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The Góry Sowie Terrane: a key to understanding the Palaeozoic evolution of the Sudetes area and beyond

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In the light of various recent data, the Góry Sowie metamorphic complex (GSMC) area should be considered to represent a thrust-nappe fragment of the Góry Sowie Terrane (GST) preserved within the Sudetic mosaic-like structure. Distinct structural-metamorphic history of the GSMC in comparison to the adjacent Saxothuringian and Moldanubian metamorphic areas (terranes) suggests that described complex is a detached fragment of the GST. The GSMC is the only area in the Sudetes with Caledonian deformations which are documented radiometrically. The oldest detrital zircons that have been recognized so far from the Sudetic metamorphic complexes, are documented by isotopic dating of the GSMC. They are of the Early Proterozoic or even Archean ages. The zircons may have come from a part of Baltica. The GSMC is herein considered to be a detached thrust-nappe relict of a Caledonian magmatic arc (GSA) thrusted into the northeastern periphery of the Bohemian Massif. This arc developed on the southwestern margin of Baltica (recent geographical reference). During the Caledonian orogeny (Late Ordovician/Early Silurian), the GST was amalgamated with the East Avalonia Terrane, and the closure of the Tornquist Ocean took place. Later on, during the Variscan orogeny (Late Devonian), a fragment of the GST i.e. GSMC, was thrusted towards SSW over an obducted, also towards SSW, ophiolitic dismembered fragments derived from the Tornquist Ocean. Almost a 20 years old suggestion expressed by Prof. J. Znosko that the GSMC is underlain by ophiolitic rocks is still valid. The GSMC itself conceived as a SW fragment of a Caledonian terrane (GST) may point out that the Caledonian orogenic belt does occur in central and southern Poland.

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INTRODUCTION

In 1981 Professor Jerzy Znosko published two papers on the oceanic crust and the tectonic position of the Sudetes ophiolites (1981*a*, *b*). Analysing gravity and magnetic data, he concluded that the Góry Sowie metamorphic complex (GSMC) was underlain in its greater part by the oceanic crust. At that time this was one of the most important conclusions on geological structures of the Sudetes resulting in the creation of new models of evolution of this composite orogenic belt. Such an innovatory outlook of the structure at the Sudetes (*sensu lato*) could have been expressed only by a scientist resistant to the influence of certain axioms — at those times already firmly established — on the geological structure of the Sudetes. The opinion that small massifs of basic and ultrabasic rocks partly surround the Góry Sowie Block, was and in fact is at present, one of such truisms (e.g. J. Oberc, 1972; L. Jamrozik, 1981, 1988; A. Żelaźniewicz, 1995, 1997).

New models of evolution of the whole Sudetes or their parts have been created — particularly in the recent years — since the paper by J. Znosko (1981*a, b*) was published (e.g. J. Don, 1985, 1995; W. Narębski *et al.*, 1986; P. Matte *et al.*, 1990; Z. Cymerman, 1991; G. J. H. Oliver *et al.*, 1993; Z. Cymerman, M. A. Piasecki, 1994; P. Aleksandrowski, 1995; A. Żelaźniewicz, 1997). These models were constructed basing upon new, more and more detailed, mainly radiometric, geochemical, petrological, structural and kinematic data from various parts of the Sudetes. A particular interest of mainly foreign scientists was focused on the GSMC. The results of these investigations have been published recently in great number in various foreign periodicals. However, these scien-

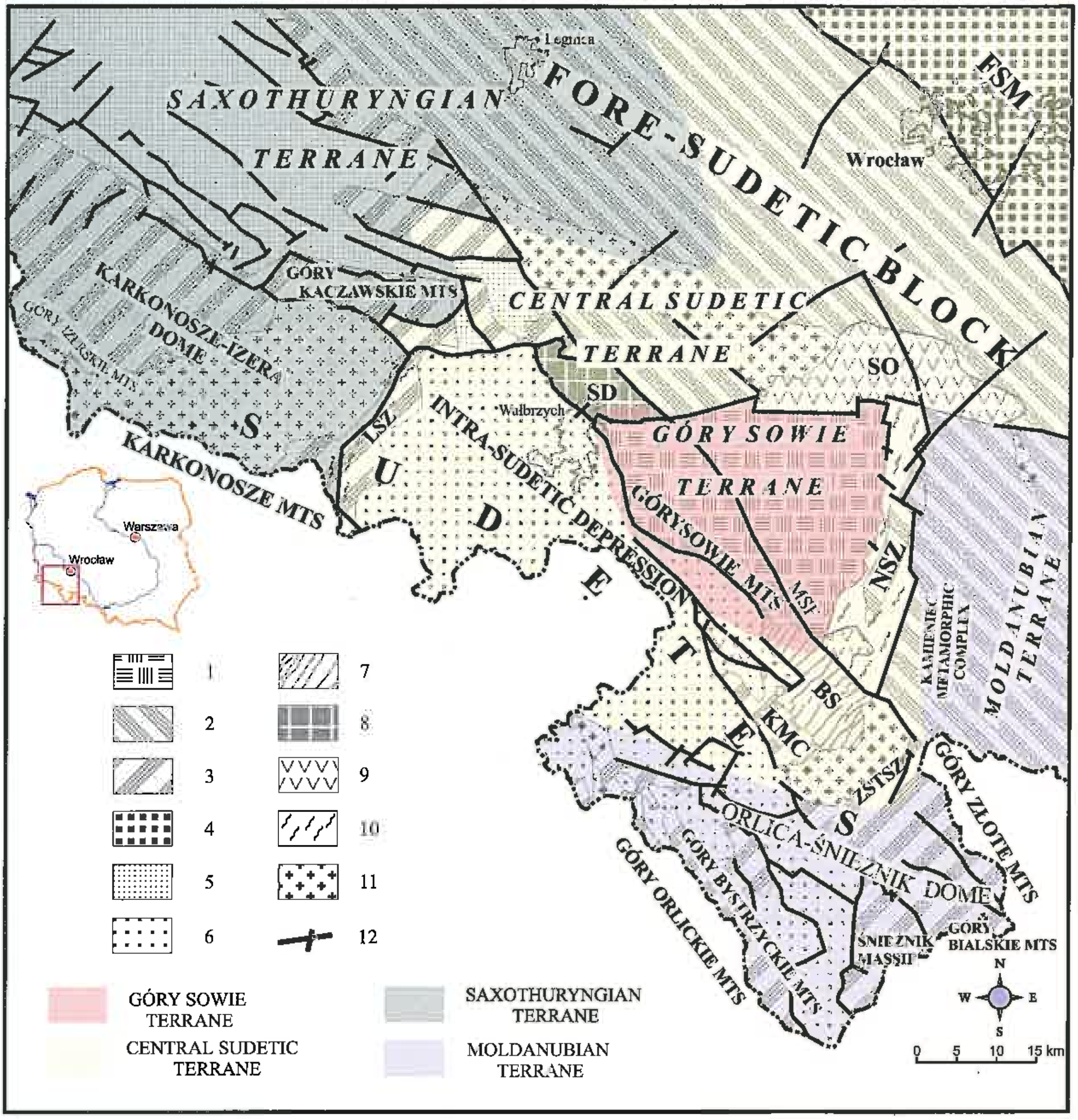

Fig 1. Map of Sudetic terranes (modified by Z. Cymerman *et al.*, 1997)

1 — Góry Sowie metamorphic complex; 2 — Fore-Sudetic Block metamorphic rocks; 3 — Sudetes metamorphic rocks; 4 — Fore-Sudetic Monocline sedimentary rocks; 5 — North-Sudetic Depression sedimentary rocks; 6 — Intra-Sudetic Depression sedimentary rocks; 7 — Silurian–Lower Carboniferous deposits; 8 — Upper Devonian–Lower Carboniferous deposits; 9 — Intra-Sudetic ophiolites; 10 — main ductile shear zones; 11 — Variscan granitoids; 12 — faults; BS — Bardo Structure; FSM — Fore-Sudetic Monocline; KMC — Kłodzko metamorphic complex; LSZ — Leszczyniec shear zone; MSF — Marginal Sudetic Fault; NSZ — Niemcza shear zone; SD — Świebodzice Depression; SO — Ślęża ophiolites; ZSTSZ — Złoty Stok–Trzebieszowice shear zone

Mapa terranów sudeckich (zmodyfikowana według Z. Cymermana i in., 1997)

1 — metamorfik sowiogórski; 2 — skały metamorficzne bloku przedsudeckiego; 3 — skały metamorficzne Sudetów; 4 — skały osadowe monokliny przedsudeckiej; 5 — skały osadowe depresji północnosudeckiej; 6 — skały osadowe depresji śródsudeckiej; 7 — osady syluru–karbonu dolnego; 8 — osady dewonu górnego–karbonu dolnego; 9 — ofiolity śródsudeckie; 10 — główne podatne strefy ścinania; 11 — granitoidy waryscyjskie; 12 — uskoki; BS — struktura bardzka; FSM — monoklina przedsudecka; KMC — metamorfik kłodzki; LSZ — strefa ścinania Leszczyńca; MSF — sudecki uskok brzeżny; NSZ — strefa ścinania Niemczy; SD — depresja Świebodzic; SO — ofiolit Ślęży; ZSTSZ — strefa ścinania Złotego Stoku–Trzebieszowic

tific studies require — from different reasons — additional comments and supplements. The overall comparison of the research results may be helpful for a better and more complete understanding of the Palaeozoic structural-metamorphic evolution of the GSMC. This is the essential aim of this paper. The author takes an attempt to answer the question why the GSMC bears a key importance in all the considerations on the Palaeozoic evolution of the Sudetes and not only the Sudetes themselves.

PREVIOUS VIEWS ON THE POSITION OF THE GÓRY SOWIE METAMORPHIC COMPLEX

The GSMC is located in the central part of the Sudetes (*sensu lato*), it occupies an area of ca. 650 km^2 and it is characterized by a triangular outline (Fig. 1). Its shape resulted from a development of brittle fault zones separating it from the surrounding, geologically diversified terrains. Only from the east, the GSMC adjoins another metamorphic complex. The regional ductile shear-zone of Niemcza separates the GSMC from the Kamieniec metamorphic complex (*sensu* S. Cwojdziński, A. Żelaźniewicz, 1995). The Niemcza Zone trending NNE–SSW is characterized by sinistral displacements with the top-to-SSW (Z. Cymerman, 1991, 1993; Z. Cymerman, M. A. Piasecki, 1994; S. Mazur, J. Puziewicz, 1995; P. Aleksandrowski *et al.*, 1997). Tectonically dismembered fragments of ophiolitic sequence occur within this zone (e.g. W. Narębski *et al.*, 1982; Z. Cymerman, 1987, 1991, 1993; C. Pin *et al.*, 1988). Processes of ductile shearing in the Niemcza shear zone continued as late as during the Early Carboniferous. This is evidenced by both ages of mineral cooling (hornblende) determined by the ^{40}Ar-^{39}Ar method (M. G. Steltenpohl *et al.*, 1993), and magmatic zircon dating from the syntectonic Niemcza granitoids (G. J. H. Oliver *et al.*, 1993; A. Kröner, E. Hegner, 1998).

Geological position of the GSMC has been differently interpreted by various scientists. The GSMC has been very frequently considered an intramontane massif around which a change in directions of tectonic structures took place in neighbouring metamorphic complexes (e.g. E. Bederke, 1924; J. Oberc, 1972; L. Jamrozik, 1981). Later on, J. Oberc (1991) changed his mind considering the GSMC to represent a kind of unrooted nappe. F. Kossmat (1927) first acknowledged the GSMC as a nappe (detached block) of a Moldanubian-type crustal fragment thrusted northwards. This opinion was also supported by H.-J. Behr (1980), and at first by Z. Cymerman (1987, 1988, 1989). A comprehensive historical review of studies on the GSMC since the beginning of the eighties is given by T. Gunia (1985).

J. Don (e.g. 1985, 1995) included the GSMC, together with the Bardo Structure, into the Sudetic Variscan Belt. These units are located north of the Intra-Sudetic Fault separating — according to this scientist — the Variscan and Caledonian belts in the Sudetes. Later on, also other scientists located along this fault either the Caledonian collision suture of several Sudetic terranes, among others the Góry Sowie one (G. J. H. Oliver *et al.*, 1993; J. D. Johnston *et al.*, 1994), or a Variscan large-scale dextral strike-slip fault (P. Aleksandrowski, 1990, 1995; P. Aleksandrowski *et al.*, 1997).

