D3 shearing was associated with a relative temperature drop. In the augen gneisses, the biotites which define the only foliation S3 also show a distinct drop in Ti contents and indicate decreasing temperature conditions. Moreover, the average amount of Ti in dark micas from the augen gneisses is repeatedly lower than in the micas from the other types of rocks studied (Text-fig. 4B).

It is noteworthy that the biotites from the migmatites, layered-streaky gneisses, banded gneisses and porphyroblastic gneisses define a nearly vertical trend of increasing Al^{VI} at relatively constant #mg on the quadrilateral classification diagram (Text-fig. 4A). Mica flakes from the augen gneisses reveal a similar trend, albeit with a greater inclination. Such a pronounced trend of increasing Al has been frequently documented in the literature as indicative of a strong contribution to the protolith from aluminous supracrustal (=sedimentary) material (see Shabani *et al*. 2003 and references therein).

In all the gneisses studied, there are mainly phengitic white micas (Si >3.12 [pfu]) and sporadically muscovites (Si= 3.00–3.12 [pfu]). The silicon content in metamorphic white micas is commonly treated as a reflection of pressure during metamorphism (see Spear 1993; Massone and Schreyer 1987). Phengite flakes with the highest silicon content occur in migmatites (up to 3.43 [pfu]) and surmicaceous restite enclaves (enclosed within the augen gneisses), but a comparably high amount of Si is also observed in the layered-streaky gneisses as well as in xenolitic (migmatitic) enclaves (Text-fig. 5). Such Si-high micas are arranged in accordance with the intrafolial folds (F1, F2) and the axial planar foliation S2, indicating changes in pressure during metamorphism (and deformation). A similarly high concentration of silicon in micas has been reported from (U)HP terrains (Chopin and Ferraris 2003; Menold *et al*. 2009). Additionally, high-Si phengites from the layered-streaky gneisses and some of the migmatites show (slight) negative correlation between Fe/Mg and Si (Text-fig. 5), a feature that is also commonly observed in the phengites from Alpine and Chinese (U)HP units. Migmatites surrounding metabasites contain medium-Si phengites accompanied by a distinct Fe_{tot}/Mg slope (Text-fig. 5), which suggests that some part of these rocks might have undergone (U)HP metamorphic conditions. In contrast, the maximum Si content in phengites from the augen gneisses (as well as FME enclosed within the augen gneisses) and porphyroblastic gneisses does not exceed 3.36 [pfu], and is even lower in the banded gneisses (3.34 [pfu]). Together with the Si independence of Fe and Mg concentration, these features suggest different (lower) pressure conditions during the subsequent stages of deformation and/or diverse preservation potential of the augen gneisses, porphyroblastic gneisses and banded gneisses in comparison with migmatites, layered-streaky gneisses as well as xenolithic and surmicaceous enclosures within the augen gneisses. However, an application of mica-based geobarometers produces comparable results for all types of gneisses, in a wide range of results (0.8–1.6 GPa), discrediting their interpretative significance (see Redlińska-Marczyńska 2011).

