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The boundary zone of the East and West Sudetes on the 1:50 000 scale geological map of the Velké Vrbno, Staré Město and Śnieżnik Metamorphic Units

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Contents

Abstract The results of field investigations carried out by the authors were used together with existing Czech and Polish cartographic publications to compile a digital geological map (1:50 000) of the boundary zone of the East and West Sudetes. This map is supplemented with a text presenting a tectonic interpretation of the cartographic picture, preceded by a brief description of all 61 of the lithostratigraphic units of the area. Apart from this printed version, the map has also been published as a digital version on CD for the first time. The map covers an area of 1875 km^2, in which three entire regional geological units occur: the Velké Vrbno dome and the Śnieżnik metamorphic unit, divided by the relatively narrow Staré Město paleorift zone, which is meridionally-stretched along a 55-kilometre long section. The Keprnik and the Vidnava domes, the Zábřeh crystalline unit, and the upper Cretaceous Nysa Kłodzka graben are all partially included in the map.

The authors experienced major difficulties regarding the correlation of lithostratigraphic units to tectonic structures interpreted in a different way; this mainly concerned those lying on opposite sides of the international border. Thus the awareness exists that necessary, although sometimes arbitrary and subjective solutions may not be upheld by the results of future investigations. The digital version of the map should facilitate the supplementation of its contents and should enable a direct correction of the present picture in the course of such future investigations.

The digital version is available on a CD-ROM at the Institute of Geological Sciences, Wrocław University. E-mail contact: romgot@ing.uni.wroc.pl.

Abstrakt Obserwacje polowe autorów oraz publikowane czeskie i polskie materiały kartograficzne posłużyły do zestawienia cyfrowej mapy geologicznej w skali 1 : 50 000 strefy granicznej Sudetów Wschodnich z Sudetami Zachodnimi. Uzupełnia ją tekstowa interpretacja tektoniczna uzyskanego obrazu kartograficznego, poprzedzona krótkim opisem wszystkich 61 wydzieleń litostratygraficznych. Oprócz prezentowanej wersji papierowej po raz pierwszy mapa publikowana jest również w formie cyfrowej na dysku CD. Obejmuje obszar 1875 km^2 na którym występują w całości trzy regionalne jednostki geologiczne: kopuła Velkého Vrbna i metamorfik Śnieżnika, obie rozdzielone południkowo wydłużoną na odcinku ponad 55 kilometrowym stosunkowo wąską strefą paleoryftu Starého Města. Graniczące od wschodu i zachodu dalsze jednostki, czyli kopuła Keprnika i Vidnavy oraz strefa krystaliniku zabřeskiego i górnokredowy rów Nysy Kłodzkiej, ujęte zostały w częściach ograniczonych ramą mapy.

Przedstawiony obszar obejmuje sudecki wycinek jednego z najważniejszych lineamentów podłoża krystalicznego nie tylko Sudetów, ale i środkowej Europy. Strefa wczesnopaleozoicznego paleoryftu Starého Města, wykorzystana następnie przez waryscyjski zespół nasunięć, stanowi północne przedłużenie nasunięcia moldanubskiego, oddzielającego Masyw Czeski od bloku Bruno-Vistulikum. Dalej ku północy przecina przedgórze sudeckie aż po okolice Wrocławia. Po obu stronach tego głębokiego i konsekwentnie odnawianego rozłamu występują jednostki różniące się rozwojem facjalno-strukturalnym. Na wschodzie pierwsza konsolidacja struktur nastąpiła przed wendem (~560 Ma), natomiast po stronie zachodniej na przełomie kambru z ordowikiem (~500 Ma). Ponowna bardzo silna przebudowa strefy granicznej tych jednostek połączona z intensywnymi procesami metamorfozy – ale szybko zanikającymi na zewnątrz zarówno ku wschodowi jak i ku zachodowi – miała miejsce podczas rozpoczętego w dewonie rozwoju waryscyjskiego łuku orogenicznego. Badany wycinek Sudetów wszedł wtedy w skład środkowoeuropejskiego progu krystalicznego, rozdzielającego internidy od eksternidów tego orogenu (Pożaryski 1992; Don 2000, 2002). Podobnie jak wzdłuż całego łuku, polaryzacja tektoniczna na jego wschodnim skrzydle – przecinającym pra-Sudety – skierowana była wyraźnie na zewnątrz, czyli na wschód. W tej konwencji badana strefa jest przedłużeniem niemieckiego odcinka środkowowaryscyjskiego progu krystalicznego, skręcającego wzdłuż Odry koło Wrocławia na południe w starą strefę rozłamową. Apogeum waryscyjskiej przebudowy tej strefy nastąpiło pod koniec wczesnego karbonu (~340 Ma).

Autorzy mapy natrafili na znaczne trudności związane z korelacją wydzieleń litostratygraficznych różnie interpretowanych struktur tektonicznych, szczególnie po obu stronach granicy państw. Zdają sobie sprawę, iż konieczne niekiedy arbitralne i subiektywne rozwiązania nie zawsze zostaną w przyszłości potwierdzone. Wersja numeryczna opracowanej mapy w znacznym stopniu ułatwi wprowadzanie uzupełnień oraz bezpośrednią korektę obecnego obrazu w toku przyszłych badań.

Równolegle z artykułem zawierajacym analogową wersję mapy przygotowana została jej numeryczna wersja (na poziomie szczegółowości skali 1:50 000), rozprowadzana na dysku CD. Informacja o warunkach nabycia w/w dysku dostępna jest pod adresem e-mail: romgot@ing.uni.wroc.pl

Souhrn K sestavení digitální geologické mapy 1 : 50 000 pásma styku Východních a Západních Sudet byly pouťity výsledky dlouholetých výzkumů a geologického mapování autorů, jakoť i publikované mapové podklady české i polské. Mapu doplňuje stručný text obsahující tektonickou interpretaci získaného kartografického obrazu a stručný popis všech 61 rozlišených litostratigrafických členů a souborů. Kromě předloťené tištěné verze je mapa rovněť poprvé publikována digitálním způsobem na disketě CD. Mapa pokrývá rozlohu 1875 km^2, na jejíť stavbě se podílejí tři regionální geologické jednotky: velkovrbenská klenba, metamorfikum Králického Sněťníku a paleorift Starého Města, který obě zmíněné jednotky odděluje v délce 55 km poměrně úzkým, poledníkově orientovaným pásmem. Sousedící jednotky, tj. klenba vidnavská, keprnická, zábřeťské krystalinikum a svrchnokřídová výplň prolomu Kladské Nysy, jsou do mapy pojaty pouze s ohledem na úplnost vymezení studovaného území.

Předkládaná mapa zahrnuje sudetskou část jednoho z nejdůleťitějších lineamentů krystalinického podloťí nejen Sudet, ale celé střední Evropy. Pásmo staropaleozoického paleoriftu Starého Města, vyuťité později k vzniku variských násunů, představuje severní pokračování moldanubického nasunutí, oddělující Český masiv od bloku bruno-vistulika. To dále k severu pokračuje v sudetském předhoří ať do okolí Wrocławi. Po obou stranách této hluboko sahající a následně obnovované labilní zóny vystupují jednotky různící se faciálním a strukturním vývojem. Na východní straně proběhla první konsolidace struktur před vendiénem (~ 560 Ma), zatímco na straně západní ať na hranici kambria s ordovikem (~ 500 Ma). Následující velmi silná přestavba styčné zóny těchto jednotek je spojena s intenzivními, ale rychle

jak k východu, tak k západu vyznívajícími metamorfními pochody, které probíhaly od devonu ve variském horotvorném oblouku. Zkoumaný úsek sudetské soustavy byl tehdy pojat do středoevropského prahu krystalinika, rozdělujícího internidy od externid tohoto orogénu (Znosko, 1965, 1974; Pożaryski, l992; Don, 2000, 2002). Podobně jako v celém variském oblouku, tektonická polarita na jeho východním křídle, protínajícím Prasudety, je výrazně orientována směrem k vnějšku čili k východu. Z toho pohledu je popisovaná část styčné zóny Západních a Východních Sudet prodlouťením německého úseku středovariského hřbetu (prahu) krystalinika, stáčejícího se podél Odry a od Wrocławi k jihu do této staré zlomové zóny (paleoriftu). Vyvrcholení variské přestavby této zóny proběhlo ve spodnim karbonu (~ 340 Ma).

Autoři mapy se setkávali se značnými potíťemi při korelaci vyčleněných litostratigrafických souborů a různě interpretovaných tektonických struktur zejména po obou stranách státní hranice. Jsou si vědomi toho, ťe některé jejich závěry a názory nebudou v budoucnosti zcela potvrzeny. Digitální zpracování mapy však značnou měrou usnadní doplňování a opravy základního pojetí mapy během příštích výzkumů.

Současně s publikovaným článkem obsahujícím tištěnou geologickou mapu v příloze byla sestavena také její digitální verze (v měřítku 1:50 000) na disketě CD. Informace o moťnosti jejího získání jsou dostupné na e-mailové adrese: romgot@ing.uni.wroc.pl

INTRODUCTION

The area presented comprises a Sudetic segment of one of the major crystalline basement lineaments of not only the Sudetes, but of the whole of Central Europe. The Staré Město early Palaeozoic paleorift zone, later reactivated by a Variscan system of thrusts, forms the northern extension of the Moldanubicum thrust, which separates the Bohemicum from the Bruno-Vistulicum. Farther north, it intersects with the Sudetic Foreland reaching as far as the Wrocław area. On each side of this deep and subsequently renewed fracture zone, there are units characterized by a different facial-structural evolution. In the east, the first consolidation of structures took place before the Vendian (~560 Ma), while in the west, at the turn of the Cambrian–Ordovician (~500 Ma). The second major remodelling of the boundary zone between these units took place during the development of the Variscan orogenic belt that commenced in the Devonian. This redevelopment was related to intense metamorphic processes, the effects of which fade not far out to the east and west. The part of the Sudetes studied then became part of the Central European Crystalline High, which divided the internides and the externides of this orogen (Znosko, 1965, 1974; Pożaryski, 1992; Don, 2000, 2002). As along the whole belt, the tectonic polarization on its eastern wall – cutting the Pre-Sudetes – was directed distinctly outwards, i.e. to the east. In this convention, the zone investigated forms an extension of the German section of the Middle Variscan Crystalline High, turning to the south along the Odra near Wrocław into an old fracture zone. The Variscan redevelopment of this zone had its peak in the Early Carboniferous (~340 Ma).

The 1:50 000 scale digital map of the units mentioned in the title covers an area of over 1875 km^2. The largest unit, the Śnieżnik metamorphic unit, belongs to the Lugicum of the West Sudetes, while the metamorphic series of the Velké Vrbno dome belongs to the Silesicum and to the underlying Cadomian Bruno-Vistulicum of the East Sudetes. The units are separated by the Staré Město paleorift zone, almost 55 km long and narrowed to 5 km wide in some places, filled with Early Caledonian (Cm_3/O_1) ophiolitic and volcanic-sedimentary formations split in two along its whole length by a Variscan (C_1/C_2) intrusion of granitoids typical of labile zones. In the west, the Śnieżnik metamorphic unit is bounded by the upper Cretaceous Nysa Kłodzka graben depression, formed in the axis of the large-radius Orlica–Śnieżnik dome. In the east, during the Variscan orogeny, the series of the Velké Vrbno dome were thrust along the Ramzova line onto the more weakly-metamorphosed Devonian (?) sediments of the Branná zone, which are underlain by the Keprnik dome crystalline rocks. The Ramzova thrust zone belongs to the system of easterly-polarized Variscan displacements, which form an extension of the Moldanubian thrusts. Other major zones in the area covered by the map are the Bialskie and the Nýznerov thrust zones. They are accompanied by tectonically-squeezed lenses of partially strongly-serpentinised ultrabasites. All the regional units and tectonic structures mentioned were meridionally stretched, and cut in the north by the Sudetic Marginal Fault and in the south by the Bušin fault, which run parallel to each other. Their spatial arrangement is shown in the tectonic sketch accompanying the main map.

The eastern and the southern parts of the map area are located in the Czech Republic, and the western part is in Poland. The international border cuts the upper Cretaceous Nysa Kłodzka graben south of Międzylesie, and then obliquely cuts the lithostratigraphic units of the Śnieżnik metamorphic unit. Only in the upper part of the Biała Lądecka catchment area does the border incise like a narrow bay into the whole width of the Staré Město paleorift zone. The Velké Vrbno dome and the Branná zone are located in the Czech Republic.

In the central part of the map, the main watersheds of Europe: the Black Sea, the North Sea and the Baltic, join on the top of the Trójmorski Wierch Mt – Klapač Mt. (1145 m a.s.l.).