The GSMC has been considered either a microplate (S. Cwojdziński, 1980) or terrane (M. J. Quenardel *et al.*, 1988; Z. Cymerman, 1991; G. J. H. Oliver *et al.*, 1993; Z. Cymerman *et al.*, 1997) since the principles of the plate tectonics were introduced into considerations on the evolution of the Sudetes. The first attempt to relate the internal evolution of the GSMC with processes of subduction and obduction of the oceanic crust, now represented in the Sudetes by dismembered fragments of ophiolitic sequence, was given by Z. Cymerman (1987). That attempt faced a public critique by L. Jamrozik (1988) and A. Żelaźniewicz (1989).

Presenting — in short — existing different interpretations of the geological structure and structural-metamorphic evolution of the GSMC, it may be noticed that they concern two fundamental problems:

1. Tectonic position of the GSMC within the Sudetes structure (autochthonous model versus allochthonous model). At present, the concept of autochthonous position of the GSMC is mainly represented by A. Żelaźniewicz (e.g. 1990, 1995, 1997). However, the view of its allochthonous position has now many more followers (e.g. J. Znosko, 1981*a*, *b*; W. Narębski *et al.*, 1982; Z. Cymerman, 1987, 1988, 1989, 1993; M. J. Quenardel *et al.*, 1988; G. J. H. Oliver *et al.*, 1993; J. D. Johnston *et al.*, 1994; P. Aleksandrowski, 1990, 1995, 1998; A. Kröner, E. Hegner, 1998).
2. Timing of the major structural-metamorphic events of the GSMC: beginning with the Precambrian deformations (e.g. J. Oberc, 1972, 1991; W. Grocholski, 1967), through Caledonian ones (e.g. E. Bederke, 1924; G. J. H. Oliver *et al.*, 1993; A. Kröner, E. Hegner, 1998), Caledonian–Variscan ones (e.g. Z. Cymerman, M. A. Piasecki, 1994) and, lastly, Variscan deformations (A. Żelaźniewicz, 1987, 1989, 1990, 1995; Z. Cymerman, 1987, 1988, 1989).

The votaries of the autochthonous origin of basic and ultrabasic rocks around the GSMC assume that these are either late Cadomian intrusions in deep crustal fractures, deformed during the early Cadomian orogeny (e.g. J. Oberc, 1972), or Early Palaeozoic tension-related diapiric protrusions (e.g. L. Jamrozik, 1981; W. Franke *et al.*, 1993; A. Żelaźniewicz, 1995, 1997). However, contrary to these concepts, it is commonly assumed that the massifs of basic and ultrabasic rocks are fragments of ophiolitic association (e.g. S. Cwojdziński, 1980; J. Znosko, 1981*a*, *b*; W. Narębski *et al.*, 1982; Z. Cymerman, 1987, 1991; C. Pin *et al.*, 1988; A. Majerowicz, C. Pin, 1992; H. Dziedzic, 1995).

Where do the differences in understanding the position of the GSMC in a mosaic structure of the Sudetes come from? To a great extent they result from a lack of direct contacts with neighbouring metamorphic complexes. The only exception is the above-mentioned Variscan shear zone of Niemcza. However, major difficulties in the previous attempts to interpret the tectonic position of the GSMC in the Sudetes resulted from a lack of reliable stratigraphic and, first of all, radiometric data, dating precisely structural-metamorphic processes within the GSMC.

NEW STRATIGRAPHIC DATA

Micropalaeontological data conducted by T. Gunia (1981, 1984) were the first departure from the commonly accepted Proterozoic or even Archean age of the GSMC rocks (e.g. J. Oberc, 1972; W. Grocholski, 1967). T. Gunia (1997) even suggests the existence of metamorphosed Cambrian deposits in the Owiesno environs within the Fore-Sudetic Block. Abundant microfloral remains and radiolarians have been

Table 1

Radiometric data from the GSMC

Method	Mineral	Dating [Ma]	Interpretation	Author(s)
K-Ar	biotite, muscovite muscovite, hornblende	412±12–486±32 643±16–655±70	historical meaning; poorly reliable data	T. Depciuch *et al.* (1980)
^{87}Rb-^{86}Sr	muscovite	370±4; 363±4–374±4	closure temperature ca. 350°C	O. van Breemen *et al.* (1988)
^{87}Rb-^{86}Sr	biotite	372±7; 360±7	closure temperature ca. 300°C	O. van Breemen *et al.* (1988)
^{87}Rb-^{86}Sr	whole rock (WR)	350±150	wide range of error	O. van Breemen *et al.* (1988)
U-Pb	monazite	381±2	closure temperature ca. 725°C	O. van Breemen *et al.* (1988)
U-Pb	zircon	369±15; 1750±270	metamorphic detrital	O. van Breemen *et al.* (1988)
^{40}Ar-^{39}Ar	muscovite	255±17; 272±12; 337±13; 383±13 544±75	closure temperature ca. 330°C relict or Ar excess	G. J. H. Oliver, S. Kelley (1993)
^{40}Ar-^{39}Ar	biotite	319±12; 319±17; 322±12; 330±13	closure temperature ca. 300°C	G. J. H. Oliver, S. Kelley (1993)
U-Pb	zircon	461[+50/–2]	syn-metamorphic garnet	G. J. H. Oliver *et al.* (1993)
Sm-Nd	Grt-Opx-Cpx-WR	402±2	isochron age of peridotite minerals	H. K. Brueckner *et al.* (1996)
Sm-Nd	garnet	397–412	garnet growth	H. K. Brueckner *et al.* (1996)
Rb-Sr	Bio-Msc-WR	362±8; 366±8; 372±7; 374±5	amphibolite facies metamorphism	M. Bröcker *et al.* (1997)
^{207}Pb-^{206}Pb	zircon	402±10	HP metamorphism (granulite)	P. J. O'Brien *et al.* (1997)
U-Pb	zircon	405±3	HP metamorphism	P. J. O'Brien *et al.* (1997)
U-Pb	zircon	452±11; 1742±9	detrital	P. J. O'Brien *et al.* (1997)
^{207}Pb-^{206}Pb	zircon	483.7±1.7; 485.8±1.7; 472.9±1.7; 487.4±1.7; 482.3±1.7	granite protolith intrusion of the Góry Sowie gneisses	A. Kröner, E. Hegner (1998)
^{207}Pb-^{206}Pb	zircon	439.8±1.7	formation of anatectic melt	A. Kröner, E. Hegner (1998)
^{207}Pb-^{206}Pb	zircon	2675; 2416; 2395; 2393; 2368; 2246; 2214; 1937; 1840; 1700; 1325; 1182; 1174; 1125	detrital and xenomorphic inhirited in orthogneisses	A. Kröner, E. Hegner (1998)

found there in calcareous-siliceous rocks. They demonstrate that the rocks cannot be older than Cambrian.

The results of micropalaeontological investigations are not contradictory to the new radiometric data obtained from the GSMC which are indicative of the Early Ordovician age of magmatic intrusions into sedimentary sequences of the GSMC (G. J. H. Oliver *et al.*, 1993; A. Kröner, E. Hegner, 1998). A particularly important fact is that the samples collected from the GSMC have not yielded so far any inherited zircons of an age approximating the Cadomian orogeny. The lack of such zircons shows that protoliths of orthogneisses from the GSMC melted from crustal material devoid of a component approximating a Cadomian orogeny age, widely developed in the northern peripheries of Gondwana. A. Kröner and E. Hegner (1998) have evidenced, basing upon the ^{207}Pb-^{206}Pb isotopic method that GSMC rocks contain a highly heterogeneous population of inherited and detrital zircons which crystallized 2620 to 1124 Ma ago, i.e. from the Late Archean until Early Proterozoic. Noteworthy is that only one paragneiss sample (Jugowice) of the analysed seven samples, has yielded detrital zircons of ages ca. 2215, 2395, 2416, 2620 and 2993 Ma (Tab. 1). This sample was collected from the exposure in which T. Gunia (1981, 1984) has described the problematic Late Proterozoic–Early Cambrian microfossils. The above detrital zircons data only give information on the "age" of supplied detrital material. The remaining zircon ages ranging between ca. 2620 and 1123 Ma have been considered to represent inherited zircons originating from the rocks, out of which a magmatic protolith of the Góry Sowie orthogneisses melted.

A. Żelaźniewicz (e.g. 1997, 1998; A. Żelaźniewicz *et al.*, 1997) is of the opinion that the GSMC, like all the geological units in the Sudetes and in the entire Bohemian Massif, developed upon the Neoproterozoic (Cadomian) continental crust. However, a lack of Neoproterozoic detrital zircons in GSMC rocks does not confirm this view in the case of the GSMC (A. Kröner, E. Hegner, 1998). Isotopic dating of detrital zircons from the GSMC points to much older (Palaeoproterozoic and even Archean, over 2500 Ma) origin of rock material transported into the Góry Sowie Basin. The results of detrital zircon studies from the GSMC show that sediments transported into the Góry Sowie Basin were highly heterogeneous and much older (ca. 2215, 2395, 2416, 2620 and 2993 Ma) than those originating from supracrustal series of other

Sudetes metamorphic complexes. P. J. O'Brien *et al.* (1997) have described detrital zircon grains of ages ca. 450 Ma from a pelitic protolith of Góry Sowie granulites. A lack of zircons of ages approximating the Cadomian orogeny may indicate that there was no Cadomian metamorphism within the GSMC area. A. Kröner and E. Hegner (1998) interpreted ages of detrital zircons from the GSMC as a proof of their provenance from as far as the Guiana Shield, as it was suggested by G. J. H. Oliver (1996).

However, there is another possible interpretation of these data. Baltica, which was located probably closer to the GSMC than the Guiana Shield at those times, might have been a sediment-source area for the Góry Sowie Basin. Baltica is composed of pre-Mesoproterozoic (>1600 Ma) rocks of the crystalline basement (e.g. S. V. Bogdanova *et al.*, 1994; I. S. Puchtel *et al.*, 1997). This interesting problem will be discussed in the last chapter.

NEW RADIOMETRIC DATA

Recently, radiometric data are the most important source of information helpful in understanding the Palaeozoic evolution of the GSMC. Results of radiometric dating may indicate the age of both a protolith of magmatic rocks and later structural-metamorphic processes. Radiometric data from the GSMC (Tab. 1) show that plenty of information have been gathered in recent years. However, radiometric studies should also be employed in the case of basic and ultrabasic rocks from the GSMC because the latter are commonly represented within a structurally deeper part of the GSMC, i.e. within the Fore-Sudetic Block.

Ages of a magmatic protolith of the Góry Sowie gneisses have been determined be at about 483–488 Ma (A. Kröner, E. Hegner, 1998). These ages are slightly younger — by ca. 10–20 Ma — than acid magmatic intrusions of the Izera–Karkonosze and Orlica–Śnieżnik Domes (G. J. H. Oliver *et al.*, 1993; A. Kröner *et al.*, 1994*b*). Both these slightly younger ages of granitoid intrusions of the GSMC, and a lack of fragments of supracrustal series, distinguish the GSMC from other Sudetes metamorphic complexes.

The first radiometric dating obtained from the GSMC using the U-Pb and Rb-Sr method were published 10 years ago (O. van Breemen *et al.*, 1988). Those results showed that metamorphic processes in the GSMC had been younger than 400 Ma. Basing on those data, A. Żelaźniewicz (1989, 1990) placed on a time scale deformation phases of the GSMC, distinguished earlier by himself (A. Żelaźniewicz, 1979, 1987; T. Morawski, A. Żelaźniewicz, 1973). This scientist assumed this way that the structural-metamorphic evolution of the GSMC was related only to the Variscan orogeny. However, later radiometric dating (Tab. 1) cast some doubt upon this scheme, showing a possibility of the Caledonian evolution of the GSMC (G. J. H. Oliver *et al.*, 1993; A. Kröner, E. Hegner, 1998). Some of the radiometric datings of metamorphic zircons from the GSMC (Pb-Pb method) point also to an older (ca. 440±2 Ma) regional high-grade metamorphism (A. Kröner, E. Hegner, 1998).

Radiometric ages (Sm-Nd method) of a garnet peridotite from Bystrzyca Kłodzka range from 403 to 386 Ma. In the garnet core they are of 402±3 Ma (H. K. Brueckner *et al.*, 1996). Similar ages (ca. 400 Ma) have been obtained using the U-Pb method for metamorphic zircon grains from the GSMC granulites (A. Kröner *et al.*, 1994*a*). P. J. O'Brien *et al.* (1997) stated that high-pressure (HP) metamorphism in a granulite facies took place within GSMC rocks ca. 400 Ma ago. However, M. O. Roberts and F. Finger (1997) have recently assumed, basing on examples from the Bohemian Massif, that growth of zircons was related to their exhumation into a shallower crust level, where medium-pressure (MP) conditions dominated. Therefore, radiometric dating of zircons from granulites, which are based on their growth, does not automatically reflect peak pressure (P) and temperature (T) conditions of regional metamorphism. The peak temperature and pressure conditions may be much older.

