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ANDRZEJ ŻELAŹNIEWICZ

Synmetamorphic penetrative mylonitization in orthogneisses of the Bystrzyca Mts, Sudetes

ABSTRACT: Medium and coarse-grained granitegneisses of the Bystrzyca Mts, western part of the Kłodzko-Orlica dome, Middle Sudetes, are characterized by a strong stretching lineation. The stretching fabric was associated with the grainsize reduction and ductile mylonitization of originally granitic rocks. Mylonitic foliation of the resultant granitegneisses was due to contrasting ductility of quartz, K-feldspar, and plagioclase during the deformation. The deformation was overlapped and followed by the main medium-grade metamorphic event in the region. It led to severe recrystallization of the minerals once ground down, in particular K-feldspar, which obliterated partly the earlier fabric, and to local increase in grainsize. Blastomylonitization of the primary granitic masses, emplaced into metasedimentary schistose rocks, was related to pervasive shearing and an easterly directed Variscan thrusting as well as napping that all took place toward the end of the main N-S oriented folding in the region. The direction of stretching ubiquitously conforms with that of the main folds and the mineral lineation in the schistose Stronie formation, hence it likely represents the Y axis of strain ellipsoid.

INTRODUCTION

The Kłodzko-Orlica dome, Middle Sudetes, is in its northwestern part built by three major lithological units. A granitegneiss series of the core (known under local names as the Bystrzyca or Śnieżnik gneisses) is followed outward by mica schists of the Stronie formation, commonly intercalated with marbles and amphibolites or quartzites, and mantled in turn by the Nové Město phyllitic formation (Text-fig. 1). The last two formations are separated by a deep-seated first-order fault referred to as the Olešnice-Uhřinov line (Opletal 1969) and a narrow body oh the Kudowa-Olešnice granitoids.

The Stronie schists and the Bystrzyca gneisses at the present erosion level, reflected in actual outcrop pattern, alternate and form roughly parallel belts. The schist complex splits up south of the Mt. Deštna into branches dying out southerly. Contacts between the gneisses and the schists are either tectonic or represented by transitional zones several tens to hundreds metres wide, in which both the lithologies densely alternate (Dumicz 1964). Rather peculiar feature of those contacts is a common presence of tens metres thick, discontinous, lensoid horizons of intervening quartzites or quartzitic schists, which adhere to strongly rodded Bystrzyca gneisses. Such a characteristic field association of the gneissic complex, being separated from the schistose one by quartzitic rocks, was reported from various parts of the Kłodzko-Orlica dome (Pauk 1977; Don 1964; Dumicz 1964; Fajst 1976; Opletal & *al.* 1980; Smulikowski 1979).

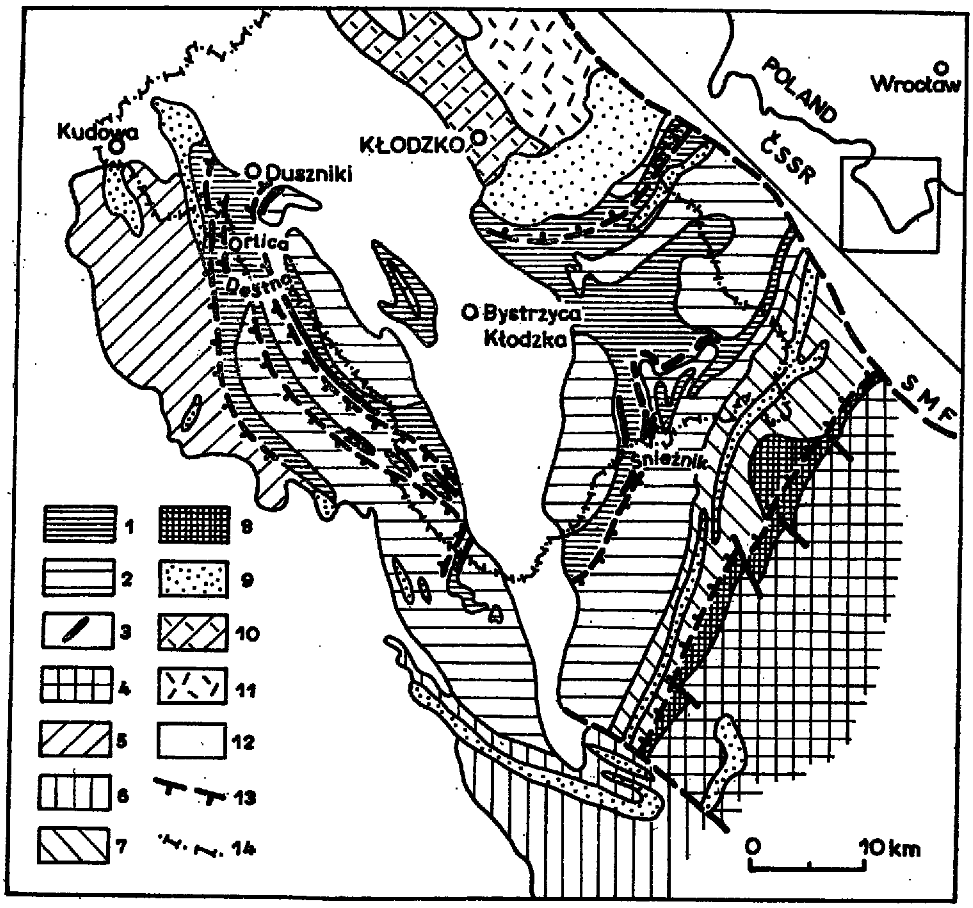

Fig. 1. Sketch-map of the Kłodzko-Orlica dome (*compiled from:* Dumicz 1964, Don 1972, Butkiewicz 1972, Fajst 1976, Pauk 1977, Opletal & *al.* 1980)

1 — Stronie formation, 2 — granitegneiss series (Śnieżnik, Bystrzyca, Gierałtów types), 3 — quartzites and quartzitic schists, 4 — Keprnik dome gneisses, 5 — Nove Mesto formation (phyllites), 6 — Zabreh series (paragneisses), 7 — Stare Mesto series (schists), 8 — Branne and Velke Verbno series (phyllites), 9 — granitoids, 10 — Kłodzko epimetamorphic unit, 11 — Bardo unit, 12 — Permo-Mesozoic cover, 13 — overthrusts, 14 — state frontier; *SMF* — Sudetic marginal fault

A couple of hypotheses was put forward in order to account for this very association. In opinion of Fajst (1976) the quartzites represent a basal member of the Stronie formation laid down upon the gneissic bedrock. Pauk (1953, 1977), advocating a largescale nappe tectonism for the Kłodzko-Orlica dome, assumed that the „boundary" quartzitic schists might represent diaphtoritic rocks derived from the Śnieżnik gneisses and developing at a base or interface of two nappe travelling eastwards (*e. g.* quartzitic schists near Velka Morava, ČSSR). Dumicz (1964) supposed that the quartzites might stop a coming-from-beneath metasomatic front that was to granitize the Stronie rocks and to convert them eventually into gneisses.