The digital map was mainly compiled from the authors' own cartographic work. The following map sheets of the Detailed Geological Map of the Sudetes (1:25000) were also used: Nowa Morawa (Kasza, 1967/1968), Międzylesie–Potoczek (Sawicki, 1968), Międzygórze (Frąckiewicz & Teisseyre, 1973–1976), Stronie Śląskie (Cwojdziński, 1983), Strachocin–Bielice (Cymerman & Cwojdziński, 1986/1988), Lądek Zdrój (Gierwielaniec,

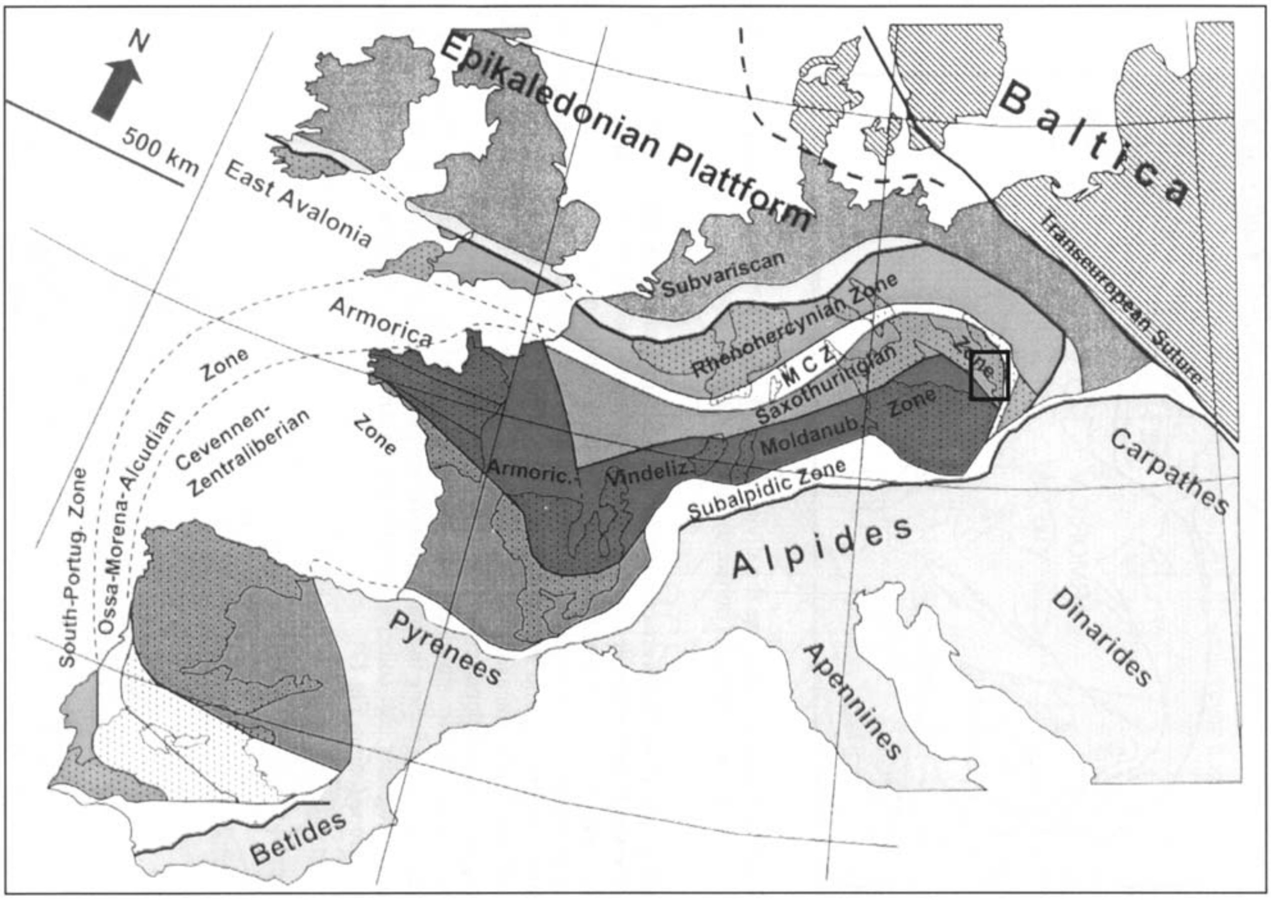

Fig. 1. Position of the investigated area to the Crystalline Rise within the European Variscan Orogen (modified after Ellenberger & Tamain, 1980); MCZ – Central European Crystalline High.

1971), Trzebieszowice (Cwojdziński, 1979), Złoty Stok (Cwojdziński, 1974), Kłodzko (Emerle-Tubielewicz, 1979), Krosnowice (Cwojdziński, 1978), Domaszków (Walczak-Augustyniak & Wroński, 1982) and Bystrzyca Kłodzka (Wroński, 1983). Geological maps issued before 1945 were also taken into consideration.

The lithostratigraphic units of the map are based on the "The Geological Map of the Śnieżnik Massif (1:50000)", which included part of the area in question (approximately 360 km^2 between parallels running through the vicinity of Kraliky in the south and Stronie Śląskie in the north (Don & Opletal, 1996).

On the Polish side, the southern part of the map, down to the Biała Lądecka valley, was compiled by J. Don, and the northern part by R. Gotowała. J. Skácel prepared the map of the whole area on the Czech side, mostly based on his own materials used in the compilation of the geological map of the Rychlebske hory Mts. (1:50 000) (Skácel & Skácelová, 1992 in: Skácel, 1995), taking into consideration previously-published 1:50 000 Czech maps: Bílý Potok (Skácelová, 1992, 1994), Javornik (Skácelová & Sekyra, 1992), Travná (Skácelová, Skácel & Sekyra, 1993), Jesenik (Žaček, Sekyra & Opletal, 1998), Bělá pod Pradedem (Opletal, Sekyra & Novak, 1998), Králiky (Opletal, 1992), Ústi nad Orlici (Rejchrt *et al.*, 1994), Šumperk (Koverdynský, 1998) and other maps published earlier. The cartographic depictions in the above-mentioned publications were not uniform, due to differences in the scales and in the criteria for defining the lithostratigraphic units, and also due to the inherent subjectivity of macrotectonic interpretations, and the varied visions of the evolution of the geological units presented by the authors of the maps. The biggest differences in the initial cartographic representations were along the border, which obliquely cuts the lithostratigraphic units. Such differences also exist between individual maps, both Polish and Czech. During the process of generalization of the units, and in part during consultations in the field, efforts were taken to remove such differences. The authors of this map are aware of the fact that further studies, mostly field investigations, and comparative studies are necessary in order to eliminate such differences. Such studies, involving a closer field cooperation between Polish and Czech geologists, should be conducted in the future. To facilitate the introduction of future corrections to the compiled map, the authors decided to publish a digital version available entirely on CD, along with the conventional version. This version was prepared by Roman Gotowała. The compiled map was presented on the basis of the geographic co-ordinate system WGS84 and the horizontal co-ordinate system Pulkovo42. The topographic base was omitted, as including it would have considerably increased the map's cost. The topography of the area is satisfactorily reflected in the river and minor water course valley alluvia, as well as in the mountain peaks and major localities of the area.

The authors would like to express their gratitude to the State Committee for Scientific Research (KBN) for their financial support of the studies and of the publication of the results (grant No. 6 PO4D 085 19). The authors are convinced that the map of the geological units divided by the international border, compiled on the basis of the uniform scheme, will facilitate the understanding of the structure and evolution of one of the most important boundary zones of the Sudetes, and that it will provide an aid for both Czech and Polish geologists in future investigations.

THE LITHOSTRATIGRAPHY OF THE BOUNDARY ZONE OF THE EAST AND THE WEST SUDETES AND A DESCRIPTION OF ITS GEOLOGICAL UNITS

The rock series of the geological units covered by the map are of various age and lithology, and have varied stratigraphic sequence and scope of metamorphic and structural alterations. Therefore, in the legend to the map, they were grouped in lithostratigraphic profiles individual for each unit, and given a symbol and a sequence number starting from the bottom. The assumed sequence was only loosely based on the results of classic stratigraphic investigations; more weight was given to fresh field observations, and to interpretations of existing geological maps, despite their being burdened to various extents with the subjective views of their authors. The more and more common isotope datings of rocks in the Sudetes have limited the range of variance in stratigraphic interpretations, facilitating generalization to an extent that would earlier not have been possible.

The total number of lithological units on the map was established as 61. In the explanatory text, each is briefly described according to the sequence presented in the legend to the map, i.e. from the Precambrian units of the crystalline basement of the East Sudetes belonging to the Bruno-Vistulicum, through the mainly early Palaeozoic rocks of the Staré Město paleorift and the Śnieżnik metamorphic unit of the West Sudetes, to the Devonian sediments of the Branná range, metamorphosed during the Variscan orogeny and included in the upper structural stage of the East Sudetes. The subsequent descriptions cover the structurally-varied middle and late Variscan granitoids, followed by the unmetamorphosed sediments.

THE KEPRNIK DOME AND VIDNAVA DOME METAMORPHIC UNIT (K–W)

The rock formations of the Keprnik dome (K–W) were not differentiated on the map. They occupy the western, lithostratigraphically-uppermost part of the Keprnik dome nappe. It is represented by an exceptionally variegated series forming the envelope of the Keprnik gneisses. The degree of metamorphism corresponds to the andalusite-staurolite-kyanite zone. In this series, metasediments prevail: mica schists, marbles partially altered to erlanes, and graphite schists and rare quartzites. In the past, the presence of the graphite schists led some geologists to assign the upper part of the series to the Silurian, as the member called "the lower Branná sub-group". In the northern part, near Dolni and Horni Lipová, among the metamorphic rocks of the lower Branná sub-group, strongly-mylonitised muscovite and two-mica orthogneisses occur. Their isotopic age turned out to be considerably older than the one previously assumed. Analyses gave new ages of 555 Ma (Kröner *et al.*, 2000) and 584 Ma (Kröner *et al.*, 1999). In the central part, near Hanušovice and Jindřichov, granitoid lenses occur within the metamorphic rocks, and near Ramzova, granitoid veins showing no preferred directions are present. Their age is not known. In the southern section of this range, the amount of metamorphic rocks is strongly reduced and in places they are entirely absent. Near Horni and Dolni Lipová, the lithostratigraphically-uppermost metasediments of the Keprnik dome are represented by several-tens-of-metres thick sericite-quartz schists, which underwent strong dynamometamorphism. They form a direct basement to the basal quartzites (B1) of the upper Branná sub-group, assigned by convention to the Siegenian (Lower Devonian).

The name of the Vidnava dome was introduced to the geological literature by Zapletal (1950). It spreads on the tectonically-lowered part of Fore-Sudetic Block and, in the structural sense, it forms the northern extension of the Keprnik dome. Due to deep-reaching denudation, the cover series of the Vidnava dome crystalline massif were preserved on its eastern wall and in part on its western wall, and also as relicts of the Variscan granitoids of the vast Žulova massif. The fragments of such relicts, some relatively large, are mainly gneisses, and less commonly amphibolites, marbles and erlanes, containing contact mineral associations. These fragments are mostly concentrated in a wide, meridionally-stretched zone east of Vápenna and Žulova, and near Čarna Voda and Stare Podhradi. The rocks present within them probably initially belonged to the upper part of the cover, i.e. to the lower and upper Branná sub-group. In the Vidnava dome, as in the Keprnik dome, one should, however, distinguish the lower and the upper members of the cover, separated in the eastern wall by light sericitic quartzites which correspond to the Early Devonian (?) basal quartzites (B1) of the upper Branná sub-group. These quartzites are absent from the western wall of the dome.

To the lower member belong: mica schists, amphibolites, erlanes, biotite-sillimanite and other paragneisses. Moreover, biotite migmatites and quartz-garnet gneisses are present here. The series form continuous horizons on the eastern dome wall, and on the western wall, only occur as fragments.

The upper member of the Vidnava dome cover consists of rocks of the upper Branná sub-group, described in more detail on page 37. They mainly occur on the eastern wall; on the western wall, they are present as tectonic scales along the Sudetic Marginal Fault near Vápenna, Skorošice, Uhelna and Javornik, and in the basement of the Miocene depression between Javornik and Uhelna and Bernartice. The cover series of the Vidnava dome's western wall did not undergo the contact metamorphism which took place in the eastern wall due to the Žulova granite. To the upper Branná sub-group, only the series above the quartzites can be included here; i.e. biotite phyllites and paragneisses, some of the marbles, and in particular the erlans and amphibolites with a sequence of outcrops north of the spa in Lazně Jesenik on the left bank of the Biała Głuchołaska river (řeka Bělá – the Bělá river).

Along the Sudetic Marginal Fault, from the Permian onwards, only block movements took place. The Fore-Sudetic Block, lowered during the upper Cretaceous–Cainozoic movements, was initially elevated and strongly denudated after the Variscan folding – according to cautious estimations, it lost at least 6 km of its overburden (Skácel, 1995).

THE VELKÉ VRBNO DOME FORMATION (V1–V8)

The Velké Vrbno formation is located between the Nýznerov dislocation zone of the Staré Město zone in the west and the Ramzova thrust zone in the east. It stretches from the Sudetic Marginal Fault near Skorošice–Vápenna to the south as far as Šléglov between Branná and Staré Město. In the Silesicum area, this formation occurs in the smallest of the domes.