A. Kröner and E. Hegner (1998), in turn, are of the opinion that the early phase of high-grade metamorphism of the GSMC is evidenced by the age of ca. 440 Ma, obtained for the anatectic granite from Potoczek.

In the Moldanubian area, occurrences of high-pressure felsitic granulites with subordinate pyroxene granulites (e.g. J. I. Wendt *et al.*, 1994; L. G. Medaris *et al.*, 1998) are well known. Radiometric dating of zircons from these rocks (U-Pb method) points to the age of high-pressure metamorphism ranging from 351 to 338 Ma, i.e. Early Carboniferous metamorphism of a granulite facies (e.g. M. Aftalion *et al.*, 1989; J. I. Wendt *et al.*, 1994; J. Kotkowa *et al.*, 1995; L. G. Medaris *et al.*, 1998). It is thus evidenced that high-pressure metamorphism in the GSMC was older — by at least 50 Ma — than in other parts of the Bohemian Massif, except in granulites from NE Bavaria (Oberpfalz) whose metamorphism is dated at ca. 424 Ma (A. von Quadt, D. Gebauer, 1993).

Using the Sm-Nd method, the isochron age of 357±12 Ma has been obtained for gabbros from ophiolitic sequence of the Middle Sudetes. This has been interpreted as a time of their magmatic crystallization (C. Pin *et al.*, 1988). However, these data point to an age when ophiolite rocks passed through temperatures of the Sm-Nd system closure during their exhumation, rather than to a real age of their crystallization. In addition, it is difficult to reconcile this late Famennian radiometric age of the gabbro with the fact that the ophiolitic sequence is overlain (Dzikowiec quarry) by Famennian rocks of the Bardo Structure (e.g. W. Narębski *et al.*, 1982). A more credible age of the formation of the Middle Sudetic ophiolites has been given by zircon dating (U-Pb method), pointing to their Silurian "age" — 420[+20/–2] Ma (G. J. H. Oliver et al., 1993). Similar data have been obtained from the Góry Sowie peridotite (Bystrzyca Górna), using the Sm-Nd method. The rock is dated at 402±3 Ma (H. K. Brueckner *et al.*, 1996). The peridotite is characterized by both a very quick growth of garnets, and rapid decompression and cooling. These processes have been interpreted as rifting indicators when hot Góry Sowie peridotites were isobarically cooled due to their tectonic displacement (H. K. Brueckner *et al.*, 1996).

Some of the radiometric datings from the GSMC, obtained using mainly the Rb-Sr method (O. van Breemen *et al.*, 1988, M. Bröcker *et al.*, 1997) and neglected in this chapter, will be discussed further on. Datings of GSMC minerals and rocks, using the K-Ar methods (T. Depciuch *et al.*, 1980) and their modification — ^{40}Ar-^{39}Ar method (G. J. H. Oliver, S. Kelley, 1993) — determine the age of the uplift and cooling of the GSMC during the Early Carboniferous. These data, 330 to 319 Ma, reflect final metamorphic processes in the GSMC during the Variscan orogeny and its uplift from a deeper part of lithosphere, probably as a tectonic horst. However, further ^{40}Ar-^{39}Ar dating is necessary to fix on a time scale, a more precise position of those, probably heterogeneous and rather fast, vertical crust movements.

GEOCHEMICAL DATA

In recent years, several important papers on acid and basic rocks geochemistry occurring in the GSMC, have been published (e.g. H. Dziedzic, 1995; J. A. Winchester *et al.*, 1998; A. Kröner, E. Hegner, 1998). However, these data cannot be easily and univocally interpreted, and geotectonic conclusions inferred, are frequently contrary (e.g. G. J. H. Oliver *et al.*, 1993; R. Kryza, C. Pin, 1997*a*, *b*; A. Kröner, E. Hegner, 1998). Lower Palaeozoic volcanic rocks from the Sudetes have been usually interpreted to be a product of metamorphic processes related to an initial rifting phase (e.g. H. Furnes *et al.*, 1994). A tendency to such an interpretation also refers to metabasic rocks, fairly common within the GSMC area (J. A. Winchester *et al.*, 1998). However, H. Dziedzic (1995) have described metatholeiites from the Bielawa environs, which are geochemically related to a N-MORB and E-MORB type. The latter data may point to a similar magma source for both the Bielawa metatholeiites and Ślęża ophiolites (e.g. A. Majerowicz, C. Pin, 1994). P. Gunia (1994) has evidenced that ultrabasic rocks lenses from the GSMC show geochemical similarities to peridotites from mid-ocean ridges.

In spite of scientific progress, basic and ultrabasic rocks from the GSMC require further detailed studies because they are characterized by a great geochemical diversity which is difficult to elucidate (J. A. Winchester *et al.*, 1998). These rocks are located within different diagnostic fields of a geochemical diagram (mainly within MORB field, see H. Dziedzic, 1995; J. A. Winchester *et al.*, 1998). This geochemical diversity is most likely related to both contamination of these rocks during their structural-metamorphic evolution and a joint activity of heterogeneous migmatitization processes with anatexis, commonly developed within the GSMC.

Much more controversial is the problem of genesis and a geotectonic environment of a protolith of the Góry Sowie gneisses. Several scientists are of the opinion that the Góry Sowie gneisses are a product of magmatism of a magmatic arc type, developed above the subduction zone (G. J. H. Oliver *et al.*, 1993; J. D. Johnston *et al.*, 1994; A. Kröner, E. Hegner, 1998). The Ordovician Góry Sowie type I granitoids show a calc-alkaline affinity and they are firmly located within the field of volcanic arc granitoids (A. Kröner, E. Hegner, 1998). $\varepsilon_{Nd(t)}$ values for the Góry Sowie granitoids considerably vary ranging from –6.2 to +1.1. The highest $\varepsilon_{Nd(t)}$ values have been recorded for samples containing abundant inherited zircon xenocrystals; the lowest — where such zircons are lacking. Their absence indirectly points to a considerable contribution of a young (juvenile) crust and a small contribution of an old crust during its formation. Only augen orthogneisses from the southern part of the GSMC and syntectonic granitoid sills (for example in Walim) of a high K content may be included into a subtype A of type I granitoids, characteristic of intraplate or late- to post-collision granitoids.

R. Kryza and C. Pin (1997*a*, *b*) and A. Żelaźniewicz (1996, 1997) do not agree with the model of evolution of the Góry Sowie granitoids in a volcanic arc environment. The first two authors point that geochemical data do not allow to infer univocal conclusions due to among others difficulties in distinguishing one geochemical environment from another on orthogneiss spider diagrams, but also due to a mobility of Rb for example, and fractional melting processes. A. Żelaźniewicz (1996, 1997) — as a creator of a basically immobilistic model of evolution of the Sudetes developing upon the Cadomian continental crust — attempts to refute the achievements of plate tectonic approach in the Sudetes. The hypothesis expressed by A. Żelaźniewicz (1996, 1997) rejects the possibility of existence in the Sudetes of not only oceanic crust subduction processes, but also the oceanic crust itself. A model of the subducted oceanic crust in the Sudetes (e.g. A. Majerowicz, C. Pin, 1994) is being replaced by a model of a rifting and synchroneous development of a mantle diapir (e.g. A. Żelaźniewicz, 1995, 1997). But how is it possible to explain the appearance of high-pressure (HP) metamorphism within the GSMC, without assuming subduction processes?

HIGH-PRESSURE METAMORPHISM

HP/MT and HP/HT metamorphism in the European Variscides is evidenced by the occurrence of eclogites and granulites. C. Pin and D. Vielzeuf (1983) included GSMC granulites into an older Variscan type of granulites (their "type I"). A few years later (1988) the same authors determined the age of the older HP/MT metamorphism at ca. 420–390 Ma. They related its occurrence to both a continent-to-continent collision type (subfluence *sensu* H.-J. Behr, 1978) and tectonic thickening of the crust during the early Variscan orogeny. This way, the scientists accounted a lack of Caledonian deformations to be a characteristic feature of the European Variscides. D. Vielzeuf and C. Pin (1989) stated that subduction processes of the continental crust gave rise to a HP/HT granulites formation in the GSMC. Recently, the same authors — together with R. Kryza — have confirmed their suggestion that GSMC granulites belong to the "type I", but of slightly older metamorphism than they initially thought (ca. 430–400 Ma, i.e. Late Silurian). GSMC granulites have been included into a fragment of the continental crust which was subjected to subduction down to a mantle depth during the earliest stages of the Variscan orogeny (R. Kryza *et al.*, 1996).

Recently, H. K. Brueckner *et al.* (1996) have interpreted the isochron "age" of peridotite of ca. 402 Ma, and the growth of garnets in the age interval 397 to 412 Ma (Tab. 1), as a result of a rifting process. In the course of this process, a hot spinel lherzolite originating from the mantle, cooled and transformed into a garnet peridotite, and then tectonically emplaced within the crust. This interpretation resembles a model of a Variscan orogeny culmination owing to a process of lithospheric delamination and astenospheric upwelling in the Moldanubian area (L. G. Medaris *et al.*, 1998). However, HP metamorphism in the Moldanubian area would have been much younger — by about 50–70 Ma — than in the GSMC. Does it entitle L. G. Medaris (the co-author of these two papers) to consider a geological development of different parts of the Bohemian Massif in the same way? I should rather say no. Different circumstances gave rise to e.g. the Early Carboniferous (ca. 340 Ma) HP/HT metamorphism of the Saxonian granulite complex (A. Kröner *et al.*, 1998) from those which resulted in HP/LT metamorphism of the Rudawy Janowickie Mts. (H. Maluski, F. Patočka, 1997), although they both were of a similar age. In general, the older stage of HP/HT metamorphism in the SGMC (temperatures 900–1000°C, pressure ca. 15–20 kbar) was later overprinted by MP/HT metamorphism of a granulite facies (775–910°C and 6.5–8.5 kbar) typical of clinopyroxene variety of felsitic granulite (P. J. O'Brien *et al.*, 1997). However, growth of zircons in the Bohemian Massif may have occurred during their exhumation into a shallower crust level where MP metamorphism conditions prevailed. This means that the zircon ages from granulites do not necessarily reflect peak pressure and temperature conditions (M. O. Roberts, F. Finger, 1997).

STRUCTURAL STUDIES

Structural investigations in the GSMC were initiated by W. Grocholski (1967, 1975) who distinguished basically three major deformation phases (Tab. 2). Slightly later, A. Żelaźniewicz (1979) doubled their number suggesting that migmatization processes took place twice in the GSMC. In following papers this author was resuming the earlier model, however, reducing the number of the phases down to five (from D_1 to D_5) (A. Żelaźniewicz, 1987, 1989, 1990). At the same time, Z. Cymerman (1988, 1989) also distinguished five deformation phases (from D_1 to D_5) in the foremountainous part of the GSMC.

However, these two last-mentioned models of structural evolution of the GSMC differed first of all in their approach to a problem of migmatitization within the GSMC and the importance of noncoaxial deformation, although the number of phases is the same. According to Z. Cymerman (*op. cit.*) a migmatitization process within the GSMC was related to phase D_3 only. A. Żelaźniewicz (*op. cit.*) was of the opinion that migmatitization processes within the GSMC took place twice during phases D_3 and D_5. Z. Cymerman (*op. cit.*) argued that the major structural elements of the GSMC were formed during deformation phases D_2 and D_3 (Pl. I, Fig. 1). In such an approach, all the tectonic structures within the GSMC recognized by A. Żelaźniewicz (*op. cit.*) to represent structures D_5 will merely be a part of structures D_3 in Z. Cymerman (*op. cit.*) scheme. Therefore, the structures from deformation phases D_4 and D_5 (Z. Cymerman, 1988, 1989) do not exist in A. Żelaźniewicz (*op. cit.*) model.

Why is it impossible to establish a univocal scheme of structural evolution of the GSMC? One of the major reasons is a lack of a new well-documented geological map of the whole GSMC area. A sketch geological map compiled by A. Żelaźniewicz (1987) for the mountainous part of the GSMC was constructed using no artificial exposures (pits) in areas partly devoid of any exposures. So, it is an open question how it has been possible to distinguish so many gneiss varieties which are heterogeneously migmatitized and with extremely complicated structural-textural transitions. This great structural-textural diversity sometimes renders it impossible to distinguish a gneiss or migmatite variety, even on a sample scale (Pl. I, Figs. 6, 7; Pl. II, Fig. 8). Thus, how was it possible to present the detailed cartographic image of interfering macroscopic fold structures of several generations (A. Żelaźniewicz, 1987)? Judging from my experience as a Sudetic field geologist, who also mapped a fragment of the GSMC (e.g. Z. Cymerman, M. Walczak-Augustyniak, 1991), it has not been practically possible.

