Geological Quarterly, Vol. 36, No. 4, 1992, p. 393–420

Zbigniew CYMERMAN

Rotational ductile deformations in the Śnieżnik metamorphic complex (Sudetes)

The Śnieżnik metamorphic complex was deformed during the Variscan orogeny by noncoaxial (rotational) deformations (simple shears). These deformations seems to be both longlived and widespread. Different asymmetrical structures was developed by the progressive rotational deformation. These kinematic indicators include e. g: σ and δ type of porphyroclasts and planar structures S–C and SB (C'). The asymmetrical ones are the most important to determine the sense of shear in the XZ plane of finite ellipsoid deformation. The kinematic analyses of Polish part of the Śnieżnik metamorphic complex indicate general tectonic transport northwards during dextral transpression. The tectonic transport in the western part of this complex (Bystrzyckie and Orlickie Mts.) was top-to-northwest. This ductile displacement was top-to-northeast in the eastern part of the Śnieżnik metamorphic complex. Moreover, in the northernmost one the sense of shear was opposite (sinistral wrenching and top-to-southwest). These complex structural patterns explain a fan-like virgation of Lądek. The change of tectonic processes in this part of complex may be connected with the presence of a dismembered ophiolite sequence and arc volcanites in the northeastern periphery of the Bohemian Massif (so called the Sudetian terrane).

INTRODUCTION

During last ten years the shear zones have been recognized and detaily characterized (see: D. Berthé et al., 1979; G. S. Lister, P. J. Williams, 1979; S. H. White et al., 1980; G. S. Lister, A. W. Snoke, 1984; S. H. White et al., 1986; S. Hanmer, 1988; G. Guerin et al., 1990). Such shear zones were found in most of orogenic belts on whole Earth, among them — in the Alps (e.g. S. M. Schmid et al., 1987), Appalachian Mts. (e.g. M. A. Piasecki, 1988; M. G. Steltenpohl, 1988) and in the Variscan belt of Europe (e.g. H. J. Behr, 1980; P. Rajlich, 1987; G. H. Eisbacher et al., 1989; P. Matte et al., 1990; Z. Cymerman, 1991*a*, *b*, *c*; K. Schulmann et al., 1991).

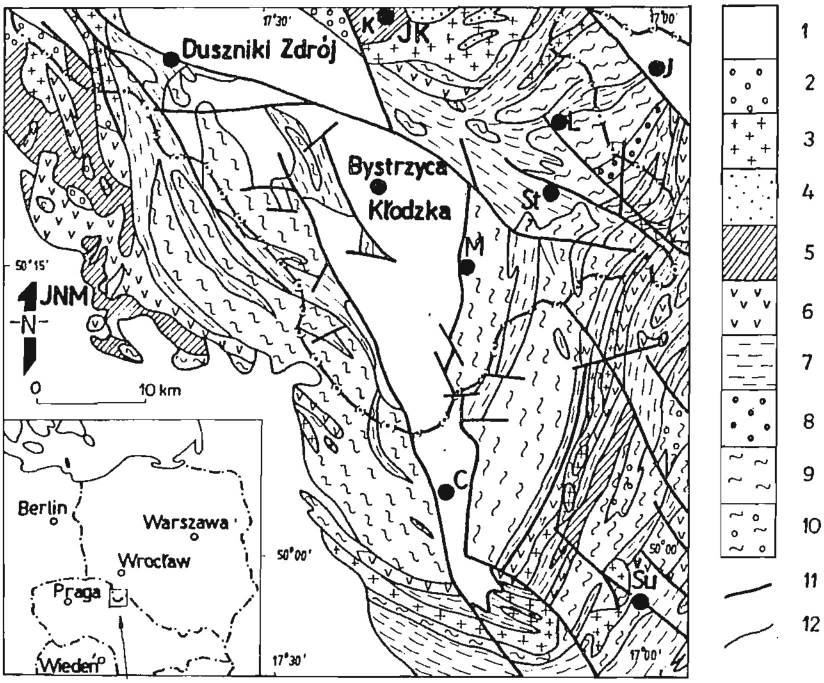

Fig. 1. The simplified geological map of the Śnieżnik metamorphic complex and neighbouring geological units

JNM — Nové Město Unit; JK — Kłodzko Unit; cities: C — Červena Voda, J — Jawornik, K — Kłodzko, L — Lądek Zdrój, M — Międzygórze, St — Stronie Śląskie, Šu — Šumperk; 1 — Upper Cretaceous and younger sedimentary rocks; 2 — Permian conglomerates and sandstones; 3 — Variscan granitoids; 4 — Lower Permian sedimentary rocks; 5 — epimetamorphic series, mainly phyllites and metavolcanites; 6 — undivided metavolcanic rocks and amphibolites; 7 — undivided supracrustal rocks of the Stronie Group (Series), mainly micaceous schists and plagioclase paragneisses with interbeds of quartzites and marbles and also micaceous schists of the Zabřeh Unit (southward from Červena Voda); 8 — granulites with eclogite intercalations; 9 — undivided gneisses (Gierałtów, Śnieżnik, Bystrzyca, Haniak, transitional); 10 — the Keprnik Gneisses; 11 — major faults; 12 — geological boundaries

Uproszczona mapa geologiczna metamorfiku Śnieżnika i sąsiednich jednostek geologicznych

JNM — jednostka Nového Města; JK — jednostka Kłodzka; miasta: C — Cervena Voda, J — Jawornik, K — Kłodzko, L — Lądek Zdrój, M — Międzygórze, St — Stronie Śląskie, Šu — Šumperk; 1 — górnokredowe i młodsze skały osadowe; 2 — zlepieńce i piaskowce permskie; 3 — granitoidy waryscyjskie; 4 — dolnokarbońskie skały osadowe; 5 — epimetamorficzne serie, głównie fyllity i skały metawulkaniczne; 6 — nie rozdzielone skały metawulkaniczne i amfibolity; 7 — nie rozdzielone utwory suprakrustalne grupy (serii) strońskiej, głównie łupki łyszczykowe i paragnejsy plagioklazowe z wkładkami kwarcytów i marmurów oraz łupki łyszczykowe jednostki Zabřeha (na południe od Cervenej Vody); 8 — granulity z wkładkami eklogitów; 9 — gnejsy nie rozdzielone (gierałtowskie, śnieżnickie, bystrzyckie, haniackie, przejściowe); 10 — gnejsy Keprnika; 11 — ważniejsze uskoki; 12 — granice geologiczne

The shear zones occur between the geological units or terranes as well as inside individual geological units and terranes. In many cases such zones were up till now unrecognized. It was due to their generation in deeper parts of Earth crust, mainly in the conditions of amphibolitic facies of a regional metamorphism. There have developed numerous ductile shear zones, generally very broad — up to several hundred meters or several kilometers wide — and of transitional, hardly discernible boundaries (e.g. M. A. Piasecki, 1988; M. G. Steltenpohl, 1988; W. J. Collins, C. Teyssier, 1989; A. G. Goldstein, 1989; R. D. Nance, J. B. Murphy, 1990). Distinguishing of these zones is particulary difficult on areas of the ductile thrusting, where the penetrative foliation within overthrusted rock domains is parallel in general to the ductile shear zones. Such situation is noticed on area of the whole Śnieżnik metamorphic complex in the Middle Sudetes (SW Poland).

New, detailed structural studies of the author, done for all Polish part of the Śnieżnik metamorphic complex, indicate that the dominated mechanism of deformations for this part of the Middle Sudetes were **the rotational (noncoaxial)** [1] **deformations.** Most typical example of such deformation is **the simple shear** [2], which corresponds with **the plane strain** [3] in case of a **homogenous deformations** [4]. The ductile shear zones of the Śnieżnik metamorphic complex have origined due to noncoaxial (rotational) processes of laminar flow during two main progressive phenomena (D_1 and D_2), including dextral and locally sinistral **transpresion** [5] (D_1) and

[1] The rotational deformation or noncoaxial deformation — such deformation characterizes with rotation (position change) of X and Z axes of the incremental strain ellipsoid ($X > Y > Z$) in relation to X and Z axes of the finite strain ellipsoid during the deformation history of studied geological medium. Position of Y axis of both ellipsoids unchanged. In other way: deformation type with non-zero value of component of rotation.

[2] The simple shear relates to type (class) of deformation as well as to mode of accumulation of deformation within geological medium. In last case it is the kinematic term. The *kinematic definition*: simple shear — noncoaxial, rotational, with constant volume of medium, planar movement (flow) with dominant rotational component and with suitable component of stretching (pure shear), enough to sustain one assemblage of material lines at the angle of 45° to stretching direction (style of the overturned pack of cards). The *deformation definition*: simple shear — planar deformation, of constant volume, rotational deformation with suitable value of rotational component around Y axis, which enables to locate one of the circles of strain ellipsoid in the same position in deformed and non-deformed stages.

[3] The plane strain or biaxal strain — deformation type, in which the intermediate Y axis of the deformation ellipsoid has still the same length as the sphere diameter, determining the strain ellipsoid, it means — $X > Y=1 > Z$.

[4] The homogenous deformation — initial straight and parallel lines became after deformation still straight and parallel. In other way: the displacement gradient is constant in deformed geological medium.

[5] The transpression is definited as the deformation origined due to the oblique convergency of the plates, it means — as the triaxial and rotational deformation, consisted of the strike-slip and contraction shortening (tectonic thickenning) components.

later dextral **transtension** [6] (D_2). The results of kinematic analysis, based on various estimation methods of the sense of shear (e.g. C. Simpson, S. Schmidt, 1983; C. W. Passchier C. Simpson, 1986; Z. Cymerman, 1989*b*) and related to the direction of tectonic transport, marked with the orientation of extensional (mylonitic) lineation (Z. Cymerman, 1989*a*), have thrown new light on the tecto-metamorphic evolution of the whole Śnieżnik metamorphic complex. Hitherto existing tectonic models have established the eastward tectonic transport of overlaying rock packages (see: F. Pauk, 1953; H. Teisseyre, 1975, 1980; A. Żelaźniewicz, 1988, 1991; J. Don et al., 1990) and they should be omitted in the light of new data, refering to kinematics of the Śnieżnik metamorphic complex (Z. Cymerman, 1990, 1991*a*, *b*, *d*; R. Grygar et al., 1991).

The aim of this paper is the new model of the Variscan evolution of the Śnieżnik metamorphic complex, based on the results of kinematic analysis of distinguished there ductile shear zones.

AN OUTLINE OF GEOLOGICAL PATTERN OF THE ŚNIEŻNIK METAMORPHIC COMPLEX

The Śnieżnik metamorphic complex (*sensu lato*), described in literature as the Orlickie — Śnieżnik Mts. (see: J. Don et al., 1990) or the Orlickie Mts. — Kłodzko dome (see: M. Opletal et al., 1980), consists of two lithostratigraphic units (groups):

— Stronie Group (Series), composed of the motley supracrustal complex (micaceous schists, plagioclase paragneisses with intercalations and interbeds of quartzities, quartzitic schists, amphibolites, amphibolitic schists, limestones and crystalline dolomites);

— Gneissic Group, composed of various kinds of gneisses (locally described as: the Śnieżnik, Bystrzyca, Gierałtów, transitional, mixed and Haniak types of gneisses), which are included within the infracrustal complex (see: J. Don, 1964; M. Dumicz, 1964; L. Kasza, 1964; H. Teisseyre, 1975, 1980; K. Smulikowski, 1979; J. Don et al., 1990).