A special feature of all the gneisses studied is the presence of anhedral garnet having skeletal to atoll form and unusual composition (Text-fig. 6). The Ca-Fe garnet (XGrs up to 50%) was interpreted as an indicator of (ultra)high pressure metamorphism which the "Gierałtów gneisses" might have undergone along with the eclogites carried by them (Bröcker and Klemd 1996) and/or migmatization under upper amphibolite facies conditions (Stawikowski 2006). None of these options serves to explain the presence of Ca-rich garnets in the augen gneisses of the Międzygórze Antiform or from other localities in the Sudetes (e.g. the Izera granites: Oberc-Dziedzic 1991). However, if the HT/HP metamorphism affected precursors of the rocks studied (and the Izera granites), the present-day composition of the garnets would match the inherited chemistry (Borkowska *et al*. 1990; Żelaźniewicz *et al*. 2006). Oscillatory compositional zoning observed in the garnet grains could correspond to relatively uninhibited diffusion of Ca, Fe, Mg ions between almandine + grossular + siderophyllite + quartz = anorthite + annite (Spear 1993). XGrs concentration is repeatedly higher in the migmatites, layered-streaky gneisses and porphyroblastic gneisses than in garnets from the augen gneisses (Redlińska-Marczyńska 2011). Moreover, in the augen gneisses, the decrease in the XGrs end-member is always accompanied by an increase in the XSps (up to 0.15), while in the migmatites, layered/streaky gneisses, porphyroblastic gneisses and banded gneisses similar XGrs depletion is associated with an increase in the XAlm end-member, with the XSps remaining constant (note different trends on Text-fig. 6). Furthermore, small, anhedral garnet grains having an unusually Fe-rich composition occur as intergrowths within plagioclase porphyroblasts in the layered-streaky gneisses, banded gneisses and porphyroblastic gneisses (Redlińska-Marczyńska 2011). The XAlm enrichment in these grains is only connected with the XGrs decrease (≤0.2). Similarly, Ca-depleted garnets (XGrs≤ 0.2) nucleate freely in the matrix in the surmicaceous enclaves and xenoliths (enclosed within the augen gneisses). In such case, Ca-loss is concurrent with Mn gains (XSps up to 0.2) while XAlm remains constant (0.6).

The correlation between Mn and Ca substitution in the garnets, as observed in the augen gneisses and felsic microgranular enclaves, shows a simple retrogressive path of metamorphism because the XSps increases with decreasing temperature if accompanied by the XGrs decrease with decreasing pressure (see Spear 1993). In contrast, small garnet intergrowths within scarce plagioclase porphyroblasts reveal some XGrs changeability. Commonly reported are situations in which the assemblage present as the metamorphic garnet grew differed from the assemblage present in the matrix of the rock (after Spear 1993). During retrogression, selective removal of components from the effective reacting system takes place (Vernon and Clarke 2008). The progressive growth of plagioclase blasts led to chemical isolation of the enclosed garnets. However, garnet grains from the matrix freely went through diffusion changes. This, at first sight similar, trend in the chemical composition of garnet intergrowths and garnets from the migmatites, layered-streaky gneisses, banded gneisses and porphyroblastic gneisses, differs with the Sps contents (always < 1%). Garnets from the surmicaceous en-

Augen gneisses	**In the position of S3:** • scarce metablasts of plagioclase feldspar (An_{15-23}), intergrown with Bt, Phg, Grt (and Ttn) - identical in composition with same minerals in the matrix.
Migmatites **Layered/streaky gneisses** **Banded gneisses** **Porphyroblastic gneisses** **Xenoliths**	**In the position of S0, S1→S3:** • Bt-Grt disequilibrium (non-stoichiometric analyses of both phases) **In the position of F1/F2:** • breakdown of the white mica at the expense of Kfs (pseudomorphoses) • breakdown of garnets (35-54% Adr+Grs) at the expense of Pl+Kfs • Bt+Grt equilibrium (stoichiometric analyses of both phases) • leucosome in migmatites is generally simple in composition (Qtz+Fsp+Ap+Mu) and its elements are in quasi-equilibrium (some orthoclase grains may be intergrown with Chl and chloritized Bt) **In the position of the axial plane foliation S2:** • substitution of Bt and Kfs by newly grown white mica (characteristic composition of biotite: ↑SiO_2, ↓MgO and newly grown muscovite: Si max = 3.16 (pfu), #mg= 0.44-0.47) • breakdown of Bt (depletion in potassium and titanium elements) at the expense of Kfs and Ttn (pseudomorphoses) • Bt-Grt disequilibrium (non-stoichiometric analyses of both phases) • metablastesis of plagioclase feldspars (An_{10-30}) with numerous intergrowths of Chl, Bt, Phg Grt, Xtm, Aln, which are different in composition from minerals in the matrix: biotites are always chloritized, phengites are Mg-depleted (#mg= 0.28), garnets are Ca-depleted (16-22% Adr+Grs, 72-81% Alm+Sps). Xenothime small grains occur only in the described position. Allanites are REE-void. • Pl porphyroblasts are antiperthites (except of the banded gneisses). Small chloritized Bt flakes found within the blasts are commonly substituted with Kfs.

