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The Złoty Stok–Trzebieszowice regional shear zone: the boundary of terranes in the Góry Złote Mts. (Sudetes)

The paper presents the results of structural and kinematic analysis of northern part of the Góry Złote Mts. (Sudetes, SW Poland), where the Złoty Stok–Skrzynka tectonic zone is known to occur; at present, the zone has been redefined as the Złoty Stok–Trzebieszowice shear zone. In general, the zone has NE–SW attitude and runs from the Trzebieszowice environs to the Złoty Stok region in a form of a belt up to 4 km wide. Domination of simple (rotational) shear mechanisms under ductile (plastic-crystalline) conditions was proven to take place here; it should be noticed that stages of dynamic recovery and dynamic recrystallization were variable. Ductile sinistral displacements within this zone caused displacement of overlying rock packages towards SSW; the displacement took place under the conditions of sinistral transpression which is similar to the situation of sinistral shear zone at Niemcza, located further northwards. Development of the zone under discussion is considered to be closely connected with an oblique collision of two terranes: the Moldanubicum one including the Śnieżnik metamorphic complex and the Central Sudetian one including the zone under consideration which makes up its most peripheral southwestern part. It was the Variscan orogeny (Upper Devonian-Lower Carboniferous) during which the collision happened and caused a sinistral transpression in this part of the Sudetes.

INTRODUCTION

A tectonic zone in the northern part of the Góry Złote Mts. has been known for scores of years; the zone is most often called the Złoty Stok–Skrzynka tectonic zone (L. Finckh *et al.*, 1942; J. Don, 1964; S. Cwojdziński, 1975, 1976*a*, 1977, 1979, 1984; K. Smulikowski, 1979; M. Dumicz, 1979, 1989; J. Żaba, Z. Będkowski, 1995; among others); sometimes it is called the Skrzynka tectonic zone (I. Wojciechowska, 1993; I. Wojciechowska, P. Gunia, 1993) or Złoty Stok–Skrzynka fault zone (A. Muszer, 1989). Lately it was defined as the Złoty Stok–Trzebieszowice shear zone (Z. Cymerman, 1992*a*, 1995; Z. Cymerman, M. P. Piasecki, 1994). The latter was selected to make the tittle of this paper as processes of regional ductile shear in the area extending from Złoty Stok to environs of Trzebieszowice

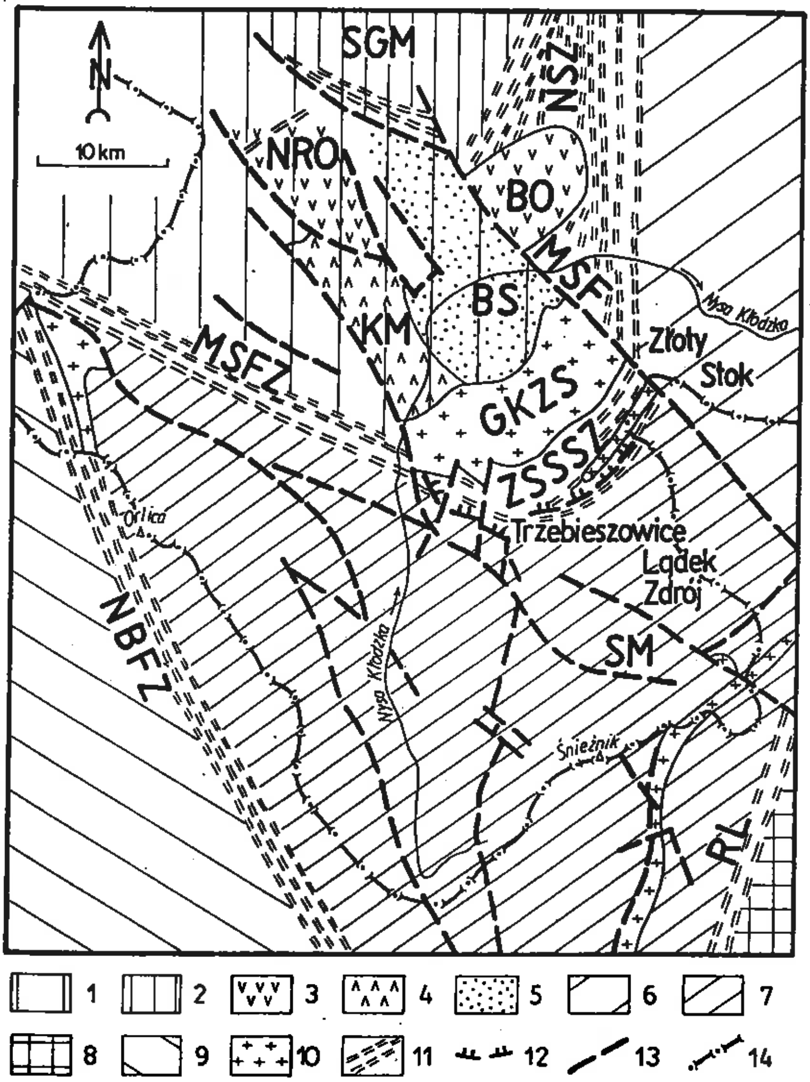


Fig. 1. Location sketch of the Złoty Stok–Trzebieszowice shear zone against the background of main tectonic units of the eastern part of the Sudetes (after Z. Cymerman, M. P. Piasecki, 1994; modified)

1 — Central Sudetian Terrane; 2 — Góry Sowie Mts. Unit; 3 — fragments of tectonically dismembered ophiolite sequence; 4 — Kłodzko Unit; 5 — sedimentary rocks of the Bardo structure; 6 — Moldanubian Terrane; 7 — Góry Orlickie Mts.–Śnieżnik Dome; 8 — Keprnik Dome; 9 — Barrandian Terrane; 10 — Late Variscan granitoids; 11 — selected boundary zone of ductile shearing; 12 — zones of ductile thrusting; 13 — main faults; 14 — state boundary; BO — Braszowice ophiolite; BS — Bardo structure; GKZS — Kłodzko–Złoty Stok granitoids; KM — Kłodzko metamorphic complex; MSF — Marginal Sudetic Fault; MSFZ — Mid-Sudetic Fault Zone; NBFZ — North-Bohemian fault zone; NRO — Nowa Ruda ophiolite; NSZ — Niemcza shear zone; RL — Ramzova line; SGM — Góry Sowie Mts. metamorphic complex; SM — Śnieżnik metamorphic complex; ZSSSZ — Złoty Stok–Trzebieszowice shear zone

have been recognized not so long ago. This regional tectonic zone has, in general, NE–SW trend and runs from the Złoty Stok area to the region of Trzebieszowice as a belt up to 4 km wide (Fig. 1).

The zone was given a special importance in evolution of the Sudetes. E. Bederke (1929) was of the opinion that its origin should be connected with development of the Ramzowa Overthrust, Variscan in age, which separates so called Moldanubicum from Moravicum. Other workers included the zone into one tectonic line with the Niemcza Zone (H. Closs, 1922; L. Finckh *et al.*, 1942). Many investigators considered this tectonic unit as the derivative element with respect to a folded structure of the northern branch of the Śnieżnik metamorphic complex. Analysing the so called Złoty Stok branch of the Śnieżnik metamorphic complex, J. Don (1964) distinguished gneissic Skrzynka aniticlinorium and schistaceous synclinorium of Orłowiec. Despite similarity in morphology and sequence of deformation, M. Dumicz (1989) distinguished two independent development sub-stages of the tectogene, the first one attributed to the Śnieżnik metamorphic complex and the second one to the Złoty Stok–Trzebieszowice tectonic zone.

In the last years, the Złoty Stok–Trzebieszowice shear zone was interpreted as the boundary of the Moldanubian and Central Sudetian Terranes (Z. Cymerman, 1991*b*; Z. Cymerman, M. P. Piasecki, 1994). In such models the Śnieżnik metamorphic complex was included in the Moldanubian Terrane while the Złoty Stok–Trzebieszowice shear zone in marginal part of the Central Sudetian Terrane which is characterized by (among others) abundant tectonically dismembered fragments of ophiolitic sequence (Fig. 1). Recently, M. S. Oczlon (1993) included the entire Góry Orlickie Mts.–Śnieżnik Dome in the so called Ligerian Terrane situated northwards of the assumed Ligerian Ocean.

Despite recognition (since couple of years) of significant role of intensive ductile deformations of shear type in tectonic evolution of the Góry Orlickie Mts.–Śnieżnik Dome (Z. Cymerman, 1990, 1991*a*, *c*, 1992*a*), a lot of questions still remains open on the tectonometamorphic development of this dome and adjacent units. This deals, among other questions, with the role and importance of faults rocks occurring in the Złoty Stok–Trzebieszowice shear zone. Considering shear sense indicators, among others (C. Simpson, S. Schmid, 1983; J. P. Platt, 1984; C. W. Passchier, C. Simpson, 1986; S. Hanmer, 1986; Z. Cymerman, 1989*b*; S. Hanmer, C. Passchier, 1991) and direction of tectonic transport (A. Escher, J. Watterson, 1974; H. G. Ave Lallemant, 1983; J. P. Burg *et al.*, 1987; Z. Cymerman, 1989*a*, 1992*b*), the author has made a structural and kinematic analysis of shear zones appearing in the northern part of the Góry Złote Mts. The analysis throws a new light

Szkic lokalizacyjny strefy ścinania Złotego Stoku–Trzebieszowic na tle głównych jednostek tektonicznych wschodniej części Sudetów (według Z. Cymermana, M. P. Piaseckiego, 1994; zmienione)

1 — terran środkowosudecki; 2 — jednostka sowiogórska; 3 — fragmenty rozczłonkowanej tektonicznie sekwencji ofiolitowej; 4 — jednostka kłodzka; 5 — skały osadowe struktury bardzkiej; 6 — terran moldanubski; 7 — kopuła orlicko-śnieżnicka; 8 — kopuła Keprnika; 9 — terran Barrandianu; 10 — granitoidy późnowaryscyjskie; 11 — wybrane, graniczne strefy ścinań podatnych; 12 — strefy podatnych nasunięć; 13 — główne uskoki; 14 — granica państwa; BO — ofiolit Braszowic; BS — struktura bardzka; GKZS — granitoidy kłodzko-złotostockie; KM — metamorfik kłodzki; MSF — sudecki uskok brzeżny; MSFZ — środkowosudecka strefa uskokowa; NBFZ — północnoczeska strefa uskokowa; NRO — ofiolit Nowej Rudy; NSZ — strefa ścinania Niemczy; RL — linia ramzowska; SGM — metamorfik Gór Sowich; SM — metamorfik Śnieżnika; ZSSSZ — strefa ścinania Złotego Stoku–Trzebieszowic

on a question of Variscan tectonic evolution in this part of the Sudetes. In addition, the analysis creats new possibilities (wider than before) for reconstruction of geometry of regional tectonic structures. Also, based on the modern structural-kinematic study the new circumstances appear for exploration for mineralization in the Góry Złote Mts., including exploration for gold among other minerals (M. Piasecki, Z. Cymerman, 1994; S. Speczik, 1994; A. Muszer, 1995). Therefore, the present paper is essentially aimed at presenting new structural and kinematic data dealing with the Złoty Stok–Trzebieszowice shear zone, and based on these tectonic data — presenting an evolution model of this part of the Sudetes during the Variscan orogeny.

RESEARCH HISTORY

L. Finckh *et al.* (1942) were the first to map the Góry Złote Mts. zone before the World War II; after the war the zone was mapped by J. Don (1964), I. Wojciechowska (1975), but above all by S. Cwojdziński (1976*b*, 1979) who is the author of the first detailed geological map on the scale 1:25 000, sheets Złoty Stok (1976*b*) and Trzebieszowice (1979).

Petrographic studies of the area were carried out by (among others): J. Burchart (1960), M. Kozłowska-Koch (1973), K. Smulikowski (1979), I. Wojciechowska, P. Gunia (1993); mineralogic studies were conducted by S. Speczik (1994) and A. Muszer (1995). It was J. Burchart's suggestion (1960) that intensive mylonitization of strongly heterogeneous complex of metamorphic rocks took place during the first evolution stage; then, a stage of plagioclase type recrystallization occurred, after which microcrystalline recrystallization followed. M. Kozłowska-Koch (1973) and K. Smulikowski (1979) were the authors who presented a scheme of composite metamorphic evolution of rocks in the zone under consideration; according to their opinion, the evolution was thought to be of three stages.

A number of studies were carried out in the Góry Złote Mts. area; they focussed on the tectonics and structure (J. Don, 1964; J. Don, R. Gotowała, 1980; I. Wojciechowska, 1975, 1986; S. Cwojdziński, 1975, 1977, 1982; M. Dumicz, 1989; Z. Cymerman, 1991*a*, 1992*a*, 1995). That was J. Don (1964) who distinguished a gneissic antyclinorium of Skrzynka and a schistaceous synclinorium of Orłowiec with Bzowiec fold within the area under disussion. S. Cwojdziński (1977) was next to separate the Haniak structure, a folded structure of the Góra Mikowa Mt.–Trzeboń, and a folded Kikoł zone; all units mentioned here occur in the northern sector of the zone. In his explanations to the map sheet of Trzebieszowice, S. Cwojdziński distinguished macroscopic tectonic elements appearing in the southern sector of the zone. These include tectonic units of Kaczyniec, Łysy Garb, Bzowiec, Biały Kamień, and Jawornik–Orłowiec.

Many researchers were involved in mesostructural analysis of the northern part of the Góry Złote Mts. I. Wojciechowska (1975, among others) was the first to initiate a classical structural study; she separated four sequentional phases of tectonic deformations (D_1–D_4). Mylonitization was thought to develop in two stages: a weaker one after the phase D_2 and a stronger one after the phase D_3. Also S. Cwojdziński (1976*a*, 1977, 1982) made some contribution to deformations overlapping by several stages; he suggested that common opinion on strong post-folding mylonitization be revised (J. Don, 1964; M. Kozłowska-Koch, 1973; I. Wojciechowska, 1975). Studying the Bzowiec fold, J. Don and R. Gotowała

(1980) also recognized four stages of deformations (D_1–D_4). M. Dumicz (1989) represented the idea that seven stages of deformation (D_1–D_7) should be distinguished within the zone under consideration; however, structures of tectonic stages D_1 and D_2 were thought to be destroyed by intensive cataclasis, mylonitization, and blastasis during stage D_3. It was also thought that penetrative metamorphic lamination and mylonitic banding originated in that time. Also A. Muszer (1989) was of the opinion that four independent deformation stages (D_1–D_4) could be separated in the southern sector of the mentioned zone. Recently, J. Żaba and Z. Będkowski (1995) distinguished seven stages of deformation (D_1–D_7) within polymetamorphic units at Złoty Stok quarry.

