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TECTOGENESIS OF THE METAMORPHOSED SERIES OF THE KŁODZKO DISTRICT: A TENTATIVE EXPLANATION

CONTENTS

Abstract

The number of arguments indicate that meso- and epizonally metamorphosed rocks of the Kłodzko District were deposited in a span from Upper Proterozoic to Lower Devonian. Tectogenic and orogenic development of these series is believed to have taken place in Orcadian Phase of Early Hercynian movements. Tectogenic stage was characterized by tangential compression (F_1 folding, prograde metamorphism) and orogenic stage commenced under nearly confining pressure but went on in the field of vertical compression (microcline blastesis leading to the development of the Gierałtów, Śnieżnik, and Bystrzyca gneisses, development of F_2 folds in S_0 and S_1 planar structures, development of S_2 nearly horizontal axial schistosity. The Early Hercynian tectogene was greatly reconstructed in Bretonian or Sudetian Phase characterized by a couple of vertical forces effecting movements along physical discontinuities once produced in the orogenic stage (mostly S_2 surfaces). Dynamic transformations, diaftoresis, decollements, and local F_3 drag folds in S_2 planes, are the main features of this reconstruction. The rock series were piled up, which produced rapid increase of temperature. Once cataclased and mylonitised rocks were subjected to blastesis and metasomatic transformations producing polymetamorphic series (e.g. the Haniak gneisses). This process was accompanied by intense folding (development of F_4 folds). At greater depth partial melting gave rise to granitoid magma which intruded in the Upper Carboniferous (development of Kłodzko—Zloty Stok, Bielice, Kudowa, and Ścinawka granitoid massifs).

INTRODUCTION

The metamorphic series of the Kłodzko District (fig. 1) have drawn attention of Polish geologists and petrologists since the end of last war. In early fifties, the tectonic investigations were started by late Professor Henryk Teisseyre's group of Wrocław University and petrographic studies were undertaken by Professor Kazimierz Smulikowski and his pupils of Warsaw University. Preliminary results of these investigations were presented at the 30-th meeting of the Polish Geological Society in 1957. It was the first confrontation of yet small scientific output by not numerous and, in general, young staff of Polish geologists with the achievements of German geologists working in this region for more than a hundred of years.

A great deal of controversions arose from that comparison, concerning mostly the age and origin of some metamorphic complexes as well as the time and style of tectonic deformations.

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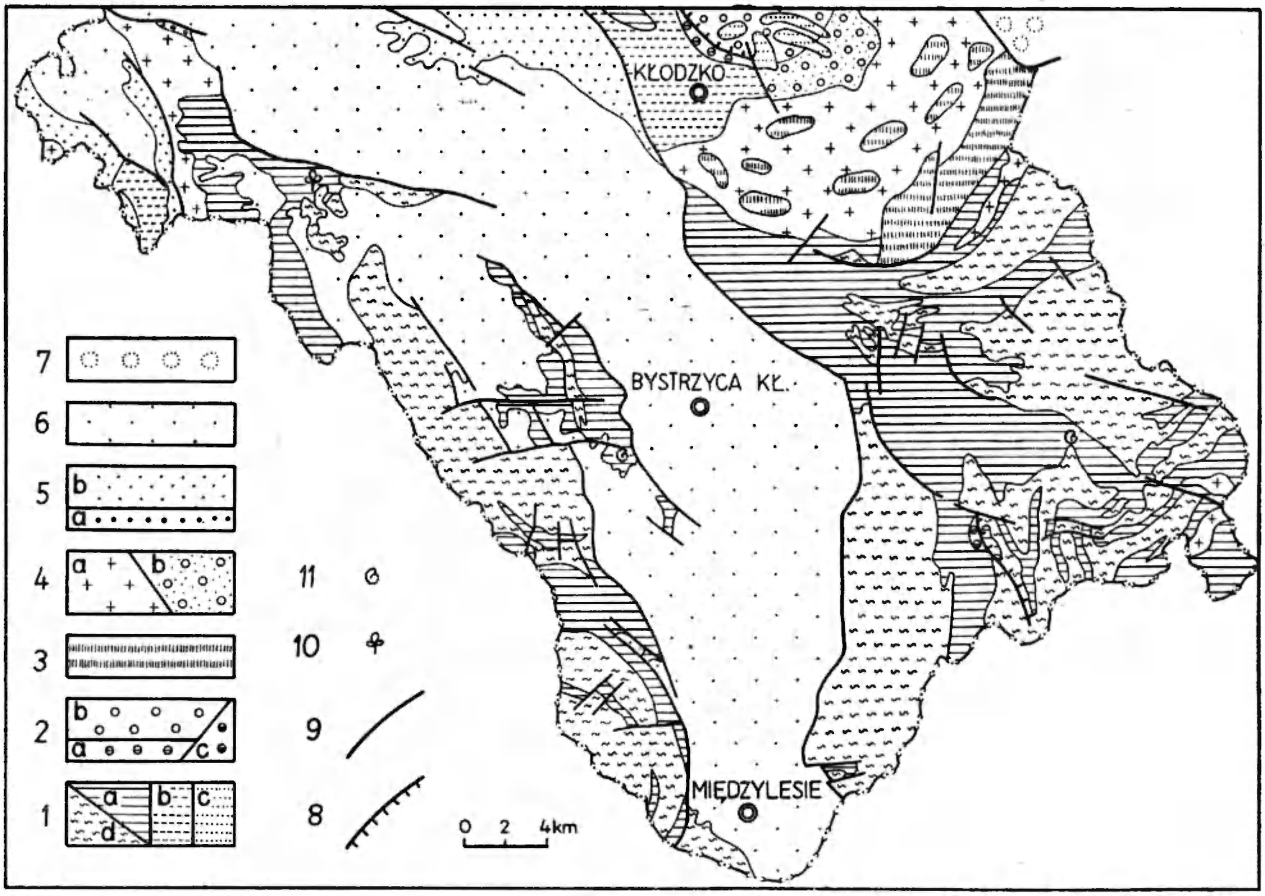

Fig. 1

Geological sketch of the Kłodzko District according to Dumicz (stratigraphy of the metamorphic series based upon results of Gunia's paleontological investigations; lithological boundaries drawn along published maps by Don, Dumicz, Gierwielaniec, Kasza, Kozłowska-Koch, Oberc, Sawicki, Smulikowski, H. Teisseyre, Wojciechowska, Żelaźniewicz)

1 — upper proterozoic-lower paleozoic geosynclinal series regionally metamorphosed and affected by plutonic processes in early hercynian eoch: *a* — mesozonally metamorphosed series (paleontologically documented not closer determined upper proterozoic near Duszniki and not closer determined near Wyszki and Goszów), *b* — epizonally metamorphosed series (paleontologically documented Ludlowian near Bożków), *c* — unmetamorphosed sedimentary and volcanic rocks (paleontologically documented silurian and devonian in the Bardo unit), *d* — early hercynian gneisses of the Gierałtów, Śnieżnik and Bystrzyca type; *2* — upper devonian and lower carboniferous sediments: *a* — upper devonian conglomerates and limestones underlying the Kłodzko overthrust, *b* — lower carboniferous (Visean) conglomerates, graywackes, and shales of Kulm facies in the Bardo unit, *c* — upper devonian and lower carboniferous Kletno conglomerates; *3* — polymetamorphic rocks of the Skrzynka-Złoty Stok tectonic zone of hercynian age (Bretonian or Sudetian) and of roof-pendants of the Kłodzko-Złoty Stok granitoid massif; *4* — late hercynian plutons and their contact zones: *a* — granitoids, *b* — lower carboniferous sedimentary rocks of the Bardo unit affected by contact metamorphism; *5* — upper carboniferous and permian sedimentary rocks: *a* — upper westphalian and Stephanian conglomerates and sandstones, *b* — Permian conglomerates, sandstones, shales, and igneous rocks; *6* — upper cretaceous deposits; *7* — tertiary and qaternary deposits; *8* — thrust; *9* — faults; *10* — microfloristic locality; *11* — faunal locality

Szkic geologiczny Ziemi Kłodzkiej według M. Dumicza (stratygrafię serii metamorficznych opracowano na podstawie wyników badań paleontologicznych T. Guni, a zarys wydzieleń litologicznych przedstawiono na podstawie publikowanych materiałów J. Dona, M. Dumicza, J. Gierwielańca, L. Kaszy, M. Kozłowskiej-Koch, J. Oberca, L. Sawickiego, K. Smulikowskiego, H. Teisseyre'a, I. Wojciechowskiej, A. Żelaźniewicza).

1 — utwory geosynklinalne wieku górnoproterozoiczno-dolnopaleozoicznego objęte na dużą skalę metamorfizmem regionalnym i procesami plutonicznymi w okresie starowaryscyjskim: *a* — serie mezozonalnie zmetamorfizowane (udokumentowany paleontologicznie górny, bliżej nie określony proterozoik w okolicy Dusznik, i dolny, bliżej nie określony paleozoik w okolicy Wyszek i Goszowa), *b* — serie epizonalnie zmetamorfizowane (udokumentowany paleontologicznie ludlow w okolicy Bożkowa), *c* — niezmetamorfizowane osadowce i wulkanity (udokumentowany paleontologicznie sylur i dewon struktury bardzkiej), *d* — starowaryscyjskie gnejsy typu gierałtowskiego, śnieżckiego i bystrzyckiego; *2* — osady górnego dewonu i dolnego karbonu; *a* — górnodewońskie zlepieńce i wapienie podścielające nasunięcie kłodzkie, *b* — dolnokarbońskie (wizeńskie) zlepieńce, szarogłazy i łupki facji kulmowej struktury bardzkiej, *c* — górnodewońskie lub dolnokarbońskie zlepieńce z Kletna; *3* — polimetamorfity waryscyjskiej (bretońskiej lub sudeckiej) strefy tektonicznej Złoty Stok — Skrzynka i osłony stropowej kłodzko-złotostockiego masywu granitoidowego; *4* — plutony młodowaryscyjskie i produkty ich przeobrażeń: *a* — granitoidy, *b* — utwory dolnokarbońskie struktury bardzkiej zmienione kontaktowo; *5* — osady górnego karbonu i permu: *a* — górnowestfalskie i stefańskie zlepieńce i piaskowce, *b* — permskie zlepieńce, piaskowce i łupki oraz skały wylewne; *6* — osady górnej kredy; *7* — osady trzeciorzędu i czwartorzędu; *8* — nasunięcia; *9* — uskoki; *10* — stanowisko z mikroflorą; *11* — stanowiska z fauną

REVIEW OF PRIOR INVESTIGATIONS

Presented at the 30-th meeting of the Polish Geological Society the results obtained by Smulikowski (1957), H. Teisseyre (1957), and Oberc (1975a), provided significant arguments for the existence of one supracrustal series in the Lądek—Śnieżnik metamorphic unit, the series being referred to as the Stronie Series and believed to have been of Proterozoic age. Hitherto the supracrustal series of this region were commonly divided, following Fischer (1936), into two different series, namely the Młynów Series of Archean age and the Stronie Series of Algonkian-Cambrian age.