Coarse-grained, often augen gneisses of the Kłodzko-Orlica dome (Śnieżnik = Bystrzyca type) were long ago interpreted (Wolf 1864) as formed due to gneissification of earlier granitic intrusion, thus much in the same way as a development of the gneisses in the Erzgebirge.

This idea was strongly challenged for the last three decades by Smulikowski (1957, 1960, 1979) and his followers postulating strong and extensive metasomatic granitization *in situ* of the Stronie schists, at the expense of which the granitegneiss series developed. Widely accepted Smulikowski's interpretation was, however, criticized by Don (1964, 1977, 1982) and questioned by some Czech geologists (*cf.* Opletal & *al.* 1980). The critics pointed out that the gneisses display occasionally intrusive contacts and form veins in the Stronie or even Nové Město rocks. Also they drew attention to signs of strong cataclastic deformation suffered by the coarse Śnieżnik (Bystrzyca) gneisses.

The present author has been prompted by a highly characteristic outlook of the gneisses and quartzites cropping out immediately south and east of Duszniki, typical of a cataclastic rock, to explore the problem once again with exemplification taken from thhe nortwestern part of the Kłodzko-Orlica dome.

STRUCTURAL SETTING

Tectono-metamorphic evolution of the NW part of the Kłodzko-Orlica dome has been described elsewhere (Żelaźniewicz 1976, 1978). A structural sequence commenced with F_1 episode producing invariably tight and isoclinal folds that are, however, scarcely distributed but accompanied by a strong penetrative axial planar foliation S_1, parallelling in general the lithological boundaries on all scales.

The F_2 deformational event produced both the small-scale and major tectonic structures in the region. The latter were tight, meridionally running, with westerly dipping axial planes. The S_2 composite axial foliation is the main planar feature developed under a garnet-biotite zone of the regional progressive metamorphism. The $F_2 + M_2$ phase appeared as the main tectonothermal episode. There is a lot of evidence that intense shearing took place toward the end of the very episode. It resulted in penetrative differential glide movements in the S_2 foliation planes and also in large-scale, eastward directed thrusting.

The main event was locally followed by the F_3 open, asymmetric folding on steep, WNW dipping axial planes that only occasionally were marked by a new mica growth. The F_3 and S_3 structures were presumably related to the thrusting and developed close to the thrust zones.

The next three consecutive deformational episodes, F_4 to F_6, accomplished on rather small scale mostly through kinking in generally brittle regime. Besides, the F_6 episode produced the large-scale, open, upright folds plunging gently northwesterly, and conspicuously affecting the outcrop pattern established by the main folding.

Accordingly, those major structures in the discussed region that controlled the actual outcrop pattern were produced by the F_2 and F_6 deformational episodes. Progressive metamorphism in the region reached its climax (M_2) syn- and posttectonically relative to the F_2 folding and soon ceased entirely. The F_4 — F_6 deformations were accompanied by virtually no metamorphic growth or significant recrystallization.

It is of interest that mica schists or marbles of the Stronie formation recorded the complete set (F_1 — F_6) of small-scale tectonic structures, whereas the Bystrzyca gneisses were totally devoid of both F_1 and F_2 folds as well as S_1 foliation. The first structural feature recognizable in the gneisses is strong, often undoubtedly mylonitic S_2 foliation being accompanied by a distinct stretching lineation in form of characteristic quartzofeldspathic rodding. The rodding conforms with the direction of F_2 fold axes and L_2 lineation recorded by adjacent rocks of the Stronie formation but it is older than F_3 structures recognized in both gneisses and schists. Hence it is considered as the L_2 lineation as well.

Quartzites and quartzitic schists occurring between the schistose Stronie formation and the Bystrzyca gneisses, except rather scarce rootless intrafolial folds in the quartzose laminae, are also strikingly short of the F_2 fold structures whereas the L_2 stretching lineation and the S_2 foliation have been developed excellently.

ROCKS WITH STRETCHING LINEATION

GNEISSES

Gneissic rocks, distinguished in the eastern limb of the Kłodzko-Orlica dome, have traditionally been divided into two textural types. The fine and even-grained, often laminated variety is known as the Gierałtów gneiss whereas the coarse and unevengrained, augen or lenticular type is called the Śnieżnik gneiss. Both types have the same mineral and chemical composition close to that of granitic rocks. As they differ only in textures and quantitative proportions of either mineral or chemical constituents, they are considered as representing one granitegneiss series (Smulikowski 1979). Gneisses of the western limb of the Kłodzko-Orlica dome, in the Bystrzyca Mts (Text-fig. 1), represent only the Śnieżnik variety. On account of their geographical location they are also referred to as the Bystrzyca gneisses.

The gneisses occurring near Duszniki represent a northwestern termination of extensive outcrops of the Bystrzyca gneisses continuing further south (Text-fig. 1). They abut here against mica schists of the Stronie formation, with which they form jointly a metamorphic basement hidden benath vast Cretaceous cover in the middle and northern part of the dome.

Petrographic recognition of the Bystrzyca gneisses (Juroszek 1972, Opletal & *al.* 1980) shows the existence of two generations of plagioclase and one of K-feldspar. Żelaźniewicz (1976) mentioned two generations of K-feldspar, found in the gneisses of Duszniki, the older frequently showing signs of cataclastic and especially ductile deformation.