It seems that future geological mapping in the strongly migmatitized GSMC area should be focused mainly on the recognition of metatexites and diatexites (*sensu* M. Brown, 1973). Metatexites are characterized by a still preserved structure of palaeosome and metamorphic structures (Pl. I, Fig. 7). Diatexites already show considerable textural modifications, destruction of structures of palaeosome and a strong development of flow magma structures and melt segregation (e.g. E. W. Sawyer, 1996). Diatexites are very common within the GSMC, where they form domains exceeding several tens of metres in thickness. It is possible that some of these domains reach even up to several hundreds of metres in thickness. However, this cannot be proved due to a lack of exposures. A critical point in the transition from metatexites to diatexites is a development of penetrative melt fractions (M. Brown, 1973; E. W. Sawyer, 1996). Small, widely dispersed diffuse "sheets" of neosome were formed during an initial phase of migmatitization. Within them, foliation gradually disappears. Simultaneously, mineral grain size increases in these "sheets" while they become gradually larger and coalesce. Such a migmatitization process leads to preservation of the relics of foliated gneiss (palaeosome) within a coarse-grained and texturally fairly homogeneous neosome (Pl. I, Fig. 7). Transitions from a metatexite to diatexite reflect a fundamental change in rheologic properties of rocks subjected to deformations. Rheologic properties of diatexites resemble those of magma. This is one of major factors which influence a heterogeneous development of tectonic structures that may be misinterpreted as resulting from separate deformation phases (Pl. II, Fig. 8).

A. Żelaźniewicz (1989, 1990) — basing upon the first radiometric dating of the GSMC (U-Pb and Rb-Sr methods) (O. van Breemen *et al.*, 1988) — placed deformation phases distinguished earlier by himself (A. Żelaźniewicz, 1979, 1987) on a time scale. This way, the structural-metamorphic evolution of the GSMC was related strictly to the Variscan orogeny (Tab. 2). Soon, however, new radiometric data undermined this suggestion, pointing to a significance of

Table 2

Characteristics of GSMC deformations

Deformation type	Number of deformation phases (main deformations in bolds)	Deformation age [Ma]	Migmatitization	Author(s)
Coaxial	three phases (B_o, **B_1**, **B_2**)	Proterozoic	simultaneous to B_1 and B_2	W. Grocholski (1967, 1975)
Coaxial	three phases (**F_1–F_3**)	no data	simultaneous to F2	T. Morawski, A. Żelaźniewicz (1973)
Coaxial	six phases (**F_1–F_3**, F_4–F_6)	no data	during phases D_2, D_3, D_5	A. Żelaźniewicz (1979)
Coaxial or noncoaxial	five phases (coaxial: D_1, **D_2, D_3**, D_5; simple shear: D_4)	before Late Devonian	during phases D_3 and D_5	A. Żelaźniewicz (1987)
Coaxial	five phases (D_1–D_5)	D2 (D_3?) — ca. 381 Ma, D_5 — ca. 370 Ma	during phases D_3 and D_5	O. van Breemen *et al.* (1988)
Coaxial or noncoaxial	five phases (coaxial: F_1, **F_3**, F_5; simple shear: F_4; general shear: **F_2**)	F_1 — 500–450? Ma F_2 — ca. 381 Ma F_3 — 381–371 Ma F_4 — 370–360 Ma F_5 — < 340 Ma	during phases D_3 and D_5	A. Żelaźniewicz (1989, 1990)
Complex: general and coaxial shear	five phases (general shear: D_1, **D_2, D_3**, D_4; coaxial: D_5)	from Silurian through Early Carboniferous	during phases D_2 and D_3	Z. Cymerman (1988, 1989)
Complex: general, simple and coaxial shear	four phases (general shear: D_1, D_3; simple shear: D_4; coaxial: D_5)	D_3 — ca. 380 Ma	during phases D_3 and D_5	A. Żelaźniewicz (1995)
Complex: general and coaxial shear, and strain partitioning	1. progressive, transpressional Caledonian deformation 2. extensional, Variscan deformation	from Ordovician (structure-forming deformations) until Early Carboniferous (exhumation)	in Ordovician and Silurian (ca. 440 Ma)	Z. Cymerman (this paper)

Silurian structural-metamorphic processes in the GSMC (G. J. H. Oliver *et al.*, 1993; A. Kröner, E. Hegner, 1998; A. Kröner *et al.*, 1994*a*). The Potoczek exposure, located near the road from Rościszów to Walim, has appeared the key site for studying relationships between tectonic structures and radiometric dating. A diatexite (nebulite migmatite) from this large exposure has yielded zircon radiometric data of ages ca. 460 Ma (G. J. H. Oliver *et al.*, 1993) and ca. 440 Ma (A. Kröner, E. Hegner, 1998). This diatexite with transitions into homogeneous granite represents the youngest, late- or even post-deformational product of regional metamorphism and migmatitization. The age of 440±2 Ma comes from typical magmatic zircons which crystallized within a granite magma; their crystallization age has been cinsidered to be a period of anatectic melt generation (A. Kröner, E. Hegner, 1998).

According to interpretation by A. Żelaźniewicz (1987, 1989, 1990), a development of the Potoczek diatexite was synchronous with the last deformation phase (D_5) in the GSMC. If the cited author's scheme (*op. cit.*) of phase deformations within the GSMC is correct then — taking into account the recent zircon datings (A. Kröner, E. Hegner, 1998) — structural evolution of the GSMC should have come to its end at the Ordovician/Silurian boundary, i.e. during the Caledonian orogeny. However, A. Żelaźniewicz does not change his opinion on the Devonian deformations of the GSMC. First, he had charged G. J. H. Oliver *et al.* (1993) with incorrect understanding of his interpretation of the tectonic structures development from Potoczek (A. Żelaźniewicz, W. Franke, 1994), and then he resigned his co-authorship of the paper by A. Kröner and E. Hegner (1998). Instead, in co-operation with German geologists (M. Bröcker *et al.*, 1997) he redated, using the Rb-Sr method, the tectonic structures — from phase D_2 to D_5 — obtaining ages ranging from 362 to 375 Ma. These data are almost identical to the earlier results for biotite using the Rb-Sr method (O. van Breemen *et al.*, 1988). According to A. Żelaźniewicz (*op. cit.*) these results are to indicate a period of structure-forming deformations of the GSMC. But how to explain a development of up to four individual deformation phases (D_2, D_3, D_4 and D_5) during such a short time and, moreover with each phase showing differently oriented stress field and interrupted by periods of tectonic quiescence?

The Late Devonian ages of GSMC minerals, obtained using the Rb-Sr method, should rather be interpreted as closure time of radioactive isotopes within a crystal lattice of minerals during cooling of rocks subjected to exhumation. Both the radiometric data obtained using the Rb-Sr method, and those yielded by the ^{40}Ar-^{39}Ar method (cooling ages) — of ca. 330–319 Ma — reflect final processes of thermal metamorphic history of the GSMC during the Variscan orogeny, and its final uplift from a deeper part of the Earth's crust, probably as a tectonic horst.

In the light of the above-presented data, it seems striking that there is a lack of tectonic structures younger than phase

D_5 according to A. Żelaźniewicz's scheme (younger than ca. 440 Ma), although regional metamorphism processes, first of a granulite facies (ca. 400 Ma), then of an amphibolite one (ca. 380 Ma) and finally of a greenschist facies, still persisted for over 100 Ma (until the Middle Viséan). This is also indicated by the Viséan age (334±6 and 332±9 Ma) of synkinematic magmatism in the Niemcza Zone (M. G. Steltenpohl *et al.*, 1993; G. J. H. Oliver *et al.*, 1993; A. Kröner, E. Hegner, 1998).

It seems to be a much better explanation that tectonic structures considered by A. Żelaźniewicz to represent the last phase (D_5), belong in fact to structures of phase D_3, according to Z. Cymerman's scheme (1988, 1989). Fold structures of the major deformation phases D_2 and D_3 are most common and difficult to discriminate (Pl. II, Fig. 8). If D_5 tectonic structures distinguished by A. Żelaźniewicz (*op. cit.*) are included into phase D_3, then the structures described by Z. Cymerman (1988, 1989) as D_4 and D_5 (post-migmatitization structures) may have developed during a period from the Silurian until Early Carboniferous. Note, that according to A. Żelaźniewicz's interpretation (*op. cit.*), no tectonic structures were formed after migmatitization and homophanization, synchronous with his last stage of deformations D_5. Completely different and still open is the question if tectonic structures of the GSMC were formed due to individual deformation phases, or they were caused by a progressive heterogeneous deformational process with a significant contribution of general shearing. A kinematic analysis throws some light on this open question.

KINEMATIC DATA

Kinematic data from the GSMC are most clearly recognized only in the southern part of the Góry Sowie Mts., where augen orthogneiss belts occur (Pl. II, Fig. 8; Pl. III, Fig. 10). Unfortunately, their considerable part is strongly brecciated and faulted (Fig. 2). Foliation surfaces in augen gneisses are very steep or horizontal, striking NNW–SSE and dipping usually towards NNE, but also SSW. Mineral stretching lineation is most frequently inclined at moderate and high angles, usually towards N, NE and E. Kinematic studies point to a thrust-type displacement with top-to-SSW (Pl. II, Fig. 9) or to S (Z. Cymerman, 1993). Some of the kinematic data from these gneisses are also indicative of sinistral or dextral oblique displacements (Pl. III, Fig. 10) (Z. Cymerman, 1993; J. D. Johnston *et al.*, 1994). Later brittle and normal faulting and displacements of hanging walls towards SW and S, have also been recognized in gneissic cataclasites and breccias from the GSMC. A development of sinistral ductile transpressional tectonics in augen orthogneisses was an older process in relation to brittle faulting and tilting well known from the contact between the GSMC and Bardo Structure (Fig. 2). A. Żelaźniewicz (1987, 1990) has described from that part of the GSMC only dextral brittle displacements related — in his opinion — to deformation phase D_4. Later, that author modified his own interpretation and reported an older dextral and younger (D_5?) sinistral deformational regime (W. Franke *et al.*, 1993).

It is difficult to recognize kinematic indicators in the remaining GSMC area due to a strong migmatitization and homophanization. According to Z. Cymerman (1989) processes of heterogeneous mylonitization were fairly common in the GSMC foreland area and they were related to all the deformation phases. Mylonitic bands are often anastomosing with their typical entanglement. Such a conjugate development of mylonitic bands points to a dominant coaxial shear component during major deformation phases (D_2 and D_3) within the GSMC. The domination of the coaxial deformation in the GSMC well explains difficulties related to the recognition of direction of tectonic transport as well as preclusion of mineral lineation of migmatites and gneisses from stretching lineation (type X lineation). A simple shear component is best expressed by a development of numerous asymmetric extensional shear bands from phase D_4 (Z. Cymerman, 1989).

Mylonitization of the eastern part of the GSMC gave rise to the regional scale sinistral shear zone of Niemcza (Z. Cymerman, 1991, 1993; S. Mazur, J. Puziewicz, 1995). Kinematic data obtained from this shear zone are indicative of dominant sinistral or rare dextral displacements representing a tectonic transport top-to-S and SSW (Fig. 2; Pl. III, Fig. 9). Such a sense of shear points to a displacement of the GSMC — in deeper parts of lithosphere — towards S and SSW (e.g. Z. Cymerman, M. A. Piasecki, 1994), also during the Early Carboniferous. Both differences in rheologic properties of the Niemcza shear zone and heterogeneity of deformations with symptoms of deformation partitioning resulted in a development of numerous anastomosing, frequently conjugate localized ductile shear zones of different intensity of simple shear. Viséan intrusions of synkinematic granitoids also took place within the Niemcza shear zone (G. J. H. Oliver *et al.*, 1993; M. G. Steltenpohl *et al.*, 1993; A. Kröner, E. Hegner, 1998). Localized ductile shear zones characterized by general NNE–SSW trends and sinistral displacements similar to those of the Niemcza shear zone (Z. Cymerman, 1993) also occur in the neighbouring gabbros from the Braszowice ophiolite. Similarly, a steeply inclined, several tens of metres wide sinistral shear zone trending NNE–SSW occurs in the Nowa Ruda ophiolite.