Also the infracrustal series were divided by Fischer into two groups of igneous rocks; the earlier, Archean was to be represented by the Gierałtów gneisses and migmatites and the later, Caledonian one embraced the Śnieżnik granite-gneisses. This division was recognised by Polish geologists as well though their opinions were strongly spilitted as to the mutal age sequence of the Gierałtów and Śnieżnik gneisses.

According to Smulikowski (1957, 1960), both the Śnieżnik and the Gierałtów gneisses developed in one, joint, likely Proterozoic, cycle owing to the granitization of the Stronie Series evoked by going-from-depth emanations. This process resulted in reomorphic mobilization of the rock substance capable to intrude locally. Such a view was adopted and even supported by numerous field observations by H. Teisseyre (1957, 1968). In much the same way Ansilewski (1966) accounted for the interrelationship of the Gierałtów and Śnieżnik gneisses, but he assumed that both the varieties were due to isochemical metamorphism, thus greatly controlled by primary composition of the initial sediments.

It was Oberc (1957a, 1972) who recognised two different generations within the Gierałtów gneisses. One of them was to be syndeformational and synchronous with the Śnieżnik gneisses of Proterozoic age whereas the other, post-deformational generation was correlated by him to the post-Late Assyntian Rumburk granites known in the Isera region.

Similar view was shared by Don (1958), but later this author (Don 1963, 1964) came to the conclusion that the Gierałtów gneisses were totally younger than the Proterozoic Śnieżnik gneisses but earlier than Hercynian granitoids and they likely represented different lithological unit which should be assigned to Caledonian epoch.

Kasza (1957) stated that possibly the rocks looking macroscopically like Gierałtów gneisses could be related to migmatitic processes accompanying the development of Hercynian Bielice granitoids. Later, however, he abandoned this view.

The presence of gneisses similar microscopically to the Gierałtów gneisses but having another age and origin, as proved by Kozłowska-Koch (1971, 1973), was earlier reported by Finckh *et al.* (1942) and his co-workers, which in the Skrzynka-Złoty Stok zone distinguished the so-called Haniak gneisses as independent lithological variety within the Lądek-Śnieżnik metamorphic unit.

Kozłowska-Koch's (1973) studies revealed that the Haniak gneisses were derived from the cataclased and mylonitised Śnieżnik and Gierałtów gneisses and Stronie Series rocks subjected to recrystallization and metasomatic reworking prior to the emplacement of the Kłodzko-Złoty Stok granitoids of Hercynian age.

It is worthy to mention the significant Gunia's discovery of relicts of Early Paleozoic fauna in the quartzites of Goszów belonging to the mesozonally metamorphosed supracrustal series of the Lądek--Śnieżnik Massif (Gunia, Dumicz 1976a).

The earliest, not metamorphosed rocks in the discussed region are represented by the conglomerates of Kletno. They were discovered by Kasza (1958, 1964) and ascribed by him to Upper Devonian or Carboniferous.

The opinions expressed by Polish geologists about the age and sequence of metamorphic series in the Góry Bystrzyckie and the Góry Orlickie are generally consistent.

H. Teisseyre *et al.* (1957) pointed out that the mica schists of the last mentioned region could be related to those of the Lądek—Śnieżnik area distinguished by Fischer (1936) as younger crystalline complex and called the Stronie Series. Also he considered the granite-gneisses of Góry Bystrzyckie and Góry Orlickie as undoubted equivalent of the Śnieżnik gneisses. This infracrustal series was regarded by Teisseyre as synorogenic rocks masses developed in the Algonkian within the supracrustal series. Both the series were to be dynamically transformed in the Caledonian orogenic cycle.

This view was adopted by Dumicz (1964) and supported by observations suggesting that the Bystrzyca and Śnieżnik gneisses could be due to metasomatic granitization. Such an interpretation was also confirmed by the results of Żelaźniewicz's (1973, 1976) investigations carried out in Polish part of the Góry Orlickie, in the vicinity of Duszniki.

The metamorphic series of the Duszniki region were conventionally assigned to the Proterozoic. But first paleontological evidence for this view was provided by Gunia (1974) who found in limestones the microflora characteristic of the Upper Proterozoic.

Gunia's (Gunia, Dumicz 1976b; Gunia 1976) discoveries of fauna in the samples collected by Dumicz in paragneiss crag near Wyszki (Góry Bystrzyckie were greatly significant. The faunal relicts allowed to ascribe these rocks to the Lower Paleozoic, which threw new light on the problem of geological development of mesozonally metamorphosed rocks of the Kłodzko District and even the whole Sudetes.

The age of rock series in the Kłodzko metamorphic unit was long discussed and variously viewed upon because of lack of any paleontological evidence. Recent faunal findings by Gunia, Wojciechowska (1964, 1971) enabled these authors to define stratigraphic position of some rock varieties in the discussed region. According to Wojciechowska's (1966) and Gunia, Wojciechowska's (1971) interpretation, the Kłodzko metamorphic unit is built of two principal rock complexes. The earlier complex is represented by blastomylonitic gneisses (known as the Ścinawka gneisses) and diaftorised amphibolites of Lower Paleozoic or Upper Proterozoic age. The younger complex embraces diversified assemblage of epizonally metamorphosed rocks. It begins with 500 m thick phyllites containing at the top limestone intercalations with Ludlowian stromathoporoides and corals and it ends with abundant products of basic volcanism accompanied by subordinate acid rocks likely of Upper Silurian or Lower Devonian age (Gunia, Wojciechowska 1971).

Thus Gunia's, Wojciechowska's (1964, 1971) works provided, for the first time, the scientific base for age identification of epizonally metamorphosed rocks of the Kłodzko metamorphic unit and their correlation to sedimentary rocks of the Bardo unit within the Ludlowian interval.

The oldest metamorphosed sediments overlying the Kłodzko metamorphic unit series are the Upper Devonian rocks evidenced paleontologically and containing pebbles of these very metamorphic rocks (Bederke 1924; Oberc 1957b; Wojciechowska 1966).

The above brief review of prior investigations on stratigraphy and age sequence of metamorphosed rocks in the Kłodzko District has distinctly shown that the main difficulties in geological interpretations of this region arise from the lack of satisfactory paleontological evidence in the Early Paleozoic series. No wonder that the opinions expressed by various authors on tectonic problems of the Kłodzko District, or its parts only, do differ remarkably. It is not the aim of this paper to discuss the detailed results obtained by individual workers. Therefore, presently will be outlined only principal ideas by H. Teisseyre and J. Oberc considering the geology of the Kłodzko District in terms of geological evolution of the entire Sudetes.

H. Teisseyre's (1968, 1975a) opinions were based upon his own investigations and those of his pupils (Dziedzicowa 1973, 1975; Gorczyca-Skała 1967, Wojciechowska 1966, 1972a, 1975a; Don 1964, 1972a, 1975; Dumicz 1964, 1975; Grocholski 1967, A. Haydukiewicz 1975, J. H. Teisseyre 1968, 1973; Żelaźniewicz 1973). He pointed out that both sequence and style of small-scale structures in rocks believed to be Upper Proterozoic and those of Lower Paleozoic age, in the Sudetes, very similar. This observation was interpreted by H. Teisseyre as follows:

"Perhaps the structural patterns of Cadomian and subsequent Caledono-Hercynian tectogenese were, in the Sudetes, generally the same. But in this case one should observe the effects of superimposition of younger structures upon the older ones, recorded by Proterozoic rocks. So far nobody has reported such a superimposition. Hence another working hypothesis may be conceivable. The small-scale structures observed both in Upper Proterozoic and Lower Paleozoic rocks (including Devonian) were due to one and the same Caledono-Hercynian or Hercynian tectogenesis. Earlier deformations would have possibly been entirely obliterated or their relicts have not been recognised yet. The Sowie Góry gneissic block would be the only exception as lineations occurring overthere are likely Precambrian in age" (H. Teisseyre 1975a).

According to H. Teisseyre (1975a, b), the main folding in the Lądek-Śnieżnik region, the Góry Bystrzyckie and the Góry Orlickie commenced in the Reusschiche Phase and gave rise to recumbent folds which were strongly modified in subsequent Hercynian phases and dismembered into numerous blocks during Alpine movements.

Oberc (1966, 1972) expressed another view about the age and sequence of deformations in Proterozoic and Early Paleozoic series of the Kłodzko District. He distinguished the Early Assyntian structural stage to which have been included the Lądek-Śnieżnik metamorphic unit, the Góry Bystrzyckie, and the Góry Orlickie. In these regions, two sets of Caledonian linear structures and one set of Hercynian lineation were recognised by H. Teisseyre (1964) and Dumicz (1964). The first two sets of lineation were assigned by J. Oberc to Early Assyntian foldings and the third one considered as Late Assyntian structures.

It was Oberc (1972) who distinguished two structural stages in the Kłodzko metamorphic unit. The older, Early Assyntian stage was to be represented by amphibolites, porphyroides, mica schists, and mylonitic gneisses of Proterozoic age. The younger, Early Hercynian one was separated from the former by great temporal disconformity ranging from Eocambrian to Ordovician. The latter stage was built of phyllites, limestones, and metavolcanic rocks of Silurian age as well as unmetamorphosed rocks of the Bardo unit, earlier than the Lower Carboniferous.