The Śnieżnik metamorphic complex is surrounded from all sides with basic rocks (amphibolites and metavolcanic rocks) or with the strongly elongated intrusions of the Variscan granitoids (Fig. 1). The basic rock complexes and syn-kinematic or late-kinematic granitoids separate the Śnieżnik metamorphic complex from less metamorphosed geological units as the epimetamorphic units of Nové Město complex or Kłodzko metamorphic tarrain.

The opinions about the age of the metamorphic rocks of Śnieżnik complex are controversial and refer both to the Stronie and Gneissic groups. Most of scientists have accepted the Precambrian age of the Stronie Group (see among others: J. Oberc, 1957, 1972; L. Kasza, 1964; J. Gierwielaniec, 1971; H. Teisseyre, 1957, 1968, 1975,

---

[6] The transtension — the triaxial and rotational deformation, composed of the strike-slip and stretching (extension, tectonic thinning) components.

1980; K. Smulikowski, 1979). The German geologists have assumed the Algonkian age for lower part of the Stronie Group but for upper one — the Cambrian dating (G. Fischer, 1936; E. F. Vangerov, 1943). The micropaleontological studies of T. Gunia (see: 1974, 1984*a, b*) indicate that at least the part of deposits of the Stronie Group could accumulated during the Middle Cambrian.

The age of both Gierałtów (grey fine-crystalline, migmatic) and Śnieżnik (redish-grey augen, mylonitic) gneisses is still discussed. From the time of division of gneisses from the Śnieżnik metamorphic complex (G. Fischer, 1936) for the Gierałtów and Śnieżnik ones they had various and controversial age and structural interpretations:

a — the Gierałtów Gneisses are older than Śnieżnik ones (see: G. Fischer, 1936; the Gierałtów Gneisses are of Archean age but the Śnieżnik ones — of Older Palaeozoic);

b — the Gierałtów and Śnieżnik gneisses are coeval (see: K. Smulikowski, 1957, 1979; J. Oberc, 1957, 1977; J. Ansilewski, 1966);

c — the Gierałtów Gneisses are younger than the Śnieżnik ones (J. Don, 1964, 1982);

d — the Gierałtów Gneisses could be older, coeval or younger than the Śnieżnik ones because exist there two generations of various age within them (Z. Cymerman, 1984, 1988*b*);

e — the younger Gierałtów Gneisses are synchronous in their development with generation of the Śnieżnik ones (M. Dumicz, 1988, 1989).

The occurrence of non-synchronous in age and different in origin gneisses within the Śnieżnik metamorphic complex is now unquestionable (J. Don et al., 1990). It seems now mostly reasonable an application of the structural and/or genetic terms instead of hitherto existing, classic, regional terminology of gneisses of the Śnieżnik metamorphic complex (G. Fischer, 1936).

Up till now the most of geologists have connected the origin of both mentioned gneiss types with the Cadomian (Assyntian; Pan-African) orogenesis (com. J. Oberc, 1957, 1972, 1977; K. Smulikowski, 1957, 1979; L. Kasza, 1964; H. Teisseyre, 1957, 1968). J. Don (1982) dated the Śnieżnik Gneisses origin for the transition between the Middle and Upper Cambrian or for Lower Ordovician but for the Gierałtów Gneisses he assumed the age — between Lower and Middle Devonian (J. Don et al., 1990). M. Dumicz (1976, 1979, 1988, 1989) connected generation of both gneiss types with the Variscan orogenesis.

The isotopic studies of the Śnieżnik metamorphic complex are scarce and difficult for univocal interpretations. The radiometric data for biotite (382±16 Ma) and for fengite (384±16 Ma), resulted from K-Ar studies (N. Bakun-Czubarow, 1968), were interpreted as an uplifting of the Śnieżnik metamorphic complex through the isograde of 250–300°C. The biotite came from the Gierałtów gneiss but fengite — from an eclogite. The similar studies of biotite from gneisses from Czecho-Slovakia (Orlické Hory Mts.) gave the age values of: 331±17 Ma, 315±15 Ma and 310±15 Ma (M. Opletal et al., 1980). Similar results, using the same dating method, were obtained for biotite from the mica schists of the Stronie Group and for muscovite from the Bystrzyca Gneisses — 315±15 Ma (M. Opletal et al., 1980).

The results of hitherto done isotopic studies, using the Rb-Sr method, are as follows:

— 487±11 Ma for whole rock from gneiss of the Śnieżnik type (?) from vicinity of Žulova in Czecho-Slovakia (O. van Breemen et al., 1982);

— 464±18 Ma for whole rock from gneisses of the Gierałtów type (M. Borkowska et al., 1990);

— 395±35 Ma for whole rock from gneiss of the Śnieżnik type (M. Borkowska et al., 1990);

— 395±35 Ma for whole rock from gneiss of the Śnieżnik type (M. Borkowska et al., 1990);

— 335±5 Ma for biotite and muscovite from gneiss of the Śnieżnik type (M. Borkowska et al., 1990).

However, the radiometric dating, obtained with the Sm-Nd method for gneisses of the Śnieżnik type is about 490 Ma (D. C. Liew, A. W. Hofmann, 1988). Data from the Śnieżnik eclogites, obtained with the same method, are as follows: 352±4 Ma, 341±7 Ma, 337±4 Ma and 329±6 Ma but from granulite — 341 Ma (N. Bakun-Czubarow, H. K. Brueckner, 1991).

The new isotopic studies, using the $^{40}Ar/^{39}Ar$ method (M. G. Steltenpohl et al., 1991) gave such results:

— 328.8±1.7 Ma — plateau age for muscovites from gneissic mylonites nearby Duszniki Zdrój;

— 328.8±1.7 Ma for muscovites from migmatitic gneiss from Lądek Zdrój;

— 327±2 Ma — nearly "plateau" age for hornblende from amphibolites nearby Lewin Kłodzki (with slightly marked discordance and correlation graph of $^{36}Ar/^{39}Ar$, indicating the isochrone age of 338 Ma);

— 342.2 Ma with about ±10–12 Ma for hornblende from amphibolites nearby Bielice (with distinct saddle-shaped graph and $^{36}Ar/^{39}Ar$ correlation suggesting isochrone age of 332 Ma);

— 328 Ma for biotite from migmatitic gneiss from Lądek Zdrój.

The radiometric data, obtained with the $^{40}Ar/^{39}Ar$ method, reflect the time of cooling of metamorphic rocks during their uplifting throughout the isotherms: 500°C for hornblende, about 350°C for muscovite and 300°C for biotite. These results indicate the rapid cooling, connected with quick uplift of the Śnieżnik metamorphic complex during the Lower Carboniferous time.

DUCTILE SHEAR SYSTEMS IN THE ŚNIEŻNIK METAMORPHIC COMPLEX

The field studies, confirmed with microstructural analysis on oriented thin sections in XZ plane indicate an occurrence of very numerous (penetrative) ductile hear zones on the area of whole Śnieżnik metamorphic complex, both within rocks of the Stronie Group and the Gneissic Group. The ductile shear zones are marked in general by the development of typical mylonitic fabric. This fabric has origined due to processes of

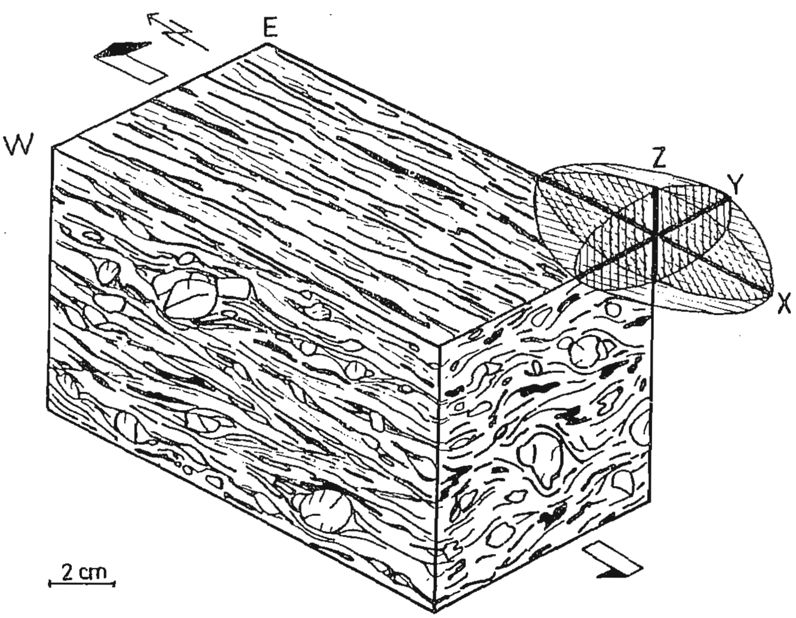

Fig. 2. The blockdiagram of extensive lineation morphology from orthogneisses nearby Duszniki Zdrój (rodding type of lineation L_{1+2}) and of orientation of main axes of finite strain ellipsoid (X > Y > Z); XZ plane used to determine the shear sense (here: *sinistral, top toward the north*)

Blokdiagram przedstawiający morfologię lineacji ekstensyjnej w ortognejsach okolic Dusznik Zdroju (typ pręcikowy — roddingowy — lineacji L_{1+2}) i orientację głównych osi elipsoidy odkształcenia końcowego (X > Y > Z); płaszczyzna XZ wykorzystywana jest do określania zwrotu ścinania (*tutaj: lewoskrętne, tzn. „góra na północ"*

plastic-crystalline reduction of size of mineral grain and synchronous dynamic recrystallization of grain due to mechanism of dislocation creep.

The microstructural studies indicate that noncoaxial laminar flow was characteristic feature of ductile shear deformation zones within rocks of the Stronie Group and within various gneiss types. The observations of the XZ sections of finite strain ellipsoid (Fig. 2) in mylonitic gneisses (of the Śnieżnik and Bystrzyca types) document all assemblages of asymmetric porphyroclasts of feldspars, mainly of σ type, as well as, more rare, porphyroclasts of δ and ϕ types (C. W. Passchier, C. Simpson, 1986). Primary phenocrystalls of K-feldspar have been transformed due the plastic-crystalline processes into porphyroclasts of σ type with characteristic, recrystallized pressure shadows (tails) — Figs. 3, 4. More microscopic data, related to mylonitic texture of gneisses, are presented in the paper of A. Żelaźniewicz (1984, 1988).