Table 2. Evidence of metamorphic reactions recorded at the microscopic scale

claves and xenoliths display similar low concentration of the Sps end-member, which may reflect the primary bulk-composition of the Śnieżnik protolith.

The complex, multi-layered pattern of Ca and Fe substitution in garnets from the migmatites, layered-streaky gneisses, porphyroblastic gneisses (and xenoliths enclosed within the augen gneisses) attests to a more complex metamorphic path of these rocks, as the XGrs increases with increasing pressure if accompanied by a reverse behaviour of the XAlm (Spear 1993). In contrast to the disputable metamorphic path(s) characteristic of the eclogite-bearing gneisses (“Gierałtów gneisses”) and migmatitic xenoliths, a rather simple, retrograde P-T path for the augen gneisses can be inferred (see Redlińska-Marczyńska 2011). Application of garnet-based geothermometers generates similar results (~ 500-550ºC) for all the types of the gneisses, reflecting conditions of the last re-equilibration in the system (see Redlińska-Marczyńska 2011).

Other records of ion diffusion and interaction between minerals also suggest differences in P-T paths of the various types of gneisses (Table. 2). More complex lines of mineral recrystallization within the migmatites, layered-streaky gneisses and porphyroblastic gneisses are again indicative of different and longer P-T evolution (progressive toward upper amphibolite facies + migmatization and retrogressive to greenschist facies) in a rather open system as compared to the plain record of recrystallization of the augen gneisses (up to lower amphibolite facies conditions and retrograde to greenschist facies) in a relatively closed system. In the augen gneisses, scarce evidence of HT/MT blastesis of feldspars which would overgrow minerals of the matrix may be taken as a manifestation of such conditions. The albitization process that is advanced mainly at grain edges and along cleavage planes is characteristic of the subsequent change from amphibolite to greenschist facies metamorphic conditions postdating the D3 event.

WHOLE ROCK GEOCHEMISTRY AND ISOTOPIC AGE OF GNEISSES

The earliest research into the bulk composition of the gneisses (Borkowska *et al*. 1990, Borkowska 1994, 1996) showed some remarkable differences in the amounts of major elements (Si, Al, Mg, Na) and trace elements (Ba, Sr) between the main types of these rocks. Based on such data, either two separate protoliths (Borkowska et al. 1990) or one protolith, albeit chemically diversified by intrusive processes (Borkowska 1994), have been suggested. In contrast, Turniak *et al*. (2000), Kröner *et al*. (2001) and Lange *et al*. (2002) proposed that all the gneisses were derived from a single, large batholith and claimed that geochemical differences between them are not sufficient to distinguish the “Śnieżnik gneisses” from the “Gierałtów gneisses”. All the variations in quantitative values of particular elements/oxides in the bulk composition (Ba, Sr, Eu, Th, U as well as Na_2O, Fe_2O_3) and mineral composition (e.g. biotites, feldspars) were ascribed to modifications accomplished during subsequent deformation and migmatization (Lange *et al*. 2005). Unfortunately, no detail of such selective tectonometamorphic transformations of a once geochemically uniform granite was given.

Our observations reported above show that, despite similarities in bulk composition of the gneisses (see analytical data in Turniak *et al*. 2000; Lange *et al.* 2002, 2005), there are some significant differences in chemical and modal composition of the rock-forming and accessory minerals in these rocks, and the differences are reproducibly systematic. Therefore our data confirm the arguments stipulated by Borkowska *et al*. (1990) and Borkowska (1994, 1996) in favour of the chemical diversification of the "Śnieżnik" and "Gierałtów" gneisses but at a mineral and not whole rock level. Taking into account the presence of migmatitic xenoliths in the augen gneisses, the bulk geochemical affinity of these gneisses can be easily reconciled with our observations. Migmatization that occurred in the lower crust produced an anatectic melt with the geochemistry controlled by mica stability (Rushmer 2001). A transient magma chamber was formed and a granitic magma became contaminated by absorbing the wallrocks, which influenced its geochemistry.