The known thickness of the Velké Vrbno formation exceeds 1000 m. Its characteristic feature is the dominance of acidic and basic paleovolcanites, which is related to the close vicinity of the Staré Město paleorift zone. As regards stratigraphy, it shows no significant differences from the rock complexes in the adjacent crystalline massifs, and is similar to the lower Branná sub-group in the Keprnik and the Vidnava domes. Not so long ago, the view was that the graphite series forming part of it were Silurian in age (Zapletal, 1950; Květoň, 1951; Svoboda, 1956). The tectonic structure of the dome is complicated and interpreted in various ways (e.g. recumbent isoclinal folds, flat overthrusts or nappes). The observed facts are: a subhorizontal setting of layers in the dome axis showing slight undulation stressed by transverse faults.

The more precise vertical division of this thick sedimentary-volcanic formation is still based upon the lithostratigraphy put forward by Květoň (1951): a) a lowe rclastic series; b) a graphite series; c) an upper clastic series. However, it should be stressed that both clastic series contain a high proportion of basic and acidic metavolcanites.

The lowermost horizon of the lower series is made up of biotite paragneisses and phyllonites (V1), distinguished by Květoň (1951) as quartz biotite phyllites. They resemble a weakly-metamorphosed rock assembly, as a result of an intensive fault tectonic event of the Alpine type, additionally complicated by subhorizontal thrusts. This tectonic type is stressed by a strong chloritisation of the lower assembly. The phyllonites interfinger locally with mica schists, and these in turn with biotite paragneisses. Amphibolites (V2) form thick and strongly varied intercalations and sills in the lower series. They were most probably formed from submarine basic lavas and their tuffs and tuffites. Amphibolites laminated with light and dark intercalations are commonly encountered among them. North of Šléglov and near Kronfelzov, and in several other places, they contain lensoidal gabbro bodies (Kopa, 1980). Moreover, numerous similar intercalations and sills occur within partly-migmatised biotite and two-mica paragneisses (V7) and in partly-phyllitised mica schists (V8) of the over-graphite series of the Velké Vrbno dome. It has not yet been explained whether all the amphibolites (V2) put in a common unit are related to one episode of volcanism ending the evolution of the supracrustal sequence of the unit or whether they accompanied the whole period of its development. In the uppermost part of the lower series, intercalations of muscovite-chlorite gneisses also occur, probably formed via the alteration of acidic effusive rocks; strongly-silicified pearl orthogneisses and cherts are present as well.

On the surface, outcrops of the graphite series (V3) form an ellipse with a varying width which dips towards the outside of the dome. The thickness of the series varies strongly from 20 to 200 m, as a result of tectonic squeezing. The series has varied lithology. Apart from graphite gneisses, pyrite-bearing graphite schists and pure graphite (exploited in an open-pit mine), there are crystalline dolomites and thremolite limestones (V4). Moreover, on the tectonically-involved planes, irregular lenses of numerous gneiss, amphibolite and pegmatite varieties occur. The rocks of the graphite series are strongly dynamically altered, as they behaved as a plastic slide mass during the tectonic processes. The extent of the graphite and limestone series is not fully known; however, it is unquestionably large. On the western and the eastern walls of the dome, this series dips at an increasing angle and becomes progressively thinner. On the southern margin of the dome, graphites occur in a tectonically-separated Šléglov block. To the north, the graphite series was encountered in boreholes in the Polka valley near Vápenna (well JS-17; Skácel & Albrechtová, 1978, Skácel, 1995), i.e. 6 km from the northernmost outcrop (the "Barbara" mining field west of Petřikov). The greatest thickness of the series was observed in the dome axis, west of Velké Vrbno (the "Konstantin" graphite deposit).

Light quartzites (V5) occupy an uncertain lithostratigraphic position. These quartzites, locally containing abundant feldspars: accompany graphite schists (V3) near Šléglov and in the dome axis in the north-eastern extension of the Adamovsky hřbiet range; and occur within paragneisses (V1) and (V7) and mica schists (V8) on the slopes of Smrk (1125.4 m a.s.l.). Their relationship with the Brousek quartzites (B1) (Brousek Mt. 1115.9 m a.s.l.), which run along the Czech–Polish border on the watershed south of Bielice, is one which remains unclear.

The upper volcanoclastic series occurs on the dome margins, mainly north of Petřikov, as far as the Sudetic Marginal Fault. These are light biotite-muscovite and amphibolite "gneisses", in places showing weak or no preferred direction and having the chemical composition of dacites (V6). They contain relicts of amphibolites and of abundant biotite and garnet gneisses. Near Lvi hora and Smrk, their thickness reaches 600 to 800 m. In the dome axis, the rocks of this series lie subhorizontally. They form the thickest accumulation of acidic and basic volcanites in the border zone of the West and the East Sudetes.

The highest position is occupied by strongly schistose biotite gneisses and paragneisses (V7), and then by mica schists and phyllonites (V8). They were preserved in the ridge zones near Brousek, Smrk and Lvi hora, where they are in contact with tectonic "metaquartzites" from "Brousek" (B1). These quartzites are very fine grained, massive and crypto-crystalline, light, locally with stripes of grey or dark varieties resembling lydites. Their main body occurs along the border watershed of the Biała Lądecka with the Vrbensky potok (a tributary of the Krupa), while thinner outcrops may be observed to the south as far as Šléglov. It is difficult to assign the quartzites to the surrounding formations. They probably occupy an allochtonous position. Their lithology most closely resembles the lithology of the basal quartzites of the Branná sub-group (B1), of Early Devonian age (?) (Skácel, 1989a). In samples of various quartzite varieties from "Brousek", collected by J. Don and M. Dumicz, no macro- or microfossils were found (personal communication, Z. Urbanek – ING PAN Wrocław).

The only isotopic dating from the area of the Velké Vrbno dome is the dating of strongly-mylonitized dacite orthogneisses (V6) at 574 Ma (Kröner *et al.*, 2000). The result of this dating may indicate that some rocks of the Velké Vrbno dome belong to the Cadomian basement of the East Sudetes, as already suggested by Skácel (1979a, 1989a).

A difference of views on the lithostratigraphic profile of the Velké Vrbno dome appeared between the authors of the map. J. Skácel was in favour of the triple division presented earlier, and proposed in its general outline by Květoň (1951). J. Don, on the other hand, proposed a division based mainly on the interpretation of the cartographic picture of the compiled map.

The main difference in the views concerns the position of the orthogneisses, the protolith of which was a subvolcanic magma of dacite chemistry (V6). Based on the interpretation of the map, the conclusion may be drawn that the intrusion of the magma of these orthogneisses took place after a strong folding of the paragneisses (V1 and V7) and amphibolites (V2). This is indicated most of all by the relicts of these rocks mapped within the described volcanites directly north of Petřikov, west of the Horni Lipova railway station and on the southern slopes of the Dlouhý hřbet range north of this railway station. The boundaries of the volcanites around these relicts distinctly cut the stratification of the older series. Similar features, although not so contrastive, are typical of the main contact plane of the mentioned intrusion with the cover rocks. As the intrusion was dated at 574 Ma (Kröner *et al.*, 2000) the cover rock assembly (V1, V2 and V7) is not only older, but it must have been folded before the described intrusion.

Another disputable issue is the high position of mica schists passing into phyllites (V8) in the upper part of the lithostratigraphic profile of this unit. Their main body, with abundant amphibolite intercalations, occurs in the core zone of the Velké Vrbno dome just east of Velké Vrbno, and on the western slopes of Lvi hora (1040.1 m a.s.l.), i.e. in the axial zone of the dome. On the other hand, the mica schists and phyllonites included in the same member, accompanying the Brousek quartzites (B1), are probably the youngest element of the lithostratigraphic profile in the Velké Vrbno dome, comparable with the Devonian (?) rocks of the Branná zone (Skácel, 1989b). It also seems necessary to distinguish between the quartzites from Brousek and the quartzites from Šléglov, the eastern slopes of Smrk (1125,4 m a.s.l.) and the western slopes of Lvi hora (V5). However, they form thin inliers within the paragneisses (V1) and the mica schists interfingered with amphibolites (V8) and do not vary from them with regard to the tectonic style.

THE STARÉ MĚSTO ZONE AND THE ZÁBŘEH UNIT (M1–M10)

The metaophiolite formation of the Staré Město paleorift fills a narrow and NNE–SSW stretched collision zone separating the Lugicum of the West Sudetes from the Silesicum of the East Sudetes. This zone contains strongly tectonically- and metamorphically-altered early Palaeozoic (~500 Ma) volcanic-sedimentary series, split along the whole length of approximately 55 km by Variscan (~339 Ma) "tonalites", i.e. granitoids typical for labile zones. The lithostratigraphy and the extent of the Staré Město formation are differently interpreted by different geologists. At present, its eastern boundary is assumed to be the eastwardly-directed Nýznerov thrust, which closes a line of deep displacements of the Nýznerov tectonic zone from the east (Skácel, 1979a). The western boundary of the paleorift formation is less clearly defined. Earlier, it was assumed to run along the Góry Bialskie Mts. The Gierałtów gneisses thrust on the "autonomic range of variegated schists of Hranična", which at present is included in the Stronie formation (Skácel, 1989b; Don, 2001a). In the Rychlebské hory Mts., another disjunctive plane occurs, accompanied by gabbro-amphibolites and lenses of serpentinised ultrabasites. Their outcrop zone may be followed from the gabbro outcrop west of Vlčice to the south through Nova Véska near Vojtovice, and as far as Hranična.

As regards lithology, in the Staré Město formation, the dominant rocks are amphibolites (M1) with intercalations of gabbro-amphibolites (M2) and lenses of serpentinites and, less commonly, eclogites (M3). The amphibolites are accompanied by metasediments represented by paragneisses passing into pearl gneisses and migmatites (M4). Minor intercalations of light quartzites (M5) interfinger with mica schists (M4) east of Chrastice. In the Zábřeh series, south-west of Štity, minor outcrops of quartzites are, according to Skácel, relicts of synclinal elements coming from adjacent structures.

Outcrops of blastomylonitic schists of the Skorošice series (M8) accompany the amphibolites on the eastern side of the Staré Město paleorift. Along the whole length, they form a continuous, up to 1 km wide, range from Skorošice in the north to Bušin in the south. The thickness of the series reaches up to approximately 600 m. The dominant rocks are: blastomylonites and phyllonites, mainly of mica schists, which form a mélange with cataclased gneisses, marbles, amphibolites, quartzites and graphite schists. Along the main dislocation zones that bound this disrupted range, serpentinite (M3) lenses, and in the Rychlebské hory Mts. near Nýznerov, gabbro-amphibolites (M2 were also dragged out. Skácel (1979a; 1989a) names the described range, closing the Staré Město zone in the east, the "Nýznerov dislocation zone", tectonically separating the Lugicum from the Silesicum. Kröner *et al.* (2000) recognised the whole Staré Město zone as a paleorift formed at the turn of the Cambrian and the Ordovician (~ 500 Ma) along a passive margin of north Gondwana.

The serpentinites and the eclogites of the Staré Město zone occur in relatively abundant but small lenses with various relationships to the surrounding rocks:

A – in the gneisses and migmatites – partly as boudins related to healed planes of lower range dislocations (in particular in the western part of the Javornik scale, to the north-east of the Sudetic Marginal Fault, where 9 serpentinite lenses form a linearly-stretched group.

B – along the main dislocations – abundant serpentinite lenses dragged out from great depths, in particular at the top of the Nýznerov zone, and rarely at its base.

C – as concordant inliers – mainly in the amphibolites of the metaophiolite Staré Město zone (in particular near Petrovice in the Rychlebské hory Mts., and as large outcrops to the north-west of Raškov and Ruda on the Morava river).

D – as lensoidal bodies in metagabbro streaks (in particular along the boundary with the Hranična series between Vlčice and Vojtovice in the Rychlebské hory Mts.)

E – as serpentinites from retrogressively-metamorphosed eclogites – in the Bialskie thrust zone of the Gierałtów gneisses over schists of the Hranična series west of Chrastice near Staré Město (Skácel, 1964). In a similar manner, serpentinites, eclogites and ultrabasites occur among the Gierałtów gneisses and migmatites, partialy retrograde changed.

The largest outcrops of serpentinites are known from the southern part of the Staré Město zone, near Ždár Mt. to the north-west of Ruda on the Morava and north-west of Raškov. Their thickness reaches several hundred metres, at a length of up to several kilometres. However, small, flattened lenses, several tens of metres thick, dominate. The source rocks were undoubtedly peridotites.

Numerous outcrops of eclogites were located based on the distribution of boulders in the weathering cover, e.g. west of Chrastice (Skácel, 1964). These rocks were retrogressively metamorphosed, as evidenced by the presence of a fine-grained simplectite of amphibole with feldspars, and the presence of individual feldspars. New outcrops of eclogites were discovered near Štédrákova Lhota in the marginal zone of the Gierałtów gneisses (Kopa, 1980, 1989a), and in the northern and western parts of the Velké Vrbno dome crystalline unit, near Vápenna–Polka, Petřikov, Ostruťná, Kronfelzov and Velké Vrbno (Kopa, 1989b).