Early Hercynian and older deformations were featured by Oberc (1972) as follows: "Early Hercynian tectonics of Alpine type could develop in the Lower Silesia because earlier foldings, especially Early Assyntian ones, had produced large-scale recumbent folds which allowed the overlying series to have been deformed in the same way, no matter whether their structural plan, that is stress directions and vergence, followed ancient foundations or not. Those fragments of the Sudetic Structure, which yielded to strong pre-Hercynian reconstruction, especially Late Assyntian one, were not be folded again, during Hercynian epoch. But they were the zones of Hercynian granitoid intrusions".

SEQUENCE OF DEFORMATIONS

Those principal and so controversial problems concerning style, age, and sequence of deformations of rock series in the Kłodzko District also were investigated by the author in the Lądek-Śnieżnik metamorphic unit and in the Góry Bystrzyckie. The methods of mesostructural analysis and geological mapping were employed.

The results obtained showed that the main schistosity is, in general, perpendicular to primary sedimentary surfaces. So far the schistosity was believed to be parallel or sub-parallel to primary bedding and it was improperly used to define the geometry of large tectonic units (figs. 2, 3, 4).

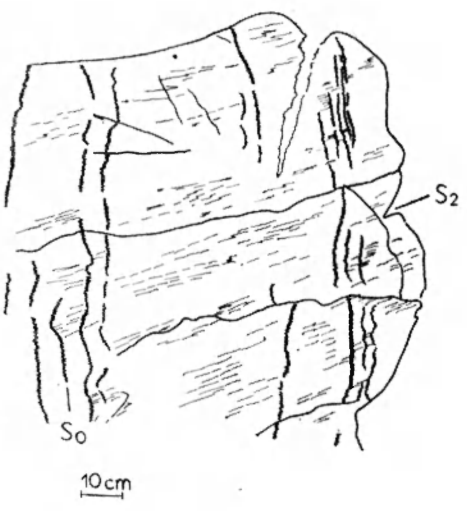

Fig. 2

Fragment of the exposure of paragneiss at Wyszki

S_0 — banding, S_2 — schistosity

Fragment odsłonięcia w paragnejsach z Wyszek

S_0 — warstwowanie, S_2 — złupkowanie krystalizacyjne

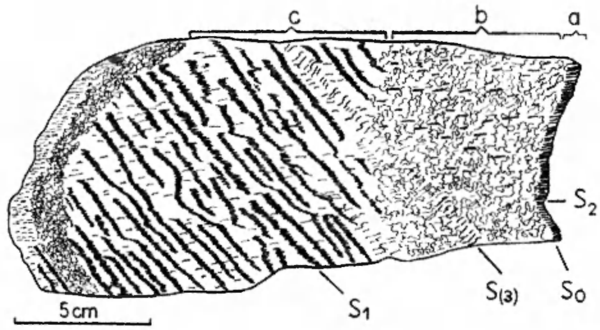

Fig. 3

Polished handspecimen of paragneiss of Wyszki

S_0 — banding represented by three kinds of laminae and bands: *a* — biotite laminae, *b* — bands of coarse- and medium-grained paragneisses, *c* — band of fine-grained paragneisses; S_1 — not closer defined biotite streaks; S_2 — schistosity; S_3 — axial zones of kink-folds

Wygładzona powierzchnia okazu paragnejsów z Wyszek

S_1 — warstwowanie reprezentowane przez trzy rodzaje lamin i warstw: *a* — laminy biotytowe, *b* — warstwy paragnejsów grubo- i średniokrystalicznych, *c* — warstwa paragnejsów drobnokrystalicznych; S_1 — smugi biotytowe bliżej nie zdefiniowane; S_2 — złupkowanie krystalizacyjne; S_3 — strefy powierzchni osiowych fałdów dachowych

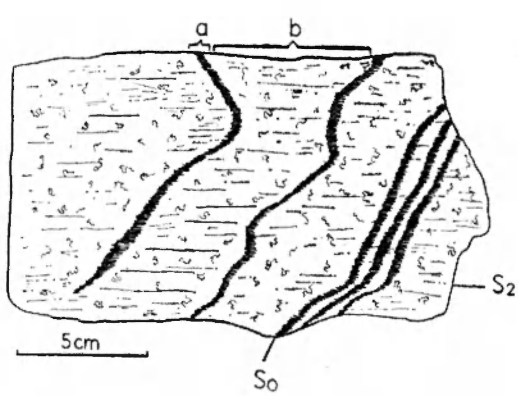

Fig. 4

Polished surface of handspecimen of paragneiss of Wyszki

S_0 — banding represented by two kinds of laminae and bands: *a* — biotite lamine, *b* — bands of coarse- and medium-grained paragneisses; S_2— schistosity

Wygładzona powierzchnia okazu paragnejsów z Wyszek

S_0 — warstwowanie reprezentowane przez dwa rodzaje lamin i warstw: *a* — laminy biotytowe, *b* — warstwy paragnejsów grubo- i średniokrystalicznych; S_2 — złupkowanie krystalizacyjne

Of great significance have appeared the folds of dysharmonic or similar type developing in the primary lamination, fairly frequently met in quartzites, amphibolites, erlans, paragneisses, and certain varieties of the Gierałtów gneisses. It was proved that the careful studies of the nature of such folds have been essential for the structural analysis aiming to explain style and sequence of deformations in metamorphosed rocks of the investigated region (Dumicz 1976a).

Similar or dysharmonic folds (figs. 5, 6) developing synchronously with the main schistosity were, in the Kłodzko District, studied by H. Teisseyre (1971, 1972, 1973, 1975b, 1975c) and his pupils (Wojciechowska 1972a, 1972b, 1972c, 1975b; Don 1972a, 1972b, 1975; Dumicz 1975; Dumicz, A. Haydukiewicz 1975; Żelaźniewicz 1976).

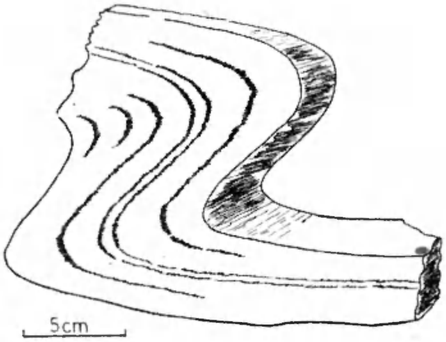

Fig. 5
Similar fold in quartzites of Goszów
Fałd typu similar w kwarcytach z Goszowa

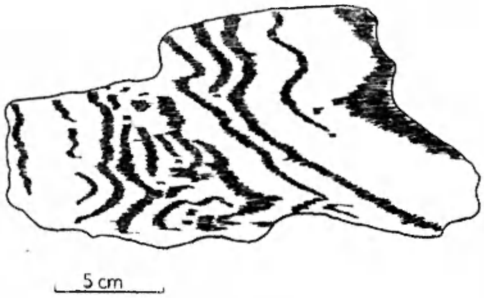

Fig. 6
Dysharmonic folds in quartiztes of Goszów
Fałdy dysharmonijne w kwarcytach z Goszowa

In the Lądek-Śnieżnik metamorphic unit and in the Góry Bystrzyckie, the enveloping surface of the mentioned folds is consistently perpendicular to the schistosity (fig. 7). Thus lamination S_0 and lithological

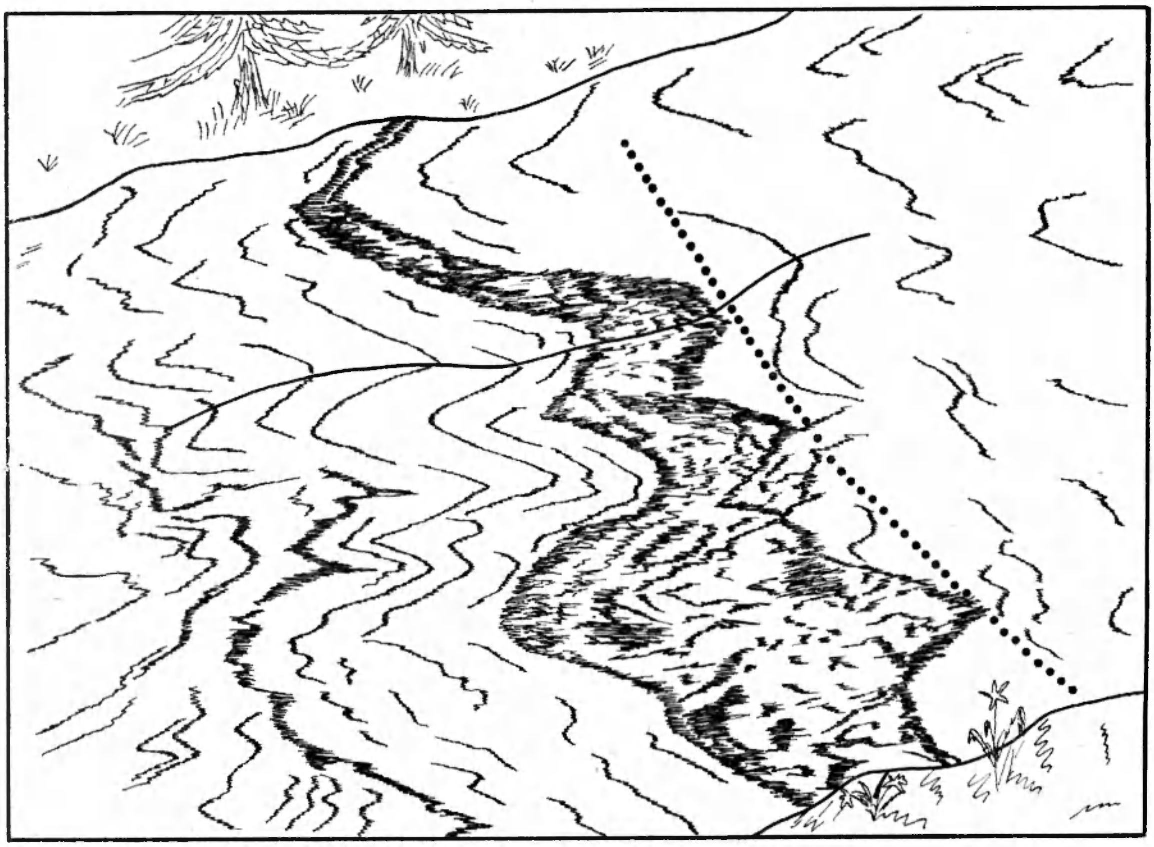

Fig. 7
Similar and dysharmonic folds in the Gierałtów gneisses (blank) intercalated with amphibolites (dark) in Lądek-Zdrój (according to Don 1972). Dotted line – enveloping surface, solid line – axial schistosity