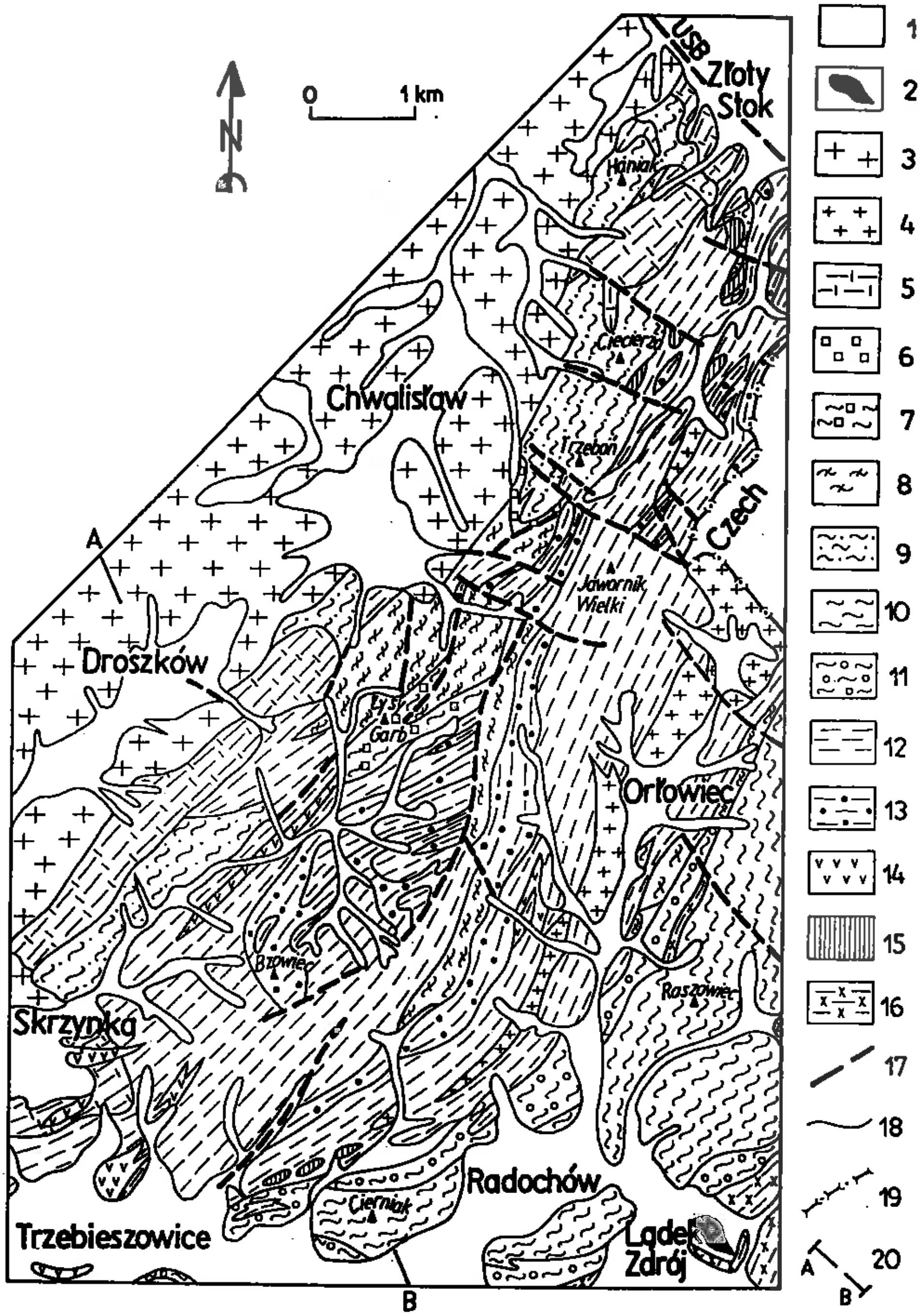
The last years make up the period during which first studies containing analysis of kinematics of deformed metamorphic rocks are being published (Z. Cymerman, 1991*a*, *b*, 1992*a*, 1995; J. Żaba, Z. Będkowski, 1995). The importance of regional sinistral dislocations of strike-slip character in the eastern sector of the Sudetes and in the Fore-Sudetic Block has lately been emphasized by P. Aleksandrowski (1995) and S. Mazur and J. Puziewicz (1995).

GEOLOGICAL SETTING

The Złoty Stok–Trzebieszowice shear zone can be divided into two parts (the western and the eastern ones). They differ from each other with respect to slightly different lithology of rock complexes, but above all — orientation of tectonic structures.

The western part, with its surface area equal to about 10 km^2, is situated westwards of Trzebieszowice. A valley of the Biała Lądecka river separates it from the Śnieżnik metamorphic complex (*sensu stricto*) on the south; the Kłodzko–Złoty Stok granitoids make up the northern boundary. In general, the NW–SE trend of lithologic boundaries and steep dips to NE are characteristic features of this western part. The trend of lithologic boundaries is consistent with orientation of regional foliation of penetrative type. In principle, the western part of the zone is built up of variety of amphibolites and gabbro-amphibolites (I. Wojciechowska, P. Gunia, 1993), also plagioclase-microcline Haniak type gneisses, blastomylonitic schists of hornfels type and biotite gneisses as well (Fig. 2).

The eastern part of the Złoty Stok–Trzebieszowice shear zone is much bigger in area (over 40 km^2). Its more diversified rock assemblage is characterized by the occurrence of numerous mylonitic and cataclastic structures (L. Finckh *et al.*, 1942; M. Kozłowska-Koch, 1973; S. Cwojdziński, 1975, 1977; I. Wojciechowska, 1975, 1993). This eastern part, extending from Trzebieszowice to Złoty Stok, is mainly composed of blastomylonitic schists and biotite gneisses (also known as gneissic blastomylonites), and blastomylonitic schists of biotite and biotite-quartzic types (Fig. 2). Of secondary importance in this assemblage are leptic gneisses (sometimes defined as the quartzic-feldspar blastomylonites), leptinites, quartzic-microcline-plagioclase schists, and blastomylonitic microcline paragneisses. Frequently, they are accompanied by mylonitic gneisses and so called Haniak type gneisses. The latter are composed of gneissic blastomylonites, leucocratic blastomylonitic gneisses, and migmatitized biotite-cordierite gneisses (the "Haniak gneisses" *sensu stricto*). Tectonic breccias (S. Cwojdziński, 1977) in the Złoty Stok–Trzebieszowice shear zone have sometimes been described as kakirites (M. Kozłowska-Koch, 1973). The eastern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part of the zone under consideration is characterized by relatively stable course of lithologic boundaries of NNE–SSW attitude and steep dip, mostly towards WNW, sometimes towards ESE (Figs. 3, 4).

The so called Radochów Anticlinorium (J. Don, 1964) within adjacent extended metamorphic Śnieżnik complex *sensu stricto*, at the contact with the Złoty Stok–Trzebieszowice shear zone, is the area of the occurrence of augen gneisses (also called the Śnieżnik gneisses). The fact is they are typical blastomylonitic gneisses that originated in the ductile shear zones (Z. Cymerman, 1991*c*, 1992*a*). Degree of intensity of simple (rotational) shear processes occurred to be a factor which — to some extent — governed a large structural-textural variability. The blastomylonitic gneisses surround so called Gierałtów gneisses among which a number of variations can be distinguished with respect to their structure and texture (including those laminated, banded, migmatite, and others). In general, only locally the Gierałtów gneisses are of mylonitic type (e.g. M. Dumicz, 1989).

The Jawornik granitoids are the rocks that occur in the Złoty Stok–Trzebieszowice shear zone close to its contact with the Śnieżnik metamorphic complex. They form elongated bodies of NNE–SSW trend and maximum thickness of around 1 km (Fig. 2). Dominant in these granitoids are monzonitic granites with weak fabric, granodiorites, and tonalites (J. Burchart, 1960; S. Cwojdziński, 1977, 1979). Parts of these granitoids were subjected to strong mylonitization; this fact indicates that mylonitization processes continued also after generation of the Jawornik granitoids (S. Cwojdziński, 1979).

DUCTILE SHEAR ZONES

The ductile shear zones are the structural domains with characteristic accumulation of large deformations in relation to envelope rocks (protolith) and noncoaxial progressive

Fig. 2. Geological map of the Złoty Stok–Trzebieszowice shear zone (after S. Cwojdziński, 1976*b*, 1979; simplified)
1 — Cenozoic formations; 2 — Cenozoic basaltoids; 3 — Kłodzko–Złoty Stok granitoids; 4 — Jawornik granitoids; 5 — hornfels-type blastomylonitic schists and biotite gneisses; 6 — cataclasites of Haniak gneisses; 7 — mylonitic gneisses and cataclasites; 8 — mylonitic gneisses and mylonites; 9 — plagioclase-microcline gneisses with cordierite (the Haniak type gneisses); 10 — plagioclase-microcline gneisses (the Gierałtów type gneisses); 11 — oligoclase-microcline augen gneisses (the Śnieżnik type gneisses); 12 — micaceous blastomylonitic schists and biotite gneisses; 13 — leptinites and leptitic gneisses; 14 — amphibolites and amphibolic schists; 15 — crystalline limestones and calcareous-siliceous rocks; 16 — micaceous schists and plagioclase paragneisses (the Stronie Series); 17 — faults; 18 — geological boundaries; 19 — state boundary; 20 — cross-section A–B; USB — Marginal Sudetic Fault

Mapa geologiczna strefy ścinania Złotego Stoku–Trzebieszowic (według S. Cwojdzińskiego, 1976*b*, 1979; uproszczona)
1 — utwory kenozoiczne; 2 — bazaltoidy kenozoiczne; 3 — granitoidy kłodzko-złotostockie; 4 — granitoidy jawornickie; 5 — zhornfelsowane łupki blastomylonityczne i gnejsy biotytowe; 6 — kataklazyty gnejsów haniackich; 7 — gnejsy mylonityczne i kataklazyty; 8 — gnejsy mylonityczne i mylonity; 9 — gnejsy plagioklazowo-mikroklinowe z kordierytem (gnejsy typu haniackiego); 10 — gnejsy plagioklazowo-mikroklinowe (gnejsy typu gierałtowskiego); 11 — oczkowe gnejsy oligoklazowo-mikroklinowe (gnejsy typu śnieżnickiego); 12 — łyszczykowe łupki blastomylonityczne i gnejsy biotytowe; 13 — leptynity i gnejsy leptytowe; 14 — amfibolity i łupki amfibolowe; 15 — wapienie krystaliczne i skały wapienno-krzemianowe; 16 — łupki łyszczykowe i paragnejsy plagioklazowe (seria strońska); 17 — uskoki; 18 — granice geologiczne; 19 — granica państwowa; 20 — linia przekroju A–B; USB — sudecki uskok brzeżny

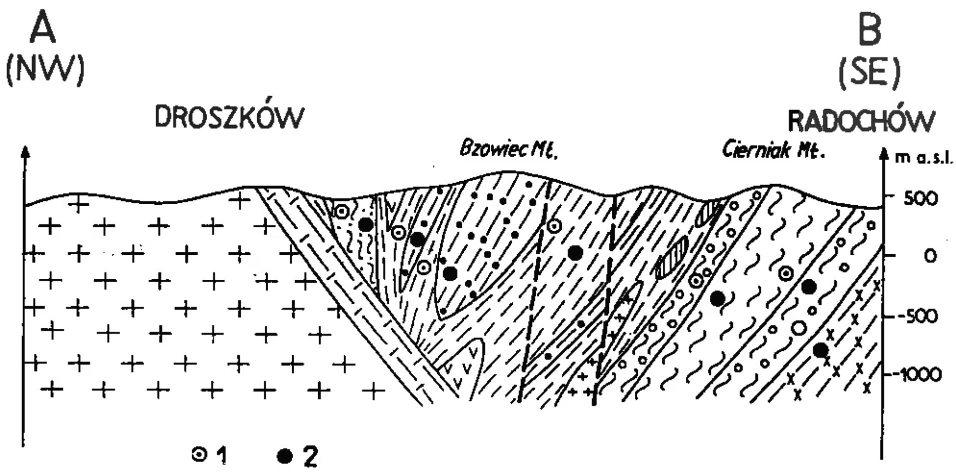


Fig. 3. Geological-structural cross-section A–B

1 — sense of displacement towards the viewer; 2 — sense of displacement from the viewer; for other explanations see Fig. 2

Przekrój geologiczno-strukturalny wzdłuż linii A–B

1 — zwrot przemieszczenia w stronę obserwatora; 2 — zwrot przemieszczenia od obserwatora; pozostałe objaśnienia jak dla fig. 2

deformation approximated to the simple shear (e.g. W. D. Means *et al.*, 1980; G. S. Lister, P. F. Williams, 1983; T. H. Bell, R. L. Hammond, 1984; S. Hanmer, C. Passchier, 1991). Shear zones are common on all scales, from microscopic streaks up to regional structures (e.g. T. H. Bell, 1978, 1985; R. D. Law *et al.*, 1984; A. Vauchez, 1987; A. G. Goldstein, 1989; S. Hanmer, 1990; P. R. Cobbold *et al.*, 1991; R. Girard, 1993). In general, shear zones comes into being when hardening ability of rock material has been overcome and localized softening strain processes have started to develop. As concluded from rheology, ductile deformations can also appear as the result of brittle mechanisms of deformations or due to combination of cataclastic and plastic deformations under lower temperature and pressure than those required for plastic penetrative deformation (e.g. R. D. Law *et al.*, 1984; S. Hanmer, C. Passchier, 1991; W. D. Means, 1990; H. Fossen, B. Tikoff, 1993). It is common that the shear zones are considered to be intensive nonhomogeneous deformations subjected to the softening strain processes.