The most typical microstructural features in metasedimentary rocks of the Stronie Group, indicating the deformations of simple shear, are structures of subgrain type, quartz ribbons and intensive fabric asymmetry (Fig. 5). Quartz recrystallized due to

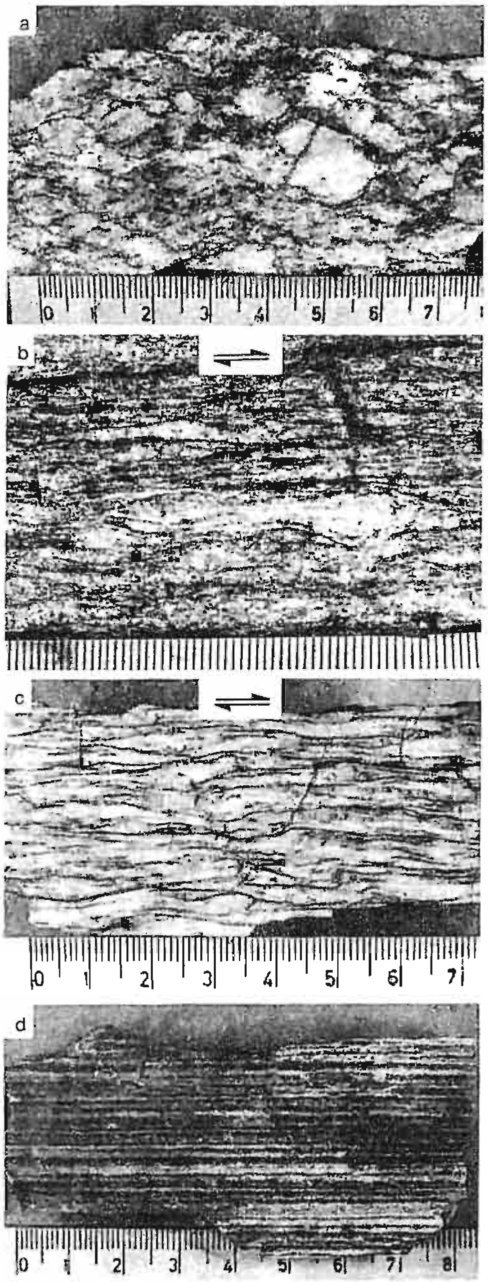

Fig. 3. The stages (a–d) of progressive strain increment, resulted from simple shear (rotational deformation); mylonitic gneisses of the Śnieżnik type from Międzygórze (the Śnieżnik Mts.)

Etapy (a–d) progresywnego wzrostu odkształcenia ze ścinania prostego (rotacyjnego); mylonityczne gnejsy typu śnieżnickiego z Międzygórza

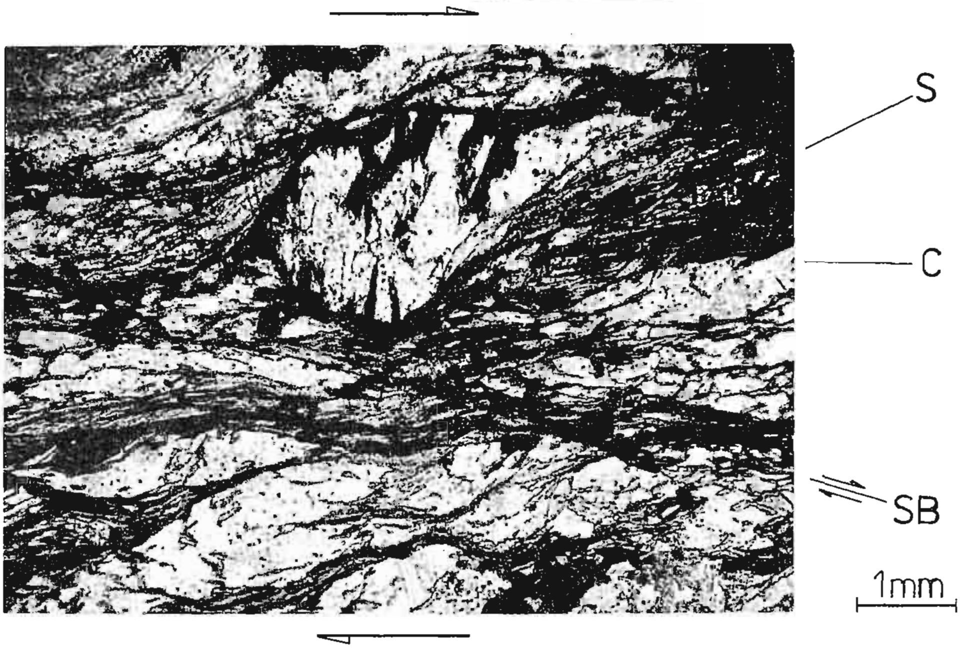

Fig. 4. K-feldspar of σ-porphyroclast type with dextral sense of shear. S–C mylonitic structure and mylonitic bands SB (C') and extensional fractures inside the feldspar indicate also dextral rotation (up to NW). Augen gneiss nearby Duszniki Zdrój (Bystrzyckie Mts.). Parallel nicoles

Skaleń potasowy typu σ-porfiroklast o prawoskrętnym zwrocie ścinania. Struktura mylonityczna S–C i pasemka mylonityczne SB (C') oraz spękania ekstensyjne wewnątrz skalenia wyznaczają również prawoskrętną rotację (góra ku NW). Gnejs oczkowy z okolic Dusznik Zdroju. Nikole równoległe

migration of grain boundaries during recrystallization, forming distinct orientation of grain shapes. Foliation planes (S), oriented parallel to XY plane of the finite strain ellipsoid, are marked by systems of parallel quartz ribbons and oriented shapes of mineral grains. S planes are often syntetically curved, transforming successively into shear planes C (see: D. Berthé et al., 1979; G. S. Lister, A. W. Snoke, 1984; Z. Cymerman, 1989*b*).

The intensive classical structural studies have been carried out on the area of the Śnieżnik metamorphic complex during over thirty years. Various numbers of deformation phases of this metamorphic complex were described using classical methods of structural analysis — from three phases (D_3) up to seven (D_7), for instance: H. Teisseyre (1968, 1975), J. Don (1982), Z. Cymerman (1982, 1984, 1988*b*), M. Dumicz (1976, 1979, 1988), I. Wojciechowska (1972, 1986), S. Cwojdziński (1977, 1982), A. Żelaźniewicz (1972, 1976, 1984, 1988). These interpretations, based on traditional studies of fold geometry, could be recently questioned because **the progressive defor-**

Fig. 5. The fabric asymmetry with dextral sense of shear indicated by S–C relationships. Crossed nicoles. Micaceous schists of the Stronie Group nearby Bielice (Bialskie Mts.), eastward from Stronie Śląskie
Asymetria więźby o prawoskrętnym zwrocie ścinania (S–C). Nikole skrzyżowane. Łupki łyszczykowe grupy strońskiej, okolice Bielic (Góry Bialskie), na E od Stronia Śląskiego

mation [7], connected with noncoaxial (rotational) plastic-crystalline processes (ductile simple shearing), has occurred on the whole area of the Śnieżnik metamorphic complex. The rotational deformations contributed to intensive development of non-cylindrical folds with strongly curved hinges, which could be interpreted as "polyphase" fold structures (Figs. 6, 7). Origin of such fold structures confirms rather the model of continuous, progressive deformations than the schemes of tectonic evolution, basing on principles of an existence of individual deformation phases, separated with periods of tectonic "silence". In new structural analysis of the Śnieżnik metamorphic complex an influence of deformation partitioning should be taken into consideration and connected with it a cooperation or coexistence of simple shear (rotational) processes together with pure (non-rotational) shearing (see: Z. Cymerman, 1988*a*). In the light of such discussion it is more of less probable to assume that the assemblages of tectonic structures on area of the Śnieżnik metamorphic complex have formed due to following stages of progressive deformation in conditions of unchanged regional stress fields.

[7] The progressive deformation — the series of deformation increments, expressed as the incremental strain ellipsoids during all history of the deformation of geological medium up to final stage, presented in form of the finite strain ellipsoid.

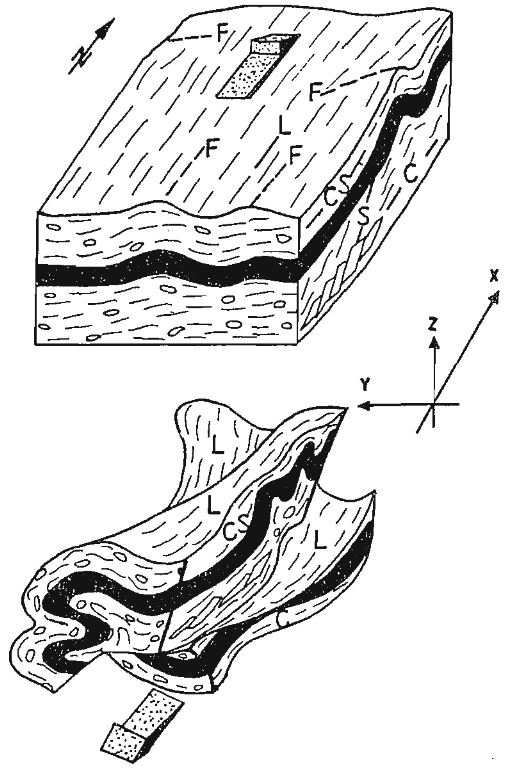

Fig. 6. The progressive development of non-cylidrical fold structures with axes (F) oblique or quite parallel to extensive lineation (L). The Śnieżnik S–C mylonitic gneisses nearby Międzygórze

Progresywny rozwój niecylindrycznych struktur fałdowych o osiach (F) skośnych lub prawie równoległych do lineacji ekstensyjnej (L). Gnejsy śnieżnickie z okolic Międzygórza; typ mylonitu S–C

The oldest, distinguished stage of deformation D_1 caused the origin of so rarely preserved mesofolds F_1, which have deformed primary lithological contacts S_0 (?). The axial planes of these folds are parallel to foliation (type of recrystallized schistosity) S_1, which was strongly transformed (transposition and reactivation processes) during successive stages of progressive deformation, mainly in next stage D_2.