Fałdy typu similar i dysharmonijne w gnejsach gierałtowskich (tło jasne) z wkładkami amfibolitów (smugi ciemne) w Lądku (wg Dona 1972b). Linia kropkowana wyznacza obwiednię fałdów, linia ciągła – położenie złupkowania krystalizacyjnego zorientowanego równolegle do powierzchni osiowej fałdów

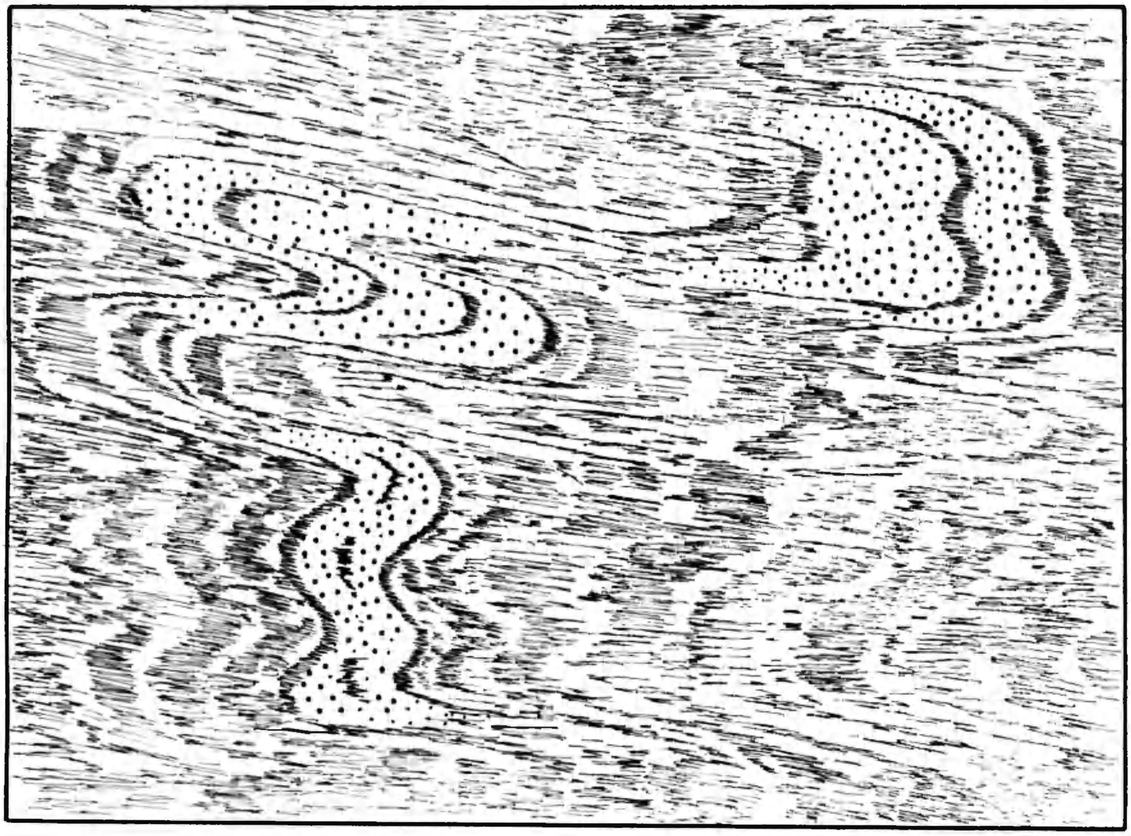

Fig. 8

Geological sketch explaining style of deformation and tectonic position of the quartzites of Goszów. Dotted areas — quartzites; mica schsits and paragneisses are dashed in parallel to axial schistosity (according to Dumicz 1975)

Szkic geologiczny wyjaśniający styl odkształceń i pozycję tektoniczną kwarcytów z Goszowa. Kwarcyty oznaczone są kropkami, a łupki łyszczykowe i paragnejsy — kreskami zorientowanymi zgodnie ze złupkowaniem krystalizacyjnym (wg Dumicza 1975)

boundaries are at the high angle to the schistosity. The same may be observed on macroscopic scale, on geological maps. Excellent example is rendered by intricate outcrop pattern of Goszów quartzites and gneisses within the Międzygórze Anticline (figs. 8, 9).

Another feature of the discussed folds is a great scatter of their axial directions, observed in the axial schistosity planes. It reaches sometimes 70° in a hand-specimen (fig. 10) and may amount even 180° in the individual exposures as shown by Don (1972b).

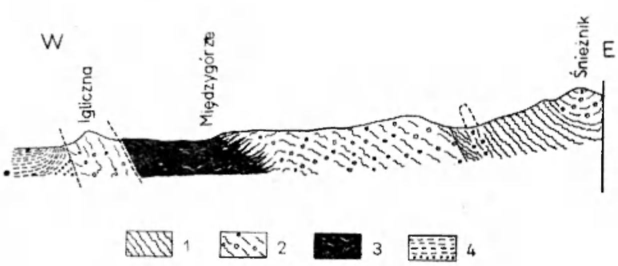

Fig. 9

Geological cross-section Międzygórze-Śnieżnik (after Don 1969)

1 — mica schists with quartzite and amphibolite intercalations (Stronie Series) *2* — augen gneisses (Śnieżnik type); *3* — migmatic gneisses (Gierałtów type) *4* — Cretaceous rocks of the Upper Nysa graben

Przekrój geologiczny Międzygórze-Śnieżnik (wg Dona 1969)

1 — łupki łyszczykowe z wkładkami kwarcytów i amfibolitów (seria strońska); *2* — gnejsy oczkowe (śnieżnickie); *3* — gnejsy migmatyczne (gierałtowskie); *4* — osady kredowe rowu górnej Nysy

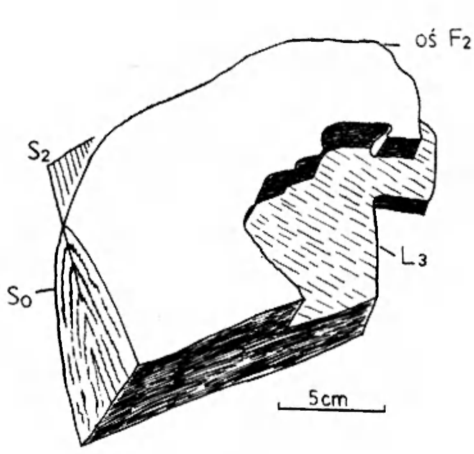

Fig. 10

Fragment of F_2 fold recorded in quartzites of Goszów Axis of this fold turns in the S_2 schistosity plane: S_0 — lamination, L_3 — lineation

Fragment fałdu F_2 w kwarcytach z Goszowa o zmieniającym się przebiegu osi w płaszczyźnie złupkowania krystalizacyjnego S_2: S_0 — laminacja, L_3 — lineacja

The third characteristic of similar folds is their penetrativity, much alike the schistosity developing synchronously with the very folds.

The folds in question represent in the Lądek-Śnieżnik metamorphic unt the second generation of small-scale structures referred to as F_2. In these folds are involved axial planes S_1 of F_1 folds recognised in the quartzites of Goszów and erlans of Kamienica (fig. 11).

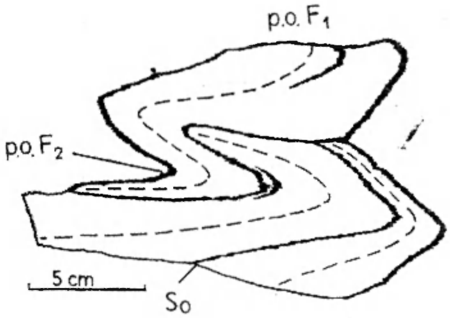

Fig. 11

F_1 fold refolded around F_2 axis in the quartzite of Goszów: S_0 — mimetic lamination probably after primary bedding; *p.o.* F_1 — axial plane to F_1 folds; *p.o.* F_2 — axial planet to F_2 folds

Fałd F_1 zdeformowany przez fałd F_2 w kwarcytach z Goszowa: S_0 — laminacja odpowiadająca prawdopodobnie pierwotnej stratyfikacji; *p.o.* F_1 — powierzchnia osiowa fałdów F_1; *p.o.* F_2 — powierzchnia osiowa fałdów F_2

The folds younger than F_2 ones deform S_2 schistosity and their enveloping surfaces are diagonal to those of F_2 similar folds (fig. 12). Development of similar folds led to the essential change of structural pattern in the discussed region.

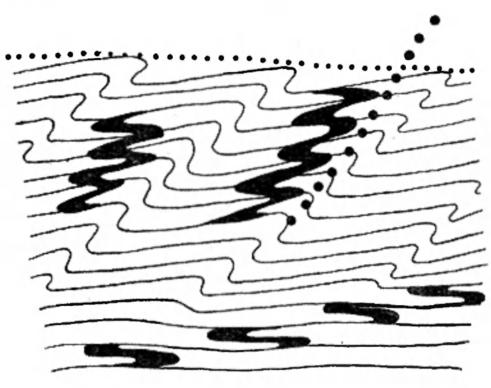

Fig. 12

Sketch illustrating interrelationships of F_2 and F_3 folds. Thick dots — enveloping surface to F_2 folds; fine dots — enveloping surface of F_3 folds. *S*-shaped black areas — relics of F_2 folds passing into intrafolial folds during the third developmental stage

Szkic wyjaśniający stosunek fałdów F_2 do fałdów F_3. Linia zaznaczona kropkami grubymi przedstawia obwiednie fałdów F_2, a cienkimi — obwiednie fałdów F_3. Pola ciemno zarysowane na kształt litery *S* — zachowane reliktowo fałdy F_2, przekształcone w trzecim etapie rozwojowym w izolowane fałdy śródfoliacyjne

For interpretation of this phenomenon in terms of structural development of the discussed region several observations already published in the literature seem to be important.

Ansilewski (1966) noted that plagioclases in the Lądek-Śnieżnik metamorphic rocks became more basic as they were developing. Thus their blastesis must have taken place during prograde metamorphism when increasing temperature was followed by increase in Ca content in plagioclases. Plagioclases having up to 18% of An crystallized under directional pressure whereas those containing more than 18% of An grew under conditions of confining pressure. Also optimum microcline blastesis started, according to Ansilewski, under nearly hydrostatic pressure.