Traditionally, the term "mylonite" was used to define a rock with characteristic reduction of grain size due to cataclastic process. As the idea is still common that mylonitization process is always followed by reduction in grain size, insufficient effort was exerted in recognizing many mylonitized fault rocks subjected to syntectonic recrystallization and increase of mineral grain size during development of ductile shear zones. This resulted in considerable simplification of terminology of so called fault rocks and their essential division into the cataclastic rocks and the mylonitic ones. Transition from frictional flow to viscous flow is the essential criterion of this genetic classification of the fault rocks.

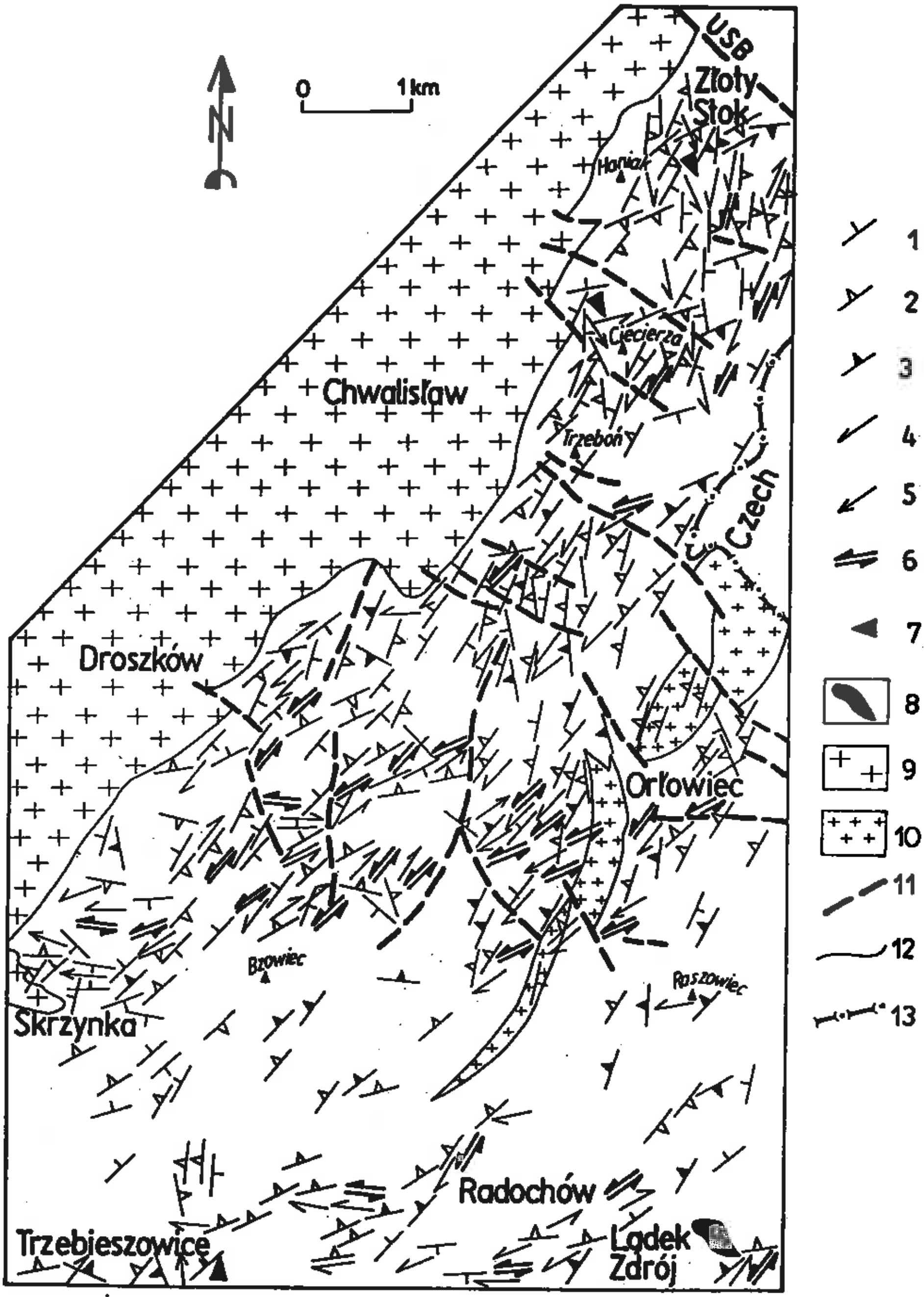
A definition of mylonite as presented in this paper is based on the G. S. Lister and A. W. Snoke's suggestion (1984) to consider it as a rock being formed as the result of intensive deformation that have been accumulated through cystalline-plastic behaviour of matrix. Important to note here is the fact that matrix minerals have been subjected to extended penetrative and dynamic recrystallization along with synchronic reduction of mineral grain size; they have also formed a well arranged crystallographic structure (comp: R. D. Law *et al.*, 1984; T. H. Bell, R. L. Hammond, 1984; W. D. Means, 1990; S. Hanmer, C. Passchier, 1991). Generation of mylonite will always remain under the influence of deformation parameters and processes of softening strain. From mechanical point of view, a softening can be defined as the reduction of stresses at constant rate of deformation or as an increase of strain rate at constant regional stress. The softening strain can include a number of different processes such as, for example: change in deformation mechanism, progressive recrystallization, softening as the result of chemical reaction, warming up in effect of both shearing and fluid pressure. It should be noticed that rapid expansion of ductile shear zone can take place if a rock has not been affected by the softening strain.

FOLIATIONS

Structures of planar (foliations), linear, and folded types together with kinematic indicators were employed to analyse the Złoty Stok–Trzebieszowice shear zone from the structural and kinematic point of view; adjacent Śnieżnik metamorphic complex was also analysed (Fig. 4). Compilation of foliation measurements within the Złoty Stok–Trzebieszowice shear zone is presented in two diagrams, separately for the northern part (Fig. 5A) and the southern one (Fig. 6A). Similar point diagrams have been prepared for adjacent Śnieżnik metamorphic complex, individually for the NE part (Fig. 7A) and the NW one (Fig. 8A). Orientation of linear and folded structures existing within the Złoty Stok–Trzebieszowice shear zone (Figs. 5B, 6B) and adjacent Śnieżnik metamorphic complex has been included in the point diagrams (Figs. 7B, 8B). Only the most representative measurements, averaged from almost 40 observation points from the Złoty Stok–Trzebieszowice shear zone and almost 50 outcrops in adjacent Śnieżnik metamorphic complex are included in the diagrams compilation. More abundant tectonic data, compiled in both point and contour diagrams for the area under consideration are available in the works by S. Cwojdziński (1976*a*, *b*, 1977, 1979), J. Don and R. Gotowała (1980), and M. Dumicz (1989).

Penetrative foliation in the Złoty Stok–Trzebieszowice shear zone was determined as S_1 (e.g. I. Wojciechowska, 1993; J. Don, R. Gotowała, 1980; A. Muszer, 1989) or S_2 (coplanar with respect to S_1) (S. Cwojdziński, 1976*a*, 1979; M. Dumicz, 1989), also as S_3 (I. Wojciechowska, 1975). S. Cwojdziński (1982, p. 176) expressed an opinion that "*...intensive shearing ... taking place in the foliation plane was the factor governing the structural and textural development of metamorphic rocks*". Micro- and mesoscopic observations from the Złoty Stok–Trzebieszowice shear zone are in full agreement with that former conclusion.

It should be noted that so called penetrative (regional) foliation is a combined structure composed of two (sometimes three) sets of planes: foliation planes (S) that cumulate the final deformation, and shear planes (C), development of which is connected with discontinuous ductile flow. It is a structure of S–C type (Figs. 9–11) which is characteristic for ductile shear zones (C. Simpson, S. Schmid, 1983; G. S. Lister, A. W. Snoke, 1984; C.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Simpson, 1986; Z. Cymerman, 1989*b*; S. Hanmer, C. Passchier, 1991). The C planes are oriented parallel to boundaries of shear zones and to dominant flow plane; usually, they are exposed as narrow zones with blastic grains and oriented arrangement of phyllosilicates. The S planes are, in general, situated at an angle of 45° to boundaries of shear zones and they define the XZ plane of finite strain ellipsoid. With the increase of dislocation rate, the S planes rotate to reach a close parallelism to the boundary of the ductile shear zone. The S planes are usually made up of phyllosilicates and directionally elongated quartz and feldspar grains.

A localized foliation appears in rocks subjected to intensive shear dislocations; they are given the SB (Figs. 11, 13) or C' designations and are defined as an extensional crenulation cleavage (J. P. Platt, 1984) or asymmetrical extensional shear bands (L. B. Harris, P. R. Cobbold, 1985; S. Hanmer, C. Passchier, 1991). The SB planes are, in general, dipping at 15–25° angle towards a bulk flow plane.

It is characteristic in the Złoty Stok–Trzebieszowice shear zone that the combined penetrative foliation is gradually changing its spatial orientation, from close to meridional in the northern part of the zone (Figs. 4, 5A) to almost parallel in the southern and southwestern parts (Figs. 4, 6A). In general, foliation of NNE–SSW orientation dominates at medium and large dip angles towards NW in the SW part while towards E in the NE part (Figs. 4, 5A, 6A). The point diagrams of foliation (Figs. 5A, 6A) clearly indicate stronger scattering of foliation attitude with respect to the Śnieżnik metamorphic complex (Figs. 9, 11). This provides evidence on stronger, more heterogenetic deformation due to shearing and on subsequent, intensive folding of foliation plane in the shear zone in comparison with the Śnieżnik metamorphic complex.

Orientation of combined regional foliation in the Śnieżnik metamorphic complex in its NE part is different from that in the NW part (Figs. 4, 7A, 8A). The foliation strikes in the NE part are arranged almost parallel to the Złoty Stok–Trzebieszowice shear zone, with dominant medium and low angles of dip towards NW (Fig. 7A). The foliation in the northwestern part of the Śnieżnik metamorphic complex is characterized by rather medium angles of dip, but towards NE, this time (Fig. 8A).

Fig. 4. Structural-kinematic map of the Złoty Stok–Trzebieszowice shear zone (after Z. Cymerman, 1991*b*; supplemented)

1 — strike and dip (70–90°) of steep penetrative foliation; 2 — strike and dip of penetrative foliation with dip angle in the range of 40–69°; 3 — strike and dip of penetrative foliation with dip angle in the range of 0–39°; 4 — strike and dip angle (0–30°) of penetrative lineation; 5 — strike and dip angle (more than 30°) of penetrative lineation; 6 — senses of displacement of strike-slip type; 7 — senses of displacements of normal "faulting" (extensional) type; 8 — Cenozoic basaltoids; 9 — Kłodzko–Złoty Stok granitoids; 10 — Jawornik granitoids; 11 — faults; 12 — geological boundaries; 13 — state boundary; USB — Marginal Sudetic Fault

Mapa strukturalno-kinematyczna strefy ścinania Złotego Stoku–Trzebieszowic (według Z. Cymermana, 1991*b*; uzupełniona)

1 — bieg i upad (70–90°) stromej foliacji penetratywnej; 2 — bieg i upad foliacji penetratywnej o kącie upadu 40–69°; 3 — bieg i upad foliacji penetratywnej o kącie upadu 0–39°; 4 — kierunek i kąt nachylenia (0–30°) lineacji penetratywnej; 5 — kierunek i kąt nachylenia (powyżej 30°) lineacji penetratywnej; 6 — zwroty przemieszczeń typu przesuwczego; 7 — zwroty przemieszczeń typu „uskokowania" normalnego (ekstensyjnego); 8 — bazaltoidy kenozoiczne; 9 — granitoidy kłodzko-złotostockie; 10 — granitoidy jawornickie; 11 — uskoki; 12 — granice geologiczne; 13 — granica państwa; USB — sudecki uskok brzeżny

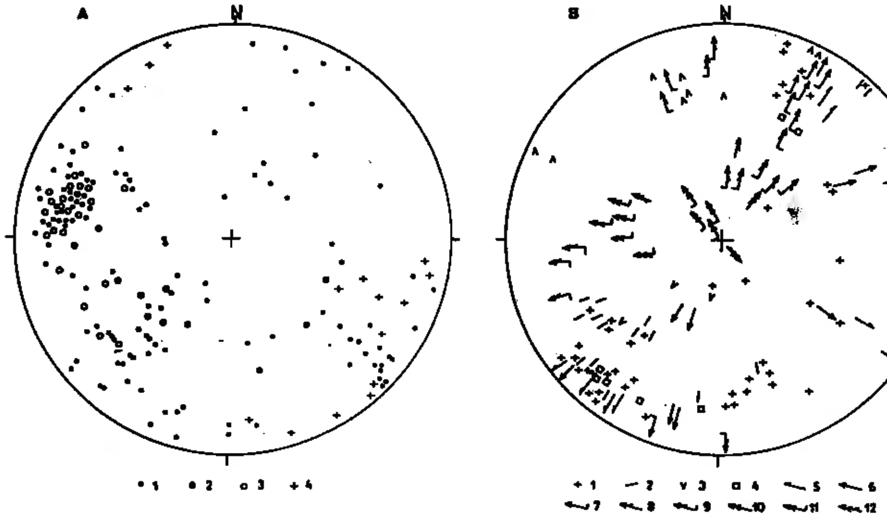

Fig. 5. Point type diagram of planar (A) and linear and fold type (B) structures for the northern part of the Złoty Stok–Trzebieszowice shear zone; lower hemisphere of the Schmidt's net

A: 1 — pole of undifferentiated, complex, penetrative foliation; 2 — pole of plane S for S–C type structure; 3 — pole of plane C for S–C type structure; 4 — asymmetric extensional shear bands of SB type; B: 1 — lineation of mineral grain; 2 — intersectional lineation; 3 — lineation of crenulation type; 4 — boudinage; 5 — isoclinal and tight folds; 6 — tight folds; 7 — tight asymmetric folds; 8 — open folds; 9 — open asymmetric folds; 10 — fault folds; 11 — fault asymmetric folds; 12 — open broad folds

Diagram punktowy struktur planarnych (A) oraz struktur linijnych i fałdowych (B) z północnej części strefy ścinania Złotego Stoku–Trzebieszowic; dolna półkula siatki Schmidta

A: 1 — biegun nierozdzielonej, złożonej foliacji penetratywnej; 2 — biegun powierzchni S ze struktury typu S–C; 3 — biegun powierzchni C ze struktury typu S–C; 4 — asymetryczne, ekstensyjne pasemka ścinania typu SB; B: 1 — lineacja ziarna mineralnego; 2 — lineacja intersekcyjna; 3 — lineacja typu zmarszczkowania; 4 — budinaż; 5 — fałdy izoklinalne i wąskopromienne; 6 — fałdy wąskopromienne; 7 — fałdy wąskopromienne, asymetryczne; 8 — fałdy otwarte; 9 — fałdy otwarte, asymetryczne; 10 — fałdy załomowe; 11 — fałdy załomowe, asymetryczne; 12 — fałdy otwarte, szerokopromienne

Apart of poles of undivided, combined, penetrative foliation, the following elements have for the first time been plotted on the point diagrams: poles of the S and C surfaces of S–C type structures and poles of mylonitic asymmetric extensional shear bands of SB type for both the Złoty Stok–Trzebieszowice shear zone (Figs. 5A, 6A) and the adjacent Śnieżnik metamorphic complex (Figs. 7A, 8A). The collected data documents the sinistral senses of shearing in the zone under consideration and dextral senses of shearing within the NW part of the Śnieżnik metamorphic complex. There are also sinistral senses occurring in the Śnieżnik complex, co-existing with the dextral ones. The sinistral senses of shearing become dominant in the boundary area between the Złoty Stok–Trzebieszowice shear zone and the Śnieżnik metamorphic complex.