In the Międzygórze Antiform, alkali-rich, migmatitic xenoliths and aluminum-rich restites show strong geochemical affinity to the host augen gneisses (Grześkowiak 2004), which indicates that the magmatic precursor of the latter either developed at the expense of related migmatites or was contaminated with rocks similar to those of the "Gierałtów complex". Xenoliths and restites are the most evident signs of such contamination (Barbarin and Didier 1990), along with locally preserved relicts of intrusive contacts (Pl. 4, Figs 7–8). Moreover, the largest differences in geochemical composition are observed at contacts of the augen gneiss body with both the "Gierałtów gneisses" and Stronie metasediments (Borkowska *et al*. 1996), which also supports our view and points to higher contamination at the margins of the granitic intrusion.

The first isotopic dates for the OSD gneisses, obtained by the Rb-Sr whole rock-mineral isochrone method, showed the minimum time of emplacement of the gneiss protolith and revealed some age difference between the "homogenous Gierałtów gneisses" (464±18 Ma after Borkowska *et al*. 1990) and the "Śnieżnik gneisses" (395±35 Ma after Borkowska *et al*. 1990 but 487±11 Ma after Van Breemen *et al*. 1982). Utilizing zircons, the U-Pb multigrain method and Pb-Pb single grain evaporation method yielded a more uniform group of ages between 515 and 480 Ma (Oliver *et al*. 1993; Hegner and Kröner 2000; Kröner *et al*. 2001), which were considered as the time of intrusion of the protolith of both the "Śnieżnik" and "Gierałtów" gneisses. Distinctly negative $\varepsilon Nd_{(t=500)}$ values scattered between –0.3 and –7.1 (Hegner and Kröner 2000; Kröner *et al*. 2001; Lange *et al.* 2005) enabled determination of T_{DM} model ages of 1.2 to 1.7 Ga and suggested derivation of the protolith from melting of Precambrian continental crust. Melting likely affected the 565–530 Ma Cadomian crust and occurred at 505–495 Ma (Turniak *et al.* 2000; Grześkowiak *et al*. 2005). A few of the ~500 Ma zircons were overgrown with 340–330 Ma metamorphic rims that were interpreted by these authors as evidence of Variscan HT/LP metamorphism and migmatization. The Variscan overprint was confirmed by Ar-Ar white mica ages of 340–325 Ma (Marheine *et al*. 2000) and Rb-Sr phengite and biotite ages of 340–330 Ma (Lange *et al*. 2002, 2005).

The isotopic systematics of the OSD gneisses are consistent with the view of a Neoproterozoic crust that underwent high-T metamorphism, and anatectic melting that produced the migmatites and granitic precursor of the augen gneisses, respectively. The ~500 Ma thermal event continued for ca. 35 Ma, a period long enough to allow oscillatory, magmatic zoning structure of zircons growing in the migmatitic leucosomes and in the anatectic melt (Brouand *et al.* 1990; Oliver *et al.* 1999; Glebovitsky *et al*. 2008). Further support for this view came from migmatitic gneisses of the "Gierałtów type" in the Zdobnice Valley (Orlické hory), which yielded an U-Pb SHRIMP age of 485±12 Ma (Żelaźniewicz *et al*. 2006). They were cross-cut by an undeformed (post-tectonic) syenite dyke that intruded at 326 ± 3 Ma, which provided the maximum age limit for Variscan deformation that occurred in the western limb of the OSD.

The ca. 35 Ma long period in which the protoliths of the gneiss formations underwent migmatization and partial melting coincides with the 530–470 Ma period of deposition of the volcano-sedimentary protoliths of the Młynowiec and Stronie formations connected with crustal thinning due to Cambro-Ordovician rifting of the Gondwana basement (Jastrzębski *et al.* 2010). The anatectic granite (precursor of the Śnieżnik augen gneisses) intruded into gneisses already deformed and migmatized under high-grade conditions at lower crustal levels. The deformational event also produced equivalent tectonic structures in the metavolcano-sedimentary rocks prior to or coevally with the granite emplacement. However, this topic is beyond the scope of the present paper.