During the continuous deformation stage D_2 very numerous group of fold structures F_2, with significantly differentiated morphology, has developed. The F_2 folds have formed most frequently in the micaceous schists and paragneisses of the Stronie Group. Most of the F_2 folds belong to type of tight or isoclinal structure, they have mainly non-cylindrical form and locally developed S_2 axial foliation (Figs. 7–9). Distinguishing of older, folded S_1 foliation from axial S_2 one is not so easy, even within hinge parts of F_2 folds. It is caused by similar mineral assemblage (quartz, feldspars, micas), marking S_1 and S_2 foliation planes as well as by reactivation of older S_1

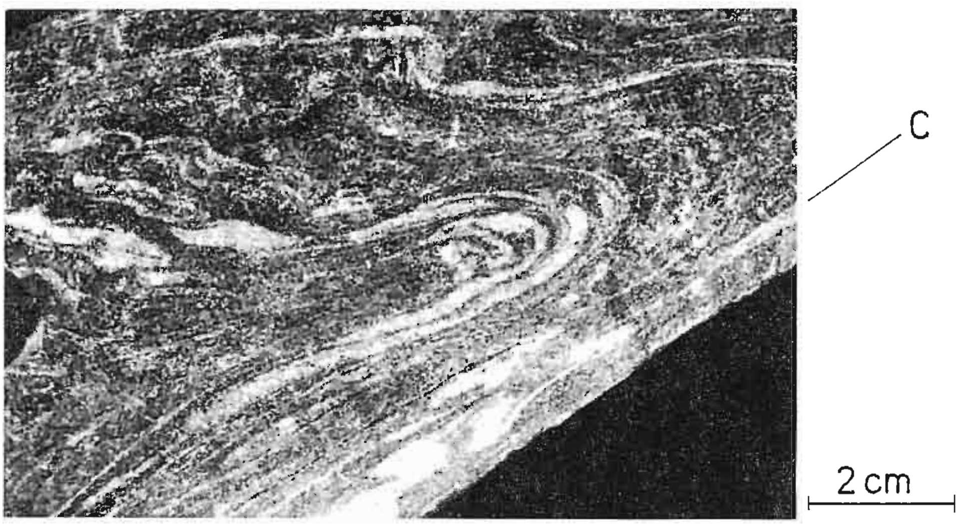

Fig. 7. The disharmonious, "polyphase" fold structures with interference structures, interpereted as: 1 — index of successive three phases of deformations (F_1, F_2, F_3); 2 — result of deformational partitioning of total deformation for a component of simple shear along with shear zones (C) and of contraction (pure shear). Graphitic schists nearby Lądek Zdrój (Złote Mts.). The Stronie Group

Dysharmonijne, „polifazowe" struktury fałdowe o interferencyjnej budowie, które można interpretować jako: 1 — wskaźnik kolejnych trzech faz deformacji (F_1, F_2 i F_3); 2 — efekt porozdzielania deformacyjnego totalnej deformacji na składową ścinania prostego (C) i skracania (ścinania czystego). Łupki grafitowe okolic Lądka Zdroju (Góry Złote). Grupa strońska

foliation during following stages of progressive deformation (comp. Z. Cymerman, 1988*a*). Due to that the variaged S_1 and S_2 foliations are practically undistinguishable, except some fragments of the hinge parts of F_2 mesofolds but only after detailed microscopic studies. Concluding this it seems possible to assume that penetrative, regional foliation in the Śnieżnik metamorphic complex is composite planar structure S_{1+2}. The augen-like isoclinal folds, deforming S_1 foliation and having limbs parallel to mylonitic foliation S_2, should be interpreted as fold structures, formed during D_2 deformation or significantly modified in shape and rotated in zones of simple shear (Figs. 6, 7). The F_2 folds are commonly non-cylindrical, with geometry similar to the sheath folds but their hinge line points partly banded structure on stereographic projection.

During increment of the next D_3 deformation numerous F_3 folds have formed, which folded penetrative foliation S_{1+2}. In general they are open folds, asymmetric, sometimes disharmonious (Figs.7, 8). Their coaxiality with F_2 folds as well as — in same range — similarity of their geometric forms indicate that the increments of D_2 and D_3 deformations have occurred in unchanged fields of regional stresses and of conditions of regional metamorphism.

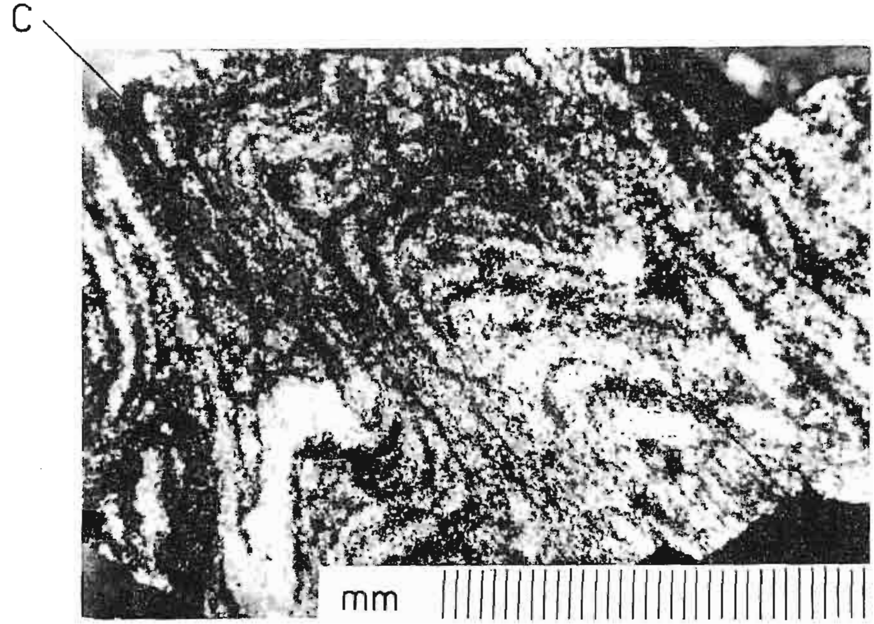

Fig. 8. Typical, disharmonious fold structures within migmatized gneisses of the Gierałtów type. Characteristic similarity of their deformation style to schists of the Stronie Group (see — Fig. 7). The example of deformational partitioning for ductile zones of simple shears and domains of progressive, synchronous contraction (ptygmatitic, disharmonious and intrafoliational folds). Lądek Zdrój

Typowe, dysharmonijne struktury fałdowe w gnejsach zmigmatytyzowanych (typu gierałtowskiego). Charakterystyczne podobieństwo stylu deformacji tych gnejsów do łupków grupy strońskiej (por. fig. 7). Przykład porozdzielania deformacyjnego na podatne strefy ścinań prostych i domen progresywnego, synchronicznego skracania (fałdy ptygmatytowe, dysharmonijne i śródfoliacyjne). Lądek Zdrój

The later deformation stages have taken place in changed conditions of pressures and temperatures (quick retrogression of regional metamorphism, documented with new radiometric data (N. Bakun-Czubarow, H. K. Brueckner, 1991; M. G. Steltenpohl et al., 1991). The D_4 deformation stage characterized with development of folds of kink bands and chevron types as well as of open F_4 folds within slightly developed S_4 axial plane cleavage. During the D_5 deformation stage have formed the F_5 folds and large deflections as well as kink-bank flexures and rare structures of "drag joints" type. Younger than the D_5 stage are numerous rock fractures, belonging to many generations but forming in wide time range — from Younger Paleozoic till Quaternary.

The penetrative lineations of mineral grains and aggregates are marked within the Gneissic Group by directionally elongated augens spindles, rods and mineral aggregates (quartz and feldspars) as well as by directioned mica packages. Within micaceous schists and plagioclase paragneisses the lineation of mineral grain is definited by directionally elongated aggregates of micas and by rods, spindles and ribbons of quartz or plagioclases.

The lineations of mineral grain are developed always on the planes of regional foliation (S_{1+2}) and they are now — in general — plunged at angles less than 40–50°.

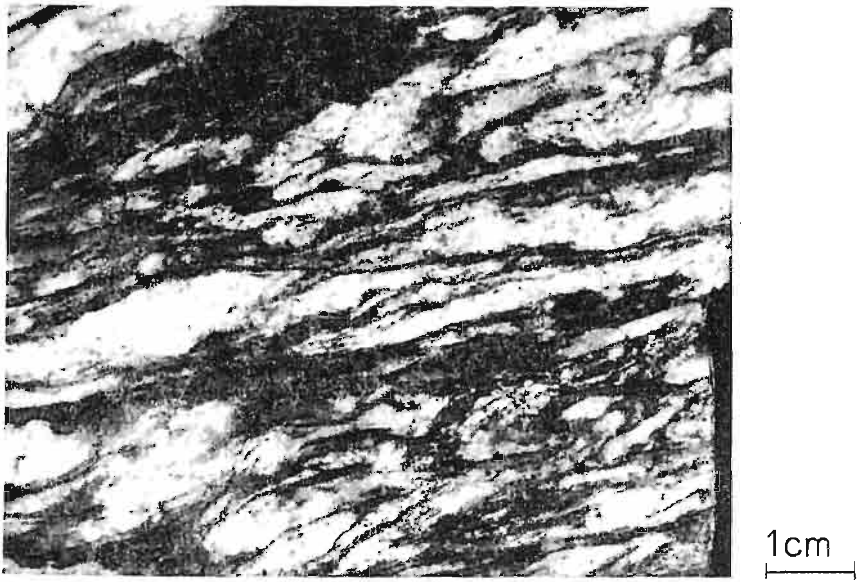

Fig. 9. The mylonite of S–C type and asymmetric intrafoliational folds (intramylonitic). Dextral shear. Plagioclase paragneisses of the Stronie Group, surroundings of Stronie Śląskie (Krowiarki Hills)
Mylonit typu S–C oraz asymetryczne fałdy śródfoliacyjne (śródmylonityczne). Prawoskrętne ścinanie. Paragnejsy plagioklazowe grupy strońskiej. Okolice Stronia Śląskiego (Krowiarki)

These lineations are oriented almost parallel to axes of F_1 and F_2 folds isoclinal but they are more and more oblique to folds of larger interlimb angle. Such observations document well the processes of progressive shear deformation, which involve rotation and modification of fold shapes — firstly broad and open structures after increase the value of shear deformations. The significant obliqueness of orientation, between mineral grain lineation and axes of majority of open folds as well as of crenulations, have not to indicate variaged development of fold and linear structures. On the contrary, the noncoaxiality of such structures could result from their synchronous development but only in condition of their origin during the progressive simple shearing (noncoaxial deformation) — see: A. J. Dennis, D. T. Secor (1987, 1990).

In sections perpendicular to S_{1+2} foliation and parallel to mineral grain lineation — it means: in section XZ of finite strain ellipsoid — are noticed numerous examples (in various scales) of progressive development of lineation of rodding type during increase of simple shear deformations (Figs. 2, 3). During increase of deformation stage in conditions of simple (rotational) shearing primary large megacrystals of K-feldspars became more prolate and directionally elongated. The reduction of grain size causes the development of distinctly asymmetric eyes and spindles of feldspars, mainly of microcline, described as σ type of porphyroblasts (C. W. Passchier, C. Simpson, 1986; Z. Cymerman, 1989*b*).