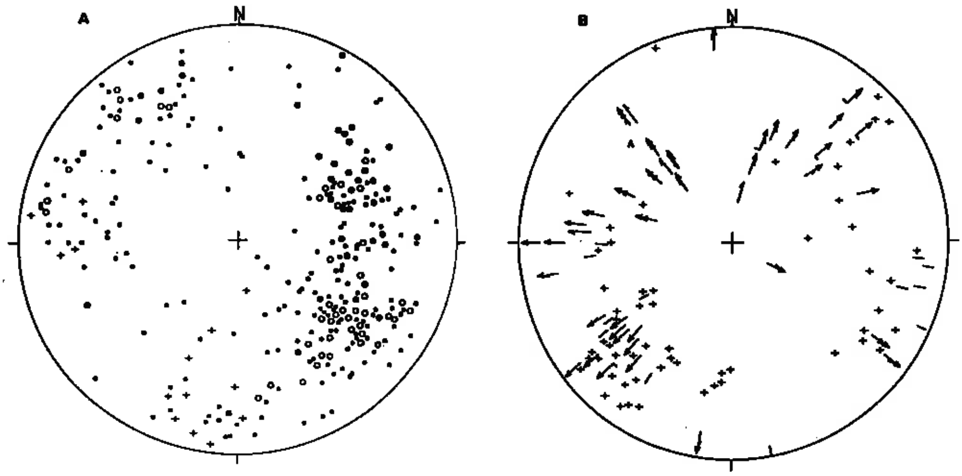

Fig. 6. Point type diagram of planar (A) and linear and fold type (B) structures for the southern part of the Złoty Stok–Trzebieszowice shear zone; lower hemisphere of the Schmidt's net

For explanations see Fig. 5

Diagram punktowy struktur planarnych (A) oraz struktur linijnych i fałdowych (B) z południowej części strefy ścinania Złotego Stoku–Trzebieszowic; dolna półkula siatki Schmidta

Objaśnienia jak na fig. 5

LINEATIONS

Such linear structure as the lineation of mineral grain occurring in the entire Złoty Stok–Trzebieszowice shear zone is the structure with features of Lx extensional lineation. The extensional lineation, also known as extensional lineation or mylonitic lineation or lineation due to elongation, always develops on the foliation planes; its orientation during progressive deformation of plane strain type or constriction strain type is always parallel to axis X of finite strain ellipsoid (X > Y > Z) and/or axis X of incremental strain ellipsoid (B. E. Hobbs *et al.*, 1976; H. G. Ave Lallemant, 1983; Z. Cymerman, 1989*a*, 1992*b*). At present, the extensional lineation of Lx type has found a wide application to determination of tectonic transport direction (e.g. H. Ave Lallemant, 1983; J. P. Burg *et al.*, 1987; Z. Cymerman, 1989*a*, 1992*a*; M. Urban, 1992; H. Fritz, F. Neubauer, 1993; S. Mazur, J. Puziewicz, 1995).

Most often, morphology of lineation of Lx type is pointed out by directional arrangement of mineral grains on the foliation planes that developed as the result of dynamic recrystallization and/or dynamic recovery. Of such type is the penetrative lineation (Lx) in the Złoty Stok–Trzebieszowice shear zone and the Śnieżnik metamorphic complex as well. The penetrative lineation of grains and aggregates in gneisses is pointed out by directional elongation of eyes, rods, and mineral aggregates; this mostly deals with quartz and feldspars, and micaceous packages as well. The Lx lineation in micaceous schists and plagioclastic paragneisses is determined by arranged elongation of micas, and rods and ribbons of quartz and plagioclases.

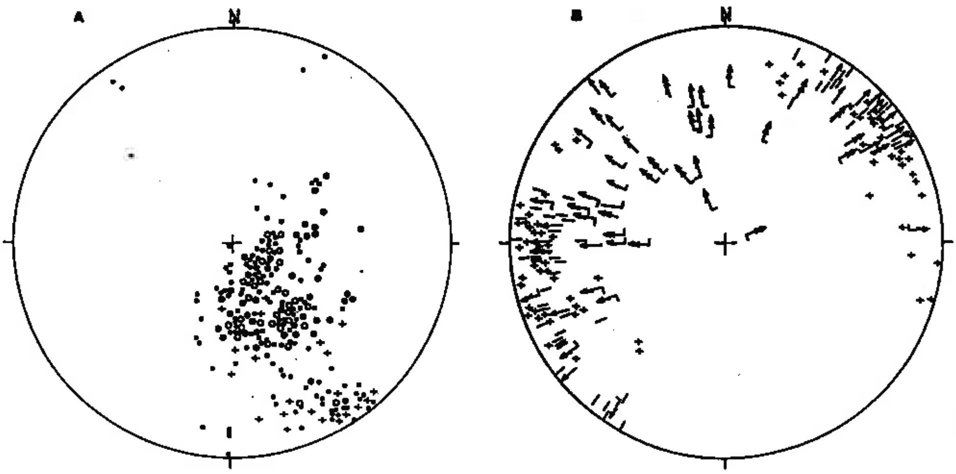

Fig. 7. Point type diagram of planar (A) and linear and fold type (B) structures for the northeastern part of the Śnieżnik metamorphic complex; lower hemisphere of the Schmidt's net

For explanations see Fig. 5

Diagram punktowy struktur planarnych (A) oraz struktur linijnych i fałdowych (B) z północno-wschodniej części metamorfiku Śnieżnika; dolna półkula siatki Schmidta

Objaśnienia jak na fig. 5

There is characteristic relatively stable spatial orientation of the Lx lineation within the Złoty Stok–Trzebieszowice shear zone; it takes a NE–SW attitude at low and medium plunge angles, mostly towards SW and S, and also to NE (Figs. 4, 5B, 6B). Some deviations from this regional direction are relatively common in the northern part of the zone; the Lx plunges here to S or SE (Figs. 4, 5B). As refers to the southern part of the shear zone, the Lx lineations plunge towards W and E too (Figs. 4, 6B).

In that part of the Śnieżnik metamorphic complex which is situated southwestwardly of the Złoty Stok–Trzebieszowice shear zone, orientation of the Lx lineation is almost the same as that in this shear zone (Fig. 7B), however, the trend of the Lx orientation is quite different in the NW part of the Śnieżnik metamorphic complex (the Krowiarki Range). The extensional lineations are of NW–SE orientation here, at low and medium plunge angles, in general towards NW (Fig. 8B). The area in the vicinity of Trzebieszowice where a change appears in the structural trends within the Śnieżnik complex, was defined as the area of the Lądek virgation (J. Don, 1964). Despite some, sometimes considerable deviations from regional trends in orientation of the Lx lineation those variances seem to be rather progressive and closely connected with heterogenetic deformation in shear zones of anastomosing type and/or subsequent folding (Figs. 12, 13) of penetrative foliation planes on which the Lx lineation developed.

Since the Lx lineation is almost parallel to orientation of majority of fold axes, then the Lx lineation was commonly considered to be of type B. It mean that lineations of mineral grains (Lx) and fold axes (structures of type B) developed perpendicular to axis σ_1 of main stress. Close parallelism of orientation of both fold axes and lineation Lx is a very characteristic feature of strongly deformed regions of all orogenic ranges (e.g. A. Vauchez,

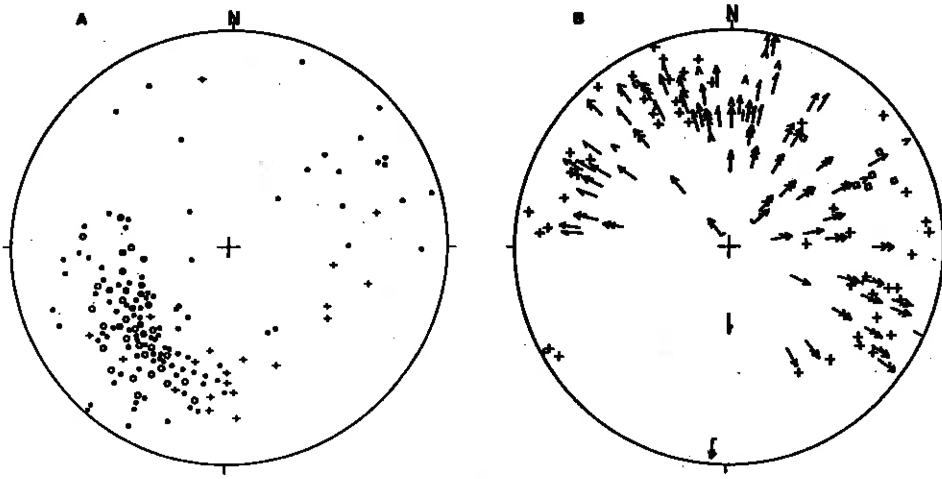

Fig. 8. Point type diagram of planar (A) and linear and fold type (B) structures for the northwestern part of the Śnieżnik metamorphic complex; lower hemisphere of the Schmidt's net

For explanations see Fig. 5

Diagram punktowy struktur planarnych (A) oraz struktur linijnych i fałdowych (B) z północno-zachodniej części metamorfiku Śnieżnika; dolna półkula siatki Schmidta

Objaśnienia jak na fig. 5

1987; R. E. Holdsworth, 1990; D. Cassard *et al.*, 1993). Currently, parallelism of lineations and folds arrangement is considered to be the result of intensive deformations due to shearing and successive rotation of fold axes in direction of shearing during progressive deformation (A. Escher, J. Watterson, 1974; T. H. Bell, 1978; P. R. Cobbold, H. Quinquis, 1980).

The Lx lineations in the Złoty Stok–Trzebieszowice shear zone are oriented almost parallel to axes of isoclinal and tight folds that traditionally have been designated as F_1 and F_2 structures (e.g. I. Wojciechowska, 1975, 1986; S. Cwojdziński, 1976*a*, 1977, 1982; J. Don, R. Gotowała, 1980; M. Dumicz, 1989). At the same time the Lx lineations are more oblique with respect to open fold's axes of significantly larger interlimb angles. These facts document well the process of progressive deformation due to shearing; apart from rotation, the process also included modification of fold shape. During this process, the large and open-type folds developed here, then — following the increment of deformation due to shearing, the folds became more and more tight and closed. Angular differences between the Lx lineation of extensional type and the axes of majority of open folds and crenulations (gouffrage) does not necessarily indicate different development of linear and folded structures. On the contrary, non-coaxiality of structures of such type could be caused by their synchronous development, but only in such circumstances in which their origin and evolution were taking place during progressive simple shearing (A. J. Dennis, D. T. Secor, 1987).