Characteristic features of those gneisses are (1) the presence of elongate and flattened grains of microcline set in much finer grained quartzofeldspathic matrix interwoven with mica (Pls. 3—4), (2) the lack of any folds or recognizable relics of earlier directional fabric, and (3) the presence of conspicuous rodding lineation. The lineation is due to distinct elongation of not only the microcline grains but also of quartz lenticles and aggregates of quartzofeldspathic matrix, and rather occasionally of plagioclase grains. The minerals and their aggregates are markedly flattened in sections parallel to the lineation, while in sections normal to the lineation they still retain their more or less rounded or roughly equidimensional outlines, thus having the prolate shapes.

Some feldspar aggregates developed through a mechanical grinding of once bigger grains into smaller fragments, now slightly differing in their optic orientations (Pls 2 and 5). Between the fragments usually invaded quartz or fine quartzofeldspathic mosaic accompanied by mica shreds (Pl. 1). Such aggregates were wrapped by mylonitic foliation (Pls 1—4). There was a strong tendency toward grainsize reduction and replacement of formerly larger grains of felsic minerals with the fine quartzofeldspathic mosaic (Pls 1 and 3—4). All the mineral grains look by far more distorted in the "*bc*" sections than in the "*ac*" ones. Accordingly, the gneisses are assignable to a $L < S$ class of prolate tectonites, with prominent stretching lineation.

Many microcline grains, mostly those of the older generation, are commonly clouded (Pls 1 and 3), partly due to incipient sericitization, but quite often due to densely distorted grid of polysynthetic twinning. This causes a widely irregular, spotted extinction of light. The failure just manifests as an apparent cloudness of the grains seen between the crossed nicols. Such grains are usually fractured and comminuted, especially along their margins oblique to the penetrative foliation. Interfaces concordant with the foliation are tightly wrapped by perfectly parallel arranged tiny scales of white mica (mainly phengite). Most of those grains are lozenge, lensoid, or strongly ribboned in the "*bc*" sections due to obvious stretching in the foliation plane (Pl. 2, Fig. 1, and Pls 3—4). Some microcline grains remained, however, untouched by the process. This suggests rather heterogenous deformation.

Due to the stretching and flattening the cloudy microcline grains tend to acquire ribbon-like outlines which evidence a ductile deformation (Pls 3—4). Frequently such grains are apparently splitted and then the foliation-parallel splinters terminate far away from them. Comminuted and granulated portions of the parent K-feldspar grains are replaced by fine quartzofeldspathic mosaic with cloudy fragments of the very grains being still recognizable. Such a mosaic frequently alternates with microcline splinters or ribbons projecting out of the grains being deformed. The fine quartzofeldspathic mosaic may cross-cut the large porphyroclastic grains and enter extensional cracks in them (Pl. 2).

Quartz also yielded to the ductile stretching, which manifested by the formation of long quartzose ribbons (rods). The mineral appears often in monomineral layers or bands produced by dynamic metamorphic differentiation (Pl. 1, Fig. 2; Pl. 3, Fig. 2 and Pl. 4, Fig. 1). Such ribbons or bands are both made of quartz that underwent substantial recrystallization following the deformation. Nevertheless they still define foliation and their arrangement is controlled by more rigid feldspars.

Of the main three rock-forming minerals in the discussed gneisses plagioclase is the most rigid. Originally larger plagioclase grains of the pre-existing rock, usually poor in inclusions, have been fractured and the resultant fragments often displaced with respect to one another owing to the glide movements in the foliation planes (Pl. 5). This is easy to detect if the fragments still maintain optical continuity or their crystallographic features may continuously be traced from one grain to another. On the account of subsequent recrystallization such grains do not display angular edges in most of the inspected cases.

In general the evidence of cataclasis and mylonitization in the Bystrzyca gneisses is rather obscured. The deformation was partly coeval with regional metamorphism, which however was largely post-tectonic and outlasted the bulk of the mylonitization.

There are several lines of evidence to support that notion. The most spectacular one is that offered by rims of clear, nicely twinned microcline growing over the older, deformed and cloudy K-feldspar grains. Such overgrowths are particularly common at pressure shadowed sides of those grains. The same limpid grid microcline, with scarce or no inclusions, appears as variously sized grains within the quartzofeldspathic matrix, or it forms big blasts surrounding the pre-existing fabric and swallowing its elements. This new microcline, no matter in whatever form it occurs, comes undoubtedly from the extensively recrystallizing older K-feldspar which suffered from the mylonitic deformation experienced by the parent granitic rocks under overall conditions of the medium-grade regional metamorphism.

The both generations of microcline represent the two types of K-feldspar reported formerly (Żelaźniewicz 1976) from the gneisses south of Duszniki. One of these generations is pre- and the other is post-deformational variety of that mineral. The older, deformed microcline has probably been overlooked by former authors, or misidentified and incorrectly assigned to the group of post-deformational, late-blastic microcline. Accordingly, the older microcline suffered from the extensive and penetrative deformation that, however, did not affect the younger microcline (if not to take into account a distinctly later, brittle fracturing of some grains).

The same is generally true about plagioclase of the discussed gneisses. There is a widely accepted view that they contain at least two generations, the older of which displays grains irregular or oval often distinctly deformed, while the younger has grains hypautomorphic or even automorphic and devoid of any signs of deformation (*cf.* Juroszek 1972). Closer inspection of the strained plagioclase grains shows that they come from larger grains broken into smaller and usually displaced pieces (Pl. 5). Even then it is sometimes well noticable that they are in optical continuity, and even the same pattern of distorted polysynthetic twin lamellae may occasionally be traced from one such individual to another. Such an evidence points unanimously to the fact that the frequently observed groups of plagioclase grains displaying those features must have formerly constituted larger entieties, which then were cataclastically dismembered. As the fragments were commonly displaced and rotated due to shearing in the mylonitic foliation, their original positions are no longer recognizable. Moreover, these new small grains were subjected to subsequent recrystallization. That is why the new plagioclase appear either as tiny grains within quartzofeldspathic mosaic or forms bigger blasts enclosing elements of the earlier fabric.