J. H. Teisseyre (1973) discussing petro- and tectogenesis of metamorphic rocks of the Rudawy Janowickie Range and Lasocki Ridge (Karkonosze Block) remarked: "Of importance for the development of the Kowary gneisses is static recrystallization between the first (F_1) and the second (F_2) episodes of foldings. Plagioclase and especially K-feldspar porphyroblastesis is widespread in evidence. Nearly automorphic, tabular individuals, randomly distributed throughout laminated fabric of the Kowary gneisses, were growing then. Porphyroblastic growth of K-feldspar was not broken down by F_2 folding but it continued as a synkinematic process".

The so far obtained results presented in this paper, being based on rich analytical material and though mesostructural studies, allow to attempt reconstruction of main developmental stages in the discussed region but omitting, however, that connected with the disposition of the parent sedimentary rocks.

In the first stage, geosynclinal sediments had been intensively folded and were progressively metamorphosed as, among others, evidenced by increasing Ca content in plagioclases. This was the proper tectogenesis which ended after tangential compression had vanished (fig. 13). Scarcely preserved F_1 folds also displaying a similar geometry refer to this very stage.

The second stage commenced under conditions close to confining pressure and was characterized by microcline blastesis. Likely in that very time, metamorphic series of the Lądek-Śnieżnik and Góry Bystrzyckie regions were differentiated into schists and gneisses (fig. 14). The rock series of the discussed tectogene had once been folded and piled up and now they became subjected to horizontal tension and isostasy. To preserve isostatic balance the tectogene was necessarily involved in general upward movement, that is proper orogenic movements. Owing to this process the deeper, plasticized portions of the tectogene yielded to horizontal migration as they could not withstand gravitational load of stiff overlying rock masses (fig. 15).

The above featured phenomenon was synchronous with the development of the gneissic series and

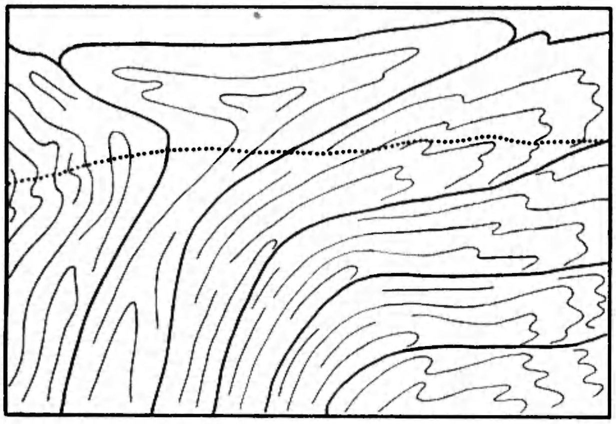

Fig. 13

Schematic sketch showing the Middle Sudetes tectogene effected by tangential compression at the first developmental stage. Thick lines — outlines of supposed geological units; fine lines — inferred sedimentary banding; dotted line — assumed upper boundary of metamorphic processes

Szkic poglądowy przedstawiający tektogen Sudetów Środkowych jako efekt kompresji tangencjalnej w pierwszym etapie rozwojowym. Linie grube — zarys przypuszczalnych jednostek geologicznych, linie cienkie — przypuszczalne powierzchnie stratyfikacji, linia kropkowana — przypuszczalny zasięg procesów metamorficznych

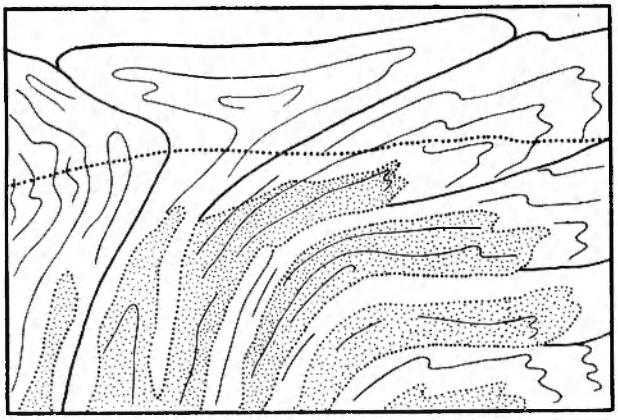

Fig. 14

Schematic sketch showing the Middle Sudetes tectogene at the beginning of the second developmental stage under conditions of nearly confining pressure. Dotted areas — rock series affected by microcline blastesis resulting in development of Śnieżnik, Bystrzyca, and Gierałtów gneisses. Other denotations as in figure 10

Szkic poglądowy przedstawiający tektogen Sudetów środkowych na początku drugiego etapu rozwojowego w warunkach ciśnienia zbliżonego do hydrostatycznego. Pola zakropkowane — serie skalne objęte blastezą mikroklinową, prowadzącą do powstania gnejsów typu śnieżnickiego, bystrzyckiego i gierałtowskiego. Objaśnienia pozostałych znaków jak na figurze 10

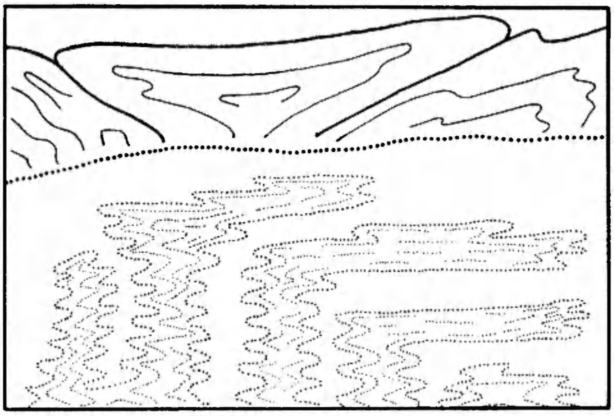

Fig. 15

Schematic sketch showing the Middle Sudetes tectogene at the second developmental stage under conditions of vertical compression evoked by gravitational load of overlying strata and tendency to isostatic compensation. Unshaded areas — mica schists series; dotted areas — gneisses of the Bystrzyca, Śnieżnik, and Gierałtów. Boundaries of these areas mark general geometry of F_2 folds having horizontal axial planes .Other denotations as in figure 10

Szkic poglądowy przedstawiający tektogen Sudetów Środkowych w drugim etapie rozwojowym w warunkach działania kompresji pionowej, wywołanej grawitacyjnym ciążeniem nadkładu oraz dążeniem tektogenu do wyrównania izostatycznego. Pola jasne — metamorficzna seria łupkowa; pola zakropkowane — gnejsy typu bystrzyckiego, śnieżnickiego i gierałtowskiego. Zarysy tych pól obrazują fałdy F_2 o połogim położeniu powierzchni osiowej. Objaśnienia pozostałych znaków jak na ryc. 10

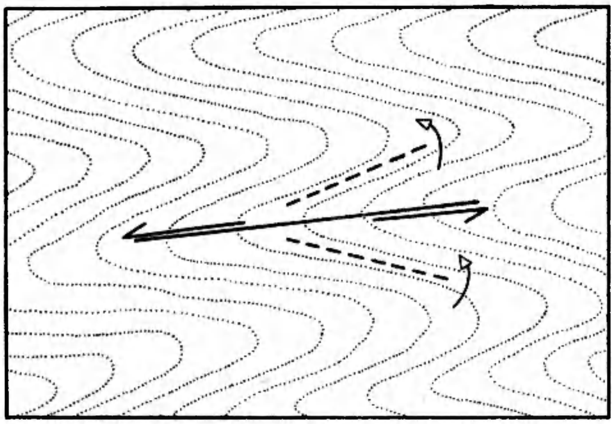

Fig. 16

Schematic sketch showing F_2 folds (dotted lines) and internal physical discontinuities: axial schistosity (solid line), lamination in fold limbs (dashed lines); stright arrows — theoretically assumed sense of movement; bowed arrows — rotation resulting from the assumed sense of movements

Szkic poglądowy przedstawiający fałdy F_2 (linie kropkowane) oraz zaznaczające się w nich powierzchnie nieciągłości fizycznej: złupkowanie krystalizacyjne równoległe do powierzchni osiowych fałdów (linia ciągła), laminacja na odcinkach międzyprzegubowych fałdów (linia przerywana). Inne objaśnienia: strzałki proste — założony teoretycznie zwrot ruchu, strzałki o linii łuku — rotacje zgodne z założonym zwrotem ruchu (homotetyczne) resulted in common formation of similar folds as well as change of anisotropy of rocks owing to production of new physical discontinuities and reorientation of the earlier ones, which dated back to the tectogenic stage. These newly involved discontinuities were mainly represented by schistosity parallel to the axial planes of similar folds. The earlier ones appeared mostly as laminae in limbs of the similar folds (fig. 16).

The tectogene, formed in this way, steadily occupied higher and higher levels in the earth's crust, yielded to further consolidation, and its upper portions were eroded. Possibly, in that time, the Lądek-Śnieżnik region was much peneplanized and locally subsiding. Such local depressions were filling up with sediments, probably like that of Kletno conglomerate discovered by Kasza (1958, 1964).

The third developmental stage went on under influence of tangential compression or speaking more strictly was controlled by a couple of forces acting in the vertical plane. Then, the movements occurred along physical discontinuities produced during the second stage.

In mica schists, tectonic transport was employed along the schistosity surfaces, which led to the formation of intrafoldial derived from the similar ones. Distinctly asymmetric folds (F_3) were developed (fig. 12).

However, in most varieties of the Śnieżnik gneisses, three sets of planar structures (discontinuities) were kinematically active but the strongest and greatest displacements took place in parallel to the axial planes of similar folds. Both limbs of the similar folds were rotating, in that time, homothetically (fig. 16). The limbs inclined in the direction opposite to that of movement were mechanically dismembered and brought into parallelism with planes of movements. The limbs inclining in the same direction as a sense of movement were subjected to destruction and the resultant individual elements yielded to strong rotation. Owing to the above featured process the Śnieżnik gneisses, likely having a primarily augen-laminated fabric, were commonly cataclased and transformed into streaky, streaky-laminated or pencil gneisses, locally passing even into cataclasites or mylonites (fig. 17).