THE GÓRY SOWIE TERRANE

During the last ten years, terrane models have been suggested for the Bohemian Massif or its fragments (M. J. Quenardel *et al.*, 1988; P. Matte *et al.*, 1990; Z. Cymerman, 1991; G. J. H. Oliver *et al.*, 1993; Z. Cymerman, M. A. Piasecki, 1994; V. Havlíček *et al.*, 1994; J. B. Edel, K. Weber, 1995; Z. Cymerman *et al.*, 1997; P. Aleksandrowski, 1998; B. Buschmann, U. Linnemann, 1998). The number of terranes itself as well as their boundaries and a history of their accretion in the Bohemian Massif are still open and controversial. The term terrane refers to an area characterized by an internal continuity of its broadly understood geological structure and bounded by fault systems, melanges, representing trench complexes or

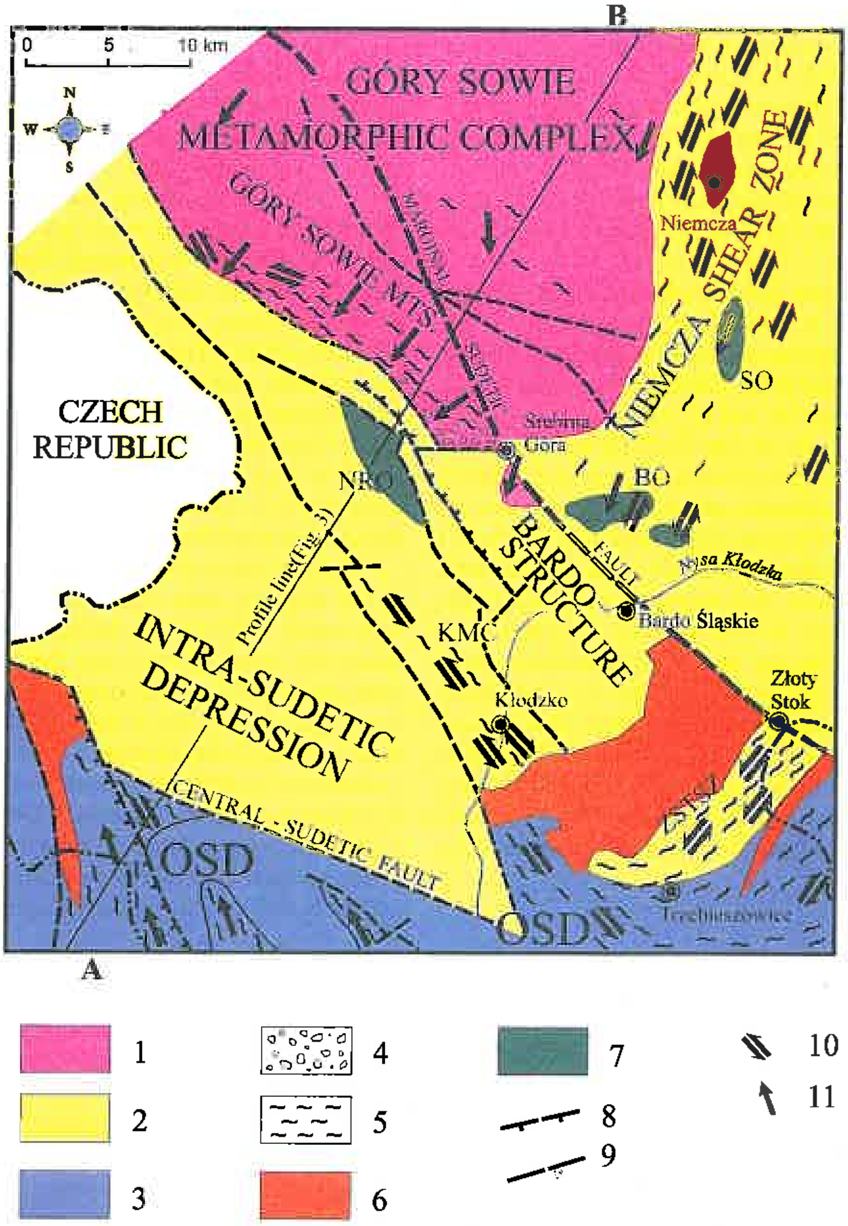

Fig. 2. Structural-kinematic sketch-map of the southern part of the Góry Sowie metamorphic complex and neighbouring areas
1 — Góry Sowie Terrane; 2 — Middle-Sudetic Terrane; 3 — Moldanubian Terrane; 4 — cataclasites and tectonic breccias; 5 — ductile shear zones; 6 — Variscan granitoids; 7 — Intra-Sudetic ophiolites; 8 — brittle overthrusts; 9 — faults; 10 — sense of ductile shear in strike-slip regime; 11 — sense of ductile thrust shear; BO — Braszowice ophiolite; KMC — Kłodzko metamorphic complex; NRO — Nowa Ruda ophiolite; OSD — Orlica-Śnieżnik Dome; SO — Szklary ophiolite; ZSTSZ — Złoty Stok–Trzebieszowice shear zone

Szkic strukturalno-kinematyczny południowej części metamorfiku sowiogórskiego i jego otoczenia
1 — terran sowiogórski; 2 — terran środkowosudecki; 3 — terran moldanubski; 4 — kataklazyty i brekcje tektoniczne; 5 — podatne strefy ścinania; 6 — granitoidy waryscyjskie; 7 — ofiolity śródsudeckie; 8 — nasunięcia kruche; 9 — uskoki; 10 — zwroty ścinań podatnych typu przesuwczego; 11 — zwroty ścinań podatnych typu nasunięciowego; BO — ofiolit Braszowic; KMC — metamorfik kłodzki; NRO — ofiolit Nowej Rudy; OSD — kopuła orlicko-śnieżnicka; SO — ofiolit Szklar; ZSTSZ — strefa ścinania Złotego Stoku–Trzebieszowic

cryptic collision suture-zones. Terranes with completely different geological structure adjoin each other along major tectonic boundaries. In the light of the above definition, the GSMC area, although of a small size (slightly more than 650 km^2), may be considered an individual terrane within a mosaic-like structure of the Sudetes. The Góry Sowie Terrane (GST) has been distinguished by the increasing number of scientists (M. J. Quenardel *et al.*, 1988; Z. Cymerman, 1991; Z. Cymerman *et al.*, 1997; G. J. H. Oliver *et al.*, 1993; Z. Cymerman, M. A. Piasecki, 1994; P. Aleksandrowski, 1998).

The GST is characterized by an internal continuity of its broadly understood geology. It refers to a character of a protolith, its age and structural-metamorphic history. A deeper part of the GST located on the Fore-Sudetic Block is characterized by a much larger area of outcrops of metabasites — almost 1/3 of the terrain — compared with its mountainous part. A magmatic protolith of the Góry Sowie gneisses, showing a magmatic arc character (supra-subductional), radiometrically documented Early Proterozoic or even Archean age of detrital zircons, pre-Devonian granulite metamorphism (HP/HT) and structural-metamorphic history that commenced as early as in the Ordovician time are all the arguments for a distinct definition of the GST within a mosaic-like structure of the Sudetes. P. Aleksandrowski (e.g. 1990, 1995, 1998) and P. Aleksandrowski *et al.* (1997) basing upon regional data, also suggests an individual character of the GSMC in relation to other parts of the Sudetes. Moreover, the GST area is bounded from neighbouring geological units by systems of faults, tectonic breccias and brittle to ductile shear zones. However, these tectonic boundaries do not allow to infer that the GST is an exotic element, chiefly because they mostly separate the GST from younger tectonic units (Intra-Sudetic Depression, Świebodzice Depression, Bardo Structure). The GST adjoins metamorphic areas with tectonically dismembered ophiolitic sequence fragments (Ślęża Mt., Nowa Ruda, Braszowice, Szklary and Gilów) only from the east, north-east and south-east.

The above chapters reviewed briefly various problems concerning geological structure of the GST. However, simple questions remain: where from, when and how the GST found its way into the mosaic structure of the Sudetes? The answer is and will remains highly speculative for a long time.

ACCRETION OF THE GST

A preliminary model of the Palaeozoic evolution of the GST is presented below. This hypothetical model is an attempt to answer the essential questions: (I) where and when did the GST come into existence? (II) when and how was it accreted to the Bohemian Massif? Its pre-accretion position plays a key role for the reconstruction of accretion history of the GST. Thus, where did the Góry Sowie Terrane come from? The answers may be extremely different.

In the first palaeotectonic sketch-maps showing geological evolution of Poland from a plate tectonics point of view (S. Cwojdziński, 1980), the Góry Sowie Block was considered a microplate and located at a constant distance from both the Bohemian Massif and southwestern margin of Baltica from the Late Proterozoic through the whole Palaeozoic. This microplate, together with the Bohemian Massif have been considered a fragment of the Prebaikalian Platform, disintegrated during the Baikalian (Cadomian) deformation events. The Góry Sowie microcontinent is interpreted by S. Cwojdziński (1980) to be a passive intramontane massif. Unfortunately, this preliminary geotectonic model has not been developed because its author became with time one of the advocates of the expanding Earth model.

The first plate tectonics model for the Sudetes (S. Cwojdziński, 1980) suggested that the Góry Sowie microcontinent came from Baltica. However, in many tens of later papers (too many to be cited) considering palaeogeographic reconstructions and plate tectonics of Palaeozoic Europe, the GSMC has not been distinguished as a separate element of the Bohemian Massif. In all those interpretations the GSMC, being a part of the Bohemian Massif, is a detached (rifted) fragment of the North African part of Gondwana. A different origin has been recently proposed by A. Kröner and E. Hegner (1998). They have considered the GSMC to be a fragment of the northern part of the Guiana Shield from which it was detached in the Late Precambrian and, together with other fragments, included into the eastern part of the Avalonia superterrane. A similar opinion has also been expressed by G. J. H. Oliver (1996).

However, Early Proterozoic, and even Late Archean detrital zircons (Tab. 1) may have originated from Baltica as well. The present author is of the opinion that some parts of Baltica may have been a sediment source area for the Early Proterozoic-Ordovician GST basin. Magmatic and metamorphic zircons older than 1600 Ma are well known from Baltica (e.g. S. V. Bogdanova *et al.*, 1994; I. S. Puchtel *et al.*, 1997). The Ordovician detrital zircons from the GSMC granulite (P. J. O'Brien *et al.*, 1997) are likely of a volcaniclastic origin being derived from a volcanic arc. The opinion presented here, that the GST might have come into existence and developed on the SW margin of Baltica (Fig. 3) is in opposition to the recently dominating models of drifting lithospheric plates and terranes (e.g. J. Tait *et al.*, 1994, 1995). However, palaeogeographic reconstructions presented by different authors for the Early Palaeozoic, are also divergent. These differences mainly refer to widths of oceans and distribution of terranes with volcanic arcs between Gondwana, Laurentia and Baltica (e.g. J. Tait *et al.*, 1994, 1995; I. W. D. Dalziel *et al.*, 1994; C. Mac Niocaill *et al.*, 1997). The south and southwestern part of Baltica was located during the Early Ordovician (ca. 490 Ma) at 60°S. At the Ordovician/Silurian boundary (ca. 50 Ma later), East Avalonia acrreted to Baltica. Palaeogeographic reconstructions for the Ordovician showing position of the GST marked as the Góry Sowie Arc (GSA) on Baltica peripheries (Fig. 4), and possible directions of drifting lithospheric plates and terranes, are mainly based upon a model by C. Mac Niocaill *et al.* (1997). In this model Avalonia is extremely removed from the Guiana Shield and northern Gondwana.

Characteristics and present orientation of the southwestern border of Baltica are among the most controversial tectonic problems of Poland. This border may be differently interpreted depending on whether the Caledonian Orogenic Belt in the Holy Cross Mts. is accepted (e.g. J. Znosko, 1985, 1986*a*, *b*; R. Dadlez *et al.*, 1994) or rejected (W. Mizerski, e.g. 1995). Terrigenous sandy-argillaceous Cambrian deposits and argillaceous Ordovician and Silurian ones (over 5 km in thickness) occur at the southwestern Baltica border. They may have infilled the back-arc basin of the GSA, however, with an undefined southwestern boundary of this basin. In this model at least a part of the SW periphery of Baltica would have been an active margin of the Early Palaeozoic Tornquist Ocean similar to the present margins of West Pacific Ocean.