Most of the older plagioclase grains are simply broken into smaller lumps and only some of them are elongated in the foliation plane. Generally, it seems that the more plagioclase in the rock occurs the less conspicuous are signs of ductile deformation experienced by this mineral and the rock itself. The two generations of plagioclase distinguished in the Bystrzyca gneisses clearly represent its pre- and post-mylonitical varieties.

Accordingly, both K-feldspar and plagioclase underwent the same developmental cycle. They belonged to once coarser grained, quartzofeldspathic rock which had yielded to mylonitic deformation, the latter being overlapped and followed by the regional metamorphic recrystallization. Nevertheless there is a significant difference in a response to the strain offered by grains of the two feldspars. K-feldspar was deformed largely in a ductile manner into the long, foliation-parallel ribbons projecting out of the parent grains. Many microcline grains were also merely simply cracked and then broken, contributing to the quartzofeldspathic mosaic. Plagioclase, however, appeared as much less flexible under the operating shear stress that, in general, made them crush only and produce a couple of fragments. The smaller fragments joined the mosaic whereas the bigger ones, more resistant to further comminution, were likely passively rotating and became more oval loosing their irregular and angular outlines. Obviously the concurrent and later recrystallization much assisted in making those plagioclase grains apparently rounded.

Quartz, in all cases, was significantly weaker than feldspars. Judging from the shapes of actual quartz domains in the Bystrzyca gneisses, the original large grains of this mineral must have been elongated and flattened into long rods and ribbons, with accompanying grainsize reduction. The resultant small grains are either equant and subpolygonal or more or less elongate with sutured boundaries. Those features are indicative of annealing or dynamic recrystallization respectively (cf White 1977). Strongly elongate quartz domains are seen well in the rock under plane polarized light due to relief contrast to other minerals (Pl. 4). Many of such domains, cannot be, however, produced merely through the ductile deformation of large parent grains; they are simply too sizable. Moreover, quartz inside them was often recrystallized into greater blasts with rather complex grain boundary shapes. Those domains, or in fact layers (bands), were undoubtedly produced by metamorphic differentiation. It is, nevertheless, hard to say now which way, mechanical or chemical, was more important for that process. Quartz of such monomineral bands underwent post-deformational recrystallization related to the main event of the regional metamorphism. The recrystallization resulted in coarsening of the grainsize, as the matter of fact not only of quartz but of mica and feldspars as well. Actually this process much obliterated the deformational, mylonitic microstructures in the discussed gneisses.

The response of both micas to the applied stress was rather complex. Most of mica grains were stretched out in the mylonitic foliation and comminuted into fine parallel shreds. Those grains that happened to lie with their longer sides parallel to the planes of the penetrative shearing movements were deformed mostly through a basal gliding. Biotite was concomitantly recrystallized into elongate aggregates of new biotite — new muscovite-chlorite-opaque, composed of fine and mainly ejuant crystals. Regional recrystallization produced again the bigger blasts of muscovite or biotite with less obvious directional arrangement.

QUARTZITES

Of numerous occurrences of quartzitic rocks intervening between mica schists of the Stronie formation and the Bystrzyca gneisses, the present author scrutinized the outcrops localized near Duszniki. There are two categories of the quartzitic rocks: (*1*) those of undoubtedly sedimentary origin, free of microcline, (*2*) those of uncertain provenance, with microcline.

The quartzites and quartzitic schists of the first category are composed a mineral assemblage Q + Msc ± Kya ± Tour ± Zr ± Ap + opaque (oxides and graphite).They preserve relics of sedimentary banding and retain elements of F_1 and F_2 fabrics, in particular S_1 schistosity and F_2 folds in that schistosity. The folds are intrafolial, hence bearing evidence of shear motion in the axial planar foliation S_2. Strong stretching lineation is seen ubiquitously.

Obviously quartz is the chief mineral of these rocks, muscovite (phengite) occurs subordinately, and the remainders, except occasionally-abundant kyanite, appear merely as accessories. The quartz grains in sections normal to the lineation have subpolygonal outlines whereas in sections parallel to it many grains are subpolygonal as well, but a lot of them appear as long rectangular plates discretely defined by the adjacent mica scales. The platy quartz, being indicative of strong dynamic engagement of the quartzitic rocks, was also subjected to annealing and postdeformational recrystallization. Then smaller but equant subgrains or new grains with lobate outlines developed.

Micas, predominantly phengitic muscovite, often rim the felsic minerals, but generally they form long and fine shreds marking the mylonitic foliation. Besides mica, also opaque appears as thin seams between the adjacent platy quartz grains. The opaque is represented mostly by graphite and less commonly by hematite. Both the minerals are associated with micaceous layers.

Quartzites of the type featured above are undoubtedly a metasedimentary rock. The second, much less common category of the quartzites and quartzitic schists differ in composition from the former having microcline and plagioclase but being devoid of graphite. Those rocks contain mineral assemblage of Q + Msc + Ksp + Plg + opaque (merely hematite and other oxides), with no visible accessories. As the Stronie schists in the northern Orlica Mts do never contain K-feldspar, the presence of microcline in the quartzites adhering to the Bystrzyca gneisses seems unusual rather and strange, which at least would suggest that they do not come from the same parent sediment that rendered the other quartzites. They did not record any small-scale tectonic structures either, except for L_2 stretching lineation and S_2 foliation. Hence the quartzites strongly resemble gneisses in their structural features and show some compositional affinities, their origin being, however, not too obvious. They might by just metasedimentary rock but they might represent product of extreme tectonization of gneisses as well. Microcline of those quartzites is highly shattered and strongly lozenge. Quartz grains are subpolygonal but a great many of them show platy rectangular habit in sections parallel to the stretching lineation.

In sections parallel to the foliation in both the types of quartzitic rocks the stretching lineation is manifested by elongate quartz grains and linear arrangement of mica scales and opaque streaks. One of characteristic features of all the quartzitic rocks near Duszniki is the presence of big, round or slightly lensoid grains of bluish quartz. Such large quartz grains (up to 5 mm) may: *(1)* be clear and virtually undeformed, *(2)* show undulose extinction, *(3)* have widely diversified subgrains, or *(4)* compose of mosaic of subpolygonal or lensoid grains (Pl. 6). Mica scales defining the S_2 foliation do not wrap the big grains but they disappear on entering the latter. Sometimes fine trails of undefined impurities or bubbles are recognizable to pass across the large blasts without being deviated from the foliation direction. In those blasts also appears delicate dust of minute shreds of white mica. It is unclear whether they represent the undigested relics inside the newly growing quartz grains or the tiny shreds come from ground down micas during the mylonitization.