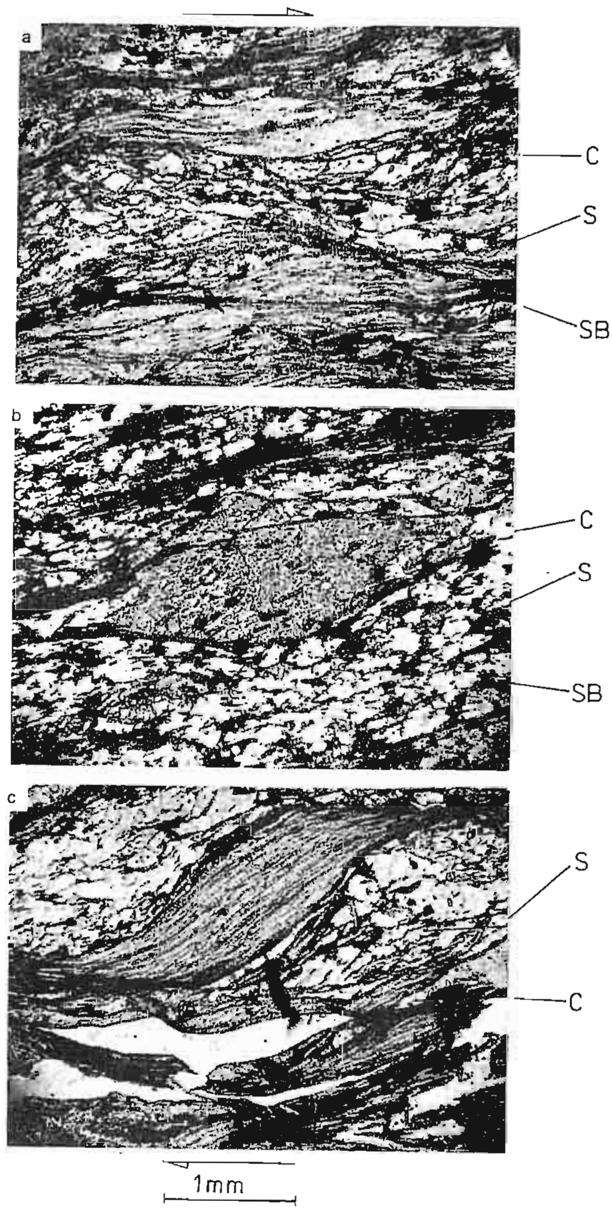

Fig. 10. Various forms of "fish" micas and SB mylonitic bands and S–C planes indicate the dextral sense of shear (top to the north). Micaceous schists of the Stronie Group. Surroundigs of Zieleniec, southward from Duszniki Zdrój (Gorlickie Mts.). Parallel nicoles

Różnorodne formy rybokształtnych łyszczyków (SB) oraz pasemka mylonityczne S–C wyznaczają prawoskrętny zwrot ścinania („góra ku północy"). Łupki łyszczykowe grupy strońskiej. Okolice Zieleńca, na S od Dusznik Zdroju (Góry Orlickie). Nikole równoległe

Because almost all lineations of mineral grain have features, classifaing such lineation type as extensional lineations, otherwise described as mylonitic lineations, they were definited by the author as lineations of X type, e.g. of similar parallelism to X axis of the finite strain ellipsoid (Z. Cymerman, 1989*a*). It relates to plane deformations, within geological medium without larger differences of viscosity and/or competency contrasts between markers of lineations and rock matrix as well as to situations, in which direction of tectonic transport was not so changed during deformation history. The complicated trajectories of extensional lineation on structural maps best indicate the direction changes of tectonic transport during deformation history. In the case of overprinted simple shears with different shear directions (orientation of kinematic axis *a*) the extensional lineation could have various orientations between axes X and Y of finite deformation ellipsoid. Such situation complicates in the case of non-plane deformations, where the volume of rock material changes and in case of possible extension along direction parallel to axes Y or Z of finite deformation ellipsoid. It should be pointed out that the direction of tectonic transport (vector of displacement of rock domains) has not be directly and univocally calculated only on basis of spatial orientation of extensional lineation. But it does not relate generally to the area of whole Śnieżnik metamorphic complex, where:

a — total deformation is similar to plane deformation ($X > Y=1 > Z$):

b — direction of tectonic transport has not changed significantly during the history of ductile shear deformation, except of a zone located northward from the line Lutynia — Lądek Zdrój — Konradów — Trzebieszowice;

c — there are no significant differences of viscosity and competency between markers of extensional lineation and rock matrix.

Due to that it could be assumed that majority of the mineral grain lineations from the area of the Śnieżnik metamorphic complex belongs to extensional type lineation, it means — X lineation, not only to B (or Y) type (see: J. Oberc, 1972; H. Teisseyre, 1968, 1975, 1980; A. Żelaźniewicz, 1972, 1976, 1984; S. Cwojdziński, 1977, 1982; Z. Cymerman, 1982). A. Żelaźniewicz (1984, 1988) suggested that the development of rodding lineation within the Bystrzyca Gneisses (Śnieżnik type) resulted due to mechanism of non-rotational deformation (pure shear). He also assumed that because these elongated (mylonitic) lineation are quite parallel to axes of F_2 folds they were parallel to Y (B) axis of finite strain ellipsoid, too. But the fold axes could developed perpendiculary, obliquely and parallely to X axis of finite strain ellipsoid and due to this such axes could not be used to determine the main axes (X, Y, Z) of finite strain ellipsoid.

KINEMATIC ANALYSIS OF THE ŚNIEŻNIK METAMORPHIC COMPLEX

Almost within all rocks of the Śnieżnik metamorphic complex occur asymmetric tectonic structures of various types, from micro- to mesoscopic scale, which enable to determine the shear senses (see: C. Simpson, S. Schmid, 1983; Z. Cymerman, 1989*b*). These observations disagree with earlier suggestions of A. Żelaźniewicz (1984, 1988) that within the Bystrzyca Gneisses that is the Śnieżnik type gneisses are only the

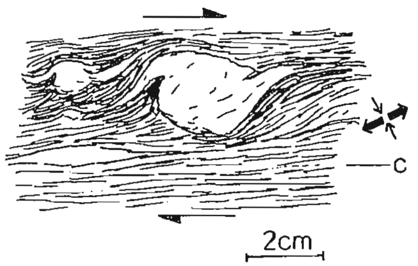

Fig. 11

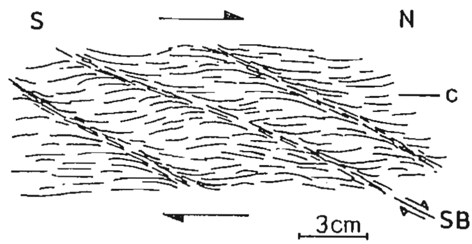

Fig. 12

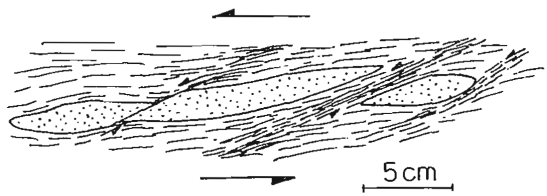

Fig. 13

Fig. 11. Rotated limbs of the sodium feldspar porphyroclasts (δ porphyroclast type). Dextral sense of shear along shear planes C (parallel arrows) and extension (thick arrows) and compresion (thin arrows) directions. Augen gneiss, surroundings of Lądek Zdrój (Złote Mts.)

Zrotowane skrzydełka porfiroklastów skalenia potasowego (typ δ porfiroklastów). Prawoskrętny zwrot ścinania wzdłuż powierzchni ścinania C (strzałki równoległe) oraz kierunki ekstensji (strzałki grube) i kompresji (strzałki cienkie). Gnejs oczkowy. Okolice Lądka Zdroju

Fig. 12. The mylonitic bands SB within micaceous schists of the Stronie Group indicate dextral sense of shear-parallel to C-plane. Surroundings of Duszniki Zdrój (Bystrzyckie Mts.)

Pasemka mylonityczne SB w łupkach łyszczykowych grupy strońskiej. Okolice Dusznik Zdroju (Góry Bystrzyckie)

Fig. 13. The extensional boudinage in the zone of sinistral shear. Quartz rods within micaceous schists of the Stronie Group, surroundings of Stronie Śląskie (Krowiarki Hills)

Budinaż ekstensyjny w strefie lewoskrętnego ścinania. Pręty kwarcowe w łupkach łyszczykowych grupy strońskiej. Okolice Stronia Śląskiego (Krowiarki)

symmetric structures, origined during non-rotational deformation (pure shear). However, lastly A. Żelaźniewicz (1991) changed his opinion, finding the asymmetric structures also within the Bystrzyca Gneisses, which — according to him — have formed due to later, overprinted simple shear (rotational deformation).

The estimation of sense of ductile shear on whole area of the Śnieżnik metamorphic complex was based of such indicative asymmetric structures:

— porphyroblasts of σ type (Figs. 3, 4);
— complex, planar fabrics of S–C type, its obliqueness (Figs. 5, 6);
— "fish" micas (Fig. 10);
— asymmetry of sheath, intrafoliation folds (Figs. 6, 7, 9);
— syndeformational porphyroblasts of δ type (Fig. 11);
— shear bands of C' type (SB) — (Fig. 12);

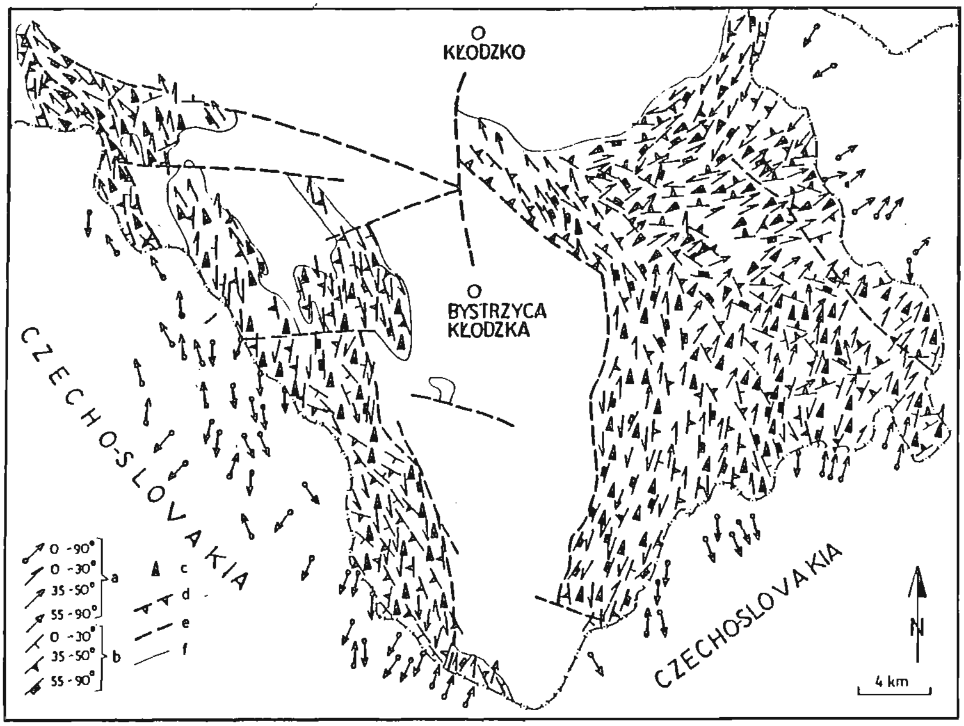

Fig. 14. The simplified structural map of the Śnieżnik metamorphic complex

a — directions and angles of inclination of the mineral grain lineation L_{1+2} (nearly parallel to X axis of finite strain ellipsoid); b — strikes and dips of penetrative foliation S_{1+2}; c — shear senses (displacements of overlaing rock packages in direction of triangle pike); d — Alpine overthrust of Zieleniec; e — faults; f — geological boundaries

Uproszczona mapa strukturalna metamorfiku Śnieżnika

a — kierunki i kąty nachylenia lineacji ziarna mineralnego L_{1+2} (prawie równoległej do osi X elipsoidy odkształcenia końcowego); b — biegi i upady penetratywnej foliacji S_{1+2}; c — zwrot ścinań (przemieszczenia wyżejległych pakietów skalnych w kierunku ostrza trójkąta); d — alpejskie nasunięcie Zieleńca; e — uskoki; f — granice geologiczne

— extensional structures, for instance — extensional boudinage (Fig. 13).