DISCUSSION

Discriminating criteria

Given the complex nature of the gneisses in the OSD, the criteria so far used to distinguish between the two principal gneiss types in the region apparently failed in many instances. Augens and augen-like objects were mixed up, grain-size misinterpreted, and layering or lamination misidentified. Some of these confusions were already noticed by Dumicz (1988, 1989), who drew attention to the oversimplified criteria which resulted in such discomforting situations when gneisses said to be of the "Gierałtów" type eventually appeared to be both older and younger than those ascribed to the "Śnieżnik" type. Recent studies that utilized geochemical and isotopic analyses have brought no remedy (Turniak *et al*. 2000; Kröner *et al.* 2001; Lange *et al*. 2002, 2005), especially when considered in conjunction with the outdated knowledge of the petrographic composition and structural history of the rocks in question.

Augen gneisses can be fine-grained and quite poor in augens whereas the objects classified as augens may be of a fundamentally different origin. Only phenocrysts that were originally grown in a granitic rock and then became deformed can now be correctly regarded as genuine augens. These must not be misidentified with porphyroblasts which grew in high-grade gneisses and polymineral lensoid aggregates extracted in migmatites, and only during later superimposed shearing were transformed to augen-like σ- and δ-clasts (porphyroclasts). Likewise, layering in gneisses can be produced by solid-state deformation, dynamic recrystallization and mechanical segregation of the granite-forming minerals into monomineral bands or by metamorphic differentiation that merely enhances already existing compositional banding in rocks of metasedimentary/volcanogenic derivation. For such reasons, we propose herein the usage of combined structural and petrographic data for discriminating between gneisses.

Significance of enclaves

The presence of enclaves in the porphyritic granite (precursor of the augen gneisses) matches the evolution of the mature magma chamber, in which some of the incorporated wall and roof rocks persist as xenoliths (conspicuously similar to migmatites from the "Gierałtów complex"), being subsequently transformed into alkali-depleted restites (surmicaceous enclaves) and schlieren. The abundant presence of felsic microgranular (microgranitoid) enclaves (FME) is very common in high-level granitoid plutons (also calc-alkaline ones). This feature is indicative of the chilled, marginal phase of the parental intrusion, incorporated during the magma emplacement (Vernon *et al*. 1983; Vernon 1986, 1991; Paterson *et al*. 2004).

The presence of quartzofeldspathic xenoliths with no or only minor features suggestive of melt extraction is explained by their late incorporation into an ascending magma or temperature peak of short duration (Maury and Didier 1991). The development of porphyroblasts that overgrow the existing ultrametamorphic fabric indicates a rather small rate of heating during a relatively short time of transportation within a granitic melt (see Vernon 1986; Barbarin and Didier 1991). A high temperature fabric should be treated as an inheritance of a fabric that that must have developed prior to the magmatic stage. The occurrence of unmodified Qtz+Fsp xenoliths and alkali-depleted restites which subsequently disseminate into disrupted schlieren strongly suggests large degrees of partial melting and feasible migration of an anatectic melt into the wall rocks affined to the "Gierałtów" gneisses. Surmicaceous enclaves commonly occur in anatectic granites associated with migmatites. Such relationships were, for instance, observed in the Variscan Velay Granite, in the French Massif Central (Montel and Cheilletz 1989; Didier 1991; Montel *et al*. 1991), and we propose that a similar model is valid for the OSD at the time of emplacement of the porphyritic granite. The abundant enclaves of different types found in the augen gneisses of the Międzygórze Antiform and elsewhere in the eastern limb of the OSD suggest that it probably embraces a marginal part of the intrusion, in contrast to the Bystrzyca and Orlica (western) fragments of the dome.

Whilst the shape, size and mineralogy of enclaves are features enabling their classification, the characters of their boundaries are indicative of thermal and rheological **relationships in the enclave-host system**. All small enclaves display features suggesting plastic behaviour within the host magma (see Vernon *et al*. 1983; Vernon 1986, 1991; Maury and Didier 1991; Poli and Tommasini 1991; Kumar *et al*. 2004; Paterson *et al*. 2004). Diffuse edges of restites and schlieren indicate high temperature equilibration during the time spent by them within the magma chamber, which enabled diffusion of alkali ions and the advancement of transformations depending on the properties of the magma. K-feldspar and quartz porphyrocrysts, which grow at random across the enclave-host boundaries and within the enclaves themselves, confirm similar rheology (temperature and viscosity) of the two rocks while the megacrysts crystallized.