It is known that the bluish colour of quartz is accounted for by the presence of tiny rutile needles in the discussed blasts of late quartz might develop at the expense of TiO_2 freed from the decomposing pre-existing biotite.

In the vicinity of Duszniki the Bystrzyca gneisses, the Stronie mica schists and separating them quartzitic rocks recorded rather locally the deformational event F_3 that produced asymmetric open folds accompanied by weak axial recrystallization. This recrystallization is seen best in the discussed quartzites (Pl. 6). Younger planar feature S_3 was superposed at an angle of 20°—40° upon the earlier fabric. Although nearly all mica flakes remained parallel to the S_2 planes, most of quartz, still defining S_2 bands, recrystallized dynamically into elongate new grains that follow now the S_3 schistosity. The two intersecting planar features give the rock characteristic lozenge texture.

EVIDENCE OF DYNAMIC METAMORPHISM

Many observations suggest that the gneisses and quartzites were actually subjected to stretching. Large, marginally or obliquely granulated porphyroclasts of microcline are accompanied by better or worse defined trails, resembling pressure shadows. They are composed of fine, often elongated and opaque-coated grains of quartz and K-feldspar. The grainsize in such trails is smaller than that outside them (Pl. 4, Fig. 2). The trails, frequently appearing as long bands, are composed of the broken off pieces of the microcline porphyroclasts, blended with the comminuted quartz and occasionally plagioclase, all tapering in ductile manner. They likely represent relics of the crushing and milling stage. Most of the grains escaped further recrystallization, probably on the account of their opaque coatings. Also such trails or bands themselves are often separated from the remainder of the mineral fabric by opaque seams marking the sites of more intense shear movements. The broken off microcline fragments, as it may be judged from their actual positions at the extreme terminations of the trails, were displaced over the distances of few (up to 3) millimetres.

The same figures have been obtained while examining the distance over which the kyanite grains in quartzites, fragmented due to stretching, were transported down the mylonitic foliation. Another evidence of the operation of stretching is the presence of tensional cracks in feldspar porphyroclasts, healed up with either fine quartzofeldspathic mosaic, quartz, or undetermined isotropic substance (Pl. 2 and Pl. 5, Fig. 1). Those mineral grains, in particular of K-feldspar, that had concomitantly been deformed through the ductile stretching were elongated into long, irregular ribbons terminating far away from their parent grains (Pls 3—4). Frequently the original grain can no longer be identified. As it may be assessed from the individual displacements of various elements of the mineral fabric, the rock masses might have travelled in total quite remarkable distances.

Mylonitic fabric has been obliterated by the post-deformational, regional metamorphic recrystallization. One of the conspicuous evidence is offered by the fact that quartz and feldspar grains of the matrix embracing porphyroclasts, outside the deformational trails mentioned above, are both larger and more equant than those inside them.

Quartz ribbons were produced by ductile deformation of much bigger parent grains. Monomineral quartz layers, ubiquitous in the discussed Bystrzyca gneisses, must have, however, been effected mostly by mass transfer in the rock. Such layers or bands are foliation-parallel and usually separated from the remainder of mineral fabric by thin mica strips. The migration of matter throughout the rock undergoing deformation and afterwards must have been obviously assisted by various metamorphic reactions, among them those involving breakdown of K-feldspar and freeing the potassium ions.

Kyanite in the quartzite is heavily fragmented, embayed by quartz, and altered to muscovite. The transformation of kyanite into white phengitic mica is likely accomplished by means of ionic exchange and trapping K-ions migrating throughout the rock, as follows:

$$2\ \mathrm{Kya} + \mathrm{K}^{+} + \mathrm{H_2O} + \mathrm{Q} \rightarrow \mathrm{Msc}.$$

The breakdown of kyanite is obviously related to the shear movement along planes of the anostomosing mylonitic foliation.

The Bystrzyca gneisses experienced also the growth of late or even post-kinematic albite as indicated by the mineral relationships. Such albite grains are always clear, unstrained, rather poorly twinned, with sparse inclusions. They are variously sized and sometimes happen to surround fragments of the pre-existing mineral farbic. There is no proof that the late albite was due to metasomatic feldspathization assisted by an afflux of Na-ions from external sources. More likely it was produced by the recrystallization of the primary plagioclase broken down during mylonitization. Accordingly, the process was similar to that experienced by the microcline, and regional metamorphic recrystallization following the deformation was of great importance here.

The mylonitic deformation, proceeding under conditions of the medium grade regional metamorphism, was accompanied by hydration evidenced by diaphtoritic alteration of biotite or garnet into chlorite or even opaque aggregate of oxides. This suggests that both biotite and garnet must have been stable in the undoubtedly coarser grained parent rock before the $F_2 + M_2$ phase. Regionally the M_1 metamorphism was of a low-grade type (Żelaźniewicz, 1976). Thus, keeping in mind the widespread evidence of the grainsize reduction, one may expect that the parent granitic rocks were subjected to both mylonitic deformation and regional metamorphism toward gneisses at the $F_2 + M_2$ phase of the tectonometamorphic evolution of the region under question.

The micaceous foliae consist mostly of phengitic muscovite. Those foliae are seldom represented by bundles of well developed flaky crystals but they are composed rather of minute shreds arranged perfectly in parallel to the foliation. Such fine shreds do not even possess interference colours characteristic of muscovite. They undoubtedly resulted from mylonitic crushing and grinding. The shreds bring another evidence that the parent rock must have had random, non-directional fabric. Otherwise the pre-existing micaceous foliae diasposed regularly would accomodate much of the shear stresses owing to the glide movements in (001) cleavage planes and the mica could hardly be fragmented into so tiny pieces as those actually observed. The fine scales of white mica, alike other minerals in the discussed gneisses, were post-tectonically recrystallized into much bigger and well defined flaky crystals, demonstrating proper interference colour and perfect basal cleavage, but naturally being much less directionally oriented.