In a number of sections XZ (perpendicular to foliation plane and parallel to the Lx lineation) of the Śnieżnik gneisses, observations were made of progressive development of

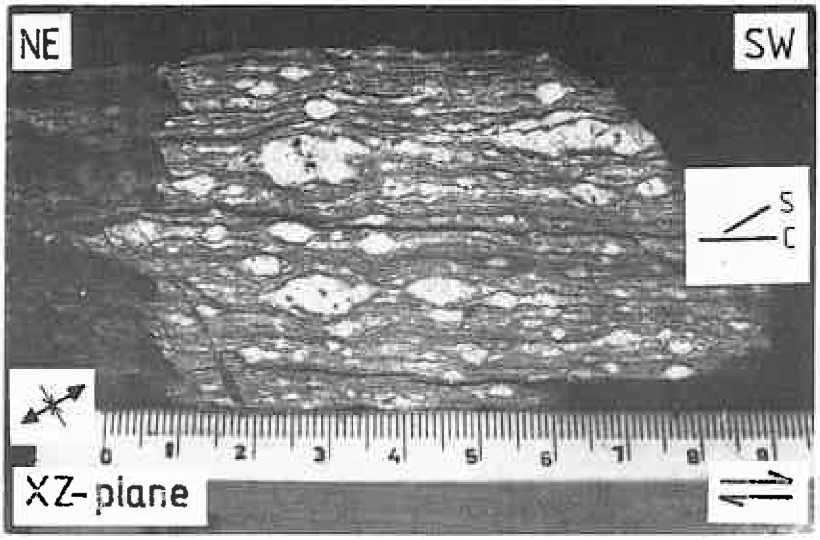

Fig. 9. Augen gneiss with planar structures of S–C type and porphyroclasts of type σ; vicinity of Radochów; scale in centimetres

Gnejs oczkowy ze strukturami planarnymi typu S–C i porfiroklastami typu σ; okolice Radochowa; skala w centymetrach

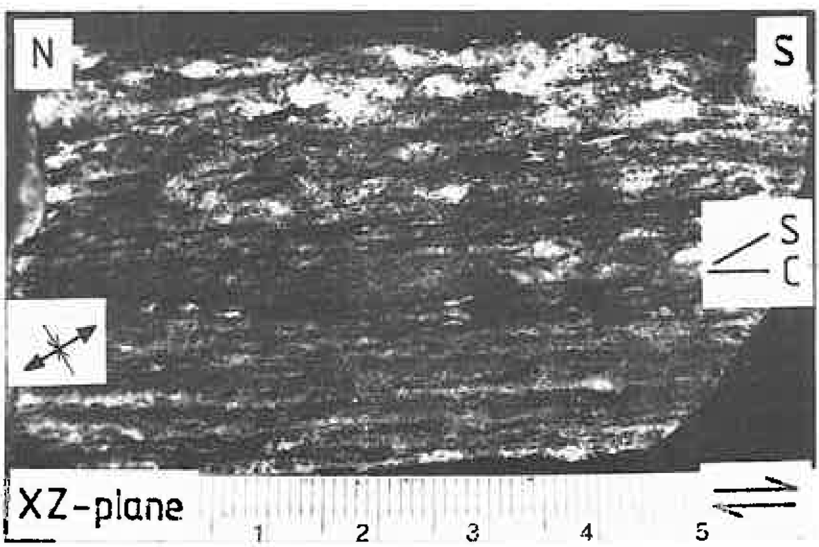

Fig. 10. Biotite gneiss showing strong recrystallization of planar structure of S–C type; vicinity of Złoty Stok; scale in centimetres

Gnejs biotytowy z silną rekrystalizacją struktury planarnej typu S–C; okolice Złotego Stoku; skala w centymetrach

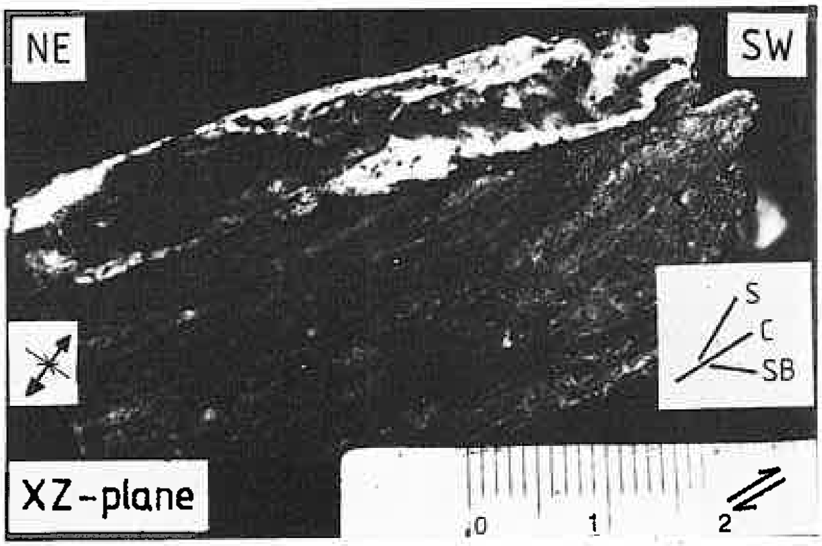

Fig. 11. Blastomylonitic schists with indicators of shear senses (structures of S–C and SB types); vicinity of Skrzynka; scale in centimetres

Łupki blastomylonityczne ze wskaźnikami zwrotu ścinania (struktury typu S–C i SB); okolice Skrzynki; skala w centymetrach

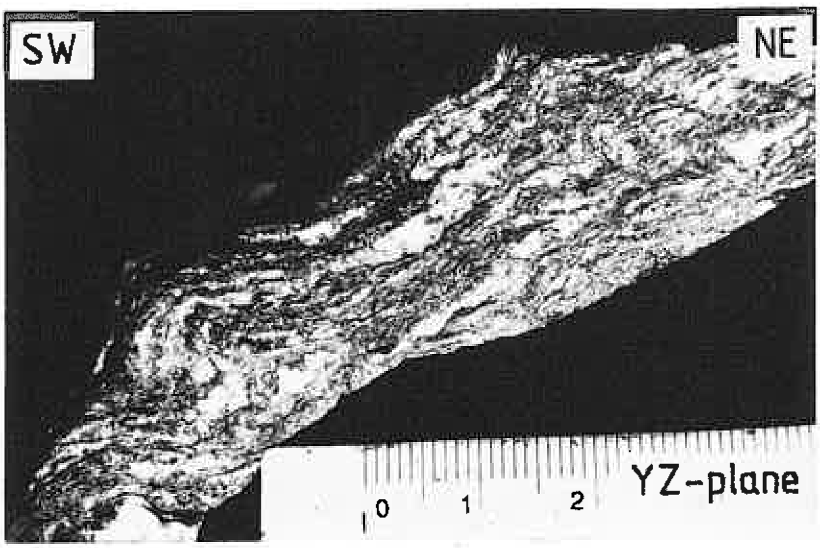

Fig. 12. Asymmetric fold type structures in plagioclase paragneisses (the Stronie Series); vicinity of Lądek Zdrój; scale in centimetres

Asymetryczne struktury fałdowe w paragnejsach plagioklazowych (seria strońska); okolice Lądka Zdroju; skala w centymetrach

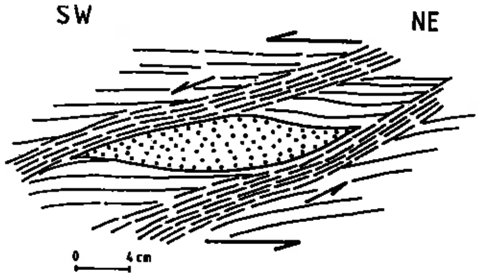

Fig. 13. Asymmetric quartz lense and synthetic structure of asymmetric extensional shear zone; blastomylonitic schists; vicinity of Orłowiec

Asymetryczna soczewa kwarcu i syntetyczna struktura typu asymetrycznej ekstensyjnej strefy ścinania; łupki blastomylonityczne; okolice Orłowca

rodding type lineation closely connected with intensification of simple shear process. With intensification of shear deformations, large K feldspar megacrystals became more and more prolate, and elongated. Process of reduction of feldspar megacrystal size contributed to gradual development of very characteristic asymmetric feldspar eyes, mostly microcline, defined as porphyroclastics of type σ (e.g. C. W. Passchier, C. Simpson, 1986; H. Takagi, M. Ito, 1988; Z. Cymerman, 1989*b*, 1992*a*; S. Hanmer, C. Passchier, 1991). If a simple shear is overprinted by other simple shear or other non-coaxial strain (general shear, for example) (W. D. Means, 1990; S. Hanmer, C. Passchier, 1991), the Lx lineation may be oriented between axes X and Y of the finite strain ellipsoid. Such a situation is rather common in the case of non-planar deformation, when volume of rock subjected to deformation has been changed. It should be emphasized here that in the event of non-plane deformation it is impossible to explicitly determine a direction of tectonic transport based on orientation of the Lx extensional lineation. Such a case is rather not connected with the area under discussion, where the total deformation being mostly close to the plane deformation ($X > Y = 1 > Z$) and direction of tectonic transport does not change in a significant way; also, there is no distinct rheological difference between constituents of Lx mineral lineation and the remaining part of the rock.

SHEAR SENSES

A kinematic-structural analysis carried out in the plane parallel to Lx lineation and perpendicular to foliation (a XZ plane of the finite strain ellipsoid) has allowed to determine shear senses. The senses have been determined for 39 points within the Złoty Stok–Trzebieszowice shear zone and the closest vicinity of the Śnieżnik metamorphic complex (Fig. 4).

Based on asymmetry of tectonic structures, different criteria were applied to determine the shear senses (e.g. C. Simpson, S. Schmid, 1983; C. Simpson, 1986; Z. Cymerman, 1989*b*, 1991*a, c*, 1992*a*). In the case of augen gneisses, the shear senses were determined from porphyroclastics of type σ (Fig. 9) and δ (C. Simpson, S. Schmid, 1983; T. H. Bell, 1985; C. W. Passchier, C. Simpson, 1986; J. van der Driessche, J. P. Brun, 1987; S. Hanmer, 1990) and mylonitic structures of S–C type discussed before, in chapter dealing with foliation (Figs. 9–11). Shear senses in the migmatized and Haniak gneisses were mainly determined from oriented thin sections according to an oblique fabric (e.g. R. D. Law *et al.*, 1984; S. Hanmer, C. Passchier, 1991). The oblique fabric and so called mica fishes were

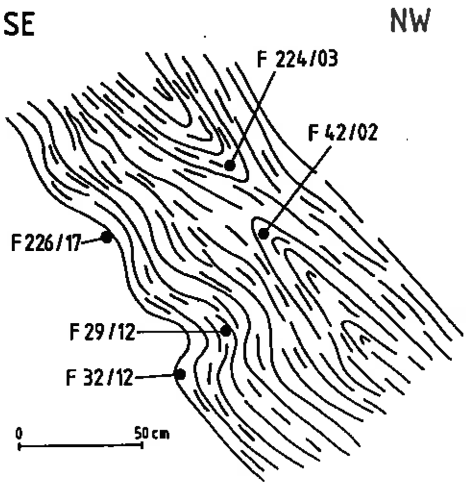

Fig. 14. Example of fold structures; leptinites; Bzowiec Mt.
Przykład deformacji fałdowych; leptynity; góra Bzowiec

the best indicators in mylonitic schists and gneisses (e.g. S. Hanmer, 1986; Z. Cymerman, 1992*a*); in most cases they were determined from oriented thin sections. Also, relatively abundant non-penetrative synthetic planar structures of asymmetric extensional shear bands of SB type were observed in mylonitic rocks (Figs. 11, 13) (R. Weijermars, H. E. Rondeel, 1984; J. P. Platt, 1984; L. B. Harris, P. R. Cobbold, 1985; S. Hanmer, C. Passchier, 1991); asymmetric quartz rods (Fig. 13), asymmetric boudinage structures (e.g. S. Hanmer, 1986; S. Hanmer, C. Passchier, 1991) and kink-bands folds were also observed (Fig. 15) (L. B. Harris, P. R. Cobbold, 1985; S. Hanmer, C. Passchier, 1991).

Data acquired from analyses of shear sense indicators for the Złoty Stok–Trzebieszowice shear zone points out a stable sinistral sense of shear (almost 95% of kinematic data). It documents sinistral displacement of strike-slip type on steep foliation planes along with almost horizontal extensional lineation Lx (Figs. 4, 5A, 5B, 6A, 6B).

DEFORMATIONAL PARTITIONING

Most likely, synchronous and progressive development of varied fold structures (Fig. 14) and ductile shear zones within the Złoty Stok–Trzebieszowice shear zone was connected with mechanism of deformational partitioning consisting in division of total deformation into domains of simple shear (non-coaxial deformation) and domains of pure shear (coaxial deformation). In Polish literature a question of deformational partitioning was discussed by Z. Cymerman (1988). In the last years a number of works were published to present different aspects of deformational partitioning; regional examples were also discussed (e.g. G. S. Lister, P. F. Williams, 1983; T. H. Bell, R. L. Hammond, 1984; T. H. Bell, 1985; M. A. Evans, W. M. Dunne, 1991; S. M. Cashman *et al.*, 1992; J. Jackson, 1992; H. Fossen, B. Tikoff, 1993; R. Girard, 1993).

In general, a simple shear component dominated in some part of domains as the result of deformational partitioning. The simple shear component has lead, among others, to development of S–C type structures, asymmetric porphyroclastics, asymmetric mica fishes,

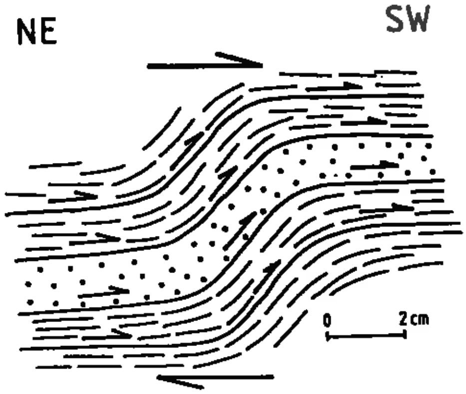

Fig. 15. Asymmetric fold of kink-bands type; blastomylonitic schists; vicinity of Skrzynka
Asymetryczny fałd załomowy typu *kink-bands*; łupki blastomylonityczne; okolice Skrzynki

and extensional shear bands. A pure shear component dominated in remaining domains where folds and crenulations developed. There are intermediate domains between both extreme domains, characterized by mixed mechanism of deformation such as general shear, for example (S. Hanmer, C. Passchier, 1991).

Before now, S. Cwojdziński (1982) assumed that "*...relics of older non-tectonic fold structures...*" have been preserved in the "predisposed" domains. Most likely, these domains originated as the result of deformational partitioning; they are not the older relics but domains of pure shearing. Processes of deformational partitioning are to large extent dependent on lithologic differentiation, orientation of earlier anisotropy planes, and both pressure and temperature conditions during regional metamorphism (e.g. processes of deformational softening at low rate of deformations and at high temperature).

In the Góry Złote Mts., the most intesive development of simple shear zones took place in mylonitic schists (phyllonites), mylonites, and mylonitic gneisses whereas pure (rotational) shear component dominated in micaceous schists and migmatite gneisses.

Almost uniform kinematic-structural picture for the Złoty Stok–Trzebieszowice shear zone indicates a stable orientation of principal strain axis. Earlier structural study of the Orłowiec area also suggested preservation of stable orientation of strain axis (J. Burchart, 1960). History of deformation, composed of stages of deformation and comprising progressive increments of deformations (the incremental strain ellipsoid) up to the state of final deformation (the finite strain ellipsoid) has been defined as the progressive deformation.