One of the most characteristic structural feature of the Śnieżnik metamorphic complex is low or moderately angle of plunging of the penetrative lineation of mineral grain (extensional lineation — X, Fig. 14). These lineations occur on moderately to steep deeping planes of penetrative foliation (S_{1+2}).

The analyzied kinematic indicators (asymmetric structures) in XZ plane of finite strain ellipsoid (it means — parallel to lineation of mineral grain and perpendicular to penetrative foliation) indicate undoubtedly the dextral senses of ductile shear it means — the displacements of overlaying rock packages northward or to NE and NW. Only in central, northern most part of the Śnieżnik metamorphic complex the shear senses are mainly sinistral that documents the transport of hanging-walls domains toward SW and S. In the zone, located northward from Trzebieszowice, Konradów and Lądek Zdrój are visible two generations of ductile shear zones, hardly dismembered. There is dominant sinistral ductile shears and ductile-brittle ones, indicating that those zones of shears were younger than obliterated and rotated, older, dextral ductile ones. It relates particulary to the area of occurrence of the Haniak type gneisses and varied mylonitic rocks from the tectonic zone Złoty Stok — Skrzynka and of amphibolites nearby Trzebieszowice (I. Wojciechowska, 1986, 1988).

Detailed kinematic analysis of the Śnieżnik metamorphic complex enables also an interpretation of characteristic, fan-shaped pattern of lineation and fold trends known well in literature as so called the Lądek virgation (J. Don, 1964). In the north-western fragment of this virgation (the Bystrzyckie and Orlickie Mts. and western part of Krowiarki Hills) the hanging-walls displacement was toward NW (Fig. 14). In north-eastern and eastern part of the Śnieżnik metamorphic complex (the Bialskie Mts. and southern part of the Złote Mts.) the ductile displacements of the hanging-walls packages have gone on mainly toward NE and NNE (Fig. 14). Because the central and northern parts of this complex virgation are occupied by the rock formations with opposite sense of shear, it is most probably that emplacement of some dismembered ophiolite sequences have caused fan-shaped, like V-shaped dispertion of the structural trends, especially well visible nearby Trzebieszowice village.

THE INTERPRETATION OF TECTONIC EVOLUTION OF THE ŚNIEŻNIK METAMORPHIC COMPLEX

All area of the Śnieżnik metamorphic complex (*sensu lato*) was subjected to intensive shear deformations probably during its whole Variscan tecto-metamorphic evolution. The earliest displacements of rock domains in ductile conditions have taken place probably just during the Lower or Middle Devonian (Acadian Phase?). The radiometric data with Rb-Sr method could confirm such opinion (395 ± 35 Ma — M. Borkowska et al., 1990).

The mylonitic fabric is characteristic feature of almost all rocks of the Śnieżnik metamorphic complex, including as well as granulites, eclogites and marbles. Primary bedding of metasediments of the Stronie Group was quite completely transformed into the S_{1+2} penetrative foliation. This foliation inherited probably large part of primary (sedimentary) rock anisotropy. The contacts between basement rock, which could be older gneisses of the Gierałtów type, and deposits of the Stronie Group were particulary predestinated to the development of ductile shear zones in conditions of progressive regional metamorphism. An increase of intensity of shear processes within gneisses as well as within rocks of the Stronie Group, with approaching to the contacts of these rock groups, could confirm best such interpretation. The characteristic feature of such contacts are numerous packages of characteristic quartz mylonites, among others — from Duszniki Zdrój, Rudawa, Sienna i Goszów vicinities.

The distinct lithological discontinuities of various rock packages, also of limestones and crystalline dolomites as well as of quartzities and amphibolites, make questionable all attempts to define the sequence and stratigraphic continuity of the

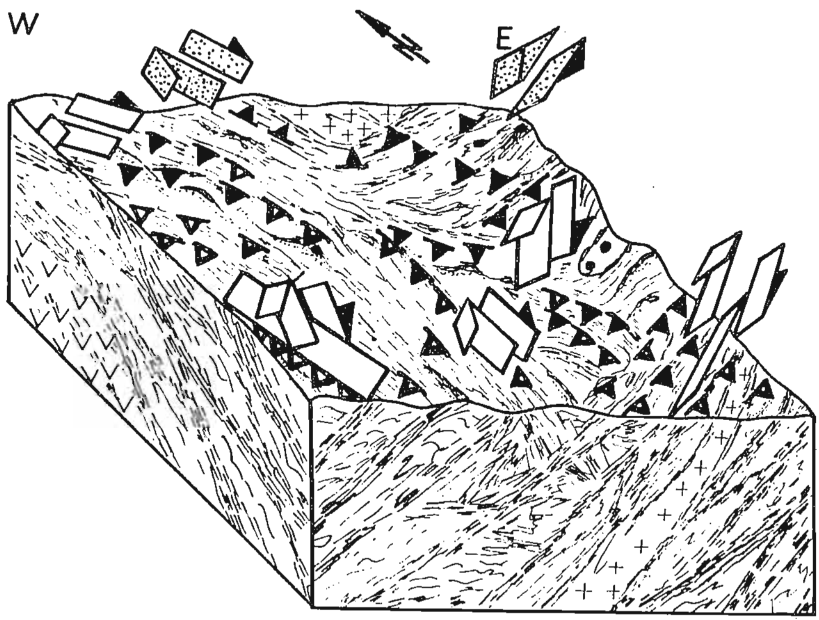

Fig. 15. The interpretation blockdiagram, presenting the style of ductile strike-slip-overthrusting deformation of the Śnieżnik metamorphic complex. Dotted arrows mark later shears in ductile and ductile-brittle conditions

Blokdiagram interpretacyjny ilustrujący styl podatnej deformacji przesuwczo-nasunięciowej metamorfiku Śnieżnika. Strzałki zakropkowane dotyczą późniejszych ścinań w warunkach podatnych i podatnokruchych

rocks of the Stronie Group. Such discontinuities were resulted from later, numerous and generally intensive deformations with dominant component of the simple shear. The differences of rheological properties of various rock packages were probably one of the most important factors, influencing on distribution of the shear and shortening zones during strain partitioning (Z. Cymerman, 1988*a*). Many studies indicate that changes of the rock rheological properties in the ductile shear zones are generally connected with the processes of strain softening (S. H. White et al., 1986).

The presented above results of the first kinematic analysis put a new light on the tectonic evolution of the Śnieżnik metamorphic complex. The dominant displacements of the strike-slip/overthrust style with top to the north, locally to NE and NW, were connected with dextral transpression during D_{1+2} continuous deformation within almost constant field of regional stresses (Figs. 15, 16A, B). The progressive shear deformation (D_{1+2}) have taken place during the maximum of regional metamorphism (pressures about 13.5–18 kb, temperatures about 620–750° C for eclogites' and nearly 880° C for omphacitic granulites — N. Bakun-Czubarow, H. K. Brueckner, 1991). The fold structures of varied vergency, often eastward, folding the penetrative foliation (S_{1+2}), compensated the shortening component (pure shear) along lateral ramps of overthrusted northward rock packages, in the strike-slip/overthrust style.

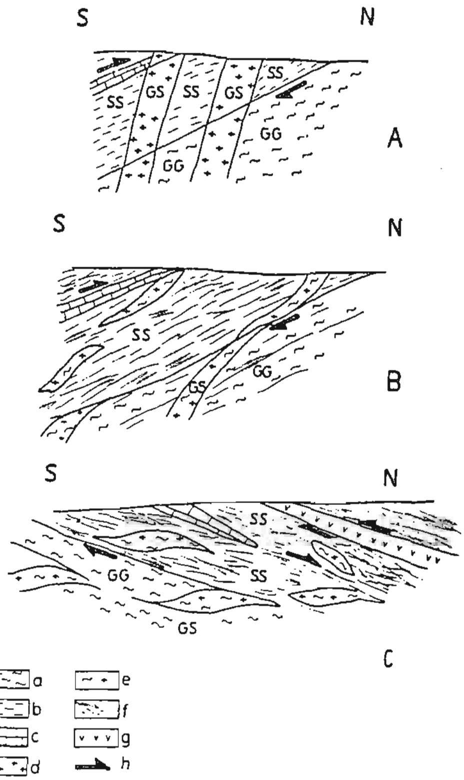

Fig. 16. The schematic interpretation sections of evolution of the Śnieżnik metamorphic complex: A — stage of D_1 deformation with syn- and pre-kinematic granitic intrusions (protolithe of mylonitic gneisses); B — stage of ductile deformations of D_2 shear in conditions of dextral transpression (tectonic thickenning); C — stage of farther ductile shears D_3 in conditions of dextral and locally sinistral transtension during quick uplifting of the Śnieżnik metamorphic complex (Upper Visean); SS — the Stronie Group; GG — the Gierałtów Gneisses; GS — the Śnieżnik Gneisses

a — basement gneisses(?), older migmatitic gneisses of Gierałtów; b — cover deposits (metasediments of the Stronie Group); c — marbles and calcareous-siliceous rocks; d — granitoid protolithe of buddy, mylonitic gneisses; e — mylonitized granites (orthogneisses of the Śnieżnik and Bystrzyca types); f — mylonitic micaceous schists and paragneisses of the Stronie Group; g — metavolcanites (and metaophiolites?) of Trzebieszowice; h — senses of ductile shears

Schematyczne przekroje interpretacyjne ewolucji matamorfiku Śnieżnika: A — etap deformacji D_1 z syn- lub prekinematycznymi intruzjami granitu (protolit gnejsów mylonitycznych); B — etap podatnych deformacji ze ścinania D_2 w warunkach prawoskrętnej transpresji (tektoniczne pogrubienie); C — etap dalszych podatnych ścinań D_3 w warunkach prawoskrętnej i lokalnie lewoskrętnej transtensji podczas szybkiego wynoszenia metamorfiku Śnieżnika (górny wizen); SS — seria strońska; GG — gnejsy gierałtowskie; GS — gnejsy śnieżnickie

a — gnejsy podłoża(?), starsze gnejsy gierałtowskie, migmatytowe; b — osady pokrywy (metasedymenty grupy strońskiej); c — marmury i skały wapienno-krzemianowe; d — protolit granitoidowy gnejsów oczkowych, mylonitycznych; e — zmylonityzowane granity (ortognejsy typu śnieżnickiego i bystrzyckiego); f — mylonityczne łupki łyszczykowe i paragnejsy grupy strońskiej; g — metawulkanity (i metaofiolity?) Trzebieszowic; h — zwroty ścinań podatnych

The deformational partitioning (see: Z. Cymerman, 1988*a*) for the components of shear and of shortening has particular value in tectonic context of transpression. The transpression movements include two components: strike-slip and thickening (contraction, shortening) of the crust (see: D. J. Sanderson, D. Marchini, 1984). The models of dividing the transpression movements for synchronous compressional overthrusts and dextral or sinistral strike-slip displacements, were presented last time in literature (see: R. E. Holdsworth, R. A. Strachan, 1991; P. R. Cobbold et al., 1991).