That the pre-existing micas of the original granitic rock were actually turned down into the minute shreds is evidenced as well by the presence of fine, randomly dispersed, white mica "dust" set in the large post-deformational blasts of quartz or feldspar. The dust does not show, however, any sign that would allow to develop the interpretation assuming feldspathization and extensive growth or feldspars at the expence of mica and quartz, with K-ions supplied from the undefined external sources.

The mylonitic deformation was accomplished largely by the shear movements parallel to the actual foliation in the gneisses and conforming with the S_2 schistosity of the Stronie formation rocks. This is evidenced for instance by big microcline porphyroclasts cut by obvious shear planes (Pl. 2, Fig. 1) or retaining traces of ductile mylonitic flowage going across them (Pl. 1). Their attitudes show that the shearing must have been evoked by a stress couple operating parallel to surfaces of the mylonitic foliation. The same is shown by discrete shear zones cutting the foliation obliquely.

A distinct ductility contrast between the main gneiss-forming minerals resulted in the actually observed fabric of the Bystrzyca gneisses. Quartz, as being the most sensitive to the ductile strain, readily formed elongate grains, ribbons, or even monomineral bands distinctly determining the mylonitic foliation. Plagioclase on the other hand responded to the strains in essentially brittle manner. Its grains were fractured and fragmented into several smaller pieces, interwoven with the foliation and displaced along it. Those grains that were more plastic became elongated.

Migration of silica throughout the rock in the course of metamorphic differentiation led to the formation of mechanically promoted accumulations of rigid fragments or new, equant blasts of plagioclase.

K-feldspar behaved in the manner apparently less ductile than that of quartz but far more ductile than plagioclase did. The strained microcline grains acquired lensoid, lozenge, and eventually ribbon-like shapes defining foliation of the rock. Nevertheless many grains remained rigid and became merely fractured. The broken off fragments of microcline porphyroclasts might travel along the mylonitic foliation over quite remarkable distances of the order of even 2 do 3 mm.

INTERPRETATION OF OBSERVATIONS

Summarizing various observations, it becomes obvious that the rocks under investigation underwent in their history the discrete mylonitic deformation. The deformation, related to the main tectonic episode F_2 in the region, was overlapped and followed by the regional metamorphic recrystallization M_2 which much obliterated the earlier mylonitic fabric and gave the rocks a blastomylonitic nature.

The original rock that yielded to generally ductile mylonitization must have been medium to coarse grained with phenocrysts reaching at least 3 — 5 mm in their size, random texture and granitic (granitoidic) composition. Mineral grains of the parent rock were crushed and ground down to form the fine-grained matrix composed of quartz, feldspar, and mica shreds. The large phenocrysts becoming frequently porphyroclasts were granulated at their margins, fractured, and fragmented into pieces between which the quartzofeldspathic matrix or mobile quartz invaded. Other phenocrysts as well as the grains of the former rock groundmass got elongated and rounded, resulting eventually in the rodding texture. Also rodded were aggregates of the quartzofeldspathic mosaic produced during the mylonitization. The rocks acquired features characteristic of a $S<L$ to L-tectonite. It was

accomplished through stretching and likely concurrent rolling out in the perpendicular direction of both mosaic aggregates and felsic porphyroclasts, all proceeding under overall control of inhomogenous shearing that preceded the bulk shortening in the region.

The mylonitic deformation affecting the granitic rocks was overlapped and largely followed by mineral recrystallization of the main regional metamorphic event. This frequently led again to the increase of once diminished grainsize. The new grains tended to assume the less energetic and more equant shapes. Most of the minerals simply recrystallized to form new, clear, and unstrained grains. That is why K-feldspar or plagioclase are easily recognizable to occur in two generations.

The older generations of each feldspar experienced, though to varying extent, the mylonitic deformation and they are represented by more or less strained survivers, many of a porphyroclastic nature. The younger generations are mostly post-deformational and grown at the expense of the former due to recrystallization of both the ground down or ductile deformed grains. The latter generations tend naturally to develop bigger blasts that embrace and overgrow the pre-existing elements of the mineral fabric. Erroneous interpretation of such an ambiguous evidence is that assuming metamorphic growth of feldspars at the expense of mica and quartz, both reacting in an open system supplied externally with sodium and potassium ions. A strong tendency toward formation of the new, large blasts is displayed in particular by microcline, which had, nonetheless, nothing in common with any widespread metasomatic feldspathization. Quartz displayed the same tendency. In quartzites and quartzitic schists developed large, foliation-controlled augen of late, blue quartz.

The Bystrzyca gneisses south of Duszniki do not show any obvious signs of synantetic reactions. Symplektitic intergrowths of perthitic or myrmekitic types are very seldom. Such symplektites are rather scarce in gneisses of the western Kłodzko-Orlica dome, except for the augen gneisses (cf. Juroszek 1972). Despite adopting Smulikowski's feldspathization hypothesis to account for the origin of the Bystrzyca gneisses, Juroszek (1972) reported, though did not interpret, many observations speaking in favour of the pre-metamorphic mylonitization of the parent rocks (considerad by him as sedimentary), or of discrete control of mylonitization zones over blastesis of late microcline, especially in the augen gneisses.

Progressive metamorphic recrystallization resulted also in differentiation of quartz into monomineral bands and in production of larger phengite flakes at the expense of fine shreds. Although the process much obscured the pre-exsisting mylonitic fabric, it did not erase all the traces of the mylonitic foliation that in the gneisses was parallel to the regional S_2 axial planar schistosity in the surrounding Stronie formation rocks.

Apparently, the microstructures observed in the Bystrzyca gneisses by Juroszek (1972) were misinterpreted by him and unreasonably taken for evidence of metasomatic granitization of the pre-existing mica schists. Also the previous authors overlooked the ubiquitous sings of shearing that manifested discretly as both intense shear zones and pervasive shear affecting inhomogenously all rocks.