Sharp boundaries of the surmicaceous enclaves are occasionally enveloped by a thin biotite encrustation (Pl. 4, Fig. 3) which under the microscope appears to be made of randomly oriented biotite flakes. Such coatings form as a result of some degree of melt extraction (partial melting) within the outer parts of the enclave: felsic components have been incorporated into a liquid phase, and refractory minerals preserved as melting residues, playing the role of an isolator inhibiting further melting. The presence of a Bt rim over Kfs porphyroclasts supports the idea of free ion diffusion between enclaves and host granite (see Vernon 1986, 1991; Kumar *et al*. 2004).

At the microscopic level, significant reactions which are indicative of both **magmatic and metamorphic equilibration of the composition of an enclave** can be observed (Table 2). Within xenoliths and restites, there are (1) plagioclase (An_{1-23}) porphyroblasts with numerous Mca, Ep/Aln, Ap, Zr intergrowths and (2) Kfs porphyrocrysts intergrown in the outermost parts with Bt, Phg, Ttn and Ilm inclusions, mainly at the enclave borders. Such an arrangement suggests two stages of (re)crystallization. Firstly, the enclaves were heated up just after they had been incorporated into the magma chamber, which induced metablastesis of plagioclase grains overgrowing small minerals in the metamorphic matrix. Secondly, after some time spent within a hot magma, some degree of thermal equilibration took place that allowed the Kfs megacrysts to crystallize from the liquid magma within the enclaves and at their margins. The outer parts of the Kfs crystals became overgrown with refractory minerals present within the enclave. In the felsic microgranular enclaves, Kfs (Ab_{5-10}) megacrysts also intergrew in their marginal parts with Mca (annite and phengite). All these features are akin to the ocelli structures and seem to indicate free ion diffusion at the enclave-host boundary.

The chemical composition and modal proportions of minerals from the FME are almost identical with those recorded by the granitic host. In contrast, the mineralogies of the xenoliths and surmicaceous enclaves are distinctly different from that of the host. These enclaves display modal proportions of feldspars that are more akin to those of the migmatites and layered gneisses (15–30% of Kfs, 25–45% of Pl, 6–15% of Ab). Ti concentration within Bt flakes also depends on their structural position in the rock in the same way as observed within the migmatites and layered gneisses. Ti [pfu] increases from the cores towards the rims of those flakes which are arranged parallel to the S2 foliation, whereas the Ti-regressive biotites form the relic foliation S1 (in xenoliths) and the mylonitic foliation S3 (in surmicaceous enclaves). Phengite flakes are arranged in the same manner as biotites and those consistent with the S2 planes preserve the highest concentration of Si up to 3.43 [pfu]. Al^{VI} in these two types of enclaves concentrate in a vast range, but is independent of the Mg and Fe amounts – exactly in the same manner as in the migmatites, porphyroblastic gneisses and layered-streaky gneisses. In the FME and xenoliths, phengite with a low Si concentration (below 3.19 [pfu] in cores) is simply lacking (Text-fig. 8), yet occurs within the host gneisses. Such a pattern of distribution may be accounted for by only limited metamorphic alteration experienced by the isolated bodies. On the other hand, the lowest-Si flakes dominate within strongly equilibrated surmicaceous enclaves and schlieren.

In the xenoliths and surmicaceous enclaves, blasts of the atoll garnet are similar in shape and complex compositional zoning to garnets that occur in the migmatites. Small, isometric, newly nucleated garnets are homogeneous, and in their composition (Fe-enriched) resemble those occurring in the porphyroblastic gneisses, layered to streaky gneisses and migmatites.

Migmatization-related structures and textures preserved in the xenoliths and surmicaceous enclaves, together with chemical and modal similarities of mineral composition to the migmatites and layered-streaky gneisses, provide evidence of the strong affinity of these types of rocks. In fact, some xenoliths are structurally and chemically indistinguishable from migmatites recognized in the Międzygórze Antiform (Redlińska-Marczyńska, 2011). Such a structural pattern was already suggested by Dumicz (1989) and Grześkowiak and Żelaźniewicz (2002), who reported the existence of isolated enclaves of "Gierałtów gneisses" within the "Śnieżnik gneisses".