The Gierałtów gneisses do not display signs of common displacements along discontinuities produced in the prior developmental stage. Nevertheless, the zones of cataclasis and mylonitization parallel, in general, to the faint S_2 schistosity, may be observed in the Gierałtów gneisses as well (cf. Ansilewski 1966).

The different response of the Gierałtów and Śnieżnik gneisses to tectonic stresses was discussed by Smulikowski (1957). "... the Gierałtów gneiss, fine-grained and having evenly distributed micas, was probably resistant to deformations of the intensity yet sufficient to crush the Śnieżnik gneiss characterized by large grains of quartz and feldspar and big concentrations of micas".

The stage in question was characterized not only by textural differentiation of the metamorphic rocks involved, but most of all by great overthrusts marked by cataclasites and mylonites. It seems that the Kletno overthrust (Kasza 1958, 1964) zone, where gneisses overlie mylonites and conglomerates of Kletno, developed in this very period (fig. 18).

In the fourth developmental stage, the discussed tectogene was once more intensely folded. Then most of synforms and antiforms seen presently on maps

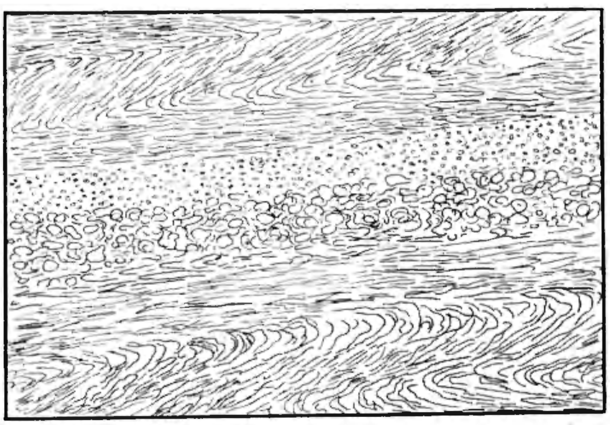

Fig. 17

Effects of dynamic transformations of the third developmental stage visible in the Śnieżnik gneisses which were folded (F_2 folds) during the second developmental stage (comp. fig. 16)

Efekty dynamicznych przeobrażeń trzeciego etapu rozwojowego widoczne w gnejsach śnieżnickich, które w drugim etapie rozwojowym objęte zostały rozwojem fałdów F_2 (por. z fig. 16)

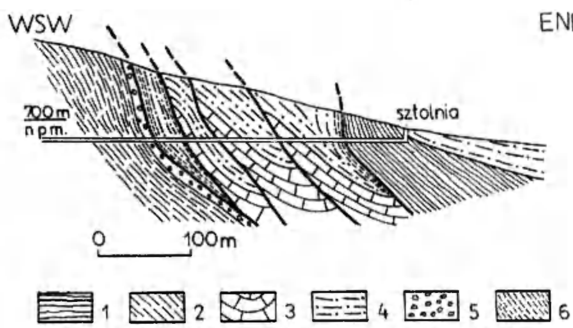

Fig. 18

Geological cross-section through the Kletno overthrust zone (after Kasza 1964)

1 — mica schists and paragneisses with intercalations of crystalline limeston and erlans; *2* — mica schists and paragneisses; *3* — crystalline limestones; *4* — gneisses; *5* — conglomerates; *6* — mylonites

Przekrój geologiczny przez sferę nasunięcia Kletna według Kaszy (1964)

1 — łupki łyszczykowe i paragnejsy z wkładkami wapieni krystalicznych i erlanów; *2* — łupki łyszczykowe i paragnejsy; *3* — wapienie krystaliczne; *4* — gnejsy; *5* — zlepieńce; *6* — mylonity or in the outcrop patterns were developed, their axial directions being fairly variable. They represent the fourth set of folds (F_4) appearing usually as concentric structures. They were accompanied by local axial recrystallization which sometimes produced rocks of migmatitic nature.

Next, the investigated region was affected by Hercynian plutonism which resulted in its further consolidation. Subsequent tectonic episodes were evidenced by broad warpings and rigid structures as kink-bands, joint-drags, faults, joints, breccias as well as cataclasites and mylonites in deeper levels.

The results of mesostructural analysis presented above allow to interpret the F_2 similar folds and related S_2 axial schistosity as the result of vertical compression produced by gravitational loading and isostatic compensation. This evoked lateral migration of plastic rock masses. Therefore F_2 axial directions are greatly divergent in planes of S_2 schistosity. Higher levels of the discussed tectogene might at the same time be jointed and some fissures could be utilised by emplacing acid magma to produce granite-gneiss bodies. In such an interpretation the room problem would be easily explained. One can also assume that in the highest level of the uplifting tectogene, the gravitational gliding of erosionally unrooted tectonic elements was employed toward depressional areas.

The above featured structural analysis throws a new light upon certain geological problems in the Sudetes and offers comprehensive interpretation for these Sudetic regions which suffered a total change of tectonic pattern (framework) during the second developmental stage. This change relied upon common production of new physical discontinuities (schistosity) and obliteration of earlier ones. To recognise this phenomenon is of great importance for the proper defining of geometry of large tectonic forms in the course of mapping or mineral resources documentation.

One may easily note that most of the tectonic forms, hitherto mapped or described in the literature of the Lądek-Śnieżnik and Góry Bystrzyckie regions, date back to the stage of reconstruction of the prior tectogene. Inferred geometry of these forms escapes sometimes very far from their true shapes. However, the macrostructures of tectogenic developmental stage have not been recognizable so far.

AGE OF DEFORMATIONS

Entering discussion about the age of the individual developmental stages one must remind of faunal discoveries by Gunia (Gunia 1976; Gunia, Dumicz 1976a,b). In paragneisses of Wyszki (the Góry Bystrzyckie) and quartizites of Goszów (the Lądek-Śnieżnik region), he found fragments of spongiae, echinodermata, brachiopods, hyolites, foraminifers, and snails. These findings radically have have changed prior opinions on the age of metamorphic series of the Kłodzko District and have defined the lowest possible age limit of initial deformations as the Lower Paleozoic.

H. Teisseyre (1968, 1975a) correlated deformations recognised in the Sudetic Early Paleozoic rocks with those recorded in rocks considered to have been the Precambrian. He arrived at the conclusion that the main folding in the Sudetes must have represented either Caledono-Hercynian or Hercynian epoch. H. Teisseyre's thesis has been confirmed by Gunia's discoveries. Thus, some important problems of Sudetic geology have seemed to be solved.

Presently, there is no reason to include longer the mesozonally metamorphosed series of the Sudetes and Sudetic Foreland to the Early Assyntian structural stage, except the Sowie Góry gneissic block and perhaps the crystalline formations of eastern Sudetes. The presence of Lower Paleozoic fauna in these series clearly indicates that they are time equivalent to the Góry Kaczawskie metamorphic rocks, the Kłodzko metamorphic unit and likely the Early Paleozoic sedimentary series of the Bardo unit.

The lowest stratigraphic limit of the mesozonally metamorphosed series of the Kłodzko District should be undoubtedly placed in the Proterozoic on the basis of the presence of Upper Proterozoic microflora in crystalline limestones of the Duszniki region (Gunia 1974).

Also the bottom of epimetamorphic series of the Góry Kaczawskie is represented by Upper Proterozoic sediments (H. Teisseyre 1975a). The Eocambrian Radzimowice slates pass lithologically into the overlying Wojcieszów Limestones ascribed to the Lower Cambrian on the basis of the presente of tabulata belonging to the genus of Cambrotrypa (Gorczyca-Skała 1966; Gunia 1967).

In the Góry Kaczawskie geosyncline, the sea bottom was several times affected by intense movements. This was evidenced by development of reef facies, flysch, conglomerates, and volcanic rocks (H. Teisseyre 1975a). These movements, however, did not give rise to strong folding or uprising the sediments above sea level. Also H. Teisseyre's (1964, 1967, 1971) and A. Haydukiewicz's (1975) structural investigations point to the continuous sedimentation except very scarce and local gaps recognised in the Góry Kaczawskie geosyncline within the span from Eocambrian to Devonian. The stratigraphic investigation indicate that the main folding and metamorphism of the Góry Kaczawskie series must have taken place after the Upper Devonian (Urbanek 1975, Chorowska, Sawicki 1975).

One can suppose, by analogy to the Góry Kaczawskie metamorphic series, that the Kłodzko District metamorphic rocks also represent the continuous sedimentary sequence from Upper Proterozoic to Lower Paleozoic. In the Lądek-Śnieżnik region, even the first results of Smulikowski's (1957), H. Teisseyre's (1957), and Oberc's (1957a) investigations have proved that there is only one supracrustal series instead of two: Archean and Algonkian-Cambrian, envisaged by G. Fischer. Later works of various authors revealed, that in the Lądek-Śnieżnik region, the Góry Bystrzyckie and the Góry Orlickie, the supracrustal series has been characterized by uniform structural development (H. Teisseyre 1964, 1968; Don 1964; Wojciechowska 1975a; Dumicz 1964; Żelaźniewicz 1976). It cannot be excluded that this series might have been deposited in one and the same sedimentary basin.

The upper stratigraphic limit of the Kłodzko District metamorphic series still remains unknown. The youngest, paleontologically documented stratigraphic members have been assigned to the Lower, not closer defined, Paleozoic (Gunia 1976).

In the Góry Bystrzyckie and the Lądek-Śnieżnik region, it is obvious that at the present intersection level are exposed the roots of tectogene eroded as deeply as meso-zone. The younger stratigraphic series forming this tectogene were to much extent removed. Thus one can suppose that the sedimentation of parent rocks to metamorphic series of the Lądek-Śnieżnik, and Góry Bystrzyckie regions was broken down by Early Hercynian foldings evidenced clearly in the Kłodzko metamorphic unit (Gunia, Wojciechowska 1964, 1971).

In the light of aforesaid remarks, the oldest tectonic unit appears to be represented by the Early Hercynian structural stage. This stage consists of Upper Proterozoic and Lower Paleozoic rocks series which were folded, regionally metamorphosed, and affected by plutonic processes in one of the earlier phases of Hercynian orogenesis.