Radiometric dating of protoliths of the GST orthogneisses shows that the emplacement of granitoids started in the Early

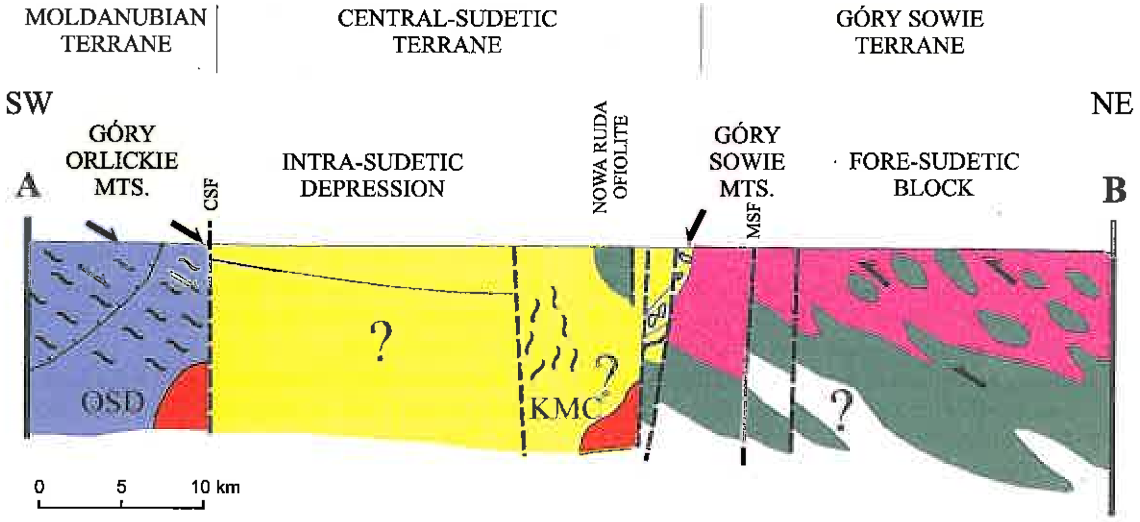

Fig. 3. Geological cross-section A–B (located in Fig. 2)

1 — tectonic transport direction; 2 — strike-slip displacements towards viewer; 3 — strike-slip displacements from viewer; CSF — Intra-Sudetic Fault; MSF — Marginal Sudetic Fault; for other explanations see Fig. 2

Przekrój geologiczny A–B zlokalizowany na fig. 2

1 — kierunek transportu tektonicznego; 2 — przemieszczenia przesuwcze w kierunku do czytelnika; 3 — przemieszczenia przesuwcze w kierunku od czytelnika; CSF — uskok śródsudecki; MSF — sudecki uskok brzeżny; pozostałe objaśnienia jak na fig. 2

Ordovician (ca. 490–470 Ma). They probably intruded into the Late Proterozoic, Cambrian and Ordovician(?) sedimentary sequences. The author is of the opinion that the intrusive processes may have taken place due to the beginning of convergence of lithospheric plates and subduction of the Tornquist Ocean under the GSA volcanic arc. These events might have initiated the long-termed processes of regional metamorphism, intense migmatitization (since ca. 440 Ma) and tectonic thickening of the crust (Taconian orogeny) in Early Ordovician time (since ca. 480 Ma). A dextral-oblique collision between the GST and SE fragment of the East Avalonia Terrane, accompanied by a sinistral rotation of Baltica, took place at the turn of Ordovician (ca. 440 Ma) when lithospheric plates were being brought closer to each other. This process may have been synchronous with the accretion of the East Avalonia Terrane to Baltica and with the ultimate closure of the Tornquist Ocean (e.g. T. H. Torsvik *et al.*, 1996; V. Bachtadse *et al.*, 1997). We approach here the key question what was the character of the Trans-European Suture Zone (e.g. A. Berthelsen, 1993; D. Franke, K. Illiers, 1994; D. Franke, 1994; R. Dadlez, 1995; R. Dadlez *et al.*, 1994, 1995). However, its nature is known practically from interpretations of geophysical data only (e.g. A. Guterch *et al.*, 1994; R. Dadlez, 1997; C. Królikowski, Z. Petecki, 1997; H. Thybo, 1997).

Palaeomagnetic data point to the sinistral Ordovician rotation of Baltica by about 90° and its northward displacement towards the equator (e.g. T. H. Torsvik *et al.*, 1996; V. Bachtadse *et al.*, 1997). The sinistral Ordovician rotation of Baltica may have caused dextral strike-slip or transpressional displacements on its peripheries. The Taconian deformation resulted in a change from a deep-water facies to shallow-marine one in the back-arc area. Probably between the GSA and Baltica — perhaps in a 200 km-wide belt — flysch deposits were accumulated during the Late Silurian. They were transported from SW (K. Jaworowski, 1971; P. Poprawa *et al.*, 1997), i.e. from the hypothetical GSA (Fig. 4). This island arc might have supplied among others material to the Peri-Tornquist basin (K. Jaworowski, 1971). The possibility of existence of such an arc in central Poland was earlier pointed by J. Znosko (1985, 1986*a*) who compared its development with the Japanese-Indonesian subduction model. J. Znosko (*op. cit.*) also discussed the problem of necessary large-scale horizontal displacements, generally of a thrust-nappe type, induced by the processes of subduction and closure of the Tornquist Ocean. A similar process of large-scale thrust-nappe displacements is schematically shown in Fig. 5. It is commonly accepted that the Tornquist Ocean was subjected to oblique, probably dextral subduction under the East Avalonia Terrane during the Late Silurian (D. Franke, 1994; P. Poprawa *et al.*, 1997; V. Bachtadse *et al.*, 1997). The Lusatian region is likely the partly exposed southeastern fragment of the East Avalonia Terrane (U. Linnemann *et al.*, 1997; Z. Cymerman *et al.*, 1997)

The Late Silurian flysch sedimentation in central Poland was probably related to the closure of the Tornquist Ocean located among Avalonia, Baltica and the Bohemian Massif. This ocean was closed in the Late Silurian (e.g. J. A. Tait *et al.*, 1994; V. Bachtadse *et al.*, 1997). Indications of the Silurian collision within Variscan structures were mentioned among others by C. Pin (1990). Obduction of the oceanic crust relics (after the Tornquist Ocean) and the nappe-package of GSMC thrusted over this dismembered fragments, might have taken place at that time in the northeastern peripheries of the Bohemian Massif, which, at that time, was colliding obliquely against the GST (*sensu lato*).

It is difficult to answer the question which process was responsible for the GST accretion into the architecture of the Bohemian Massif Variscan orogenic belt. One of the possible accretion processes is that of underplating in subduction

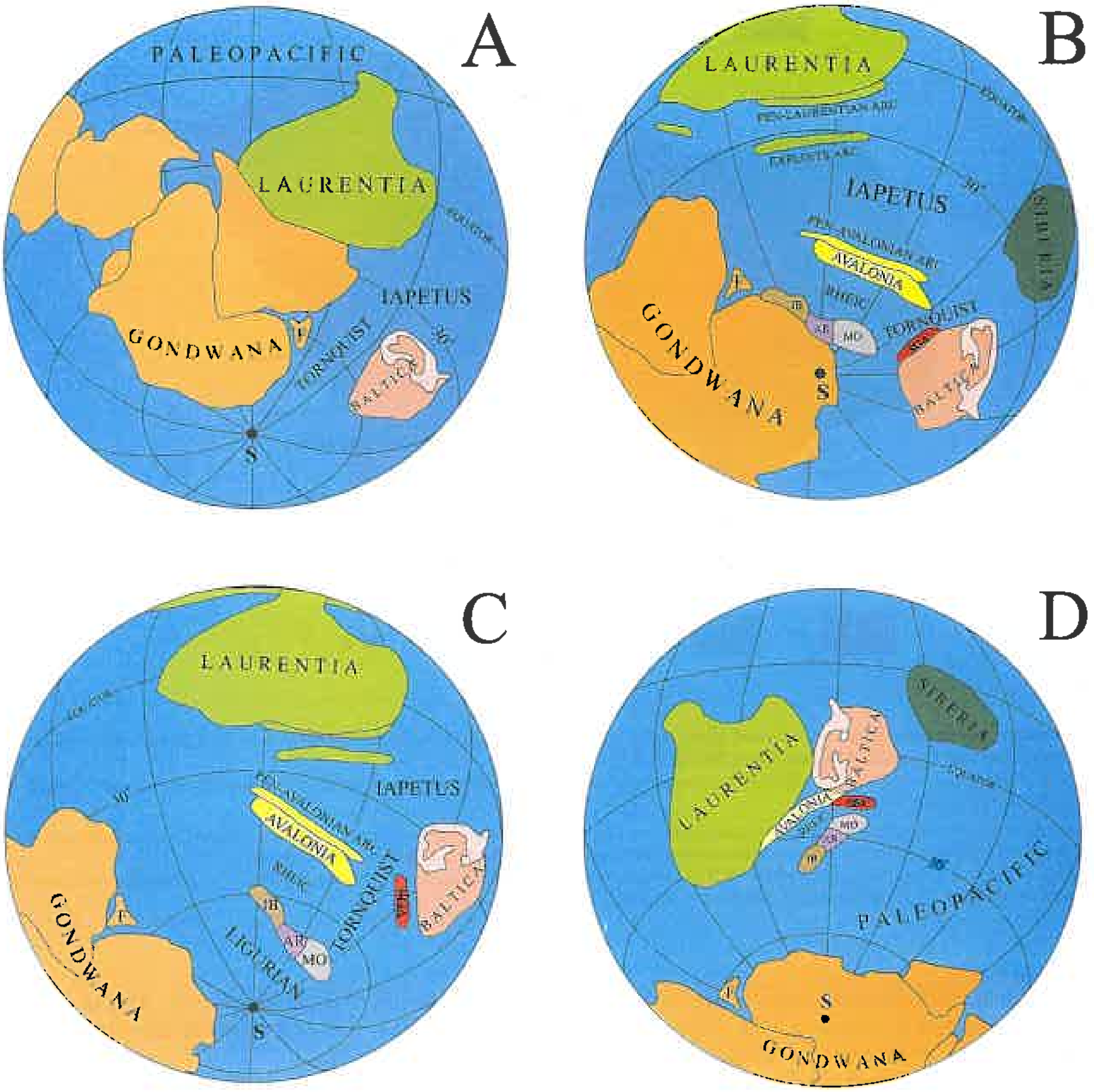

Fig. 4. Ordovician and Silurian evolution of the Iapetus Ocean

A — Middle Ordovician palaeogeographic reconstruction (after I. W. D. Dalziel *et al.*, 1994); B — Early–Middle Ordovician palaeogeographic reconstruction (after C. Mac Niocaill *et al.*, 1997), supplemented; C — Late Ordovician palaeogeographic reconstruction (after C. Mac Niocaill *et al.*, 1997), supplemented; D — Silurian palaeogeographic reconstruction (after T. H. Torsvik *et al.*, 1996 and C. Mac Niocaill *et al.*, 1997), supplemented; AR — Armorica; F — Florida; IB — Iberia; MO — Moldanubian; GSA — Góry Sowie arc

Ordowicka i sylurska ewolucja oceanu Iapetus

A — Rekonstrukcjadla środkowego ordowiku (według I. W. D. Dalziela i in., 1994); B — rekonstrukcja paleogeograficzna dla wczesnego-środkowego ordowiku (według C. Mac Niocailla i in., 1997), uzupełnione; C — rekonstrukcja paleogeograficzna dla późnego ordowiku (według C. Mac Niocailla i in., 1997), uzupełnione; D — rekonstrukcja paleogeograficzna dla syluru (według T. H. Torsvika i in., 1996 i C. Mac Niocailla i in., 1997), uzupełnione; AR — Armorica; F — Floryda; IB — Iberia; MO — Moldanubian; GSA — łuk Gór Sowich

zones. Another process explaining the Devonian accretion of the GST to the northern peripheries of the Bohemian Massif is a large-scale mid-crustal thrusting (Fig. 5). Such processess with a widespread and diverse tectonic transport, and additionally differing in terms of shape and magnitude of nappe slices, are usually related to a development of vast ductile