The age of the Staré Město metagabbros (M2) was isotopically determined at 514 Ma, while the age of the metapelite series, metamorphosed in the granulite facies (6–8 kbar and 800–850°C), at 501 Ma (Kröner *et al.*, 2000). These results are slightly surprising, due to the similar age of the granite magma intrusion in the Śnieżnik massif neighbouring in the west, which was the protolith of a vast complex of augen gneisses in that unit.

South of the Bušin fault, there are rocks of the Zábřeh crystalline massif. They have been regarded by Czech geologists, starting with Kettner (1922), as an Algonkian equivalent of the Desna gneisses and the Staré Město formation. The Zábřeh crystalline massif is stretched towards the WNW, i.e. perpendicular to the direction of elongation of the Staré Město formation. This could be related to a fault of the same age, transforming the Staré Město paleorift.

The same rocks occur within the Staré Město formation as among the metamorphic rocks of the Zábřeh series, although to the south, their degree of regional metamorphism drops significantly.

In the area covered by the map between Štity and Zábřeh, paragneisses (M9) dominate. They pass through pearl varieties to migmatites (M4). To the south, the proportion of mica schists (M10) increases. There are less amphibolites (M1) here than in the Staré Město metaophiolite zone. Scarce serpentinite (M3) lenses and single outcrops of quartzites (M5) also occur.

THE LITHOSTRATIGRAPHY OF THE ŚNIEŻNIK METAMORPHIC UNIT (S1–S21)

The Śnieżnik metamorphic unit consists of two supracrustal (sedimentary-volcanic) formations – the monotonous Młynowiec paragneisses (?Pt_2) and the variegated Stronie series (Pt_3–Cm_2) – and of two complexes of rocks of granitoid origin. The latter complexes – the Śnieżnik augen gneisses (Cm_3/O_1) and the Gierałtów gneisses and migmatites (?D_2–C_1) – are younger than the former.

The monotonous Młynowiec paragneiss formation (S1 and S2)

The Młynowiec paragneisses (?Pt_2) were distinguished by Fischer (1936) in the central part of the Śnieżnik metamorphic unit. On the basis of general mapping work, that author recognized the formation to be the oldest one in the described geological unit, and assigned it to the Archean. The need to distinguish this formation was questioned for a long time (Oberc, 1957; Smulikowski, 1979; Cymerman & Cwojdziński, 1986; Cymerman, 1997). Detailed mapping, performed on both the Polish (Don & Dowidar, 1988; Dowidar, 1990) and Czech sides (Opletal *et al.*, 1980), fully justifies the need to distinguish this formation.

In the Polish part of the Śnieżnik Massif, the formation under discussion is represented by an over 2000-m thick complex of monotonous paragneisses (S1) that are only in places interfingered by mica schists and injected by mafic protolith of the amphibolites (S2). The paragneisses form a compact outcrop near Stara Morawa, Młynowiec and Bolesławów. To the east and south-east, in the Góry Bialskie Mt. area, they gradually pass into and "vanish" within the Gierałtów migmatites, which entirely incorporate the bottom parts of that series (Fischer, 1936; Don, 1991b). At the top, on the other hand, they have a sharp boundary with the overlying basal quartzites (S3) of the Stronie formation (Don, 1991a), which form a distinct morphologic high between Goszów, Stara Morawa and Kletno, following the pattern of fold forms of the younger system of Krowiarki (F_3 according to Teisseyre, 1968). The traced lithological boundary is related to a longer sedimentary gap, probably preceded by the folding of the Młynowiec formation, as suggested by the results of the structural investigations (Dowidar, 1990). Between Stara Morawa and Goszów, the boundary is obliquely cut by a younger plane of the Śnieżnik granites (gneisses), which, farther south near Kletno and Janowa Góra, as far as Stroma Mt. (1166 m a.s.l.) and the Śnieżnik slopes, are in the direct contact with the basal quartzites of the Stronie formation. They occur there on both limbs of the meridionally-stretched Sienna synform (Don, 1982a).

On the Czech side of the massif, in the Morava valley, at the extension of the Sienna synform, from below the quartzites, the analogues of the monotonous Młynowiec paragneisses occur again (Kočandrle & Opletal, 1985), mainly on its west wall near Dolna Morava, where one can trace them along the eastern slopes of the Mały Śnieżnik Mt (1318 m a.s.l.), Trójmorski Wierch Mt–Klepač Mt (1143 m a.s.l.) and Jeleni Wierch Mt (935 m a.s.l.). The Młynowiec paragneisses also appear from below the light quartzites on the north-eastern slope of Siniak Mt (657 m a.s.l.) between Radochów and Kąty Bystrzyckie, and in the Nysa Kłodzka gorge in Długopole Zdrój. In the Góry Orlickie Mts., they were distinguished as the lower, sub-quartzite member of the Stronie formation (Opletal & Domečka, 1976; Opletal *et al.*, 1980).

In the Góry Złote Mts. and the Rychlebske hory Mts. (an extension of the Góry Złote on the Czech side), the monotonous Młynowiec paragneisses form a narrow, partly-migmatised zone among the Gierałtów gneisses and migmatites. It is possible to trace them down from Nowy Gierałtów to the Sudetic Marginal Fault near Uhelná. The tectonic position of these paragneisses has not yet been explained. In the Czech literature, they are described as the "Hřibova mica schists". A second outcrop of these paragneisses is known from within the Gierałtów gneisses, south-west of Bily Potok.

The monotonous paragneisses that compose the Kaczyniec (602 m a.s.l.) – Wilcza Góra (711 m a.s.l.) range between Skrzynka and Droszków in the Góry Złote Mts were also assigned to the Młynowiec formation. They were partly-migmatised during the evolution of the Haniak gneisses, which are comparable with the Gierałtów gneisses (Don, 1964).

Within the paragneisses of the Młynowiec and Bolesławów area, there are sparse lenses of amphibolites (S2), probably representing younger intrusions of magmas related to the development of the Staré Město paleorift (Cm_3–O_1).

The age of the Młynowiec formation paragneisses was indirectly determined as being Middle Proterozoic, since these rocks may be regarded as parallel with the monotonous paragneisses of the so called Želiv group of the Bohemian Massif (Suk *et al.*, 1984). They have not yet been isotopically dated.

The variegated Stronie formation (S3–S7) with alkaline and acidic effusives (S8–S9)

The variegated Stronie series formation (Pt_3–Cm_2) was distinguished by Fischer (1936), and lithostratigraphically divided by Vangerow (1943). Outcrops of this formation occupy almost half of the Śnieżnik metamorphic massif area, and compact outcrops dominate in the Krowiarki range, in the Sienna synform (the Morava valley), and in the Góry Złote and the Rychlebské hory Mts. The thickness of this series is most often estimated at approximately 6000 m, but this value is probably too high, because its common monoclinic attitude, resulting from isoclinal folding. The Stronie formation is lithologically varied (Vangerow, 1943). At its base, there are light basal quartzites (S3) which may be traced near Kąty Bystrzyc- kie, Goszów, Stara Morawa, Kletno, Janowa Góra, Sienna and on the slopes of Siniak, Stroma and Śnieżnik, and farther in the Morava valley in the Czech Republic and in the Orlickie Góry Mts. The quartzites' thickness reaches 25 m. These rocks are as a rule massive, show planar parting, and in places have the appearance of conglomerate rocks, possibly due to secondary tectonic lens formation. On the basis of microfossils, Gunia (1984a) determined their age as Late Proterozoic–Early Cambrian. He related the local additions of heavy minerals with the conditions of a littoral-beach environment. Opletal *et al.* (1980) and Kočandrle & Opletal (1985) proved that quartzites of the Góry Orlickie Mts. have an elevated K_2O content. According to Cymerman (1997), the quartzites in the Śnieżnik metamorphic unit are a product of the mylonitization of the Śnieżnik gneisses.

The main component of the variegated Stronie formation is strongly-varied mica schists (S4). Their variability is the result of a highly varied share of the main rock-forming minerals, both the primary and the secondary ones, in part related to feldspathization processes (Milewska, 1958; Butkiewicz, 1968). The most complete petrographic description of the Stronie series mica schists was presented by Smulikowski (1979). Within these rocks, there are numerous thin intercalations of graphite schists and quartzites (S5) and crystalline limestones lenses (S6) passing in neighbourhood of the Śnieżnik gneisses into erlanes (S7). In places, the crystalline limestones and dolomites form vast bodies, the thickness of which varies greatly, reaching several hundred metres in some localities (Kuźniar, 1960; Koszela, 1992). In the Kamienica syncline, they were altered by contact metamorphism to erlanes (J. Teisseyre, 1961). Amphibolite schists (S8), metarhyolites, porphyroids and leptinites (S9) mainly occur in the top parts of the Stronie formation. The latter rocks are particularly frequent in the "Hranična variegated series", which shows similarities to the schists of the Stronie formation in the Góry Złote Mts. formation.

Isotopic age datings of the Stronie series metarhyolites near Romanów and Rogóżka in the Krowiarki range (521 Ma; Kröner *et al.*, 2001) confirm their temporal relationship to the granite magma intrusion, the protolith of the Śnieżnik augen gneisses. The German authors of the maps for Złoty Stok and Lądek Zdrój (Finckh *et al.*, 1942) had already suggested a similar relationship between the Śnieżnik gneisses, with the Góry Złote Mts. leptinites as their subvolcanic analogues. This opinion is supported by, for example, their concentration mostly in the Góry Złote and the Rychlebske hory Mts. and in the Hranična range schist zone, i.e. far from the occurrence of the Śnieżnik gneisses. Other pieces of evidence are the observations that suggest the injection of their magmas into the earlier folded (F_1) Stronie formation (Don, in preparation).

In a lithostratigraphic profile compiled from several cross-sections made in different parts of the Śnieżnik metamorphic unit, Vangerow (1943) assigned the porphyroids with the accompanying amphibolites and the crystalline limestones to the upper part of the Stronie formation. He regarded the limestones in the Śnieżnik metamorphic unit as Cambrian on the basis of an analogy with lithostratigraphic profiles of the Góry Kaczawskie Mts. metamorphic unit. The age of the limestones in the Góry Kaczawskie Mts. was described as Early Cambrian, based on a paleontologically documented age of the limestone-pelitic series from the Zgorzelec area (Schwarzbach 1938). The Lower Cambrian age of the crystalline limestones of the Stronie formation was confirmed for the first time by Gunia (1984b) on the basis of microfossils.

The sedimentation of the Stronie series was interrupted by the Old Caledonian folding (F_1) that ended with the Śnieżnik magma intrusion, the age of which was isotopically determined at 520–490 Ma (van Breemen *et al.*, 1982; Liew & Hofman, 1988; Oliver *et al.*, 1993; Kröner *et al.*, 1994, 1999; Turniak *et al.*, 2000.

At the eastern margins of the Śnieżnik metamorphic unit, a narrow zone of the "Hranična variegated schists" occurs (Skácel, 1995), bordering the rocks of the Staré Město paleorift. Their lithology reveals the most similarities with the Stronie formation schists of the Złote Góry Mts. and blastomylonites of the "Bílá Voda range" of the Rychlebské hory Mts. Some Czech geologists include the "Hranična variegated schists" as part of the upper part of the Staré Město paleorift metamorphic rocks. Due to the similarity with the variegated schists of the Śnieżnik metamorphic unit, on this map they were included in the Stronie formation.

The supracrustal series of the Stronie metamorphic unit were metamorphosed regionally in the lower and middle range of the amphibolite facies before the intrusions of the Variscan granitoids, accompanied by a rim of contact alterations. The degree of alterations related to the regional metamorphism decreases towards the north-west in the Krowiarki range. In the eastern part, these alterations took place in the temperature range 560–620°C and the pressure range 7–8 kbar (Jastrzębski, 2002; Nowak & Żelaźniewicz, 2002). The last phase of the retrograde alterations related to the uplifting and cooling of the rock mass was dated with the use of the Ar-Ar method at 330–290 Ma on average (Steltenpohl *et al.*, 1993).

The Śnieżnik augen orthogneiss complex (S10–S11)

The Śnieżnik gneisses are characterized by a strong variability of structure and texture. Within them, the following varieties are distinguished: coarse-augen, flaser, fine-flaser (S10) and fine-augen (S11). The latter variety mainly occurs along the intrusive contacts with the envelope rocks. In the scale of an outcrop, these gneiss types show gradual passages between one another.

The petrography and the geochemistry of the Śnieżnik gneisses was presented by Smulikowski (1979) and Borkowska *et al.* (1990, 1998). The main constituents of the Śnieżnik gneisses are quartz, microcline, plagioclase, biotite, chlorite and muscovite. Accessory minerals are opaque minerals: apatite, zircon, titanite and epidote. Augens, with a diametre of up to several centimetres, consist, as a rule, of one or more grains of a pink or white microcline, and reveal sigmoid or deltoid shapes, with a varied length of up to a dozen or so centimetres. Mica stripes envelop the augens, following their shape. Among them, there is a dominance of muscovite and in places dark, commonly strongly chloritized biotite and fresh biotite, discordantly overprinted onto linear structures (L_2) of the Śnieżnik gneisses in the contact zones with the Gierałtów gneisses (Don, 1977; 1982b). Accessory minerals concentrate in the mica strips. Quartz is present in almost monomineral, strongly stretched bands as euhedral grains. Strips and small lenses are also formed by plagioclase.