The local change of shearing sense has occurred in northernmost part of the Śnieżnik metamorphic complex, probably during the next D_3 deformation increment (Figs. 15, 16C). In conditions of dominated in other area of the Śnieżnik metamorphic complex the dextral strike-slip shear and the ductile overthrusting toward the north, the sense of shear has changed for sinistral strike-slip one and parts of rock packages have been later overthrusted southward or to SW in the most northern part of the metamorphic complex. Probably also during this stage the syn-kinematic granitoid intrusions have origined, for instance: Jawornik (S. Cwojdziński, 1977), Bialskie Mts. and Kudowa — Oleśnica granitoid intrusions. The development of such intrusions mainly on borders of the Śnieżnik metamorphic complex, as well as the extensional tectonic structures (ductile, normal faults) could indicate the change of tectonic regime for the transtension conditions. It is confirmed — to some extent — by new radiometric studies of rocks from Śnieżnik metamorphic complex, which documented their rapid cooling, connected with its extremely quick uplifting into the subsurface zones during the Lower Carboniferous (M. G. Steltenpohl et al., 1991). The Śnieżnik metamorphic complex have thicked tectonically up to the Middle Visean in conditions of dextral transpression but later — in the Upper Visean (the Sudetic Phase?) it was rapidly uplifted in upper parts of the Earth crust.

The regional change of structural directions in northern part of the Śnieżnik metamorphic complex (the Lądek virgation) resulted probably due to the emplacement — in ductile conditions — of dismembered elements of the oceanic crusts or arc islands. These fragments were displaced toward the south and SW in the strike--slip/overthrust style. The incoming from the north the large elements of tectonically fragmented ophiolites which belongs of the Sudetian terrane (Z. Cymerman, 1991*b*) have influenced decisively on the regional and local distribution of stress fields in northernmost part of the Śnieżnik metamorphic complex.

CONCLUSIONS

The structural studies and first kinematic analysis of the Śnieżnik metamorphic complex document the dominance of simple (rotational) shear mechanisms in the plastic-crystalline conditions, but with changing stage of dynamic recovery and dynamic recrystallization during the Variscan tecto-metamorphic evolution of this complex. The mylonitic structures have developed in all its rocks. During the Variscan dextral transpression the rock packages, accretioning generally northward, have caused significant thickenning of rock series of the Śnieżnik metamorphic complex. The ductile, dextral displacements of these packages and their northward overthrusting have resulted from the dextral transpression, being characteristic feature of the north-eastern part of the Bohemian Massif (see: P. Rajlich, 1990; Z. Cymerman, 1991*c*). The dextral transpression, lasting up to the Middle Visean, has led to the approaching of the Śnieżnik metamorphic complex to the large bodies tectonically fragmented and dismembered packages of ophiolitic and/or arc island sequences, building the fragment of the southern part of the Sudetian terrane (Z. Cymerman, 1991*b*). The oblique vergency and collision of these two terranes (Sudetian and Moldanubian ones — see: P. Matte, 1991; Z. Cymerman, 1991*b*) was probably the basic reason of the direction change of the ductile shear sense in the northern part of the Śnieżnik metamorphic complex. According to such interpretation the Trzebieszowice amphibolites together with mylonites of the Złoty Stok — Skrzynka zones and the Haniak Gneisses are not included into the Śnieżnik metamorphic complex (*sensu stricto*) but they belong to so called the Sudetian terrane. In the Upper Visean time the Śnieżnik metamorphic complex was rapidly uplifted in conditions of dextral transtension with syn-kinematic emplacement of late-tectonic granitoids on its external zones.

Translated by Grzegorz Czapowski

Oddział Dolnośląski
Państwowego Instytutu Geologicznego
Wrocław, al. Jaworowa 19
Received in revised form: 24.02.1992

REFERENCES

ANSILEWSKI J. (1966) — Petrografia metamorfiku Gór Bialskich. Geol. Sudetica, **2**, p. 121–260.

BAKUN-CZUBAROW N. (1968) — Geochemical characteristic of eclogites from environs of Nowa Wieś in the region of Śnieżnik Kłodzki. Arch. Miner., **28**, p. 243–382, z. 1.

BAKUN-CZUBAROW N., BRUECKNER H. K. (1991) — Eklogity właściwe i granulity omfacytowe jako wskaźniki waryscyjskiego epizodu wysokociśnieniowego w metamorfiku Śnieżnika. In: Mater. Konf. Teren., Lądek 1991,p. 98–121. Wyd. U Wrocł. Wrocław.

BEHR H. J. (1980) — Polyphase shear zones in the granulite belts along the margins of the Bohemian Massif. J. Struct. Geol., **2**, p. 119–126.

BERTHÉ D., CHOUKROUNE P., JEGOUZO P. (1979) — Orthogneiss, mylonite and non-coaxial deformation of granites: The example of the South Armorican Shear Zone. J. Struct. Geol., **1**, p. 31–42.

BORKOWSKA M., CHOUKROUNE P., HAMEURT J., MARTINEAU F. (1990) — A geochemical investigation of the age, significance and structural evolution of the Caledonian-Variscan granite-gneisses of the Śnieżnik metamorphic area (Central Sudetes, Poland). Geol. Sudetica, **25**, p. 1–27, nr 1–2.

BREEMEN O. van, AFTALION M., BOWES D. R., DUDEK A., MISAR Z., POVONDRA P., VRANA S. (1982) — Geochronological studies of the Bohemian massif. Czechoslovakia, and their significance in the evolution of Central Europe. Trans. Roy. Soc. Edinburgh. Earth Sci., **73**, p. 89–108.

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.

COLLINS W. J., TEYSSIER C. (1989) — Crustal scale ductile fault systems in the Aruna Inlier, central Australia. Tectonophysics, **158**, p. 49–66.

CWOJDZIŃSKI S. (1977) — Stosunek granitoidów jawornickich do deformacji metamorfiku lądecko-śnieżnickiego. Kwart. Geol.,**21**, p. 451–465, nr 3.

CWOJDZIŃSKI S. (1982) — Ewolucja strukturalna wschodniej części Ziemi Kłodzkiej w świetle interpretacji fałdów najstarszej generacji. Biul. Inst. Geol., **341**, p. 169—182.

CYMERMAN Z. (1982) — Następstwo deformacji serii metamorfiku Śnieżnika w okolicy Kątów Bystrzyckich. Kwart. Geol., **26**, p. 1–12, nr 1.

CYMERMAN Z. (1984) — Wstępne wyniki badań tektonicznych gnejsów masywu Gierałtowa. Kwart. Geol., **28**, p. 766–767, nr 3/4.

CYMERMAN Z. (1988*a*) — Znaczenie deformacji porozdzielanej w analizie strukturalnej. Prz. Geol., **36**, p. 582–588, nr 10.

CYMERMAN Z. (1988*b*) — Objaśnienia do Szczegółowej mapy geologicznej Sudetów 1:25 000, ark. Strachocin i Bielice. Inst. Geol. Warszawa.

CYMERMAN Z. (1989*a*) — Charakterystyka i znaczenie lineacji ekstensyjnej. Prz. Geol., **37**, p. 488–494, nr 10.

CYMERMAN Z. (1989*b*) — Określanie zwrotu ścinania. Prz. Geol., **37**, p. 605–613, nr 12.

CYMERMAN Z. (1990) — Mapy strukturalne Sudetów 1:50 000, ark.: Mostowice, Bystrzyca Kłodzka, Stronie Śląskie i Międzylesie. Arch. Państw. Inst. Geol. Wrocław.

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

CYMERMAN Z. (1991*b*) — Czy w Sudetach są terrany? Prz. Geol., **40**, p. 450–456, nr 10.

CYMERMAN Z. (1991*c*) — Regionalna strefa ścinania we wschodniej części bloku przedsudeckiego. Prz. Geol., **40**, p. 457–463, nr 10.

CYMERMAN Z. (1991*d*) — Mapy strukturalne Sudetów 1:50 000, ark. Uniemyśl, Duszniki Zdrój, Kudowa Zdrój, Kłodzko, Złoty Stok, Radków, Nowa Ruda i Ząbkowice Śląskie. Arch. Państw. Inst. Geol. Wrocław.

DENNIS A. J., SECOR D. T. (1987) — A model for the development of crenulations in the shear zones with applications from the Southern Appalachians Piedmont. J. Struct. Geol., **9**, p. 809–817.

DENNIS A. J., SECOR D. T. (1990) — In resolving shear direction in foliated rocks deformed by simple shear. Geol. Soc. Am. Bull., **102**, p. 1257–1267.

DON J. (1964) — Góry Złote i Krowiarki jako elementy składowe metamorfiku Śnieżnika. Geol. Sudetica, **1**, p. 79–117.

DON J. (1982) —) Die Entwicklung der Migmatite in der Zone der Übergangsgneise von Międzygórze (Metamorphikum des Śnieżnik — Sudety). In: Deformation und Metamorphose der Gesteine II. Veröff. Zentralst. Physi. Erde., **72**, p. 5–20.

DON J., DUMICZ M., WOJCIECHOWSKA I., ŻELAŹNIEWICZ A. (1990) — Lithology and tectonics of the Orlica–Śnieżnik Dome, Sudetes — Recent state of knowledge. N. Jb. Geol. Paläont., Abh., **179**, p. 159–188.

DUMICZ M. (1964) — Budowa geologiczna krystaliniku Gór Bystrzyckich. Geol. Sudetica, **1**, p. 169–208.

DUMICZ M. (1976) — Próba wyjaśnienia tektogenezy serii zmetamorfizowanych Ziemi Kłodzkiej. In: Problem wieku serii zmetamorfizowanych Ziemi Kłodzkiej. Mater. Konf. Teren., Międzylesie. Inst. Nauk. Geol. UWr. Wrocław.

DUMICZ M. (1979) — Tectogenesis of the metamorphosed series of the Kłodzko District: a tentative explanation. Geol. Sudetica, **14**, p. 29–46, nr 2.

DUMICZ M. (1988) — Strefa tektoniczna Złoty Stok — Skrzynka w świetle analizy mezostrukturalnej Lądka — Śnieżnika. Geol. Sudetica, **23**, p. 83–106, nr 2.

DUMICZ M. (1989) — Następstwo serii gnejsowych Masywu Śnieżnika w świetle analizy mezostrukturalnej wybranych obszarów w jednostkach geologicznych Międzygórza i Gierałtowa. Geol. Sudetica, **24**, p. 139–189, nr 1–2.

EISBACHER G. H., LÜSCHEN E., WICKERT F. (1989) — Crustal-scale thrusting and extension in the Hercynian Schwarzwald and Vosges, Cenral Europe. Tectonics, **8**, p. 1–21.

FISCHER G. (1936) — Der Bau des Glatzer Schneegebirges. Jb. Preuss. Geol. Landesanst., **56**, p. 712–732.

GIERWIELANIEC J. (1971) — Objaśnienia do Szczegółowej mapy geologicznej Sudetów 1:25 000, ark. Lądek Zdrój. Inst. Geol. Warszawa.

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.

GRYGAR R., VAVRO M., BIUGOOTH G. (1991) — Kinematics of deformation of the Kłodzko Dome and its peripherial envelope units. In: Abstracts of geological workshop Moravian Windows, p. 38. Moravský Krumlov.

GUÉRIN G., BRUN J. P., DRIESSCHE J. van der (1990) — Kinematics of pre-Miocene ductile deformation in the Santa Catalina core complex and adjacent regions. Tectonics, **9**, p. 1305–1326.