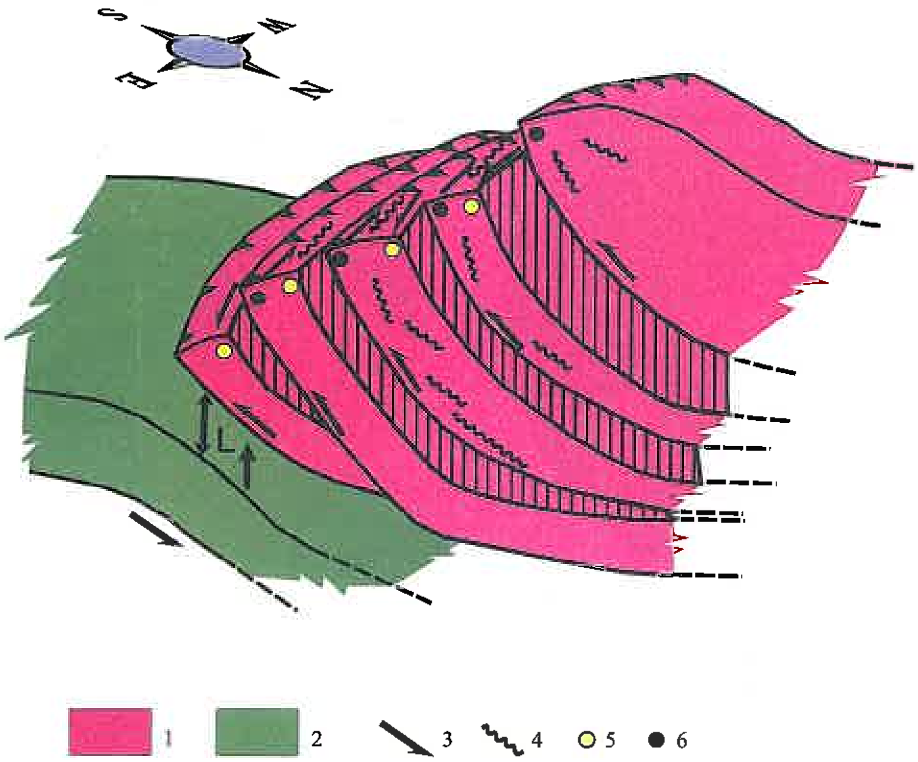

Fig. 5. Schematic diagram illustrating transpressional (thrust-strike-slip), sinistral (parallel to symbol L) model of large-scale ductile displacements of thrust sheets package within the Góry Sowie Terrane during the Caledono-Variscan orogeny

1 — Góry Sowie Terrane; 2 — Central-Sudetic Terrane; 3 — tectonic transport direction; 4 — fold structures; 5 — strike-slip displacements towards viewer; 6 — strike-slip displacements from viewer

Schematyczny diagram ilustrujący transpresyjny (nasunięciowo-przesuwczy), lewoskrętny (równoległy do symbolu L) model wielkoskalowego, podatnego nasuwania pakietu typu *thrust sheets* wewnątrz terranu sowiogórskiego podczas orogenezy kaledońsko-waryscyjskiej

1 — terran sowiogórski; 2 — terran środkowosudecki; 3 — kierunek transportu tektonicznego; 4 — struktury fałdowe; 5 — przemieszczenia przesuwcze w kierunku do czytelnika; 6 — przemieszczenia przesuwcze w kierunku od czytelnika

shear zones in deeper parts of the Earth's crust in the course of progressive regional metamorphism. The large-scale thrusting processes, embracing the GSMC along with the obducted (towards SSW) oceanic crust in the northeastern margin of the Bohemian Massif, appears to be the best explanation of a mosaic-like structure of the Sudetes. Stages of the thrusting history of the GSMC are evidenced by the deformation phase D_4 in the deformation sequence scheme constructed by Z. Cymerman (1988, 1989), as well as deformation phase D_4 according to A. Żelaźniewicz (1987, 1989, 1990). However, the GSMC invariably occupied an autochthonous position in the latter author's interpretation.

Obduction of the oceanic crust (Middle Sudetic Terrane) with the overthrusted GST fragment took place during the Late Devonian Variscan orogeny. The interpretation of Ordovician through Late Devonian progressive history of deformation, migration and oblique convergence in the GSMC is evidenced by petrological data showing that gradually changing metamorphic processes (from a granulite facies through amphibolite one to greenschist facies) reigned there at that time. Some exhumed fragments of the GSMC were already eroded before the Middle Viséan time. This is indicated by the occurrence of the Culm clastic facies in tectonic grabens of the Góry Sowie Mts.

It seems probable that, in the light of various new data discussed in this paper, the GST was formed as a volcanic arc on the present southwestern periphery of Baltica, and drifted northwards together with Baltica. The GST was subjected to an oblique collision against East Avalonia during the Caledonian orogeny. A fragment of this terrane (GSMC) as a thrust-nappe (detached block), together with the obducted fragment of the Tornquist oceanic crust, were included during the Variscan deformations into a mosaic-like structure of the Sudetes. The above-presented considerations support the earlier concept of J. Znosko (e.g. 1985, 1986*b*) that there does exist the Caledonian orogen in central and southern Poland. The GST (*sensu lato*) should be its major component and may be preliminarily named the Peribaltic Terrane. J. Znosko's (1986*a*, p. 4) conclusion that "...there are still many inscrutable matters between the border of the Old Platform and Sudetes..." is still up-to-date.

CONCLUSIONS

1. In the light of various recent data, the Góry Sowie metamorphic complex area should be considered to represent a far-travelled thrust-nappe fragment of the Góry Sowie Terrane (*sensu stricto*) preserved within the Sudetic mosaic. The remaining part of the GST (*sensu lato*) occurs probably in central and southern Poland under a sedimentary cover.

2. Distinct structural-metamorphic history of the GSMC in comparison to the adjacent Saxothuringian and Moldanubian metamorphic complexes (terranes) suggests that described complex is a detached fragment of the GST. The GSMC is the only area in the Sudetes with Caledonian deformations which are documented radiometrically.

3. The oldest detrital zircons that have been recognized so far from the Sudetic metamorphic complexes, are documented by isotopic dating of the GSMC. They are of the Early Proterozoic or even Archean ages. The zircons may have come from a part of Baltica.

4. The GSMC is herein considered to be a detached mid-crustal relic thrust-nappes of a Caledonian magmatic arc (GSA) thrusted into the northeastern periphery of the Bohemian Massif. This arc developed on the southwestern margin of Baltica (recent geographical reference). At least a fragment of this margin might have been an active margin of the Baltica continent during the Early Palaeozoic, may be similar to the West Pacific Ocean type.

5. During the Caledonian orogeny (Late Ordovician/Early Silurian), the GST was probably amalgamated with the East Avalonia Terrane, and the closure of the Tornquist Ocean took place. Later on, during the Variscan orogeny (Late Devonian), a fragment of the GST i.e. GSMC, was thrusted towards SSW over an obducted, also towards SSW, dismembered ophiolitic fragments derived from the Tornquist Ocean.

6. Almost a 20 years old suggestion expressed by Prof. J. Znosko that the GSMC is underlain by ophiolitic rocks is still valid. The Góry Sowie Block itself (GSMC), conceived as a fragment of a Caledonian terrane (GST) may prove that the Caledonian orogenic belt does occur in central and southern Poland.

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TERRAN SOWIOGÓRSKI: KLUCZ W ZROZUMIENIU PALEOZOICZNEJ EWOLUCJI SUDETÓW I NIE TYLKO

Streszczenie

Już w 1981 r. J. Znosko doszedł do wniosku, że metamorfik sowiogórski (MS) jest podścielony w znacznej części przez skorupę oceaniczną. Było to jedno z najważniejszych spostrzeżeń dotyczących budowy geologicznej Sudetów. Od tego czasu pojawiły się różne modele ewolucji całych Sudetów lub ich części. Powstawały one na podstawie napływu nowych danych. Celem artykułu jest krytyczna analiza wszystkich nowych danych z MS, często bardzo specjalistycznych. Ich analiza prowadzi do wniosku, że MS jest obszarem o kluczowym znaczeniu we wszystkich rozważaniach dotyczących paleozoicznej ewolucji Sudetów i nie tylko.

Badania mikropaleontologiczne T. Guni (1981, 1984, 1997) dokumentują w MS osady górnego proterozoiku i kambru. W MS brakuje dowodów na neoproterozoiczną (kadomską) skorupę kontynentalną. Oznaczenia izotopowe detrytycznych cyrkonów z MS wskazują na ich staroproterozoiczne, a nawet archaiczne pochodzenie (A. Kröner, E. Hegner, 1998). Cyrkony te mogą pochodzić z Baltiki. Wiek magmowego protolitu gnejsów sowiogórskich ustalono na około 473–488 mln lat (G. J. H. Oliver i in., 1993; A. Kröner, E. Hegner, 1998). Nowe datowania radiometryczne (tab. 1) podważają schemat waryscyjskiej, pięciofazowej ewolucji strukturalnej MS (A. Żelaźniewicz, 1987, 1990). Obecnie MS jest jedynym obszarem w Sudetach i na terenie całego Masywu Czeskiego, z udokumentowanymi radiometrycznie na cyrkonach deformacjami kaledońskimi.

Obecnie zaznacza się tendencja do interpretacji metabazytów z MS jako efektu ryftogenezy skorupy kontynentalnej w dolnym paleozoiku (J. A. Winchester i in., 1998). Jednak większość metabazytów występują głównie w polu MORB-u diagnostycznych diagramów geochemicznych. Zróżnicowanie geochemiczne metabazytów z MS najprawdopodobniej związane jest z kontaminacją tych skał podczas ich ewolucji tektonometamorficznej i współdziałania procesów heterogenicznej migmatytyzacji i anateksis. Jeszcze większe kontrowersje budzi zagadnienie genezy i środowiska geotektonicznego protolitu dolnoordowickich gnejsów sowiogórskich. Część badaczy uważa, że gnejsy te są produktem magmatyzmu typu łuku magmowego powstałego nad strefą subdukcji (G. J. H. Oliver i in., 1993, J. D. Johnston i in., 1994; A. Kröner, E. Hegner, 1998).

A. Żelaźniewicz (1989, 1990) umiejscowił w skali czasowej wydzielone przez siebie fazy waryscyjskiej deformacji w MS (tab. 2). Nowe datowania radiometryczne podważają ten schemat, wskazując już na ordowicki metamorfizm i deformacje MS (G. J. H. Oliver i in., 1993; A. Kröner i in., 1994*a*; A. Kröner, E. Hegner, 1998). Z diateksytu sowiogórskiego otrzymano dane radiometryczne magmowych cyrkonów o wieku ca. 460 mln lat (G. J. H. Oliver i in., 1993) i ca. 440 mln lat (A. Kröner, E. Hegner, 1998). Diateksyt ten reprezentuje najmłodszy, późno- lub nawet post-deformacyjny produkt regionalnego metamorfizmu i migmatytyzacji. Powstanie tego diateksytu wiązał A. Żelaźniewicz (1987, 1989, 1990) z ostatnią (D_5) fazą deformacji synchroniczną z drugą migmatytyzacją MS. Dziwny jest też fakt braku struktur tektonicznych w MS młodszych od fazy D_5 A. Żelaźniewicza (młodszych od ca. 440 mln lat), chociaż warunki metamorfizmu regionalnego, zarówno facji granulitowej (ca. 400 mln lat), a potem amfibolitowej (ca. 380 mln lat) czy wreszcie zieleńcowej panowały jeszcze przez ponad 100 mln lat (do wizenu środkowego). Bardziej prawdopodobne jest, że struktury tektoniczne uznane przez A. Żelaźniewicza jako ostatnie (D_5) należy zaliczyć do struktur z fazy D_3 Z. Cymermana (1988, 1989). Wtedy opisane przez tego ostatniego struktury z faz D_4 i D_5 (post-migmatytyzacyjne) mogły rozwijać się przez 100 mln lat. Otwarta pozostaje kwestia czy struktury tektoniczne MS powstawały w wyniku odrębnych faz deformacji, czy też były raczej efektem progresywnej, heterogenicznej deformacji, ze znaczącym udziałem ścinania ogólnego.

W artykule wskazano także na trudności ustalenia jednoznacznego schematu rozwoju strukturalnego MS. Między innymi przejścia od metateksytu do diateksytu (*sensu* M. Brown, 1973) oznaczają fundamentalną zmianę właściwości reologicznych deformowanej skorupy litosfery. Jest to jeden z najważniejszych czynników heterogenicznego rozwoju struktur tektonicznych, które mogą być zinterpretowane jako wynik odrębnych faz deformacji, także na obszarze MS.

Dane kinematyczne z MS są najbardziej czytelne tylko S części Gór Sowich, gdzie występują pasma oczkowych ortognejsów. Badania kinematyczne wskazują tam na przemieszczanie typu nasunięciowo-przesuwczego z przemieszczaniem wyżejległych domen strukturalnych ku SW i S. Część danych kinematycznych wskazuje także na lewoskrętne przemieszczenia typu przesuwczego. Na całym pozostałym obszarze MS trudno jest rozpoznać wskaźniki kinematyczne. Wynika to z silnej migmatytyzacji i homofanizacji skał MS. Według Z. Cymermana (1989) procesy heterogenicznej mylonityzacji były dość pospolite i związane ze wszystkimi etapami deformacji w MS. Pasemka mylonityczne często są anastomozujące. Taki rozwój sprzężonych, anastomozujących pasemek ścinania wskazuje na ich rozwój w warunkach deformacji koaksjalnej (nierotacyjnej). Znacznie lepiej wyrażone są asymetryczne, ekstensyjne pasemka ścinania z etapu D_4.