All the varieties, above all the streaky and the banded gneisses, show signs of intensive deformation up to and including mylonitization, accompanied by grain size reduction and segregation in bands. Moreover, rodding lineation is typical for them. Teisseyre (1968) determined it as L_2, and gave it the name "the Śnieżnik lineation". Granites underwent this dynamometamorphism, and during the early Variscan folding, those granites were gradually altered in conditions progressively changing from epi- to

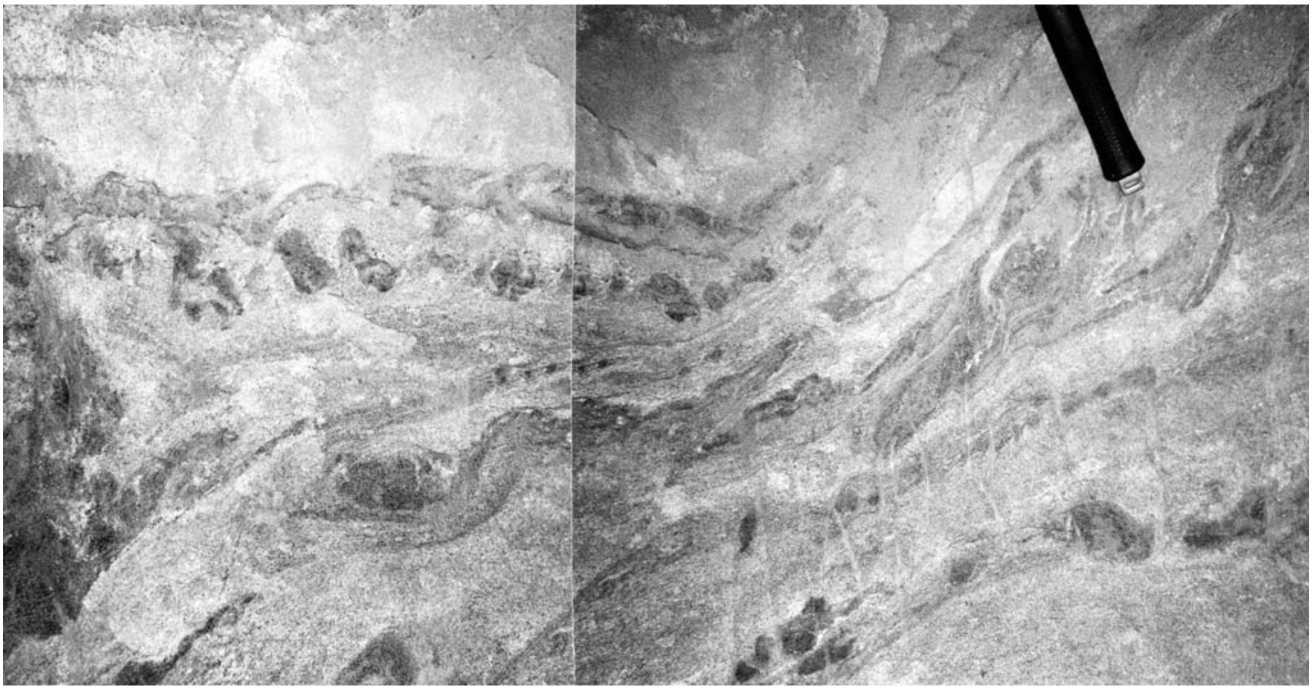

Fig. 2. Linear arrangement of the eclogite relicts within the granulites and Gierałtów migmatites. Outcrop in the right bank of the Biała Lądecka river in Stary Gierałtów. (Photo by J. Don)

mesozonal, from rodding L-tectonites to thin-laminated S-tectonites.

The Śnieżnik gneiss outcrops concentrate in the south-western part of the Śnieżnik metamorphic unit, while in the Międzygórze, Śnieżnik and Kletno anticlinorium they form compact massifs, at their bases diffused by the Gierałtów migmatites. In the Krowiarki range, they are folded intensively with the Stronie formation schists (Don, 1972). To the north-east in the Góry Bialskie and Góry Złote Mts., their proportion decreases rapidly. There, they are substituted by paleorhyolites and leptinites.

The Śnieżnik gneisses have sharp and mainly discordant boundaries with various lithological varieties in the both the supracrustal formations. Their parent rock was porphyroid granites, the magma of which intruded along the metamorphic foliation plane (S_1), i.e. into series that were already folded and metamorphosed (Don, 1991a). These contacts are accompanied by an aplitic variety of the marginal facies of the Śnieżnik gneisses, in places up to 100 m wide. The envelope rocks underwent no more distinctly expressed contact metamorphism, except for marbles, which in their vicinity were altered to calc-silicate erlanes (J. Teisseyre, 1961).

The age of the Śnieżnik gneiss protolith was dated via various isotopic methods at 520–490 Ma (van Breemen *et al.*, 1982; Liew & Hofmann, 1988; Oliver *et al.*, 1993; Kröner *et al.*, 1994, 1997; Turniak *et al.*, 2000), i.e. Middle Cambrian–Ordovician, or at 385 ± 35 Ma (Borkowska *et al.*, 1990), which corresponds to the Middle Devonian. According to the first group of datings, they were related to the old Caledonian (Don, 1982a, 1989a), and according to the second one, to the late Caledonian or early Variscan orogeny (Dumicz,1989).

The Gierałtów para- and orthogneiss-migmatite complex (S12–S21)

The Gierałtów para- and orthogneisses and anatectic migmatites are mainly represented by grey or grey-pink, usually laminated, fine-grained, nebulite or migmatic (S12) varieties. In places, they are accompanied by granulites (S13) and granulite gneisses (S14), eclogites or ultrabasites (S15 and S21), diffused amphibolites, partially retrograded from eclogites (S16), and pyroxene granulites and eclogites that are partially serpentinised (S17) and enveloped with retrometamorphic amphibolites.

The Gierałtów gneisses and migmatites, unlike the Śnieżnik augen gneisses, form transition zones up to hundreds of metres wide, containing relicts of more weakly or strongly metamorphosed paragneisses of the Młynowiec formation (S18), schists of the variegated Stronie formation (S19) and dynamically gneissified Śnieżnik granite-gneisses (S20), recrystallized in the migmatization process. The Gierałtów migmatites display no penetrative dynamic deformations so typical of the rock series older than them, particularly visible in the Śnieżnik gneisses. In the recrystallized transition zones, there are signs of the penetrative dynamic deformations and previously rotated rod structures (L_2) of the Śnieżnik gneisses, masked by a younger (L_3) oveprinted biotite lineation (Don, 1977, 1982b).

Concentrations of outcrops of the Gierałtów gneisses and migmatites mainly occur in the axes of the Międzygórze, Śnieżnik, Gierałtów–Góry Bialskie, Radochów and

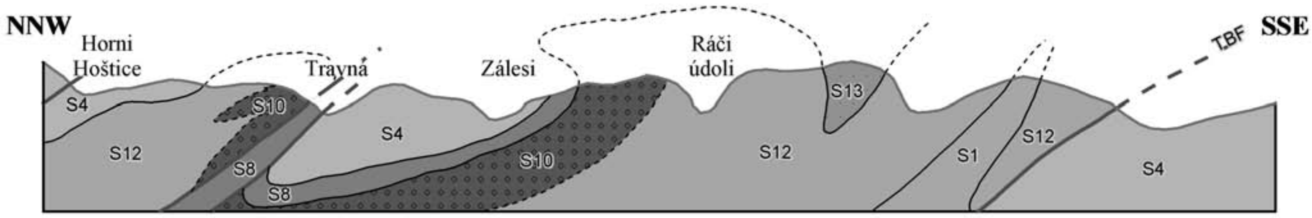

Fig. 3. Schematic cross-section to explain the attitude of the granulites within the Gierałtów gneiss massif according to J. Skácel.

Skrzynka brachysynclinal structures, which have a regional extent. South of the Góry Bialskie Mts. on the Czech side, some of the outcrops are even 7 km wide. They occupy the whole area between the Nysa Kłodzka graben and the Staré Město zone, down to the Bušin fault in the south.

In the core of the Gierałtów massif, north of Biała Lądecka, the widest zone of granulites in the Sudetes occurs. It is stretched to the north-north-east towards the Sudetic Marginal Fault near Nove Vilémovice, and has a width of several hundred metres up to 3 kilometres in its southern part. Within the dominant granulite gneisses, eclogites and ultrabasites (Fig. 2) and pyroxene granulites were preserved in places (Kozłowski,1965; Smulikowski, 1967; Bakun-Czubarow, 1991, 1992). On the Czech side, they were studied by Paděra and Pouba (1985). These rocks formed in conditions of deep metamorphism in the 21–28 kbar pressure range and the 800 to 1000°C temperature range (Bakun-Czubarow, 1998; Klemd & Bröcker, 1999). This corresponds to the P-T conditions of the adjacent granulites (Kryza *et al.*, 1996). These catazonal, high-pressure rocks were the focus of a lot of attention, but their origin has not yet been univocally defined. They are closely related, spatially and genetically, with the Gierałtów gneisses, and, according to Czech geologists and Dumicz (1991), they fill a narrow synclinal structure. According to the views of Finckh & Fischer (1938) and Don (1991b, 2001b) they occur in the axis of a mush- room-shaped anticline. They were most probably formed from deeply-metamorphosed sedimentary and volcanic rocks of MORB type (Bakun-Czubarow, 1998), which subsequently underwent a polyphase retrograde metamorphism during the migmatization process. Skácel (1995) put forward the suggestion that the initial rocks could have been amphibolites and marbles of the Stronie formation, the association of which is known from the Zalesi vicinity (north-east of Lądek Zdrój) (Fig. 3).

In the Gierałtów gneisses of the Międzygórze anticlinorium, eclogites (S15 and S21) occur in a meridionally stretched belt, parallel to the transition gneisses of the contact zone with the Śnieżnik gneisses (Bederke, 1943; Teisseyre, 1973; Don 1982a, b). Their petrology was described in detail by Smulikowski (1967), and Bakun-Czubarow (1968, 1991, 1996). Brueckner *et al.* (1989, 1991) used the Sm-Nd method to determine the age of eclogites from numerous outcrops at 330 to 350 Ma. This is probably the age of their exhumation from a depth of 120 km (Bakun-Czubarow, 1998). It should be stressed that similar ages were obtained for dark euhedral zircons from the Gierałtów gneisses of the Międzygórze anticlinorium and for the dark rims around the cores of older zircons (~500 Ma) with a completely different structure of alternating bands, prevalent in the Śnieżnik gneisses (Turniak *et al.*, 2000).

In the Góry Bialskie Mts., as in the Międzygórze and Kletno anticlinorium, the Gierałtów migmatization front is obliquely overimposed on the regional directions of the "Śnieżnik" F_2 folds (Don, 1989a, b, 2001a). This fact, together with mesostructural observations (Don, 1977, 1982a), implies a much younger age for this process than stipulated by Fischer (1936), Smulikowski (1979), and – on the basis of isotopic datings – by Borkowska *et al.* (1990), Kröner *et al.* (1997), and to a certain extent by Turniak *et al.* (2000). Due to the great differences between views on the ages of the Gierałtów gneisses and migmatites, some hopes were put in isotopic dating. The oldest datings were made for gneisses which envelop eclogites in Nowa Wieś. Using the K/Ar method, the micas in these rocks were dated at 382 and 384 Ma (Bakun-Czubarow, 1968), i.e. Middle Devonian. Similar dates (372 ± 17 Ma) were obtained from the Gierałtów migmatites enveloping eclogites in Międzygórze (Bröcker *et al.*, 1997). However, the results of datings from other localities within the Międzygórze anticlinorium are different and quite divergent. Using the Rb/Sr method, their age was interpreted as 464 Ma (Borkowska *et al.*, 1990), while the Pb/Pb method (Kröner *et al.*, 1997) and the SHRIMP method (Turniak *et al.*, 2000) gave a mean age of 500 Ma. A mean age of 342 Ma was determinated for the dark rims frequently surrounded discordantly the zoned zircon cores. It is identical with the age of the uniformly dark euhedral zircons from the Gierałtów gneisses. On the basis of these results, the authors mentioned above recognized the Gierałtów gneisses as a facies variety of the Śnieżnik gneisses, and correlated the dark rims with the regional Variscan metamorphism. The comparison of the statistics of 24 datings of zircons from the Śnieżnik gneisses and 24 datings of zircons from the Gierałtów gneisses (Turniak *et al.*, 2000 – Fig. 10) is very meaningful. From the Śnieżnik gneisses (sample MS10), a distinct peak of 495 ± 7 Ma was obtained and a much weaker peak in the 320–350 Ma range. On the other hand, in the Gierałtów gneisses (sample MS16), a strong maximum of 342 ± 6 Ma was obtained and a second, much weaker and less focused, in the 420–560 Ma range. Unfortunately, this method was not used to date the Śnieżnik gneisses from outcrops located outside of the extent of the Gierałtów migmatization front, and to date the Gierałtów gneisses formed at the expense of the Młynowiec series (Fischer, 1936) and the Stronie series (Don *et al.*,1990; Don, 2001a, b) in the Góry Bialskie Mts.