PROGRESSIVE DEFORMATIONS

In classical structural geology an assumption was common that total deformation is of epizodic character and that consecutive stages during timely differentiated regional "epizodes" have caused formation of separate generation of structural elements. This concept of so called overprinting of generations of structures does not necessarily means epizodic deformations. From consideration of (for instance) two consecutive tectonic structures a conclusion can be drawn that both could originate during stages separated from each other by hundred million years or could come into being during a continuous progressive deformation (B. E. Hobbs *et al.*, 1976). New evidences are still appearing indicating that, in general, deformations were of continuous character and that more than one generation of structures formed during individual progressive deformations (T. H. Bell, 1978; P. R. Cobbold, H. Quinquis, 1980; H. Helmstaedt, J. M. Dixon, 1980; J. P. Platt, 1983; O. T. Tobisch, S. R. Paterson, 1988 ; R. E. Holdsworth, 1990; C. K. Mawer, P. F. Williams, 1991).

It is common that complicated relationship of overprinting (superposition) among structures may cause a false idea on independent phenomena (O. T. Tobisch, S. R. Paterson, 1988; C. K. Mawer, P. F. Williams, 1991). Processes of overprinting at the time of progressive deformation can be caused by spatial differences in the rate of deformation (J. P. Platt, 1983; R. E. Holdsworth, 1990), kinematic enlargement of deflection on anisotropy planes (P. R. Cobbold, H. Quinquis, 1980), or changes in orientation of principal stresses with respect to earlier tectonic structures (H. Helmstaedt, J. M. Dixon, 1980). It should be remembered that usually it is not easy to separate an epizodic deformation from a progressive one, particularly when reliable data on age of deformation is missing. In the absence of radiometric data for the Złoty Stok–Trzebieszowice shear zone, only structural-kinematic criteria can be applied; the said criteria are based on geometry of tectonic structures, shear factors, relationship between different structures, and distribution of those structures with respect to change in intensity of deformation (under the conditions of deformational partitioning, for example) (T. H. Bell, 1978; O. T. Tobisch, S. R. Paterson, 1988; R. E. Holdsworth, 1990).

Manifestation of locations of stronger deformations, also those occurring within limbs of large tectonic structures such as the Bzowiec fold among others, and similar kinematic display for the entire Złoty Stok–Trzebieszowice shear zone is consistent with a model of progressive deformation. Indirectly, it also suggests large-scale deformational partitioning to take place during deformation. An agreement between general kinematic frames during folding in the Złoty Stok–Skrzynka zone and the stability of direction of tectonic transport towards SW suggests a sequence taking place in development of tectonic structures during individual and, in principle, continuous tectonic process. And though each separate generation of tectonic structures (mostly of folds) could be caused by a separate pulse of deformation, a general similarity of kinematic frames is much easier to explain using a concept of progressive deformation than by particular deformational epizodes.

Development by stages within the Złoty Stok–Trzebieszowice shear zone as suggested on the basis of variability of folds' geometry (Fig. 5B), their dispersion and vergence, most often from stage D_1 and D_4 (e.g. S. Cwojdziński, 1975, 1976*a*, 1979; I. Wojciechowska, 1975, 1993; J. Don, R. Gotowała, 1980; M. Dumicz, 1979, 1989) results from deformational partitioning during progressive increments of deformations within stable stress field rather than from the effect of superposition of structures that originated during different stages of deformations within variable stress field.

Recently, J. Żaba and Z. Będkowski (1995) presented a sequence of up to seven consecutive generations of shear zones (S_1–S_7) in the vicinity of Złoty Stok. During undifferentiated stages D_1 and D_2 of deformations, the oldest foliation known under the term S_1+S_2 was expected to originate. This foliation was described as the mylonitic structure, and sense of tectonic displacements on those penetrative planes — as a reversed one (as concluded from figures contained in their paper), or top-to-the W oriented. However, important to note here is the fact that those senses have been defined on improper planes (i.e. planes perpendicular to foliation and also to lineation, thus on the YZ planes of the finite strain ellipsoid). The shear senses should always be determined on the XZ plane of the finite strain ellipsoid (e.g. Z. Cymerman, 1989*b*; S. Hanmer, C. Passchier, 1991); therefore, the J. Żaba and Z. Będkowski's (1995) concept of kinematic stage D_1–D_2 cannot be considered correct. Moreover, the most brittle fault of both authors consists in their interpretation of extreme lineation Lx as "*...the commonly observed mylonitic lineation...*" (p. 23) which should be considered the lineation L_3. Development of mylonitic foliation and mylonitic (extensional) lineation Lx is always synchronous and forms a matrix of mylonitic rock. Penetrative extensional lineation (by both authors improperly designated L_3) had to form synchronously also on penetrative planes of mylonitic foliation which by both authors was considered to be the S_1+S_2 structure. Therefore, the penetrative foliation and the lineation under discussion are the synchronous structures that have been formed during the main deformation.

RELATIONSHIP BETWEEN FOLDS AND SHEAR ZONES

Classical reconstructions of kinematics of deformation stages in the Sudetes (including the Złote Góry Mts.) were based on assessment of fold vergence (Figs. 12, 14). However, axes of different folded structures can develop perpendicularly, obliquely, and parallelly to axis X of the finite strain ellipsoid (e.g. J. Ridley, 1986; J. P. Burg *et al.*, 1987; S. Hanmer, C. Passchier, 1991; J. Jackson, 1992; Z. Cymerman, 1992*b*; H. Fossen, B. Tikoff, 1993; R. W. Krantz, 1995). It simply means that fold axis cannot be used to determine the X, Y, and Z axes of the finite strain ellipsoid. Scattered attitude of folds and lineation as well as "superimposed" fold structures, frequently non-cylindrical and with curvilinear course of fold crest (e.g. S. Cwojdziński, 1982) were customarily interpreted as the result of several independent deformation stages (e.g. S. Cwojdziński, 1975, 1976*a*, 1977, 1979; I. Wojciechowska, 1975, 1993; M. Dumicz, 1989). Lately, J. Żaba and Będkowski (1995) presented a sequence of up to seven consecutive generations of shear zones (S_1–S_7) in the Złoty Stok area.

Currently, a common idea is accepted that fold axes with orientation almost parallel to direction of tension X of the finite strain ellipsoid have formed as the result of progressive rotation from their initial orientation being close to intermediate axis Y of the finite strain ellipsoid (A. Escher, J. Watterson, 1974; P. R. Cobbold, H. Quinquis, 1980; J. Ridley, 1986). This requires strong deformations of simple shear type (with $\gamma > \approx 10$ for example) and passive fold development up to formation of structures of sheath fold type (P. R. Cobbold, H. Quinquis, 1980). However, a lot of natural folds with their axes parallel to extensional lineation Lx do not exhibit features of sheath folds, and frequently they are structures of open type without clear evidences of very strong strains supposed to be connected with their development. Their development is connected with active (dynamic) folding of rock media showing distinct differences in rheological properties.

If folds are younger than the extensional lineation Lx, then shear factors on their limbs are characterized by opposite shear senses. Such relationship is missing in the Bzowiec fold being a largest fold structure within the area under present study. Observations exclude the possibility of rotation and deflection of limbs of the Bzowiec fold after the shear type

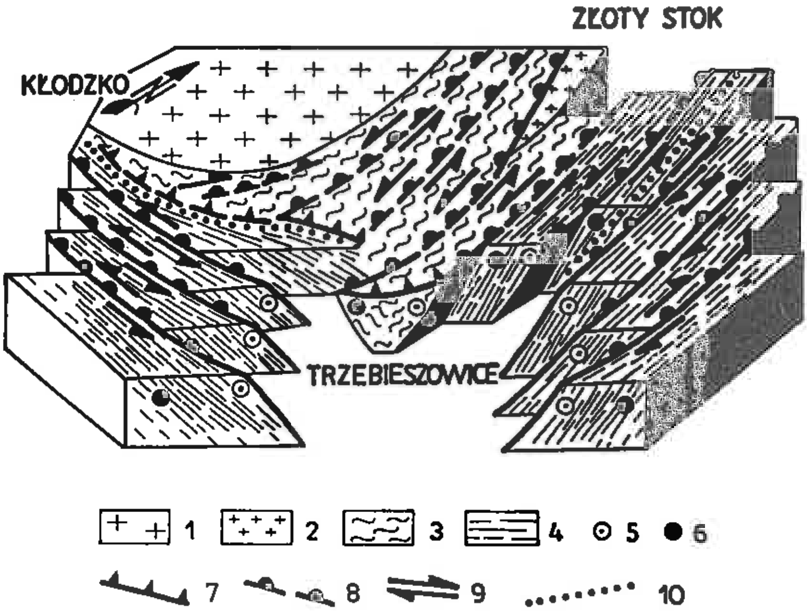

Fig. 16. Interpretation scheme of development of the Złoty Stok–Trzebieszowice shear zone

1 — Kłodzko–Złoty Stok granitoids; 2 — Jawornik granitoids; 3 — fault rocks of the Złoty Stok–Trzebieszowice shear zone; 4 — rocks of the Śnieżnik metamorphic complex; 5 — displacements towards the viewer; 6 — displacements from the viewer; 7 — frontal planes of ductile thrusts; 8 — lateral planes of ductile thrusts; 9 — senses of displacements of strike-slip type; 10 — boundary of areas with different kinematics

Schemat interpretacyjny rozwoju strefy ścinania Złotego Stoku–Trzebieszowic

1 — granitoidy kłodzko-złotostockie; 2 — granitoidy jawornickie; 3 — skały dyslokacyjne strefy ścinania Złotego Stoku–Trzebieszowic; 4 — skały metamorfiku śnieżnickiego; 5 — przemieszczenia w stronę obserwatora; 6 — przemieszczenia od obserwatora; 7 — powierzchnie frontalne podatnych nasunięć; 8 — powierzchnie lateralne podatnych nasunięć; 9 — zwroty przemieszczeń typu przesuwczego; 10 — granica obszarów o odmiennej kinematyce

deformation took place. This suggests that this fold developed under the sinistral shearing conditions. J. Don and R. Gotowała (1980) were right when interpreting development of the Bzowiec fold as a macrostructure which originated during the main stage of deformation in this part of the Góry Złote Mts. It was not possible to define that the shear type deformation happened after the main deformation stage. The shear senses in the crest zone of the Bzowiec fold are the same as those in the fold limbs, therefore the crest of this macrostructure does not represent relic, older domain, unaffected by later shear type deformations.

It should be noted here that it is not easy to differentiate the older fold structures, later subjected to intensive noncoaxial deformations, from new folds that originated during deformational partitioning under the general shearing. For instance, the fold structures and crenulations that are oblique oriented with respect to the Lx lineation could originate during shear type deformation of older anisotropy planes inclined at a high angle towards the shear plane. It seems logic to assume that for areas of strong deformation the axes of folds perpendicular to the direction of tectonic transport could not develop there; the fold structures of later age are excluded from this assumption.

It seems likely that a majority of tectonic structures observed in the Złoty Stok–Trzebieszowice shear zone generated as the result of progressive deformation under the conditions of deformational partitioning and considerable participation of simple shear component as well as general shearing comprising a stronly diversified rock sequence.

As the coaxial deformation (a pure shearing) creates so called "space problem", it was suggested (A. Escher, J. Watterson, 1974) that noncoaxial deformation (a simple shearing) is the best solution to this question, on a regional scale. However, the "space problem" connected with coaxial deformation can be solved assuming large scale discontinuities on the orogene scale. Therefore, it is possible that both coaxial and noncoaxial deformations coexist on a regional scale.

DEVELOPMENT OF THE ZŁOTY STOK–TRZEBIESZOWICE SHEAR ZONE

Direction of tectonic transport as defined for the Złoty Stok–Trzebieszowice shear zone is inconsistent with overthrusting, assumed before, towards SE of different tectonic units described in the Złoty Stok–Trzebieszowice shear zone along the Orłowiec or Gołogóra Overthrust (A. Muszer, 1989). This assumption was based on the idea that mineral lineations were parallel to the axis Y of the finite strain ellipsoid. The kinematic data of the northern sector of the Góry Złote Mts. is rather homogenous and stable; important to note here is the fact that such kinematic picture is overpassing the boundaries of the Złoty Stok–Trzebieszowice shear zone and enters the northwestern part of the Śnieżnik metamorphic complex (Fig. 3).

A progressive partitioned deformation in the northern sector of the Góry Złote Mts. is connected with tectonic transport towards SSW (Figs. 4, 6A and 16). This deformation caused development of strike-slip structures showing features of lateral planes of structural domains within entire eastern part of the Złoty Stok–Trzebieszowice shear zone; structures of the strike-slip-and-thrusting type on the contact of this regional zone with the Śnieżnik metamorphic complex (at Krowiarki Range) was also caused by the same deformation (Fig. 16). S. Cwojdziński (1976*a*, 1979) assumed that tectonics of the Złoty Stok–Trzebieszowice shear zone is of fold-boudinage style. Presently, the tectonic style of this zone is better reflected by the term of strike-slip-and-folded. Under conditions of transpression (W. B. Harland, 1971; D. J. Sanderson, W. R. Marchini, 1984), an oblique approaching of two rigid block happened. Material situated between both obliquely colliding blocks was subjected to synchronous compression and shear (D. J. Sanderson, W. R. Marchini, 1984; J. S. Oldow *et al.*, 1990; P. Y. Robin, A. R. Cruden, 1994). Large-scale transpressional zones are characterized by changes in the nature of movement from a pure strike-slip one to a compressional one. Lately, a number of cases have been presented as the examples of division of transpressional movements into synchronous ductile thrusting and displacements of the strike-slip type (J. S. Oldow *et al.*, 1990; R. E. Holdsworth, 1990; P. R. Cobbold *et al.*, 1991; M. T. Swanson, 1992).

Also, more and more numerous structural-kinematic analyses of the border zone between the Moldanubian and Moravian Terranes lead to conclusion that the conditions of transpressional deformation along with displacement towards NE of overlying rock domains were taking place in the whole Moldanubian Terrane (e.g. P. Rajlich, 1990; M. Urban, 1992; H. Fritz, F. Neubauer, 1993).