The gneisses south of Duszniki (Text-fig. 1) are identical with those cropping out further south in the Bystrzyca Mts, *e.g.* between the Spalona Pass and village of Poniatów, put by Juroszek (1972) into his laminated-augen textural type. In the present author's opinion, there can be no doubt that all the Bystrzyca gneisses represent the same dynamometamorphosed and once igneous granitic body. The actual coarse-grained augen gneisses come likely from central parts of the intrusion, whereas the other, finer grained varieties enveloping the former, represent presumably more marginal zones of that intrusion.

DISCUSSION ON TECTONIC IMPLICATIONS

The stretching lineation in gneises and "border" quartzites near Duszniki is parallel regionally to F_2 folds and L_2 mineral lineation recorded by rocks of the Stronie formation. The linear features in the latter rocks do not show any conspicuous sign of extension. In fact the spatial accordance of the prominent stretching lineation with the main fold axes appears as a striking structural feature of the western part of the Kłodzko-Orlica dome. Thus the question arises: what is the reason for such a parallelism? Does the stretching represent the direction of an overall tectonic transport or lateral elongation of rock masses normally to that direction?

The metamorphic rocks of the northwestern part of the dome were brought during the F_2 deformational phase, considered as the main tectonic episode in the region, into a series of large-scale, eastward inclined, tight to isoclinal folds (Żelaźniewicz 1977). Such folds have never been recognized in the Bystrzyca gneisses, though the small-scale F_2 folds were occasionally reported. Hence accepting an igneous provenance of the gneisses, one may assume that the parent granitic masses must have been emplaced upwards, piercing and arching their envelope. Most likely they intruded after the F_1 folding episode and invaded the country rocks along surfaces of their S_1 foliation. This assumption agrees with Don's (1964, 1977) conclusion as to the structural position of the Śnieżnik gneisses. The masses kept moving upward, pushed their wall rocks aside, and climaxed syntectonically with the F_2 episode.

Geodynamic reason for F_2 folding still remains unclear, but undoubtedly it was due to an overall E-W directed compression. Toward and end of the F_2 episode a large-scale napping had started, likely in the eastern direction (*cf.* Teisseyre 1973, Don 1977, Żelaźniewicz 1977). The napping and tectonometamorphic event with which it was associated must have taken place later than the Ludlovian but earlier than the late Devonian (*cf.* Don 1977, Gunia & Wojciechowska 1979, Wojciechowska 1979).

Such a tectonic activity reflected the large-scale movement pattern characteristic of the Bohemian Massif at the early Variscan times, when the eastern part of the massif and its basement were transected by a number of intense shear zones dipping generally to the W and NW. The shear zones kept producing a sort of large-scale tectonic slices, younging eastwards in this part of Europe, and eventually led to perhaps the most spectacular effect of overriding of the Moldanubian easterly or southeasterly upon the Moravo-Silesicum at the post-Visean time (*cf.* Unrug & Dembowski 1971). This is particularly well illustrated by the course of sedimentation in the Moravo-Silesian basin. The deposition started in its western, nearest to the Moldanubian portion, in the early Devonian with a deep-marine-volcanic series. The series was followed then by a flysch succession getting both younger and shallower eastwards, where coal-bearing parallic deposits passed into limnic deposits of late Carboniferous (Westphalian) age (Unrug & Dembowski 1971). Those facts suggest the easterly shift of Variscan diastrophism in the questioned part of the orogenic belt. It must be stressed that the oldest western portion of the Moravo-Silesian basin was epimetamorphosed. Accordingly, it seems that the easterly migrating long-lived imbrication of the Moldanubian and Moravo-Silesian zones strongly controlled both sedimentation and tectonometamorphic. Variscan events in the regions localized east of the areas subjected actually to the intense tectonic slicing.

In western part of the Kłodzko-Orlica dome the prolonged shearing took place toward the end of regional F_2 buckling and produced the imbricated thrust zones (*e.g.* the Orlica thrust; Żelaźniewicz 1977). It gave also rise to more or less pronounced penetrative modification of mineral fabric of the rocks involved, evolution of small-scale tectonic structures toward flow folds, and production of the similar folds (*cf.* Dumicz 1979).

The upward emplacing granitic mases, that later became the Bystrzyca gneisses, had yielded to F_2 regional compression and then to shearing which produced the granitegneisses with foliation parallel to the S_2 axial planar schistosity recorded by the country rocks. The granitegneiss series themselves were also cut by widely dimensionally varying zones of more intense shear movements, directed generally eastwards. At that time the mineral farbic and tectonic structures of the enveloping rocks were modified by the shearing, whereas the still granitic or already granitegneissic rocks with poorly developed planar feature suffered from lateral stretching of the mineral grains or their fragments and concurrent rolling of those grains. Obviously both the stretching and rolling resulted in grinding the mineral grains and grainsize reduction. The granites and granitegneisses lost their primary igneous textures and in zones of more intense shear became even the finegrained gneissose rock with well developed mylonitic banding. The mylonitization to which had yielded the granitic rocks due to the overall shearing was then followed by the M_2 episode of the regional metamorphism. Hence the mylonitic textures were much obliterated by the subsequent recrystallization and production of new feldspar, quartz, and mica growing at the expense of the pre-existing grains of the same minerals.

There is no doubt that the main folds (F_2), not only in the Orlica Mts but in the entire Kłodzko-Orlica dome, run generally N-S and plunge in either direction. The stretching direction is meridional as well, thus agrees in the region with that of the main folding, no matter what a distance to any shear zone actually is. Such a structural pattern is then different from those reported for instance from Appalachians (Bryant & Reed 1969), Cornwall (Sanderson 1972), or Norway (Williams 1977), where also pronounced extension lineation was observed. In each of those instances the striking parallelism of fold axes and stretching lineation, that is tectonic transport direction, was interpreted in terms of the rotation of the fold axes within shear planes, being the axial planes to those folds, from the Y-axis toward the X-axis of the finite strain ellipsoid; the closer to a shear zone centre or nappe base the greater rotation had been commonly recorded.