In the discussion of the age of the Gierałtów migmatites, one should not forget that the eclogites present within them are dated at 350 to 330 Ma (Brueckner *et al.*, 1989, 1991). Supporters of an older age for the Gierałtów migmatites (~500 Ma) should explain how the much younger eclogites could occur within them (Fig. 2 and map) and why they are not present within the Śnieżnik gneisses.

THE UPPER BRANNÁ SUB-GROUP (B1–B5)

The rocks of the upper Branná sub-group, regarded as early Devonian, belong to the east Sudetic cover of the Keprnik dome and the Vidnava dome crystalline massifs. In the Sudetic part, they form a narrow, continuous belt on the eastern side of the Ramzova overthrust, stretching from the Sudetic Marginal Fault to the south-south-west to the Bušin fault. There are the most weakly-metamorphosed rocks. The have appearance of phyllites, but at their base they contain minerals indicating deeper thermal alterations, such as andalusite, staurolite, biotite and muscovite. The amount and the size of these minerals decrease towards the top, i.e. west towards the Ramzova overthrust.

No macro- or microfossils have been found in the rocks of the Branná sub-group. The rocks are assigned to the Devonian in the interval from the Siegenian, on the basis of lithological similarities with the rocks of the Vrbno group, which contain Devonian fauna (not to be confused with the Velké Vrbno formation) of the eastern slope of the Keprnik and the Desna dome (Roemer, 1865).

The outcrops of rocks of this group reach their greatest width of over 2 km in the northern part near Horni and Dolni Lipova. The intensity of the fold tectonics of the eastern vergence is weaker there.

The lithostratigraphic profile of the Branná sub-group commences with light sericite quartzites, in places laminated (B1). Their thickness ranges from 10 to 20 m. Near Branná, they occur as pseudo-conglomerates. The quartzites are by convention (on the basis of comparison with the Velké Vrbno group) assigned to the Siegenian-Pragian (Early Devonian). Between the Sudetic Marginal Fault and Branná they form one continuous outcrop, while farther to the WSW as far as Hanušovice, they are tectonically doubled. They do not occur on the surface south of Ruda nad Moravou.

The quartzites pass mainly into grey phyllites (B2) on the eastern side commonly enriched in biotite, andalusite, fine staurolite and quartz veins (B3). In places, the phyllites are substituted by light and grey banded marbles (B4). The marbles are fine-or medium-crystalline, and form a number of parallel intercalations. The uppermost of them occur directly under the Ramzova overthrust and are the most weakly crystallised and have finest grain. Close to the Sudetic Marginal Fault, karst processes in the marbles led to formation of caves, e.g. “Na Pomezi” and near Vápenna, and of ponors in the Ramzova overthrust zone. The thickness of individual crystalline limestone units falls within the range from one to several tens of metres. Along the whole stretch they are exploited in numerous quarries. In the beds uncovered there, folds with eastern vergence are observable.

The phyllites (B2) that predominate in the upper Branná sub-group dip to the west and north-west at a mean angle of 60° (range: 45° to 70°). In the phyllites north-north-east of Hanušovice and near Dolni and Horni Lipova, up to several metre thick metabasites (B5) occur, related to waning sea-floor volcanism. They are represented by, for example, chlorite-actinolite schists. Moreover, thin intercalations of meta-greywackes and greywacke sandstones occur in the phyllites.

NON-METAMORPHIC (INTRUSIVE, VOLCANIC AND SEDIMENTARY) ROCKS

The oldest non-metamorphic rocks in the boundary zone of the East and the West Sudetes are Variscan granitoids. They can be divided into (1) linearly-stretched structures, to various extents interfingering concordantly with the metamorphic series, and (2) horizontally-extended massifs with relatively well-defined and as a rule discordant contacts with the cover rocks. As regards their age, the “linear” granitoids (the Javornik granitoids and the Staré Město granitoids) are related to labile early-Variscan zones, and the granitoid massifs of Žulova and Kłodzko–Złoty Stok to young Variscan block movements. The latter are accompanied by abundant cover rock xenoliths and by veins that radially cut the structures of the metamorphic series.

In the early Permian, Rotliegendes sediments entered the described area from the side of the Intra-Sudetic Basin, and after a long break, sediments of the Late Cretaceous sea were deposited. The sea withdrew in the Late Coniacian as the block movements of the Sudetes uplift commenced. Locally, in the Nysa Kłodzka graben, and mainly in the depressions accompanying the Sudetic Marginal Fault, limnic Miocene–Pliocene sediments were preserved. Basalt lavas spilled onto Eo-Pleistocene gravels near Lądek Zdrój–Lutynia. The youngest sediments include slope weathering covers, passing in the lower parts into vast but thin solifluction covers interfingered with gravels of river valley terraces.

An important role in discussions on the evolution of the Śnieżnik metamorphic unit was played by the discovery of polymictic conglomerates in the adits of the uranium-fluorite mine (Kasza, 1964) and of sandstone in the adits made in the eastern slope of Śnieżnik Mt (Przeniosło & Sylwestrzak, 1969, 1971). The then-suggested late Devonian age for their sedimentation was brought into question upon the publication of new isotopic datings of the youngest processes of the regional metamorphism of the Śnieżnik rock series. Said dates oscillate around the turn of the Early and the Late Carboniferous (Borkowska *et al.*, 1990; Stentelpohl *et al.*, 1993; Maluski *et al.*, 1995; Bröcker *et al.*, 1997). Thus, it is necessary to refer to the earlier disregarded view on an Late Cretaceous age for these sediments. This age is suggested both by their tectonic position (Don, 1989a), and by their similarity to the polymictic Idzików beds of Coniacian age (Don & Don, 1960). The conglomerates and the sandstones discovered within the metamorphic series occur in a zone of a reverse fault, locally of an overthrust character, which from the vicinity of Staré Město cuts the Śnieżnik metamorphic unit towards the north-west (Don, 1988, 1989a), and from Nowy Waliszów extends towards Mielnik and Krosnowice as the marginal fault of the Late Cretaceous Nysa Kłodzka graben.

Ascribing the Kletno conglomerates, wedged in the described dislocation zone, to the Late Cretaceous, creates the need to assign a considerably younger age to the uranium-fluorite mineralization that had been previously related to Variscan plutonic phenomena (Banaś, 1965). The zone is cut crosswise by an up to 20-metre wide and approximately 300-metre long vein of quartz with similar mineralization. The vein is not disturbed tectonically (Don, 1988).

Variscan granitoid complex (g)

Variscan granitoids occur in the mountain part of the Sudetes and on the Fore-Sudetic Block. Their isotopic ages range from 340 to 240 Ma, i.e. from the Sudetic Phase in the Middle Carboniferous up to and including the Permian. In the area described, the greatest areas are occupied by granitoids of the Žulova massif and the Kłodzko–Złoty Stok massif. A distinctly linear stretch is a feature that distinguishes them from the Javornik granitoids and the Staré Město and Zábřeh zone granitoids.

Javornik granitoids (gS)

In the Góry Złote and the Rychlebské hory Mts., they form a partly concordant, up to one km wide and north-west dipping vein, which is accompanied by a rim of streaky granitization of blastomylonites and phyllonites of the Stronie formation, particularly well-developed in the tectonic overburden (on the north-western side). The main body of the Javornik granitoids, having the form of a compact, up to 1200 m thick vein, is on the Czech side, between the Růťenec pass in the south and the Bilá Voda in the north (Němec, 1951, 1954, 1957). Here, these granitoids represent deeper, root parts of the intrusion. To the south-west, on the Polish side, the granitoid vein narrows down and thins out on the progressively lower limbs of transverse faults. South-west of Biały Kamień hill, one may observe only apical parts of this intrusion, showing clear directional setting, concordant with the foliation of the metamorphic envelope. In these zones, there are also mylonitic varieties of granitoids. It is also possible to find them in the fold setting typical for the envelope. The tectonic involvement of the Javornik granitoids was mentioned by Finckh *et al.* (1942) and Cwojdziński (1977b, 1979). A detailed petrographic description of the Javornik granitoids in the Polish part of the Śnieżnik metamorphic unit was presented by Burchart (1960), and in the Czech part by Němec (1951). These two fundamental petrographic studies contain totally different interpretations of the described granitoids' origin: Němec opted for an intrusive origin, while Burchart saw metasomatism as the major factor responsible for the formation of these rocks.

The only isotopic dating of the Javornik granitoids was made for biotite via the K-Ar method by Borucki (1966). The result, 335 Ma, overlaps with both the age of the Staré Město granitoids (gM) and the isotopically determined age of the formation of the Gierałtów migmatite complex (S12), as well as with the age of the eclogites (S15) that occur within them.

Staré Město – "Bialskie" granitoids (gM)

These rocks, known in the Polish literature as the "Bialskie tonalites", divide a tectonically-renewed zone of the old Caledonian paleorift of the Staré Město. The term "Staré Město granitoids" was introduced into the Czech literature by Kopa (1984). They form a narrow stripe of outcrops between the Sudetic Marginal Fault and the Bušin fault. In the Zábřeh zone, their equivalent are monzonites. In the north, in the Rychlebské hory Mts., the outcrop of the Staré Město granitoids widens to over 1 km. They contain differentiates of several generations. The main body is formed by quartz-biotite-amphibole diorite (=tonalite), interfingered with a lighter variety of diorite, and finally intruded by veins of amphibole microgranites and aplites. In places, more basic differentiates, i.e. gabbrodiorites, also occur. In the marginal parts of the intrusion, in particular in the south and in the overburden, the granitoids display distinct preferred directions. On the east side, the contact is sharp, and oblique in relation to the underlying metaophiolites, or in places perpendicular. In the widest granitoid zone, a Q, S and L fissure system formed. In the south section between Staré Město and Bušin, the granitoid line becomes narrower and disrupted, or passes into the front of injection and granitization of the envelope rocks. Isotopic datings of the Staré Město granitoids range from 255 to 289 Ma (Rb/Sr). The datings obtained via $^{207}Pb/^{206}Pb$ zircon evaporation gave an age 339 Ma (Parry *et al.* 1997). Their injection and structural development is related to an old labile zone that separates the Brunovistulicum from the Lugicum which became tectonically renewed during the Variscan movements as a dextral transpression (Parry *et al.* 1997).

The Žulova massif granitoids (gŽ)

They fill the core of the Vidnava dome and probably have a connection with the granites near Strzelin. On the basis of fissure analysis, it is suggested that the root of the southern part of the intrusion is located near Vápenna. The granitoids are strongly varied. The oldest variety (275–290 Ma) is represented by fine-grained amphibole-biotite diorites (dŽ), present in the form of fragments and smaller xenoliths. They were intensively exploited for decorative purpose as the 'dark Silesian granites' (tmavá slezská ťula). The initial diorite pipe was burst and fragmented by a younger generation of biotite diorites and granodiorites (gŽ). They represent the main body of the intrusion and were known under the commercial name of 'light Silesian granites' (svetlá slezská ťula). To the north, the granodiorites gradually pass into biotite-muscovite granite. Along the south and south-east marginal parts, contaminated biotite granites occur, partially showing a preferred direction, and fine-grained leucocratic granites (mŽ). The youngest differentiates are numerous aplite, pegmatite and quartz veins (ż). The eastern side of the Žulova massif is accompanied by a wide zone of granitization and migmatization of the envelope rocks.

Kłodzko–Złoty Stok massif granitoids (gKZ)

Their crescent-like form separates the Góry Złote Mts. and the Krowiarki of the mesozonal Śnieżnik metamorphic unit from the regionally unmetamorphosed series of the Góry Bardzkie (O_3 - S - D-C_1) and the epizonal Kłodzko metamorphic unit (?Cm-O - S - D_1). According to Bederke (1927, 1928, 1929), the crescent-like shape of the massif implies that the intrusion has a syntectonic and concordant character. He related this intrusion with the Sudetic Phase. On the north-eastern side, it is cut by the Sudetic Marginal Fault. Towards the south-west, the rocks of the massif, after crossing the regional Trzebieszowice–Biela fault (on the Dolni Lipova–Stronie Śląskie–Trzebieszowice line) form, near Żelazno, smaller isolated isle outcrops within the metamorphic rocks of the Stronie formation of the Krowiarki. The tectonics pattern of the Kłodzko–Złoty Stok granitoids has been investigated and described in detail by Wieser (1958) and Wojciechowska (1975). The presented map includes only the south-eastern part of the massif (approximately 80 km^2). In the lithological sense, the Kłodzko–Złoty Stok massif rocks are varied like the Žulova massif granitoids. This variation is related to the intrusion having formed in several stages. Three stages are distinguished (Cwojdziński, 1977a, b): (1) the oldest variety, composed of granodiorites, porphyry granitoids and aplite leucogranites; (2) younger varieties, discordantly cutting the main plutonic body, consisting of red syenodiorites and porphyry monzodiorites; (3) the youngest variety, consisting of vein aplites, pegmatites and lamprophyres, which penetrate the envelope rocks via fissure systems to a great distance from the contact zone and not only the massif itself. These varieties were presented on the map as one unit.