GUNIA T. (1974) — Mikroflora prekambryjskich wapieni okolic Dusznik Zdroju (Sudety Środkowe). Rocz. Pol. Tow. Geol., **44**, p. 65–92.

GUNIA T. (1984*a*) — Mikroskamieniałości z łupków kwarcytowych okolic Goszowa w masywie Śnieżnika Kłodzkiego (Sudety Środkowe). Geol. Sudetica, **18**, p. 47–60, nr 2.

GUNIA T. (1984*b*) — Mikroflora z wapieni krystalicznych okolic Nowego Waliszewa (Krowiarki — Sudety Środkowe). Geol. Sudetica, **19**, p. 75–87, nr 2.

HANMER S. (1988) — Great Slave Lake Shear Zone, Canadian Shield: reconstructed vertical profile of a crustal scale fault zone. Tectonophysics, **149**, p. 245–264.

HOLDSWORTH R. E., STRACHAN R. A. (1991) — Interlinked system of ductile strike slip and thrusting formed by Caledonian sinistral transpression in northeastern Greenland. Geology, **19**, p. 510–513.

KASZA L. (1964) — Budowa geologiczna górnego dorzecza Białej Lądeckiej. Geol. Sudetica, **1**, p. 119–162.

LIEW D. C., HOFMANN A. W. (1988) — Precambrian crustal components, plutonic associations, plate environment of the Hercynian Fold Belt of Central Europe: indicators from a Nd and Sm isotopic study. Contr. Miner. Petr., **98**, p. 129–138.

LISTER G. S.,, WILLIAMS P. J. (1979) — Fabric development in shear zones: theoretical controls and observed phenomena. J. Struct. Geol., **1**, p. 283–297.

LISTER G. S., SNOKE A. W. (1984) — S–C mylonites. J. Struct. Geol., **6**, p. 617–638.

MATTE P., MALUSKI H., RAJLICH P., FRANKE W. (1990) — Terrane boundaries in the Bohemian Massif: Result of large-scale Variscan shearing. Tectonophysics, **177**, p. 151–170.

MATTE P. (1991) — Accretionary history and crustal evolution of the Variscan belt in Western Europe. Tectonophysics, **196**, p. 309–337.

NANCE R. D., MURPHY J. B. (1990) — Kinematic history of the Bass River Complex. Geol. Soc. Spec. Publ., **51**, p. 395–406.

OPLETAL M., DOMEČKA K., ČECH S. (1980) — Geology of the Orlicke Hory Mountains. Academica. Praha.

OBERC J. (1957) — Zagadnienia geologii metamorfiku zachodniej części Gór Bialskich i obniżenia Stronia Śląskiego. Przew. 30 Zjazdu Pol. Tow. Geol., p. 72–89.

OBERC J. (1972) — Sudety i obszary przyległe. In: Budowa geologiczna Polski, **4**. Tektonika, cz. 2. Inst. Geol. Warszawa.

OBERC J. (1977) — The Pre-Assyntian and Assyntian (Baikalian) elements in South-Western Poland. In: Geology of Poland, **4**, Tectonics, p. 99–173. Inst. Geol. Warszawa.

PAUK F. (1953) — Poznamky ke geologii Orlickych hor a Kralickego Śnieżniku. Vestn. Ustř. Ust. Geol., **28**, p. 193–212.

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

PIASECKI M. A. (1988) — A major ductile shear zone in the Bay d'Espoir area, Gander Terrane, southeastern Newfoundland. Current Research Newfoundland Department of Mines, **88**, p. 135–145.

RAJLICH P. (1987) — Variszische duktile Tektonik im Böhmischen Massiv. Geol. Rundsch., **76**, p. 755–786.

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

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

SCHMID S. M., ZINGG A., HANDY M. (1987) — The kinematics of movements along the Insubric Line and the emplacement of the Ivrea Zone. Tectonophysics, **135**, p. 47–66.

SCHULMANN K., LEDRU P., AUTRAN A., MELKA R., LARDEAUX J. M., URBAN M., LOBKOWICZ M. (1991) — Evaluation of nappes in the eastern margin of the Bohemian Massif: a kinematic interpretation. Geol. Rundsch., **80**, p. 73–92.

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

STELTENPOHL M. G. (1988) — Kinematics of the Towaliga, Bartletts Ferry, and Goat Rock fault zones, Alabama: The late Paleozoic dextral shear system in the southernmost Appalachians. Geology, **16**, p. 852–855.

STELTENPOHL M. G., CYMERMAN Z., KUNK M. J. (1991) — 40Ar/39Ar termochronology and tectonic evolution of the Śnieżnik complex, easternmost Alleghanian-Variscan orogeny, Sudety Mountains, Poland. Geol. Soc. Am. (Abstracts).

SMULIKOWSKI K. (1957) — Formacje krystaliczne grupy górskiej Śnieżnika Kłodzkiego. Przew. 30 Zjazdu Pol. Tow. Geol., p. 37–54. Wyd. Geol. Warszawa.

SMULIKOWSKI K. (1979) — Ewolucja polimetamorficzna krystaliniku Śnieżnika Kłodzkiego i Gór Złotych w Sudetach. Geol. Sudetica, **14**, p. 7–79.

TEISSEYRE H. (1957) — Budowa geologiczna okolic Międzygórza. Przew. 30 Zjazdu Pol. Tow. Geol., p. 54–72. Wyd. Geol. Warszawa.

TEISSEYRE H. (1968) — Serie metamorficzne Sudetów. Uwagi o stratygrafii, następstwie i wieku deformacji oraz metodach badawczych. Geol. Sudetica, **4**, p. 7–45.

TEISSEYRE H. (1975) — Rozwój i sekwencja deformacji tektonicznych w metamorfiku Śnieżnika. Przew. 47 Zjazdu Pol. Tow. Geol., p. 21–33. Wyd. Geol. Warszawa.

TEISSEYRE H. (1980) — Precambrian in South-Western Poland. Geol. Sudetica, **15**, p. 7–42, nr 1.

VANGEROV E. F. (1943) — Das Normalprofil des Algonkiums und Kambriums in den mittleren Sudeten. Geol. Rundsch., **34**, p. 10–12.

WHITE S. H.,, BURROWS S. E., CARRERAS J., SHAW N. D., HUMPHEREYS F. J. (1980) — On mylonites in ductile shear zones. J. Struct. Geol., **2**, p. 175–187.

WHITE S. H., BRETAN P. R., RUTTER E. H. (1986) — Fault-zone reactivation: Kinematics and mechanisms. Phil. Trans. Royal Soc. London A, **313**, p. 81–89.

WOJCIECHOWSKA I. (1972) — Preliminary results of investigations on so-called "Quartzites" in the neighbourhood of Romanowo (Stronie complex), NW part of Krowiarki (East Sudetes). Bull. Acad. Pol. Sc., Sér. Sci. Terre, **20**, p. 273–277, nr 4.

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

WOJCIECHOWSKA I. (1988) — Zarys budowy geologicznej północnej części metamorfiku Śnieżnika. In: Wybrane zagadnienia..., p. 10–16. Mater. Konf. Teren., Żelazno 1–3 września 1988. Wyd. UWr. Wrocław.

ŻELAŹNIEWICZ A. (1972) — Some remarks on the deformation sequence in the northern part of the Orlica Mts. (Middle Sudetes) Bull. Acad. Pol. Sc., Sér. Sci. Terre, **20**, p. 97–105, nr 2.

ŻELAŹNIEWICZ A. (1976) — Tectonic and metamorphic events in the Polish part of the Orlickie Mts. Geol. Sudetica, **11**, p. 101–177, nr 1.

ŻELAŹNIEWICZ A. (1984) — Synmetamorphic penetrative mylonitization in orthogneisses of the Bystrzyca Mts., Sudetes. Acta Geol. Pol., **34**, p. 111–130, nr 1–2.

ŻELAŹNIEWICZ A. (1988) — Orthogneisses due to irrotational extension. a case from the Sudetes, Bohemian massif. Geol. Rundsch., **77**, p. 671–682.

ŻELAŹNIEWICZ A. (1991) — Uwagi o deformacji ortognejsów oczkowych w kopule orlicko-śnieżnickiej. In: Wybrane zagadnienia..., p. 122–136. Mater. Konf. Teren., Lądek Zdrój. Wyd. UWr. Wrocław.

Zbigniew CYMERMAN

PODATNE DEFORMACJE ROTACYJNE W METAMORFIKU ŚNIEŻNIKA (SUDETY)

Streszczenie

Nowe badania strukturalne i pierwsza analiza kinematyczna całego obszaru metamorfiku Śnieżnika (*sensu lato*) — na obszarze polskiej części tej jednostki — wskazują na dominujący mechanizm ścinania prostego (deformacji rotacyjnej). Procesy ścinania odbywały się w warunkach plastyczno-krystalicznych (tzw. ścinanie podatne), ze zmieniającym się jednak stopniem dynamicznego odzyskania i dynamicznej rekrystalizacji. Procesy podatnego ścinania odbywały się podczas całej waryscyjskiej ewolucji, najintensywniej jednak w okresie karbonu dolnego. Struktury mylonityczne, związane z procesami podatnego ścinania, rozwinęły się zarówno wśród serii gnejsowych, jak i wśród skał serii strońskiej.

Podczas waryscyjskiej prawoskrętnej transpresji, udokumentowanej przez struktury asymetryczne, m. in. σ typ porfiroklastów i skośność więźby, przyrastające w kierunku północnym, pakiety skalne były przyczyną znacznego tektonicznego pogrubienia serii skalnych metamorfiku Śnieżnika. Prawoskrętne, podatne przemieszczenia pakietów skalnych i nasuwanie ku północy i NW oraz NE jest cechą charakterystyczną całej północno-wschodniej części Masywu Czeskiego, m. in. metamorfiku strzelińskiego i metamorfiku kamieniecko-niemczańskiego.

Prawoskrętna transpresja, trwająca na obszarze metamorfiku Śnieżnika najprawdopodobniej aż do środkowego wizenu, doprowadziła do kolizji (prawie prostopadłej) tego metamorfiku z południowym fragmentem terranu sudeckiego (Z. Cymerman, 1991*b*). Skośna konwergencja i kolizja terranu sudeckiego (rozczłonkowane tektonicznie fragmenty sekwencji ofiolitowej) z terranem moldanubskim (metamorfik Śnieżnika) była najprawdopodobniej zasadniczą przyczyną zmiany zwrotu ścinania w północnej części metamorfiku Śnieżnika. Przy poprawności takiej interpretacji amfibolity okolic Trzebieszowic razem z różnorodnymi mylonitami strefy Skrzynki nie należą już do metamorfiku Śnieżnika (*sensu stricto*), ale do terranu sudeckiego. Po okresie tektonicznego pogrubienia metamorfiku Śnieżnika doszło następnie do gwałtownego wynoszenia tej jednostki na pograniczu karbonu dolnego i górnego w warunkach prawoskrętnej transtensji. W tym samym czasie na obrzeżach metamorfiku Śnieżnika intrudowały późnotektoniczne granitoidy.