It seems that this is not the case, however, of the Orlica Mts and Kłodzko-Orlica dome, where the main fold axes have been commonly concordant throughout with the stretching direction. Regionally the F_2 fold axes likely conformed there with the Y-axis of the finite strain, that is the "b" kinematic axis. The majority of them had been accomplished by flexure mechanism though subsequently modified by flattening and axial shearing (Żelaźniewicz 1976). Accordingly, the concordance should be considered rather as being due to remarkable side relief of the folded rock masses that yielded laterally to dissipate tectonic overload received from the strata piled up in the course of napping and tectonic slicing in the shear zones. Otherwise one would explain the actual structural pattern assuming a generally southward tectonic transport, which cannot be reconciled rather with the regional geology data recorded in the discussed part of the Bohemian massif.

As the quartzites and quartzitic schists demonstrate strong linear fabric, controlled greatly by shearing, they must have found themselves in the shear zones of ductile type. High ductility of quartz under the given conditions, feasible hydrolitic weakening of that mineral could turn the quartzitic horizons, or at least some of them, into a sort of tectonic lubricant appearing between two major units of contrasting properties, namely the Stronie formation and the Bystrzyca granitegneisses. It seems that the strain rate during the operation of shearing was highest in certain quartzitic horizons which eventually were brought by differential shear movements into their actual intervening position. That is why most of the quartzites occur at the boundary between the granitegneiss and mica schist series, in close association with the discrete thrust zones (*cf.* Text-fig. 1).

Explanation, suggesting that the peculiar position of the quartzites might have resulted from their original position within a primary sedimentary pile, is rather unlikely in view of strong dynamometamorphic engagement of these rocks and igneous provenance of the granitegneisses. Accordingly, Pauk (1953, 1977) was generally right in pointing to a strong control exerted by the tectonic factor over the quartzitic rocks. His suggestion that the quartzites might represent diaphtorites derived from the granitegneisses is also valid, though it can be applied only to some quartzitic layers (microcline-in ones) as most of them, despite extensive tectonization, are undoubtedly of sedimentary origin.

It seems that the easterly verging F_3 folds, recorded locally near Duszniki by mica schists and granitegneisses, as well as S_3 planes, defined in the latter rock and "border" quartzite by discrete directional recrystallization of quartz and weak mica reorientation, were effected by the easterly directed napping and overthrusting that commenced toward an end of the main deformational episode F_2.

The "border" quartzite, being a site of particularly intense shearing, may be considerad as occurring at a nappe base or overthrust zone. Prolonged movement in such zones erected, due to inhomogenous deformation, subsidiary folds with axial recrystallization of quartz in quartz-rich rocks, that is quartzites and granitegneisses. The new planar feature was taken over then by the continuing shear movements as shown by kyanite grains grown in quartzite in S_2 foliation during the M_2 episode but stretched later along the S_3 planes. The same effect of superimposition of new zones of shearing upon the S_2 mylonitic foliation is frequently displayed by mienral fabric and microstructures of the investigated rocks.

CONCLUSIONS

The Bystrzyca gneisses were developed by means of extensive dynamometamorphic transformation of once igneous granitoidic rocks. This took place toward the end of the main deformational episode, belonging to the Variscan epoch, when the initial buckling ceased in favour of later pervasive shearing in the axial planar foliation. Mostly ductile deformation gave rise to the production of characteristic fluxion structure and porphyroclastic augen in the questioned rocks. The actual mylonitic foliation of the granitegneisses was developed due to marked ductility contrasts between quartz, K-feldspar, and plagioclase. Grains of the first two minerals were much more ductile than those of the latter mineral. Most of the individual grains of the quartzofeldspathic matrix got elongated as well. The ductile penetrative mylonitization was pre- and synmetamorphic relative to the extensive mineral recrystallization of the main, medium-grade metamorphic episode in the region. Thus the granitegneisses represent in fact a blastomylonitic series.

Evidence of widespread blastomylonitization has been reported many times from the northern part of the Kłodzko-Orlica dome (cf. Smulikowski 1979, Don 1982). The extensive blastomylonite development was most likely connected in the region with the pervasive shearing that culminated in numerous zones of more intense shear movements manifesting as overall tectonic slicing and nappes or overthrusts. Such a tectonic style seems to have been characteristic of the eastern Bohemian massif and the adjacent Moravo-Silesian zone since at least early Devonian times.

Polish Academy of Sciences,
Institute of Geological Sciences,
Laboratory of Sudetic Geology,
ul. Podwale 75,
50-499 Wrocław, Poland

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A. ŻELAŹNIEWICZ

SYNMETAMORFICZNA MYLONITYZACJA W ORTOGNEJSACH GÓR BYSTRZYCKICH

(Streszczenie)

Średnio- i gruboziarniste granitognejsy Gór Bystrzyckich i Orlickich (*patrz* fig. 1 oraz pl. 1—6) posiadają bardzo dobrze rozwiniętą lineację z wyciągnięcia, ekstensyjną. Wyciągnięcie więźby mineralnej łączyło się z pomniejszeniem rozmiarów ziarna i ciągliwą (ang. *ductile*) mylonityzacją pierwotnych skał granitowych, ulegających przeobrażeniom w granitognejsy. Blastomylonityczna foliacja granitognejsów powstała wskutek różnic w ciągliwości okazywanej przez kwarc, skaleń potasowy i plagioklaz w trakcie deformacji. Deformacja ta wyprzedzała, a potem czasowo zazębiała się z głównym epizodem średniego stopnia metamorfizmu w regionie. Prowadziło to do silnej rekrystalizacji rozdrobnionych uprzednio ziarn mineralnych, szczególnie kwarcu i skalenia potasowego. Rekrystalizacja przebudowywała starszą więźbę i prowadziła do wtórnego wzrostu wielkości ziarna. Blastomylonityzacja i zgnejsowanie granitowych mas intrudujących zgodnie, po pierwszej fazie deformacji regionalnych, w łyszczykowe łupki strońskie związane były z powszechnym ścinaniem wzdłuż powierzchni foliacji oraz licznymi nasunięciami w kierunku wschodnim, dokonującymi się przy końcu głównego fałdowania skał regionu w południkowo biegnące fałdy. Ścinanie i mylonityczne płynięcie skał odbywało się równolegle do powierzchni osiowych owych fałdów. Kierunek lineacji z wyciągnięcia w granitognejsach pokrywa się z orientacją głównych fałdów oraz lineacji w kompleksie łyszczykowym — jest on zatem najprawdopodobniej zgodny z osią Y elipsoidy deformacji.