In the Kłodzko–Złoty Stok massif, numerous meso- and macro-enclaves of the envelope rocks occur, mainly regarded as contact metamorphosed, hard to identify rocks of the Śnieżnik metamorphic unit and sedimentary rocks of the Góry Bardzkie Mts. In these outcrops, hornfelses and dark hornfels gneisses dominate (hKZ).

The age of the massif rocks was determined using the K-Ar method. The ages obtained for the main stage of the formation and consolidation of the massif were 301 Ma (Borucki, 1966) and 298–280 Ma (Depciuch, 1972), and for the next stage of the transformation and renewal of the magmatic processes, 262 Ma (Depciuch, 1972). These results would indicate a Late Carboniferous age for the intrusion, related to Asturian Phase movements, as pointed out earlier by Petrascheck (1933) and Oberc (1953, 1957, 1966).

Permian sediments and volcanites (P1)

The rocks of this period only occur in the map area in the north-western margin of the Krowiarki near Krosnowice, and belong to the young-Variscan depression of the Intra-Sudetic Basin. They form a 400 m-wide belt of outcrops south-west of Kłodzko (outside of the map), which is stretched to the north-west through the ridge and culmination of Czerwoniak (397 m a.s.l.) on the western side of the Nysa Kłodzka valley. From the north-east side, they are bounded by the marginal fault of the Krowiarki graben, along which they were, together with upper Cretaceous sediments that occur on the south-western side, flecsurally stretched in the vertical direction.

These rocks belong to the Early Permian, i.e. the Rotliegendes. The older part is represented by red sandstones with clayey intercalations, and the younger by brown-red clayey shales. They are separated by a concordant lens of melaphyres (Cwojdziński, 1978).

In the area covered by the map, strongly weathered red-brown clayey shales were encountered in a several-tens-of-metres long section in the incision of a terrace of the Biała Lądecka valley south-east of Krosnowice. There, they are wedged within Late Cretaceous sediments in the zone of a longitudinally stretched section of the fault cutting the Krowiarki range in the west. In the downthrown wall, both the Permian and the Cretaceous sediments are tectonically deflected and have dips of up to 50° to the east and west.

To the south, the lower Permian rocks were drilled under the Late Cretaceous sediments as far as Gorzuchów, where they were cut by a longitudinal-stretched Duszniki fault before the Late Cretaceous sea transgression. Beyond this fault, only the upper Cretaceous sediments directly lie on the erosionally cut metamorphic rocks of the Orlica–Śnieżnik dome. Mineral water springs are related to the fault, which was renewed in the Cainozoic.

Late Cretaceous sediments of the Nysa Kłodzka graben (K2)

The upper Nysa Kłodzka graben is a regional tectonic element that meridionally stretches to a length of over 50 km, of which 17 km lie in the Czech Republic. It manifests clearly in the morphology as a depression, closed in the east and north-east by the Śnieżnik Massif Mts. and the Krowiarki range, and in the west and south-west by the Góry Orlickie and Góry Bystrzyckie Mts., which rise step-like from it. The width of the graben in the north reaches 10 km, narrowing down to 2 km in the south. The graben is mainly filled with upper Cretaceous sediments lying on an erosionally cut surface of metamorphic rocks, and in the northern part also on Rotliegendes rocks. Their total thickness is within the 900 to 1100 m range, and is thrice the total thickness of the Late Cretaceous sediments in the adjacent (to the north-west) Intra-Sudetic Basin The basement of the Cretaceous beds was uncovered in the gorge valley of the Nysa Kłodzka cutting a local brachyanticline in Długopole. Steeply dipping paragneisses resembling the monotonous Młynowiec formation appear from beneath weakly-disturbed Cretaceous sediments.

The Cretaceous layers in the Nysa Kłodzka graben as a rule lie subhorizontally. They were locally folded into flat large-radius brachyanticlines (of Długopole and Bystrzyca Kłodzka) and brachysynclines (of Idzików and Międzylesie). These structures are stressed by flexures of Cretaceous rocks uplifted along infrequent faults that diagonally cut the Nysa graben in the north-west to the WNW. However, the most significant displacement from their original position is observed along marginal dislocations, where they dip vertically, and on the north-west/south-east inversion faults, they are overturned under the metamorphic rocks of the Krowiarki and the Góry Bystrzyckie Mts., which were thrust onto them in the direction of the graben (Don, 1996).

On the complied map, the Late Cretaceous sediments were grouped in two assemblages: Cenomanian–Turonian (K2c-t) and Coniacian (K2cn). The older is represented by glauconite sandstones thinning out to the east; "ringing" marls divided by sandstones of locally conglomerate character. The thickness of this assemblage rises to the north-west from several tens of metres near Międzygórze to more than 102 m near Bystrzyca Kłodzka and Krosnowice. The lower marls that belong here are very compact and hard, and macroscopically closely resemble basalts. They contain a large proportion of clay minerals cemented with calcite and silica (reaching up to 50%). Clusters of glauconite, sponge spiculae, and rare fossils, including the bivalve *Incoeramus labiatus* of the Lower Turonian (Radwański, 1975), are also present. Towards the top, they contain more and more clay and sand inliers covered with light-grey, vari-grained quartz- and arkosic sandstones with inclusions of conglomerates. The conglomerates are mainly quartz (90%) without pebbles of the crystalline basement rocks. Their age was determined by Sturm (1901) as Middle Turonian. Rode (1934) included them with the above-lying upper marls as part of the *Inoceramus lamarki* horizon. The thickness of these sandstones increases to the north-west from approximately 30 m near Idzików to 80 m in Bystrzyca Kłodzka. At the top they pass into clayey-sandy shales. In Krosnowice, a second horizon above their main occurrence also occurs. It has a thickness of up to 12 m and quickly thins out towards the south (Grocholski & Grocholska, 1958).

The upper "ringing" marls, which are massive, steel-grey and show planar parting, lie on the clayey-sandy shales. Their thickness reaches 30 m in the western part of the graben. At the top, they gradually pass into the Idzików clays with a thickness of up to 500–600 m (Don & Don, 1960).

The Idzików clays, together with the interfingering sandstones and conglomerates at the top (K2cn), occupy the greatest area, mainly in the central, morphologically-flattened part of the Nysa Kłodzka graben between the Idzików and Międzylesie brachysynclines. The clays are soft, part irregularly and rarely form natural outcrops. They are mainly composed of clay minerals, tiny flakes of micas scattered mostly on the parting planes, quartz grains and unidentified opaque minerals. At the top, the clays contain siderite concretions of 10 cm diametre, and shelly parting. Their presence allows the conclusion to be drawn that the sedimentation was quiet and took place in an environment with the low oxygen content and reducing conditions of a stagnant lake separated from the open sea.

The thickness of the Idzików clays decreases to the west to 60–80 m near Szczytna (outside the Nysa graben). Thus, for the first time, the thickness of the Cretaceous sediments is many times greater in the Nysa graben than in the Intra-Sudetic Basin, which confirms the commencement of block movements in the Sudetes in the Coniacian. These movements intensified in the Late Coniacian, as indicated by more and more frequent sandstone beds, fine-grained and of a flysch character, at the beginning (Jerzykiewicz, 1970, 1971) and then beds of conglomerate type sandstone passing into up to 30 m thick beds of polymictic conglomerates with pebbles mainly from the nearby Śnieżnik metamorphic unit (Don & Don, 1960; Radwański, 1961). In the relief, they are visible as distinct perches, in places manifesting as crag lines, such as the Skałki Pasterskie crags near Idzików. The number of horizons with conglomerates and their thicknesses drop rapidly towards the west, where they vanish entirely at a distance of up to 2 km from the eastern marginal fault of the Nysa graben. The short extent of inliers and the petrographic composition of their pebbles, which changes along their extent, indicate deltaic sediments and near-shore accumulation fans, supplied with material from the uplifted and incised tectonic edge of the Śnieżnik metamorphic unit, covered with a thin cover of Cretaceous sediments occasionally occurring among the pebbles (Don & Don, 1960).

Tectonic movements caused a regression of the Cretaceous sea from the generally uplifted Sudetic block. However, it is difficult to determine when the sea receded totally, as the upper part of the Cretaceous sediments was removed by erosion. In the southern part of the graben, on the Czech side, flysch-like Santonian sediments of the Březno formation were also observed.

Kletno conglomerates and sandstones (?K2cn)

In the 1950s, within the metamorphic rocks, conglomerates and sandstones were discovered in a number of the then-exploited adits in the Kletno deposit zone (Kasza, 1964 – Fig. 2) and later in adits on the eastern slope of Śnieżnik (Przeniosło & Sylwestrzak, 1971). Due to the great influence of this discovery on discussions of the Śnieżnik metamorphic unit's evolution, and due to the absence of natural outcrops and the present inaccessibility of the adits, we present a slightly abbreviated version of their description from Kasza (1964 – page 136): ..."The conglomerates from Kletno, with pebbles of up to 15 cm across, form massive and thick beds. At the top, crushing of pebbles is common, while in the other parts of the bed the pebbles are fractured, displaced along fractures and cemented again. Rounded elements of less resistant rocks, such as clay shales and graphite shales, were in most cases totally crushed down or deformed. The most typical components of the conglomerates are pebbles of a light- and dark-grey quartzite, vein quartz and aplite gneiss. Graphite quartzites, porphyries, silica shales and clayey shales bearing no signs of metamorphism occur in smaller amounts. The diametre of individual pebbles is from 2 to 15 cm. Pebbles with diametres of 2–5 cm are the most common kind. The degree of rounding is 3 and 4, rarely 2 (on the 4-point scale). The largest pebbles are those of the aplite gneisses and graphite quartzites. At the same time, they show a poor degree of rounding. The highest degree of rounding is found for porphyries, quartzite and some quartz pebbles. Shale pebbles have discoid shapes. The ratio of the pebble mass to the cement mass, of a sandy type, is varied. It is difficult to assess whether the quantitatively variable proportion of the sand fraction is a result of sedimentary phenomena, or is at least in part related to the tectonic grinding of some pebbles. In their vertical profile, the Kletno conglomerates show a uniform petrographic composition and a degree of rounding of the rock fragments. The presence of pebbles of aplite gneisses, porphyries, silica shales and probably keratophyres suggests that this material could have been transported from the east, or possibly from the north, where such rocks occur; e.g. in the Góry Bardzkie Mts. The lithological similarity of the Kletno conglomerates with the lower Carboniferous sediments of the Intra-Sudetic Basin and with the upper Devonian conglomerates, could indicate that they are of the same age. In the determination of the age of the Kletno conglomerates, it is very important that they occur at the bottom of an overthrust, which is related to the Variscan orogeny"...

The Kletno conglomerates and the sandstones in the adits on the eastern slope of Śnieżnik occur in the zone of the regional dislocation Staré Město–Kletno–Marcinków–Waliszów, traced down during later detailed mapping (Don, 1988). The dislocation continues to the north-west into the marginal fault of the upper Cretaceous Nysa graben with the inversionally uplifted north-east wall of the Krowiarki. The zone was healed near Kletno–Sienna with magnetite-polymetallic-fluorite mineralization. According to previous speculations, the mineralization was related to the granite Variscan magmatism (Banaś, 1965). One of greater quartz-fluorite veins, up to 20 m wide and visible in the relief as a 300 m long and 10 m high perch, almost perpendicularly cuts the dislocation zone mentioned earlier, together with the accompanying conglomerates, and was not disturbed by the post-Cretaceous dislocations (Don, 1988 – Fig. 22). These observations may point to a much younger age, i.e. Tertiary, for the fluorite-uranium mineralization in the Śnieżnik metamorphic unit. This problem should be solved on the basis of isotopic investigations.