New subdivision of gneisses

Recognizing that traditional names of gneisses can be hardly abandoned (Redlińska-Marczyńska 2011), a new proposal retains the old names albeit only after significant revision taking into account the structural and petrographic data featured in this paper.

The term Śnieżnik augen gneisses (in short: augen gneisses or Śnieżnik gneisses) should only be applied to gneisses with a clear magmatic origin and derivation from the porphyritic granite (Redlińska-Marczyńska 2011). In these gneisses, original Kfs porphyrocrysts were turned to porphyroclasts (=monomineral cores with "tails") and wrapped by a foliation defined by alternating monomineral laminae/layers of quartz, feldspars, and micas. The single foliation set, accompanied by a single stretching lineation locally with small-scale transversal folds and a weak overprint of biotite lineation, represents the tectonic fabric of the augen gneisses, which thus differ from the other gneisses with a much more complex structural inventory and history (compare Pls. 1–3).

The term Gierałtów gneisses should collectively refer to a plethora of gneisses including migmatites, layered to streaky gneisses, banded gneisses and porphyroblastic gneisses. Their common features are signs of multiple deformation and metamorphism testified by intrafolial and interfering folds, shear zones, compositional banding, polymineral lensoid aggregates (leucosome) and porphyroblasts, and varied migmatic textures up to granite-like recrystallization. All these features were acquired by the Gierałtów gneisses prior to the overprint of ductile shearing (D3) – the same event that transformed the porphyritic granite into the Śnieżnik augen gneisses (Redlińska-Marczyńska 2011).

The progressive shearing (D3) imposed on both the porphyritic granite and the Gierałtów gneisses often obliterated earlier features and zonally turned all the affected rocks into mylonites and ultramylonites. These have a similar appearance and simplified composition no matter which type of gneiss they have been derived from, thus often making it hard to distinguish whether the Śnieżnik gneiss or any of the Gierałtów gneisses was involved. We therefore propose to name such rocks simply mylonite or ultramylonite according to the intensity of the mylonitic deformation, with indication of the protolith whenever possible.

CONCLUDING REMARKS

Summing up our structural observations at meso- and microscopic levels, and the data on the modal and chemical compositions of the main and accessory minerals, we propose to maintain the two traditionally distinguished categories of gneisses in the Orlica-Śnieżnik Dome but redefine them as formations characterized by different lithological associations. Moreover, mylonites to ultramylonites derived from the gneisses can be recognized.

The **Śnieżnik Gneiss Formation** refers to the genuine augen gneisses (L, L>S and L<S tectonites), which have a single set of metamorphic foliation that developed during shearing under amphibolite to greenschist facies conditions of the regional D3 event when they acquired true augen and rodded textures. The foliation is consistent with the occasionally recognizable earlier magmatic foliation, but the kinematics of primary and secondary movements were different (E–W directed magma flow versus N–S directed metamorphic shearing). Subsequent deformation of the Śnieżnik Gneiss Formation involved N-vergent F3 and E-vergent F4 folds developed during regional D3 and D4 events under amphibolite and greenschist facies conditions respectively. The rock-forming minerals of the Śnieżnik gneisses have a significantly more uniform composition (Text-figs 3–7) than those of the migmatites, layered to streaky gneisses, banded gneisses and porphyroblastic gneisses. Among reproducible features of the augen gneisses are: [1] roughly equal amounts (modal %) of quartz, potassium feldspar and plagioclase feldspar with minor biotite, [2] weakly diversified, generally alkaline plagioclase feldspar, twinned and normally zoned, [3] weakly diversified biotites with a moderate range of Al^{VI} contents. Such an obvious tendency toward a more uniform composition has been acquired in the process of homogenization of the anatectic melt via partial melting of rocks akin to those found in the enclaves and surrounding gneisses. Homogenization attained by the parent magma probably occurred during melt segregation and accumulation in the deeper crust with slow prograde heating (compare Spear 1993 and Gerdes 2001). The retrograde metamorphic transformations of minerals in the Śnieżnik gneisses indicate that the granitic magma was emplaced into country rocks undergoing amphibolite facies followed by greenschist facies metamorphism.