At the present intersection level, this stage is represented: in the Lądek-Śnieżnik, Góry Bystrzyckie, and Góry Orlickie regions by mesozonally metamorphosed and igneous series (the Śnieżnik, Bystrzyca, and Gierałtów gneisses); in the Kłodzko region by meso-and epimetamorphic series; in the Góry Bardzkie region by unmetamorphosed sedimentary and volcanic rocks.

One cannot exclude, however, that the lower structural element underlying the Early Hercynian stage may be exposed in tectonic elevations subject to deep erosion. In the light of the results so far obtained such a possibility is admissible but not proved. The same is true about possible sedimentary gaps and angular unconformities within the Early Hercynian structural stage.

The initial foldings which produced the Early Hercynian structural stage in the Lądek-Śnieżnik and the Góry Bystrzyckie metamorphic units, took place in two episodes, the younger following immediately the older one. The earlier, tectogenic episode (fig. 13) took place under conditions of tangential compression (development of F_1 folds and prograde metamorphism) and the younger, orogenic episode (figs. 14, 15) began under conditions of nearly confining pressure and went on under control of vertical compression (microcline blastesis resulting in the formation of the Śnieżnik and Gierałtów gneisses, development of similar and dysharmonic F_2 folds, development of S_2 axial schistosity — then nearly horizontal). The scarce data so far collected do not allow to define precisely the age of those foldings. But one must keep in mind the above featured phenomena indicating that the formation of the Śnieżnik and Gierałtów gneisses was synchronous with F_2 similar folding and development of S_2 axial schistosity.

Bakun-Czubarow (1968) reported about the radiometric age of biotite of the Gierałtów gneisses determined by means of K/Ar method ($_B = 4{,}74\times10^{-10}$ per annum and $_K = 0{,}584\times10^{-10}$ per annum). This yielded the age of 366 m.y. Surely, this result cannot be strictly related to the Gierałtów gneisses or even indirectly to the Śnieżnik gneisses, F_2 similar folds, and S_2 schistosity. But one must be aware of the fact that the metamorphic series of the Kłodzko District have faunal evidence for unprecised Lower Paleozoic age in the Lądek-Śnieżnik and Góry Bystrzyckie regions (Gunia 1966), and for Upper Silurian age in the Kłodzko metamorphic unit (Gunia, Wojciechowska 1964, 1971). Moreover, these series have been unconformably covered with the deposits of which the earliest stratigraphic horizons are ascribed to the Upper Devonian (Bederke 1924).

Conclusively one can assume that the initial foldings and accompanying metamorphic and plutonic processes (Śnieżnik and Gierałtów gneisses) must have taken place about 366 m.y. ago, then at the beginning of the Middle Devonian, possible in the Orcadian Phase.

The main folding in other Sudetic regions might have been a little earlier or later. For example in the Góry Kaczawskie and their western extension at Northern Lusatia, the age of the main folding got progressively younger along the strike of the main structures, ranging from the Bretonian Phase on the east to the Sudetian Phase on the west (H. Teisseyre 1975a).

In the Bardo unit, however, the sedimentation was continuous from the Silurian till the Middle Devonian (Oberc 1957b, 1968, 1972) which passed lithologically into the Upper Devonian (J. Haydukiewicz 1974). Thus, it is obvious that the Early Hercynian foldings (pre-Upper Devonian, Orcadian Phase), so distinct throughout the Kłodzko District and well evidenced in the Kłodzko metamorphic unit (Gunia, Wojciechowska 1971), did not manage to break sedimentary processes in the Bardo basin which likely also belonged to the Upper Proterozoic-Lower Paleozoic geosyncline of the Middle Sudetes. This basin had been probably surrounded, after Early Hercynian foldings, by mountainous chains from which the erosionally unrooted tectonic elements were transported downwards due to gravitational gliding. Oberc (1972) and B. Wajsprych (pers. comm.) mentioned the development of Visean olisthostroms in the Bardo unit. Perhaps the same phenomena took place overhere in the Middle Devonian.

The initial foldings in the Early Hercynian tectogene of the Lądek-Śnieżnik and Góry Bystrzyckie regions produced very complicated tectonic pattern. It consisted, to simplify the problem, of F_1 folds (perhaps passing into overthrusts), upright in deep and recumbent at shallower levels (effect of tangential compression), F_2 recumbent and similar folds any nearly horizontal S_2 axial schistosity discordantly overprinted upon F_1 structures (effect of vertical compression).

The subhorizontal attitude of these newly introduced physical discontinuities (S_2 axial schistosity) largely controlled all these subsequent geological events which took place after consolidation and erosion of the Early Hercynian tectogene and after deposition of the Kletno conglomerates likely representing Upper Devonian or Lower Carboniferous sediments (cf. Kasza 1958, 1964).

The process of rebuilding of the Early Hercynian tectogene which had started under still tangential compression, made active the subhorizontal discontinuities. The effects of this phenomenon have been described earlier while characterizing the third developmental stage. The age of this stage is not determined precisely. It seems that the Kletno thrust zone should be referred to the very stage. In this zone the Śnieżnik gneisses were thrust over the Kletno conglomerates ascribed to the Bretonian or Sudetian Phase.

The same geological situation may be observed in the western Sudetes where, according to H. Teisseyre, the Góry Kaczawskie metamorphic series contact through brecciated mylonites with underlying Devonian and Lower Carboniferous sediments of the Świebodzice depression (H. Teisseyre, Smulikowski, Oberc 1957). H. Teisseyre, however, considered these mylonites to have been of pre-Upper Devonian age. The overthrust itself was interpreted by him as due to uplifting of deeply eroded Góry Kaczawskie tectogene and gravitational gliding of erosionally unrooted elements toward the Świebodzice depression.

Much in the same way may be explained the geological position of the Kletno overthrust. At first the mylonites had been developing in the regions not subject to subsidence and devoid of cover of the Kletno conglomerates. Next, along the very mylonitic zones the erosionally unrooted tectonic elements moved downard due to gravitational gliding into the depression filling up with conglomerates. It cannot be, however, excluded that the Kletno overthrust was developing synchronously with the mylonites occurring at the bottoms of each slices in the imbricated zone. The following data speaks for such a thesis. Though the amplitude of the discussed overthrust remains unknown, one can assume that it is not lesser than a total thickness of rock masses removed due to erosion from the Visean or Upper Carboniferous till recent times. This thickness must amount at least a couple of kilometres as the Lądek-Śnieżnik metamorphic series were intruded by Upper Carboniferous granitoids now well exposed at the surface. Therefore the Kletno overthrust amplitude must be of the same order of magnitude. Accordingly, it may be stated with a great probability that the Śnieżnik gneisses observed at the recent exopsure level to overlie along the thrust plane the Kletno conglomerates, occur as far as several kilometres from the bow of overthrust to which they have belonged. They must have been transported along the very distance through the metamorphic series before they reached the pre-Upper Devonian or a little younger earth surface covered with the Kletno conglomerates. One can assume that the mylonites could develop in decollement zone in the metamorphic basement and jointly with detached gneissic masses were overthrust upon the Kletno conglomerates. The above interpretation is supported by Kasza's (1964) observations reporting lack of mylonites and cataclastic gneisses of the Śnieżnik type among the pebbles constituting these conglomerates.

Neither the Upper Devonian nor Lower Carboniferous sediments in the Świebodzice depression contain pebbles made of cataclastites recognised in the metamorphic series of the Góry Kaczawskie

(H. Teisseyre 1956). J. H. Teisseyre (1973) studied the pebbles occurring in Kulm deposits of western Intrasudetic Basin. He recognised that the pebbles of metamorphic rocks preserve here relics of small-scale folds characteristic of the first and second fold episodes in the Rudawy Janowickie Range and Lasocki Ridge (Karkonosze Block).

Process of rebuilding of the Early Hercynian tectogene resulted in significant piling up of the rock masses involved. This pile had the shape of dome over the area of the Lądek-Śnieżnik, Góry Bystrzyckie, and Góry Orlickie regions. The dome itself was marked by spatial attitude of S_2 schistosity throughout those regions, the schistosity being frequently transformed into surfaces of tectonic gliding.

As may be judged from Kozłowska-Koch's (1971, 1973) and Smulikowski's (1973) works on the Skrzynka-Złoty Stok tectonic zone, the above featured phenomena gave rise to a rapid increase of temperateure which affected the Stronie Series, Śnieżnik, and Gierałtów gneisses. The cataclased or mylonitised series were subject to blastesis and metasomatic reconstitution leading to the formation of polymetamorphic rocks (e. g. the so-called Haniak gneisses). Increase of temperature was followed by partial melting and production of magma at greater depths. According to Kozłowska-Koch (1973), this magma intruded either concordantly into the metamorphic complex which had resulted from regional metamorphism in the same phase of Hercynian orogenic cycle.

Geological observation indicates that the post-mylonitic blastesis must have taken place during intense folding (development of F_4 folds accompanied by feldspar blastesis at their hinge zones) but granitoid magma (granitoid massifs of Kłodzko-Złoty Stok, of Bielice, of Kudowa, and of Ścinawka) was emplacing uder control of tangential extension (granitoid dikes cross-cut F_4 folds too). Those intrusions are commonly believed to have been uf Upper Carboniferous age.

In the above presented geological evolution of the Kłodzko District, striking is the so long geo, synclinal cycle continuing from the Upper Proterozoic up to the Lower Devonian. On the other hand-the Early Hercynian tectogene was consolidated in relatively short span lasting from the Middle Devonian to an end of the Carboniferous, but being very rich in various geological events.

Subsequent tectonic events, continuing through the Late Hercynian and whole Alpine epoch, were expressed mainly as broad mega-warpings and rigid deformations. In the light of so far gathered experience, to reconstruct both sequence and mutal relationships of those events seems to be a very difficult task.

The above presented idea on development, sequence, style, and age of deformations affecting the mesozonally metamorphosed series of the Kłodzko District should be treated as a working hypothesis. All the tectonic events are thought to have taken place in the Hercynian mountain-building epoch, from initial foldings up to complete consolidation of the discussed tectogene. The featured developmental cycles of the Kłodzko District are very similar to those inferred for the Middle and Western Sudetes and differ substantially from the evolution of Eastern Sudetes. In the latter region, mesozonally metamorphosed formations had been discordantly covered with epimetamorphic series commencing in the Lower Devonian.