Also structural evolution of the Śnieżnik metamorphic complex can adequately be explained by the idea of Variscan transpression in the collision zone between the Moldanubian and Moravian Terranes. During dextral Variscan transpression, a considerable thickening of the continental crust followed as the result of accretion processes and intensive ductile thrusting as well (Z. Cymerman, 1991*c*, 1992*a*). This caused late orogenic (Visean) extension being well documented along the Ramzowa line (Z. Cymerman, 1993; J. Cháb *et al.*, 1994). Lately, processes of this regional post-orogenic extension have also been proven using the $^{40}Ar/^{39}Ar$ radiometric age dating method (M. G. Steltenpohl *et al.*, 1993; H. Malouski *et al.*, 1995).

A change in direction of tectonic transport has appeared in the vicinity of Trzebieszowice (Figs. 4, 16). I. Wojciechowska (1986) and I. Wojciechowska *et al.* (1988) suggested that metabasites in the Trzebieszowice area played a key part in development of the Lądek virgation. Most likely, the origin of this virgation was caused by the oblique collision of two terranes (Z. Cymerman, 1992*a*; Z. Cymerman, M. P. Piasecki, 1994) and thrusting towards SSW of tectonically dismembered fragments of ophiolitic sequence (Z. Cymerman, 1991*a*, *c*, 1992*a*). The occurrence of metabasite rocks (showing features of MORB thölleites) in the Złoty Stok–Trzebieszowice shear zone emphasizes the importance of this tectonic line as the old trail of tectonic suture (I. Wojciechowska, P. Gunia, 1993). Similar metabasite rocks are known to occur far to the W in the Kłodzko epimetamorphic unit (e.g. W. Narębski *et al.*, 1988).

It is commonly accepted that intensive mylonitization along with diaphtoresis (choritisation of biotite, among others) dominated in the Złoty Stok–Trzebieszowice shear zone first, then intensive processes of recrystallization and blastesis (cordierite, among others) followed under high-temperature and low-pressure regional metamorphism conditions ($T \approx 700$–$750°$ and $P \approx 2$–2.5 kbr) (M. Kozłowska-Koch, 1973; K. Smulikowski, 1979). In the Złoty Stok–Trzebieszowice shear zone an emplacement of syn-kinematic Jawornik granitoid happened (S. Cwojdziński, 1977). This intrusion resulted from a local transtension which, most lokaly, was caused by difference appearing in the rate of displacements of rock domains. Emplacement of the Kłodzko–Złoty Stok granitoids took place also under conditions of late-orogenic transtension; the emplacement was associated with localized, anastomosing zones of ductile-brittle shear zones (S. Cwojdziński, 1976*b*, 1979). At present, it seems likely that development of these granitoids was causually connected with fast uplifting of the Śnieżnik metamorphic complex under the conditions of regional extension in the Lower Carboniferous (M. G. Steltenpohl *et al.*, 1993).

Since reliable criteria are missing, it is not possible to prove shifting of mylonitization zone north-westwardly with time (A. Muszer, 1989). And despite missing radiometric determinations for the Złoty Stok–Trzebieszowice shear zone (except 335 Ma for the Jawornik granitoid — J. Borucki, 1966), data existing for adjacent area of the Śnieżnik metamorphic complex and other adjacent geological units (C. Pin *et al.*, 1988; M. Borkowska *et al.*, 1990; H. K. Brüeckner *et al.*, 1991; M. G. Steltenpohl *et al.*, 1993; G. J. Oliver, W. Kelley, 1993; G. J. Oliver *et al.*, 1993; A. Kröner *et al.*, 1994; H. Malouski *et al.*, 1995) allows to define that the main progressive deformation in the Złoty Stok–Trzebieszowice shear zone (similarly to the case of the Śnieżnik metamorphic complex) was taking place as the result of the Variscan tectogenesis.

CONCLUSIONS

1. Both structural study and kinematic analysis of the Złoty Stok–Trzebieszowice shear zone document a dominant position of simple shearing mechanism (of rotational type) under the ductile (plastic-crystalline) conditions, but subject to alternating stages of dynamic recovery and dynamic recrystallization.

2. Sinistral ductile displacements in the Złoty Stok–Trzebieszowice shear zone caused displacement of overlying rock packages towards SSW under the conditions of sinistral transpression; this is similar, to considerable extent, to the situation in the sinistral shear zone at Niemcza.

3. Deformational partitioning played an important role during structural evolution in the heterogenetic Złoty Stok–Trzebieszowice shear zone.

4. The Złoty Stok–Trzebieszowice shear zone originated during the sinistral transpression that was most likely caused by the oblique collision of the Moldanubian and Sudetian Terranes taking place at the time of the Variscan deformations.

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REFERENCES

ALEKSANDROWSKI P. (1995) — The significance of major strike-slip displacement in the development of Variscan structure of the Sudetes (SW Poland) (in Polish with English summary). Prz. Geol., **43**, p. 745–754, no. 9.

AVE LALLEMANT H. G. (1983) — The kinematic significance of mineral lineations in a late Jurassic thrust and fold belt in eastern Oregon, USA. Tectonophysics, **100**, p. 389–404.

BEDERKE E. (1929) — Die Grenze von Ost- und Westsudeten und ihre Bedeutung für die Einordnung der Sudeten in den Gebirgsbau Mitteleuropas. Geol. Rdsch., **20**.

BELL T. H. (1978) — Progressive deformation and reorientation of fold axes in a ductile mylonite zone: the Woodroffe thrust. Tectonophysics, **44**, p. 285–321.

BELL T. H. (1985) — Deformation partitioning and porphyroblast rotation in metamorphic rocks: a radical reinterpretation. J. Metam. Geol., **3**, p. 109–118.

BELL T. H., HAMMOND R. L. (1984) — On the internal geometry of mylonite zones. J. Geol., **92**, p. 667–686.

BORKOWSKA M., CHOUKROUNE P., HAMEAURT J., MARTINEAU F. (1990) — Geochemical investigations of the age, significance and structural evolution of the Caledonian-Variscan granite-gneisses of the Śnieżnik metamorphic area (Central Sudetes, Poland) (in Polish with English summary). Geol. Sudetica, **25**, p. 1–27.

BORUCKI J. (1966) — Preliminary results of the absolute age determination (K-Ar) of the Lower Silesian granitoidic rocks (in Polish with English summary). Kwart. Geol., **10**, p. 1–19, no. 1.

BRÜECKNER H. K., MEDARIS L. G., BAKUN-CZUBAROW N. (1991) — Nd and Sr age and isotope patterns from Variscan eclogites of the eastern Bohemian Massif. Neues Jahr. Miner. Abh., **163**, p. 169–196, no. 2/3.

BURCHART J. (1960) — On the Jawornik granitoids (Eastern Sudeten) (in Polish with English summary). Arch. Miner., **22**, p. 237–348 .

BURG J. P., BAL P., BRUN J. P., GIRARDEAU J. (1987) — Stretching lineation and transport direction in the Ibero-Armorican Arc during Siluro-Devonian collision. Geodinamica Acta, **1**, p. 71–87.

CASHMAN S. M., KELSEY H. M., ERDMAN C. F., CUTTEN H. N., BERRYMAN K. R. (1992) — Strain partitioning between structural domains in the forearc of the Hikurangi subduction zone, New Zealand. Tectonics, **11**, p. 242–257.

CASSARD D., FEYBESSE J. L., LESCUYER J. L. (1993) — Variscan crustal thickening, extension and late overstacking during the Namurian-Westphalian in the western Montagne Noire (France). Tectonophysics, **222**, p. 33–52.

CHÁB J., MIXA P., VANĚČEK M., ŽAČEK V. (1994) — Evidence of an extensional tectonics in the NW part of the Hrubý Jesenik Mts. (The Bohemian massif, Central Europe) (in Czech with English summary). Věst. Čes. Geol. Úst., **69**, p. 7–153.

CLOSS H. (1922) — Der Gebirgsbau Schlesiens und Stellung seiner Bodenschatze, Born. Berlin.

COBBOLD P. R., QUINQUIS H. (1980) — Development of sheath folds in shear regimes. J. Struct. Geol., **2**, p. 119–126.

COBBOLD P. R., GAPAIS D., ROSSELLO E. A. (1991) — Partitioning of transpressive motions within a sigmoidal foldbelt: the Variscan Sierras Australes, Argentina. J. Struct. Geol., **13**, p. 743–758.

CWOJDZIŃSKI S. (1975) — On the origin and evolution of the northern part of the Złoty Stok–Skrzynka (in Polish with English summary). Kwart. Geol., **19**, p. 789–802, no. 4.

CWOJDZIŃSKI S. (1976*a*) — Meso- and macrostructural observations from the northern part of the Złoty Stok–Skrzynka tectonic zone (in Polish with English summary). Kwart. Geol., **20**, p. 485–501, no. 3.

CWOJDZIŃSKI S. (1976*b*) — Szczegółowa mapa geologiczna Sudetów 1:25 000 ark. Złoty Stok. Inst. Geol. Warszawa.

CWOJDZIŃSKI S. (1977) — The relation of Jawornik granitoids to deformation of Lądek–Śnieżnik metamorphic area (in Polish with English summary). Kwart. Geol., **21**, p. 451–464, no. 3.

CWOJDZIŃSKI S. (1979) — Szczegółowa mapa geologiczna Polski 1:25 000 ark. Trzebieszowice. Inst. Geol. Warszawa.

CWOJDZIŃSKI S. (1982) — Structural evolution of the eastern part of the Kłodzko region based on a new interpretation of folds of the earliest generations (in Polish with English summary). Biul. Inst. Geol., **341**, p. 169–182 .

CWOJDZIŃSKI S. (1984) — Strefa tektoniczna Niemczy a strefa Złoty Stok–Skrzynka — próba porównania. Kwart. Geol., **28**, p. 766–767, no. 3/4.

CYMERMAN Z. (1988) — Significance of deformation partitioning in structural analysis (in Polish with English summary). Prz. Geol., **36**, p. 582–588, no. 10.

CYMERMAN Z. (1989*a*) — Characteristics and significance of the extensional lineation (in Polish with English summary). Prz. Geol., **37**, p. 488–494, no. 10.

CYMERMAN Z. (1989*b*) — Determination of the sense of shear (in Polish with English summary). Prz. Geol., **37**, p. 605–613, no. 12.

CYMERMAN Z. (1990) — Mapa strukturalna Dolnego Śląska 1:50 000, ark.: Mostowice, Bystrzyca Kłodzka, Stronie Śląskie, Międzylesie–Potoczek. Arch. Państw. Inst. Geol. Wrocław.

CYMERMAN Z. (1991*a*) —Mapa strukturalna Dolnego Śląska 1:50 000, ark.: Uniemyśl, Radków, Nowa Ruda, Ząbkowice Kłodzkie, Kudowa Zdrój, Duszniki Zdrój, Kłodzko and Złoty Stok. Arch. Państw. Inst. Geol. Wrocław.

CYMERMAN Z. (1991*b*) — Do exist terranes in the Sudetic Mountains? (in Polish with English summary). Prz. Geol., **39**, p. 450–456, no. 10.

CYMERMAN Z. (1991*c*) — Ductile thrusting in the Śnieżnik terrain, the Sudetes: an example of the Variscan orogeny. In: Abstracts of geological workshop Moravian Windows; Moravsky Krumlov, p. 35–37.

CYMERMAN Z. (1992*a*) — Rotational ductile deformations in the Śnieżnik metamorhic complex. Geol. Quart., **36**, p. 393–420, no. 4.

CYMERMAN Z. (1992*b*) — Lineacja w strefach ścinania a kierunek transportu tektonicznego. Prz. Geol., **40**, p. 748–751, no. 12.