The rocks subject to partial melting were akin to those of the presently outcropping migmatites, layered to streaky gneisses, banded gneisses and porphyroblastic gneisses or to their deeper level equivalents. This view is supported by the presence of enclaves occurring exclusively in the Śnieżnik Gneisses. The enclaves reflected the evolution of an anatectic magma chamber under conditions enabling development (and later conservation) of some marginal phases (felsic microgranular enclaves). The magma chamber was contaminated with partially molten protolith and/or wall rocks. The assimilated fragments persisted in the form of unchanged xenoliths (migmatites), partly changed restites (alkali-depleted gneisses = surmicaceous enclaves) or strongly diffused and assimilated schlieren. Rocks in the xenoliths are very akin to the migmatites into which the granitic precursor of the Śnieżnik Formation at least locally intruded.

The **Gierałtów Gneiss Formation** includes banded gneisses, layered-streaky gneisses, porphyroblastic gneisses and migmatites. Rocks of this formation underwent a longer tectonothermal history and developed far more tectonic structures than the Śnieżnik metagranite. They possess two sets of metamorphic foliations together with early shear and fold records, metablastesis and ultrametamorphism (D1-D2), subsequently overprinted by shearing (D3), which gave rise to more or less advanced mylonitization under amphibolite to greenschist facies conditions. Subsequent D4 folds developed under greenschist facies conditions. Characteristic is the presence of polymineral aggregates (leucosome) and/or porphyroblasts (with Qtz, Fsp and Mca intergrowths), particularly in the hinge zones of (relic) intrafolial folds. The chemical and modal composition of minerals from the rocks of the Gierałtów Formation indicate strong heterogeneity of their protolith, as [1] plagioclase feldspars occur in a wide range of modal percentages and their end-member compositions differ widely, [2] alkali feldspars are minor components in those gneisses which happened to avoid migmatization and/or metablastesis, [3] biotites show pronounced enrichment in aluminous supracrustal material.

Owing to metamorphic homogenization, some rocks of the Gierałtów Formation tended to converge towards the Śnieżnik-type gneisses in the course of migmatization and metablastesis, when the amount of Kfs increased and changed the Pl-Kfs modes (mainly in the porphyroblastic gneisses and in xenolithic enclaves). Such (ultra)metamorphic processes could bring a given rock closer toward an anatectic granite. The chemical and modal compositions of the metamorphic mineral assemblages of the rocks of the Gierałtów Formation evidence a more complex evolution than that of the gneisses of the Śnieżnik Formation. The migmatites, layered-streaky gneisses, porphyroblastic gneisses and banded gneisses of the Gierałtów Formation have: [1] Ca-Mg garnets with a complex zonation that reflects the P-T conditions during metamorphism from the upper amphibolite facies with migmatization to greenschist facies conditions; and [2] micas of different composition controlled by deformational stages, revealing that both the pressure and temperature peaks were related to the D2 event (folding and inter- to post-kinematic ultra/metamorphism).

As the Śnieżnik anatectic magma developed via lower crustal melting of migmatized gneisses similar to those of the Gierałtów Formation, the two formations recorded a major thermal event at 515–480 Ma and the zircons grown in that time span reveal a common pattern of growth zoning typical of crystallization from an igneous melt. For the same reason, the two formations retained xenocrystic zircons aged 580–560 Ma (together with some inheritance of older age clusters), which suggests that the protolith represented reworked crust formed largely in the Cadomian orogeny. The original intrusive contacts of the augen gneisses with the migmatites and porphyroblastic gneisses that are locally preserved in the Międzygórze Antiform indicate that the granitic precursor of the Śnieżnik Formation must have been emplaced in the already deformed and migmatized rocks of the Gierałtów Formation, syn- or post-tectonically with respect to the D2 event. The Śnieżnik magma was apparently emplaced in a W–E direction (possibly westward), as implied by the present-day orientation of the longer axes of the enclaves and undeformed Kfs porphyrocrysts.

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