The present state of investigations does not allow to state whether the Kłodzko District metamorphic series were whatever, whenever, and whereever affected by these processes which caused the formation of two distinct structural stages within the crystalline rocks of the Eastern Sudetes.

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PRÓBA WYJAŚNIENIA TEKTOGENEZY SERII ZMETAMORFIZOWANYCH ZIEMI KŁODZKIEJ

STRESZCZENIE

W niniejszym artykule autor przedstawił próbę rekonstrukcji głównych etapów rozwojowych serii zmetamorfizowanych Ziemi Kłodzkiej (fig. 1) i wypowiedział się na temat wieku depozycji i przeobrażeń tektonicznych tych serii.

Etap pierwszy to intensywne sfałdowanie utworów geosynklinalnych, połączone z progresywnym metamorfizmem, uzewnętrzniającym się m. in. rozwojem coraz bardziej zasadowych plagioklazów. Jest to okres właściwej tektogenezy (fig. 13), zakończony ustąpieniem kompresji tangencjalnej. Z okresu tego pochodzą zachowane fragmentarycznie fałdy F_1, być może mające również charakter fałdów similar.

Etap drugi rozpoczyna się w warunkach ciśnienia zbliżonego do hydrostatycznego i zaznacza się rozwojem blastezy mikroklinowej. Jest to więc okres, w którym nastąpiło wyraźne zróżnicowanie metamorfiku Lądka-Śnieżnika, i prawdopodobnie także Gór Bystrzyckich, na serię łupkową i gnejsową (fig. 14). Spiętrzone uprzednio masy skalne tektogenu znalazły się obecnie w polu poziomej tensji i podlegały już izostazji. W dążeniu do zachowania równowagi izostatycznej litosfery tektogen objęty został ruchami wypiętrzającymi, tj. właściwymi ruchami orogenicznymi. W wyniku tego procesu głębsze, uplastycznione partie tektogenu uległy migracji poziomej, gdyż nie były w stanie oprzeć się ciążeniu grawitacyjnemu nadległych, nie uplastycznionych mas skalnych (fig. 15).

Zjawisko to przebiegało synchronicznie z formowaniem się serii gnejsowej i spowodowało powszechny rozwój fałdów similar oraz powszechną zmianę anizotropii skał, przez wprowadzenie nowych nieciągłości fizycznych i reorientację starych z okresu rozwoju tektogenicznego. Pierwsze zaznaczają się przede wszystkim złupkowaniem krystalizacyjnym rozwijającym się zgodnie z powierzchniami osiowymi fałdów similar, a drugie — laminami na odcinkach międzyprzegubowych tych fałdów (fig. 16).

Tak ukształtowany tektogen zajmował stopniowo coraz wyższe poziomy hipsometryczne, ulegał dalszej stopniowej konsolidacji, a jego górne partie były degradowane. Należy przypuszczać, że na obszarze metamorfiku Lądka-Śnieżnika w tym czasie doszło do znacznego zrównania reliefu i lokalnej subsydencji, która doprowadziła do gromadzenia się osadów. Okres ten rejestrują zapewne zlepieńce z Kletna, odkryte przez Kaszę (1958, 1964).

Trzeci etap rozwojowy przebiegał w warunkach kompresji tangencjalnej, a ściślej w polu pary sił działającej w płaszczyźnie pionowej. Powierzchniami ruchu były wówczas nieciągłości fizyczne, ustalone w drugim etapie rozwojowym.

W łupkach łyszczykowych transport tektoniczny przebiegał głównie wzdłuż powierzchni złupkowania krystalizacyjnego, stąd częste przekształcenia fałdów similar w fałdy śródfoliacyjne. Tworzy się nowy garnitur fałdów F_3, wyraźnie asymetrycznych (fig. 12).

W większości odmian gnejsów śnieżnickich natomiast czynne były w tym czasie wszystkie trzy systemy powierzchniowych nieciągłości, z tym jednak że maksymalne przemieszczenia przebiegały wzdłuż płaszczyzn zorientowanych zgodnie z powierzchniami osiowymi fałdów similar, oba skrzydła tych fałdów ulegały zaś w tym czasie rotacji z reguły homotetycznej, tj. zgodnej ze zwrotem ruchu (fig. 16). Skrzydła nachylone przeciwnie w stosunku do zwrotu ruchu były mechanicznie rozlaminowywane i przybierały położenie mniej więcej zgodne z pwierzchniami trakcyjnymi, natomiast skrzydła nachylone zgodnie ze zwrotem ruchu ulegały często destrukcji, a poszczególne ich elementy doznawały daleko idącej rotacji. W wyniku tego zjawiska gnejsy śnieżnickie, pierwotnie — jak się wydaje — laminowo-oczkowe zostały powszechnie skataklazowane i przybrały strefowo teksturę słojową, słojowo-laminową i pręcikową, a lokalnie przeszły w kataklazyty i mylonity (fig. 17).

Co do gnejsów gierałtowskich, nie zauważono, żeby w tym czasie doszło tutaj do powszechnego uruchomienia nieciągłości fizycznych założonych w poprzednim etapie. Niemniej jednak obserwuje się w nich strefy i laminy kataklazytów oraz mylonitów o przebiegu na ogół zgodnym ze słabo wyrażonym złupkowaniem krystalizacyjnym, co wynika także z obserwacji mikroskopowych Ansilewskiego (1966).

Nad przyczyną różnego reagowania gnejsów śnieżnickich i gierałtowskich na stressy zastanawiał się już Smulikowski (1957), pisząc „... gnejs gierałtowski drobnoziarnisty, z bardziej wyrównanym rozproszeniem łyszczyków, był prawdopodobnie odporny na deformacje o tym natężeniu, które dla gnejsu śnież-

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nickiego, o dużych ziarnach skaleni i kwarcu o zwartych zgrupowaniach łyszczyków, były już wystarczające, aby dokonać skruszenia i wywalcowania skały".

Omawiany okres zaznaczył się nie tylko zróżnicowaniem teksturalnym skał, ale przede wszystkim powstaniem potężnych — jak należy przypuszczać — nasunięć, rozwijających się jednocześnie i zgodnie ze strefami kataklazytów i mylonitów. Wydaje się prawdopodobne, że odkryte przez Kaszę (1958, 1964) nasunięcie gnejsów wzdłuż mylonitów na zlepieńce z Kletna pochodzi z tego okresu rozwojowego (fig. 18).

W etapie czwartym omawiany tektogen uległ jeszcze raz dość intensywnemu sfałdowaniu, w wyniku którego powstała większość obserwowanych obecnie dużych form fałdowych wydzielanych na mapach geologicznych jako synkliny i antykliny o dość zróżnicowanym przebiegu osi. Jest to czwarta generacja fałdów (F_4), która zaznaczyła się w mezostrukturach przeważnie fałdami koncentrycznymi, wykazującymi często w swych partiach przegubowych zjawiska lokalnej rekrystalizacji, prowadzącej niekiedy do powstania skał o charakterze migmatytów.

Badany obszar został objęty następnie plutonizmem waryscyjskim, co doprowadziło do jego dalszej konsolidacji. Późniejsze fazy tektoniczne zaznaczyły się tutaj wielkopromiennymi spaczeniami i deformacjami sztywnymi, jak: fałdy załomowe typu „kink-band", „joint drag", uskoki, spękania i brekcje a w niższych poziomach hipsometrycznych prawdopodobnie również mylonitami i kataklazytami.

Przystępując do zagadnienia wieku poszczególnych etapów rozwojowych należy przypomnieć, że przeprowadzona przez H. Teisseyre'a (1968, 1975a) korelacja deformacji między poszczególnymi regionami staropaleozoicznymi i uważanymi w Sudetach za prekambryjskie wskazuje na kaledono-waryscyjski bądź starowaryscyjski wiek głównego fałdowania. Odkrycia mikroflorystyczne i faunistyczne Guni (Gunia 1974, 1976; Gunia, Dumicz 1976a, 1976b) potwierdzają tę tezę. Wskazują one bowiem, że serie mezozonalnie zmetamorfizowane Ziemi Kłodzkiej reprezentowane są przez proterozoik i dolny, bliżej nie określony, paleozoik. Ponadto w seriach epizonalnie zmetamorfizowanych (metamorfik kłodzki) udokumentowany jest ludlow (Gunia, Wojciechowska 1964, 1971). Jak wynika z prac H. Teisseyre'a (1968, 1975a i in.) obie te serie odznaczają się jednolitym rozwojem strukturalnym, co może wskazywać, że osadzały się one w jednym basenie. Nasuwa się przypuszczenie, że rozwój tego basenu sedymentacyjnego na obszarze Lądka-Śnieżnika i Gór Bystrzyckich przerwały fałdowania wczesnowaryscyjskie, udokumentowane w metamorfiku kłodzkim przez Gunię i Wojciechowską (1964, 1971). Fałdowania te przypisuje autor fazie orkadzkiej i wiąże z nią oba pierwsze etapy: tektogeniczny, wywołany kompresją tangencjalną i orogeniczny, przebiegający w polu kompresji pionowej spowodowanej grawitacyjnym ciążeniem nadkładu oraz dążeniem tektogenu do wyrównania izostatycznego.

Proces przebudowy tektogenu starowaryscyjskiego autor przypisuje trzeciemu etapowi rozwojowemu. Związane z nim jak należy przypuszczać, nasunięcie gnejsów śnieżnickich (wzdłuż mylonitów) na zlepieńce z Kletna może wskazywać na fazę bretońską lub sudecką. Powstają wówczas na dużą skalę przeobrażenia dynamiczne, diaftoreza i nasunięcia z odkłucia, a lokalnie fałdy F_3 typu ciągnionego, rozwijające się z powierzchni S_2. W następstwie tych zjawisk doszło do znacznego spiętrzenia mas skalnych i szybkiego wzrostu temperatury. Skataklazowane lub zmylonizowane serie skalne uległy blastezie i metasomatycznej przeróbce wiodącej do powstania polimetamorfitów, w tym również tzw. gnejsów haniackich. Na proces ten nałożyło się intensywne fałdowanie (etap czwarty), a w większych głębokościach dochodziło do coraz silniejszego i masowego upłynnienia łatwo topliwych składników. Doprowadziło to w karbonie górnym do intruzji magmy granitoidowej (powstanie masywów granitoidowych kłodzko-złotostockiego, bialskiego, kudowskiego i Ścinawki).