CYMERMAN Z. (1993) — Does the Ramzova Overthrust exist in the Sudetes? (in Polish with English summary). Prz. Geol., **41**, p. 700–706, no. 10.
CYMERMAN Z. (1995) — Lewoskrętna strefa ścinania Złoty Stok–Trzebieszowice z Gór Złotych. In: Góry Złote — geologia, mineralizacje rudne i ekologia (ed. A. Muszer), p. 11–19. Mat. Konf. Nauk. Wrocław–Złoty Stok 9–10 czerwiec 1995.
CYMERMAN Z., PIASECKI M. P. (1994) — The terrane concept in the Sudetes, Bohemian Massif. Geol. Quart., **38**, p. 191–210, no. 2.
DENNIS A. J., SECOR D. T. (1987) — A model for the development of crenulations in shear zones with applications from ther Southern Appalachian Piedmont. J. Struct. Geol., **9**, p. 809–817.
DON J. (1964) — The Złote and Krowiarki Mts. as structural elements of the Śnieżnik metamorphic massif (in Polish with English summary). Geol. Sudetica, **1**, p. 79–117 .
DON J., GOTOWAŁA R. (1980) — Structural analysis of the Bzowiec fold (Śnieżnik metamorphic unit, Sudetes) (in Polish with English summary). Geol. Sudetica, **15**, p. 107–119, no. 2.
DUMICZ M. (1979) — Tectogenesis of the metamorphosed series of the Kłodzko District: a tentative explanation. Geol. Sudetica, **14**, p. 29–46, no. 2.
DUMICZ M. (1989) — Złoty Stok–Skrzynka structural element in the light of mesostructural analysis of Lądek–Śnieżnik metamorphic terrain (in Polish with English summary). Geol. Sudetica, **23**, p. 83–106, no. 2.
ESCHER A., WATTERSON J. (1974) — Stretching fabrics, folds and crustal shortening. Tectonophysics, **22**, p. 223–231.
EVANS M. A., DUNNE W. M. (1991) — Strain factorization and partitioning in the North Mountain thrust sheet, central Appalachians, U.S.A. J. Struct. Geol., **13**, p. 21–35.
FINCKH L., MEISTER F., FISCHER G., BEDERKE E. (1942) — Geologische Karte des deutschen Reiches 1:25 000. Blatt Glatz, Königshein, Reichenstein und Landeck. Erlauterungen. Berlin.
FOSSEN H., TIKOFF B. (1993) — The deformation matrix for simultanous simple shearing, pure shearing and volume change, and its applicaton to transpression-transtension tectonics. J. Struct. Geol., **15**, p. 413–422.
FRITZ H., NEUBAUER F. (1993) — Kinematics of crustal stacking and dispersion in the south-eastern Bohemian Massif. Geol. Rdsch., **82**, p. 556–565.
GIRARD R. (1993) — Orogen-scale strain partitioning and an analogy to shear-bands in the Torngat Orogen, NE Canadian Shield. Tectonophysics, **224**, p. 363–370.
GOLDSTEIN A. G. (1989) — Tectonic significance of multiple motions on terrane-bounding faults in the northern Appalachians. Geol. Soc. Am. Bull., **101**, p. 927–938.
HANMER S. (1986) — Asymmetrical pull-aparts and foliation fish as kinematic indicators. J. Struct. Geol., **8**, p. 111–122.
HANMER S. (1990) — Natural rotated inclusions in non ideal shear. Tectonophysics, **176**, p. 245–255.
HANMER S., PASSCHIER C. (1991) — Shear-sense indicators: a review. Geol. Surv. Canada. Spec. Paper, **90–17**, p. 1–72.
HARLAND W. B. (1971) — Tectonic transpression in the Caledonian Spitzbergen. Geol. Mag., **108**, p. 27–42.
HARRIS L. B., COBBOLD P. R. (1985) — Development of conjugate shear bands during bulk simple shearing. J. Struct. Geol., **7**, p. 37–56.
HELMSTAEDT H., DIXON J. M. (1980) — Superposed crenulation cleavages resulting from progressive deformation. Tectonophysics, **66**, p. 115–126.
HOBBS B. E., MEANS W. D., WILLIAMS P. F. (1976) — An outline of structural geology. John Wiley and Sons. New York.
HOLDSWORTH R. E. (1990) — Progressive deformation structures associated with ductile-thrusts in the Moine Nappe, Sutherland, N Scotland. J. Struct. Geol., **12**, p. 443–452.
JACKSON J. (1992) — Partitioning of strike-slip and convergent motion between Eurasia and Arabia in Eastern Turkey and the Caucasus. J. Geophys. Res., **97**, p. 12 471–12 479.
KOZŁOWSKA-KOCH M. (1973) — Polymetamorphites of the Złoty Stok–Skrzynka dislocation zone (in Polish with English summary). Geol. Sudetica, **8**, p. 121–160.
KRANTZ R. W. (1995) — The transpressional strain model applied to strike-slip, oblique-convergent and oblique-divergent deformation. J. Struct. Geol., **17**, p. 1125–1137.
KRÖNER A., JÄECKEL P., OPLETAL M. (1994) — Pb-Pb and U-Pb zircon ages for orthogneisses from eastern Bohemia: further evidence for a major Cambro-Ordovician magmatic event. J. Czech Geol. Soc., **31**, p. 61–61.
LAW R. D., KNIPE R. J., DAYAN H. (1984) — Strain partitioning within thrust sheets: microstructural and petrographic evidence from the Moine Thrust zone at Loch Eriboll, northwest Scotland. J. Struct. Geol., **6**, p. 477–497.
LISTER G. S., SNOKE A. W. (1984) — S–C mylonites. J. Struct. Geol., **6**, p. 617–638.

LISTER G. S., WILLIAMS P. F. (1983) — The partitioning of deformation in flowing rock masses. Tectonophysics, **92**, p. 1–33.

MALOUSKI H., RAJLICH P., SOUEK J. (1995) — Pre-variscan, Variscan and Early Alpine thermo-tectonic history of the north-eastern Bohemian Massif: an Ar/Ar study. Geol. Rdsch., **84**, p. 345–358.

MAWER C. K., WILLIAMS P. F. (1991) — Progressive folding and foliation development in a sheared, coticule-bearing phyllite. J. Struct. Geol., **13**, p. 539–555.

MAZUR S., PUZIEWICZ J. (1995) — Deformation and metamorphism of rock series east of the Sowie Góry Block — new data and interpretations (in Polish with English summary). Prz. Geol., **43**, p. 786–793, no. 9.

MEANS W. D. (1990) — Kinematics, stress, deformation and material behaviour. J. Struct. Geol., **12**, p. 8.

MEANS W. D., HOBBS B. E., LISTER G. S., WILLIAMS P. F. (1980) — Vorticity and non-coaxiality in progressive deformations. J. Struct. Geol., **2**, p. 371–378.

MUSZER A. (1989) — The Orłowiec thrust and its relation to the Jawornik granitoids (Złoty Stok–Skrzynka dislocation zone) (in Polish with English summary). Acta Univ. Wratis., **1053**, Pr. Geol.-Miner., **15**, p. 31–48.

MUSZER A. (1995) — Geneza okruszcowania skał w Górach Złotych. In: Góry Złote — geologia, mineralizacje rudne i ekologia (ed. A. Muszer), p. 28–32. Mat. Konf. Nauk. Wrocław–Złoty Stok 9–10 czerwiec 1995.

NARĘBSKI W., WOJCIECHOWSKA I., DOSTAL J. (1988) — Geochemistry of metabasic rocks of the Kłodzko metamorphic unit: petrogenetic and palaeotectonic implications. In: Lower and Upper Palaeozoic metabasites and ophiolites of the Polish Sudetes (eds. W. Narębski, A. Majerowicz), p. 157–174. Wrocław.

OCZLON M. S. (1993) — Palaeogeographic and metamorphic evolution of the Ligerian Belt in Europe. In: Rhenohercynian and Subvariscan Fold Belts (eds. R. A. Gayer *et al.*). Vieweg Publishing. Wiesbaden.

OLDOW J. S., BALLY A. W., AVE LALLEMANT H. G. (1990) — Transpression, orogenic float, and lithospheric balance. Geology, **18**, p. 991–994.

OLIVER G. J., KELLEY W. (1993) — Ar-Ar fusion ages from the Polish Sudetes: Variscan tectonothermal reworking of Caledonian protoliths. N. Jb. Geol. Paläont. Abh., **6**, p. 321–334.

OLIVER G. J., CORFU F., KROGH T. E. (1993) — U-Pb ages from SW Poland: evidence for a Caledonian suture zone between Baltica and Gondwana. J. Geol. Soc. London, **150**, p. 355–369.

PASSCHIER C. W., SIMPSON C. (1986) — Porphyroblast systems as kinematic indicators. J. Struct. Geol., **8**, p. 831–843.

PIASECKI M., CYMERMAN Z. (1994) — Shear zones and gold in Sudeten (SW Poland) (in Polish only). Prz. Geol., **42**, p. 337–341, no. 5.

PIN C., MAJEROWICZ A., WOJCIECHOWSKA I. (1988) — Upper Palaeozoic oceanic crust in the Polish Sudetes: Nd-Sr isotope and trace element evidence. Lithos, **21**, p. 195–209.

PLATT J. P. (1983) — Progressive refolding in ductile shear zones. J. Struct. Geol., **5**, p. 619–622.

PLATT J. P. (1984) — Secondary cleavages in ductile shear zones. J. Struct. Geol., **6**, p. 439–442.

RAJLICH P. (1990) — Strain and tectonic styles related to Variscan transpression and transtension in the Moravo-Silesian Culmian basin, Bohemian Massif, Czechoslovakia. Tectonophysics, **174**, p. 351–367.

RIDLEY J. (1986) — Parallel stretching lineations and fold axes oblique to a shear displacement direction — a model and observations. J. Struct. Geol., **8**, p. 647–653.

ROBIN P. Y., CRUDEN A. R. (1994) — Strain and vorticity patterns in ideally ductile transpression zones. J. Struct. Geol., **16**, p. 447–466.

SANDERSON D. J., MARCHINI W. R. (1984) — Transpression. J. Struct. Geol., **6**, p. 449–458.

SIMPSON C. (1986) — Determination of movement sense in mylonites. J. Geol. Educ., **34**, p. 246–261.

SIMPSON C., SCHMID S. (1983) — An evaluation of criteria to deduce the sense of movement in sheared rocks. Geol. Soc. Am. Bull., **94**, p. 1281–1288.

SMULIKOWSKI K. (1979) — Polymetamorphic evolution of the crystalline complex of the Śnieżnik and Góry Złote Mts. in the Sudetes (in Polish with English summary). Geol. Sudetica, **14**, p. 7–79, no. 1.

SPECZIK S. (1994) — Metasomatic processes in the vicinity of the Kłodzko–Złoty Stok massif. In: 2nd Workshop on Variscan Metallogeny, p. 85–101. Cracow–Wrocław–Warsaw.

STELTENPOHL M. G., CYMERMAN Z., KROGH E., KUNK M. J. (1993) — Exhumation of eclogitized continental basement during Variscan lithospheric delamination and gravitational collapse, Sudety Mountains, Poland. Geology, **21**, p. 1111–1114.

SWANSON M. T. (1992) — Late Acadian Alleghanian transpressional deformation: evidence from asymmetric boudinage in the Casco Bay area, Coastal Maine. J. Struct. Geol., **14**, p. 323–341.

TAKAGI H., ITO M. (1988) — The use of asymmetric pressure shadows in mylonites to determine the sense of shear. J. Struct. Geol., **10**, p. 347–360.

TOBISCH O. T., PATERSON S. R. (1988) — Analysis and interpretation of composite foliations in areas of progressive deformation. J. Struct. Geol., **10**, p. 745–754.

URBAN M. (1992) — Kinematics of the Variscan thrusting in the Eastern Moldanubicum (Bohemian Massif, Czechoslovakia): evidence from the Naměšt granulite massif. Tectonophysics, **201**, p. 371–391.

VAN DER DRIESSCHE J., BRUN J. P. (1987) — Rolling structures at large shear strain. J. Struct. Geol., **9**, p. 691–704.

VAUCHEZ A. (1987) — Brevard fault zone, southern Appalachians: a medium-angle, dextral, Alleghanian shear zone. Geology, **15**, p. 669–672.

WEIJERMARS R., RONDEEL H. E. (1984) — Shear band foliation as indicators of sense of shear: field observations in central Spain. Geology, **12**, p. 603–606.

WOJCIECHOWSKA I. (1975) — Tectonics of the Kłodzko–Złoty Stok granitoids massif and its country rocks in the light of mesostructural investigations (in Polish with English summary). Geol. Sudetica, **10**, p. 61–121, no. 2.

WOJCIECHOWSKA I. (1986) — Metabasites in the NW part of the Śnieżnik metamorphic unit. Geol. Rdsch., **73**, p. 585–593.

WOJCIECHOWSKA I. (1993) — Geological setting and tectonics of the Złote Góry Mts and the Krowiarki Mts at the background for ore mineralization evolution (Ziemia Kłodzka, the Sudetes) (in Polish with English summary). Acta Univ. Wratis., **1412**, Pr. Geol.-Miner., **33**, p. 5–61.

WOJCIECHOWSKA I., GUNIA P. (1993) — Geotectonic position of metabasites of the border zone of the Śnieżnik metamorphic complex and the Skrzynka tectonic unit (Ziemia Kłodzka region, the Sudetes) (in Polish with English summary). Acta Univ. Wratis., **1412**, Pr. Geol.-Miner., **33**, p. 209–239.

WOJCIECHOWSKA I., NARĘBSKI W., DOSTAL J., PIN C. (1988) — Palaeotectonic setting of metabasites of NW part of the Śnieżnik metamorphic unit: geological and preliminary geochemical evidences. In: Lower and Upper Palaeozoic metabasites and ophiolites of the Polish Sudetes (eds. W. Narębski, A. Majerowicz), p. 157–174. Wrocław.

ŻABA J., BĘDKOWSKI Z. (1995) — Następstwo stref ścinania w NE części metamorfiku Śnieżnika (na przykładzie polimetamorfitów z kamieniołomu „Złoty Jar" w Złotym Stoku). In: Góry Złote — geologia, mineralizacje rudne i ekologia (ed. A. Muszer), p. 20–27. Mat. Konf. Nauk. Wrocław–Złoty Stok 9–10 czerwiec 1995.

Zbigniew CYMERMAN

REGIONALNA STREFA ŚCINANIA ZŁOTEGO STOKU–TRZEBIESZOWIC: GRANICA TERRANÓW W GÓRACH ZŁOTYCH (SUDETY)

Streszczenie

Przedstawiono wyniki analizy strukturalnej i kinematycznej z północnej części Gór Złotych (Sudety), gdzie znajduje się jedna z najbardziej znanych w Sudetach strefa tektoniczna. Strefa ta była najczęściej określana jako strefa tektoniczna Złotego Stoku–Skrzynki; obecnie została ona poprawniej zdefiniowana jako strefa ścinania Złotego Stoku–Trzebieszowic. Strefa ta przebiega generalnie w kierunku NE–SW od okolic Trzebieszowic aż po rejon Złotego Stoku w pasie o szerokości prawie do 4 km. W strefie tej udokumentowano dominację mechanizmów ścinania prostego (rotacyjnego) w warunkach podatnych (plastyczno-krystalicznych), ale ze zmieniającymi się etapami dynamicznego odzyskania i dynamicznej rekrystalizacji. Podatne lewoskrętne przemieszczenia w tej strefie spowodowały przemieszczenia wyżejległych pakietów skalnych ku SSW w warunkach lewoskrętnej transpresji, podobnej do sytuacji z lewoskrętnej strefy ścinania Niemczy, położonej bardziej na północ na bloku przedsudeckim.

Procesy porozdzielania deformacyjnego odegrały znaczącą rolę podczas ewolucji strukturalnej tej regionalnej strefy tektonicznej. Rozwój strefy zinterpretowano jako ściśle związany ze skośną kolizją terranu moldanubskiego, którego częścią jest metamorfik Śnieżnika, i terranu środkowosudeckiego, którego najbardziej peryferyjną, południowo-wschodnią częścią jest rozpatrywana regionalna strefa tektoniczna. Do kolizji tej i wywołanej przez nią lewoskrętnej transpresji w tej części Sudetów doszło podczas orogenezy waryscyjskiej (dewon górny-karbon dolny).