Po analizie różnych danych wydaje się zasadne przyjęcie, że MS powinien być uznany za terran, którego mały fragment zachował się jedynie w waryscyjskiej mozaice sudeckiej. W odtworzeniu historii akrecji terranu sowiogórskiego kluczowe znaczenie ma jego przedakrecyjna pozycja. Prawdopodobnie znaczna jego część znajduje się pod grubą pokrywą skał osadowych Polski centralnej i południowej. Za uznaniem MS za terran, przemawia głównie jego historia tektoniczna i metamorficzna, odrębna od historii innych kompleksów metamorficznych Sudetów. Terran sowiogórski (*sensu stricte*) można wstępnie uznać za relikt większego kaledońskiego łuku magmowego (łuku perybałtyckiego). Łuk ten rozwijał się na SW obrzeżeniu Baltiki. Dlatego też SW część Baltiki podczas dolnego paleozoiku mogła być aktywnym brzegiem, zbliżonym do typu zachodniopacyficznego.

Podczas orogenezy kaledońskiej (takońskiej) w okresie górny ordowik/dolny sylur doszło do akrecji terranu sowiogórskiego (*sensu lato*) z terranem wschodniej Avalonii i zamknięcia oceanu Tornquista. Prawdopodobnym wynikiem tej akrecji były wielkoskalowe procesy nasunięciowe, z rozległym transportem tektonicznym różnych pod względem kształtu i wielkości płyt (łusek) głębszego podłoża w obrębie stref nasunięciowych. Następnie podczas orogenezy akadyjskiej (starowaryscyjskiej) w środkowej i górnej części skorupy litosfery doszło do nasunięcia ku SSW fragmentu terranu sowiogórskiego (*sensu stricto*) na obdukowany również ku S fragment sekwencji ofiolitowej będącej reliktem po oceanie Tornquista. Do obdukcji skorupy oceanicznej (terran środkowosudecki) z nasuniętym fragmentem terranu sowiogórskiego doszło w czasie orogenezy starowaryscyjskiej w Sudetach (fazy bretońskie). Być może w przypadku terranu sowiogórskiego orogeneza takońska i akadyjska nie reprezentują oddzielnych zjawisk tektonicznych, ale progresywną, ciągłą historię deformacji, migracji i skośnej konwergencji. Regionalna, postkolizyjna, głównie wizeńska ekstensja w Sudetach spowodowała szybką ekshumację terranu sowiogórskiego z synchronicznym rozwojem lokalnych rowów tektonicznych, wypełnionych osadami kulmowymi.

EXPLANATIONS OF PLATES

PLATE I

Fig. 6. Examples of ptygmatitic folds F_3 from the Góry Sowie migmatite. Bielawa environs. Plane perpendicular to fold axes and mineral lineation. Scale in millimetres

Przykłady fałdów ptygmatytowych F_3 z migmatytu sowiogórskiego. Okolice Bielawy. Płaszczyzna prostopadła do osi fałdów i lineacji ziarna mineralnego. Skala w milimetrach

Fig. 7. Relic of palaeosome (fine-crystalline, banded gneiss) in neosome (coarse-crystalline, thin-layered stromatitic migmatite). Jugowice environs. Scale in millimetres

Relikt paleosomu (drobnokrystaliczny, cienko laminowany gnejs) w neosomie (grubokrystaliczny, warstewkowy migmatyt stromatytowy). Okolice Jugowic. Skala w milimetrach

PLATE II

Fig. 8. Examples of various fold structures in migmatites, northern part of the Góry Sowie metamorphic complex (Owiesno environs). Plane perpendicular to fold axes and mineral lineation. Scale in millimetres

Przykłady zróżnicowanych struktur fałdowych w migmatytach z północnej część metamorfiku sowiogórskiego (okolice Owiesna). Płaszczyzna prostopadła do osi fałdów i lineacji ziarna mineralnego. Skala w milimetrach

Fig. 9. Augen gneisses steeply plunging towards NNE. Dextral thrust sense of shear (top-to-SSW) evidenced by "eye-like" and "fusiform" porphyroclasts of type σ. XZ plane of deformation ellipsoid parallel to foliation and perpendicular to stretching lineation. Southeastern part of the Góry Sowie metamorphic complex (Sokolec environs). Scale in centimetres

Stromo zapadające ku NNE ortognejsy oczkowe. Nasunięciowy, prawoskrętny zwrot ścinania ("góra" ku SSW) wyznaczony przez "oczkowe" i "wrzecionowate" w formie porfiroklasty typu σ. Płaszczyzna XZ elipsoidy deformacji równoległa do foliacji i prostopadła do lineacji z rozciągania. Południowo-wschodnia część metamorfiku sowiogórskiego (okolice Sokolca). Skala w centymetrach

PLATE III

Fig. 10. Augen-leyered gneisses steeply plunging towards SW. Dextral sense of shear (top-to-NW) evidenced by large porphyroclasts of type σ and type S–C mylonitic structures. XZ plane of deformation ellipsoid perpendicular to fold axes and stretching mineral lineation. Southeastern part of the Góry Sowie metamorphic complex (Jugowice environs). Scale in centimetres

Stromo zapadające ku SW gnejsy oczkowo-warstewkowe. Prawoskrętny zwrot ścinania („góra" ku NW) wyznaczony przez duże porfiroklasty typu σ i struktury mylonityczne typu S–C. Płaszczyzna XZ elipsoidy deformacji prostopadła do foliacji i równoległa do lineacji z rozciągania. Południowo-wschodnia część metamorfiku sowiogórskiego (okolice Jugowa). Skala w centymetrach

Fig. 11. Gneissic mylonite dipping at ca. 55° towards ESE. Dextral sense of shear (top-to-SSW) evidenced by numerous porphyroclasts of type σ and rare type δ, as well as extensional, asymmetric shear bands of type C'. Plane perpendicular to foliation and parallel to stretching lineation. Northern part of the Niemcza shear zone (Piekiełko ravine near Gilów). Scale in centimetres

Mylonit gnejsowy upadający pod kątem ca. 55° ku ESE. Prawoskrętny zwrot ścinania („góra" ku SSW) wyznaczony jest przez liczne porfiroklasty typu σ i rzadsze — typu δ oraz ekstensyjne, asymetryczne pasemka ścinania typu C'. Płaszczyzna prostopadła do foliacji i równoległa do lineacji z rozciągania. Północna część strefy ścinania Niemczy (wąwóz Piekiełko koło Gilowa). Skala w centymetrach

Fig. 6

Fig. 7

Fig. 8

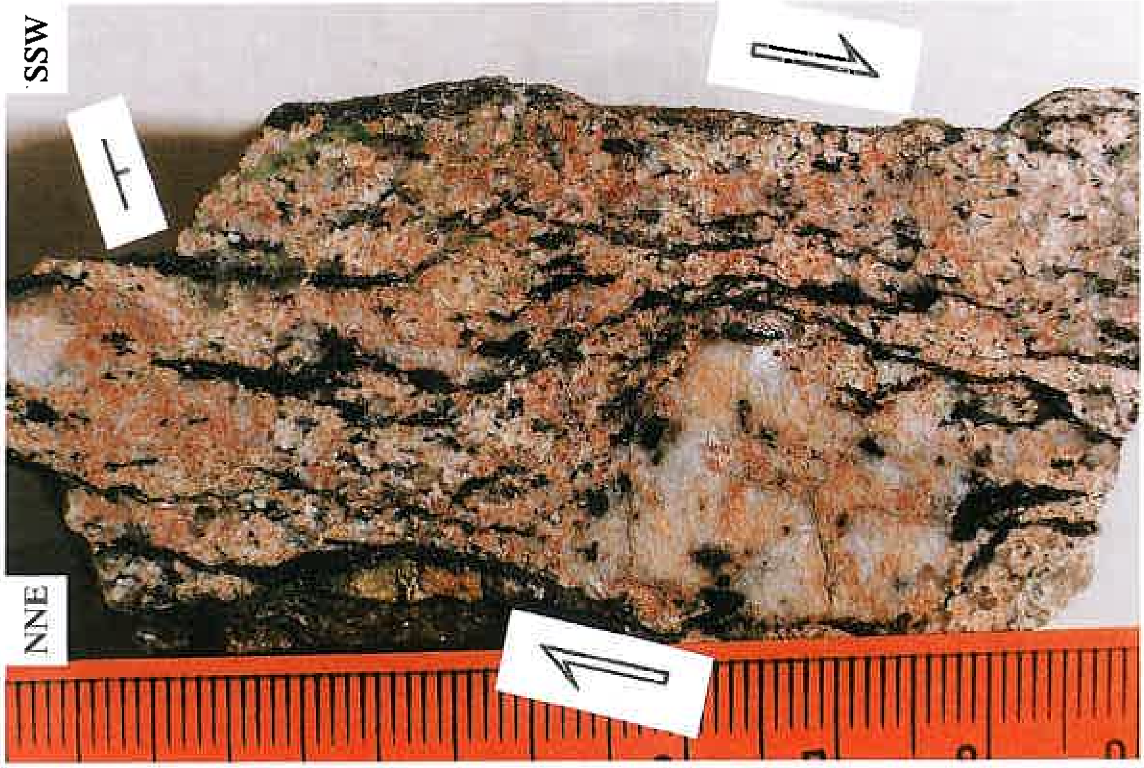

Fig. 9

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Fig. 10

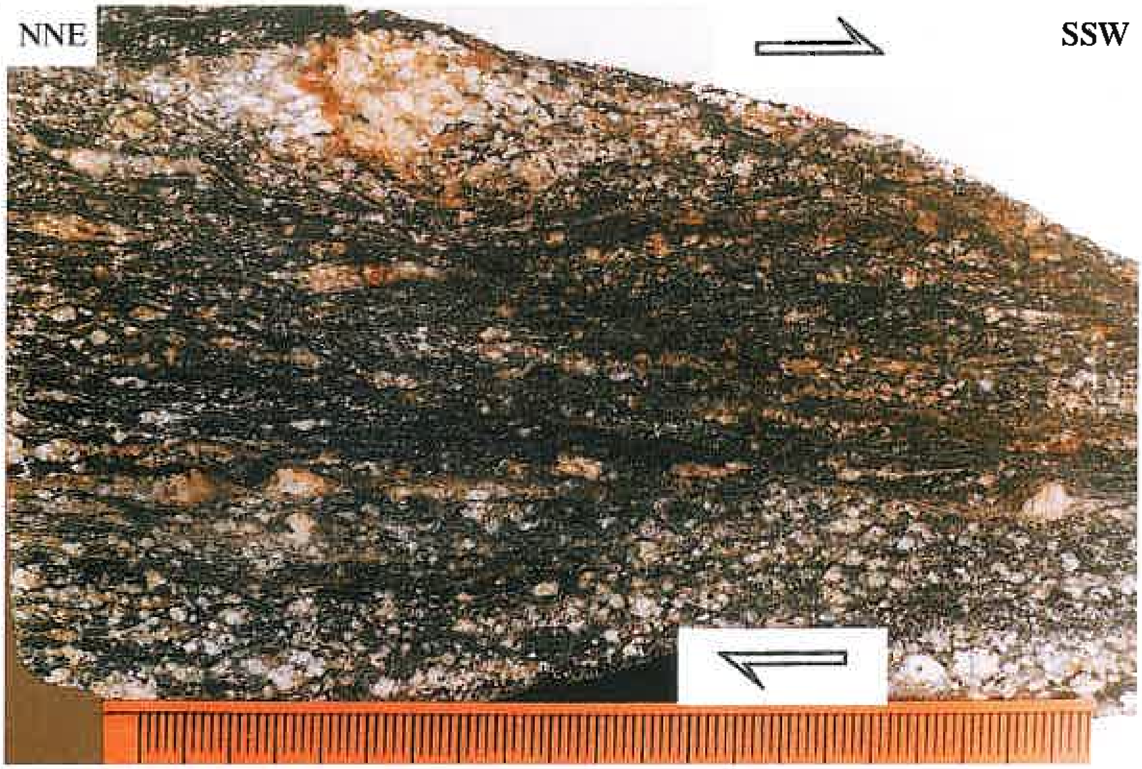

Fig. 11

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