The Kletno conglomerates and sandstones were regarded as the first unmetamorphosed sediment in the evolution of the Śnieżnik metamorphic unit. The lack of access to the abandoned adits makes further studies on their relationship to the crystalline basement rocks, which are the dominant pebble type, impossible. They mostly come from the variegated Stronie formation, and the gneisses are mainly represented by aplite varieties not described more precisely. In theory, they might represent marginal facies of the Śnieżnik gneisses as well as aplite varieties of the Gierałtów migmatites. The high proportion of unmetamorphosed rocks, including porphyries, should be stressed. The Kletno conglomerates and sandstones have not been dated biostratigraphically. On the basis of regional considerations and lithological comparisons, their relationship with the upper Cretaceous sea transgression sediments was excluded earlier. Attention was paid to their similarity to the upper Devonian conglomerates from the vicinity of Kłodzko, or to the polymictic lower Carboniferous conglomerates of the Intra-Sudetic Basin. Upper Visean deltaic conglomerates are also known from the Drahany upland near Račic and Luleč (Štelcl, 1960). In their polymictic composition, pebbles of the strongly metamorphosed rocks of the Moldanubicum dominate, including pebbles of granulites, the isotopic age of which is within the 351–369 Ma range (Matte *et al.*, 1985). The assumed late Devonian age of the Kletno conglomerates (Kasza, 1964) may now be questioned on the basis of current isotopic datings. However, within the area of the Śnieżnik metamorphic unit, the dislocation zone in which they occur cuts the front of the Gierałtów migmatization, dated at 342 Ma on average (Early Carboniferous). The conglomerates described, and the sandstones from the adit on the eastern slope of the Śnieżnik correlated to them (Przeniosło & Sylwestrzak, 1969, 1971), were not subject to this process; thus, they are much younger than Early Carboniferous. They contain abundant porphyry pebbles, typical of the Idzików bed conglomerates of the Late Coniacian in the Nysa Kłodzka graben (Don & Don, 1960), cut by the dislocation zone mentioned earlier. The observations quoted here should indicate the need for a revision of the age of the sediments discovered during mining work in the ore zone in Kletno.

Miocene–Pliocene sediments (Tr2)

The fore-Sudetic area and the paleorelief of the low situated basins of the southern part of the Nysa Kłodzka graben are filled with Miocene–Pliocene sediments. These were not precisely subdivided on the map.

Limnic sediments dominate in the Javornik–Vidnava basin, on the Sudetic foreland. They outcrop near Uhelne. As a rule, these sediments are covered with fluvioglacial sediments and Holocene sediments of up to 20 m thick. The Early Tortonian (? Badenian) clays, sands and gravels are interfingered by lignite horizons and ceramic clays near Uhelna. Both these sediments were exploited in open pits in the first half of the 20th century. The thickness of the Miocene sediments near Bily Potok and Bernatice, assessed via boreholes, ranges from 200 to 300 m.

In the Nysa Kłodzka graben along the Polish/Czech border zone, in the watershed of the three seas, gravels and sands were preserved as isolated isles, up to 15 m thick, of probably Lower Tortonian age (Sroka & Kowalska, 1998). They have a greater extent south of Kraliky. Gravels with pebbles of limnic quartzite also occur along the banks of the Krupa river near Staré Město, Chrastice and Habartice north of Hanušovice. They were not shown on the map.

Late Tertiary volcanic rocks (bTr2)

Four small stratovolcanoes formed at the end of the Miocene in the area that is now between Lądek, Lutynia and Travna–Zálesi. In an unused quarry near Lądek, gravels and dark-grey silts pierced by a basalt pipe were uncovered. The pouring magma burned the underlying sil-sediments red. In other outcrops, under the basalts, basalt tuffs lie directly on the weathering cover of the crystalline basement. The tuffs also separate the lower basaltic cover from the upper one. In the petrographic sense, they were named nepheline basanites (Frejková, 1954). All the basalt outcrops were used as sources of aggregate in the past.

It is assumed that these volcanoes formed before the Pleistocene. At a distance of 3 km north-east of the volcano in Travna, basalt ash was found in trenches, under a 20–30 cm thick weathering clay (Skácel, 1963). This could suggest a young, pre-Pleistocene volcanic activity. The basalts from the vicinity of Lądek were isotopically dated between 5.46 and 3.83 Ma (Birkenmajer *et al.*, 2002).

Quaternary deposits (Q)

Only the older (Pleistocene) and younger (Holocene) Quaternary rocks were distinguished on the map. The following sediments were assigned to the Pleistocene: loesses, slope solifluction tills passing upwards into under-slope debris fans and block fields, and lower-slope gravels of upper river terraces and varve clays (Qp1). Fluvioglacial and moraine sediments (Qp2) are mainly present at the fore-Sudetic area, and in the intramontane dales and valleys connecting them with the foreland, as well as in the lower passes (Růťanec and Kukačka). Northern rock erratics were sporadically encountered in the Sudetes up to the 440–500 m mark. On the basis of the grey Halštrov moraine tills, the older sediments were assigned to the southern Polish glaciation (Elstere–Mindel), and the upper fluvioglacial and moraine sediments to the central Polish glaciation (Solava–Riss).

Apart from the weathering covers and slope tills, the only distinguished sediments of the Holocene on the map are the alluvia (Qh) of rivers and streams. This was done to make the relief more visible.

THE TECTONIC SETTING AND EVOLUTION OF GEOLOGICAL UNITS OF THE BOUNDARY ZONE OF THE EAST AND WEST SUDETES

The tectonic character and development of the geological units in the area mapped are described below in two sections: the older metamorphic and structural changes and the younger block tectonic changes.

METAMORPHIC AND STRUCTURAL TRANSFORMATIONS

The Velké Vrbno dome, together with the Keprnik, Vidnava and Desna domes on the east side and the Śnieżnik metamorphic unit on the west side, belong to two super-regional geological units, namely the pre-Vendian Bruno-Vistulicum and the Late Proterozoic/ Early Palaeozoic Lugicum. They are separated by the almost meridionally-stretched (north-north-east/south-south-west), narrow, strongly tectonically-squeezed zone of the old Caledonian paleorift of the Staré Město. It is filled with crystalline rock, among which basic and acidic early-Palaeozoic (~500 Ma) paleovolcanites dominate. The zone was strongly tectonically disturbed by younger longitudinal dislocations, some of which were used by the intruding early-Variscan magma (~340 Ma) of the Staré Město granitoids (“Bialskie tonalites”). The geological interpretation of the external boundaries of the Staré Město zone is complicated by the presence of similar paleovolcanites in the adjacent units on the eastern and western sides of the paleorift.

The origin of this zone, so important to the geological evolution of Central Europe, is related to pre-Caledonian displacements of the two aforemantioned great units: the Bruno-Vistulicum and the Lugicum (with Moldanubicum). Its second activation took place during the Variscan folding.

The tectonic description and interpretation of the evolution of the major geological units of this map are based on macro- and mesostructural observations in the field, and mainly on the analysis of the obtained picture of the geological map, with necessary reference to petrography, stratigraphy and geophysics as well as to radiometric datings. This interpretation concerns geological structure with a multi-stage origin, which may be traced from Precambrian metamorphic-structural alterations to Tertiary block movements.

The geological evolution of the units described here has been interpreted in various ways, depending on the subjective selection of a hierarchy of criteria in assumed dynamo-metamorphic schemes. Certain differences between the points of view of the authors of this map exist, and are briefly described wherever possible.

The tectonic setting and evolution of the Keprnik–Vidnava and the Desna domes

Both of the major dome structures of the Silesicum, namely the Keprnik dome and the Desna dome situated farther east, have cores of the Cadomian (pre-Vendian) crystalline series (~560 Ma), belonging to the Bruno-Vistulicum, covered in the souther part of the Upper Silesia by Vendian and Lower Cambrian sediments (Orłowski, 1975; Kotas, 1982). The envelope of the Keprnik and Desna domes are formed by the rocks of the lower Branná subgroup, covered by Devonian (?) rocks of the upper Branná subgroup. The level of regional metamorphism of the latter decreases to the east.

The core of the Keprnik dome is mainly formed of garnet-andalusite-staurolite schists, intercalated by erlanes and interfingered with gneisses and migmatites. Rocks of volcanic origin are rather sparsely present. In the upper units of the schist series between Branná and Lipova, there are also intercalations of graphites, quartzites and limestones, most probably forming an analogue of the central part of the lithological profile of the Velké Vrbno dome. In the deeper parts of the dome, the Keprnik augen orthogneisses occur. They were earlier put on a par with the Biteš orthogneisses of the Moravicum. On the basis of the newer isotopic investigations, the intrusion of the magma of the Keprnik orthogneisses was related to the Cadomian tectogenesis (~570 Ma). A continuation of the Keprnik dome on the Fore-Sudetic Block is the Vidnava dome, the rocks of which only occur in the envelope of the Žulova massif.

The Desna dome is in fact avolcanic. The predominating rocks are Desna biotite paragneisses which are strongly chloritized under the Devonian envelope, in particular on the eastern slope. According to investigations carried out by Gunia (1987), these paragneisses belong to the Late Riphean. From the south, they interfinger with amphibolites of the Sobotin massif, probably of Early or Middle Devonian age, as well as with small intrusions of Variscan granites with pegmatite rims. The chloritized biotite paragneisses were folded and metamorphosed again, together with faunally-documented Devonian sediments of the Vrbno group (not to be confused with the Velké Vrbno dome), which envelop the dome (Roemer, 1865; Chlupač, 1975). Greywackes and other clastic rocks are regarded as the protolith of the Desna paragneisses. The degree of metamorphism of the Devonian sediments increases rapidly towards the Velké Vrbno dome and the eastern part of the Śnieżnik metamorphic unit (the development of the Gierałtów migmatites and the accompanying eclogites) and equally quickly decreases in the direction of the Kłodzko metamorphic unit and the Bardo structure. A zone of strongly altered crystalline series extends to the north onto the Fore-Sudetic Block and connects, via the Strzelin and Middle Odra (Wrocław) crystalline massifs, with the Middle-Variscan (Mid-German) Crystalline High, thus separating the Variscan externides from the internides (Znosko, 1965, 1974; Pożaryski, 1996; Don, 2000, 2001).

The Keprnik and the Desna domes are separated by the Kouty dislocation zone forming an almost continuous outcrop of Devonian metasediments and amphibolites of the Červenohorské Sedlo sub-group.

Above the Kouty dislocation zone, a distinct gravitation gradient was determined, testifying to a sudden change in basement type. The Desna gneisses and the Devonian rocks of the Vrbno group and the rocks of the Lower Carboniferous of the Nisky Jesenik lie on a vast and distinct elevation, expressed in higher gravitation force gradient values, caused by a shallower occurrence of heavy rocks of basalt type. West of the Kouty zone, towards the Keprnik and the Velké Vrbno domes, the gravitation value decreases, and above the Śnieżnik metamorphic unit, a vast depression is visible in the gravimetric picture, due to the concentration of light bodies of granitoids and gneisses.

The tectonic setting and evolution of the Velké Vrbno dome

The Velké Vrbno dome is the smallest and the westernmost unit of the East Sudetes, geologically distinguished as the Silesicum, underlain by the pre-Vendian Bruno-Vistulicum. Previously, authors compared the crystalline series of this dome to the "external" phyllites of the Moravian windows. Zoubek (1948) and other authors included them litho-stratigraphically to the Cambrian–Ordovician, or to the Silurian (Kvétoň 1951; Svoboda 1956). Later, however, Misař (1958) related them to the Algonkian. Contemporary geochronological investigations using radiometric methods indicate considerable differences between the older rocks of the Śnieżnik metamorphic unit (maxima ~500 Ma) and the older metamorphic rocks of the Velké Vrbno, Keprnik and Vidnava domes (maxima ~570 Ma). On the other hand, isotopic datings of the Variscan metamorphic processes are similar in all the units described and range from 350 to 330 Ma.

The crystalline units of the East Sudetes, i.e. the Silesicum with the underlying Bruno-Vistulicum, are characterized by the development of large structures of a dome type, with older series lying subhorizontally in the cores and with the Devonian envelope on the limbs. In fact, it was due to the swelling of scales overthrust onto each other along tectonic planes with a western dipping.

In the Velké Vrbno dome, Květoň (1951) distinguished three horizons: lower, middle (graphite) and upper. He suggested assigning the graphites to the Silurian. This division enabled the acceptance of several tectonic interpretations, e.g. recumbent isoclinal folds, possibly passing into scales, truncated folds, and nappes with a normal or reversed rock sequence. The presence of graphites in the northernmost drilling near Polka south of Vápenna confirms the wide extent of this unit, and is evidence rather in favour of a normal sequence for the crystalline series in the Velké Vrbno dome.

Within the graphite shales of the middle horizon, crystalline limestones, quartzites, discontinuous lenses of gneisses, amphibolites and mica schists occur. They are dominant in the upper unit and in places – in particular in the lower unit – resemble 'phyllites' or phyllonites, which are accompanied by ultrabasites, metagabbros and eclogites. This extraordinary accumulation of volcanites supplemented the deposition of sediments in the vicinity of the metaophiolite zone of the Staré Město paleorift.

The Velké Vrbno dome is wedged between two regional dislocations. On the western side, this is a 60–800 m wide belt of the Nýznerov dislocation, assigned to the Staré Město zone, filled with blastomylonitic Skorošice schists (M8) and a mélange of various cataclastic rocks. Both the main and deep-reaching fault planes of the Nýznerov zone that bound this zone, are accompanied by boudins and lenses of serpentinised ultrabasites dragged from great depths. On the eastern side, the Velké Vrbno dome is bounded by a relatively shallow Ramzova overthrust, earlier regarded as the boundary between the East and West Sudetes. Along this plane, during the Variscan orogeny the crystalline series of the Velké Vrbno dome were overthrust to the east onto the more weakly metamorphosed rocks of the Branné sub-group, probably representing the Lower or the Middle Devonian. In the high elevated (in the orographic sense) watershed of Biała Lądecka and Krupa (1120 m a.s.l.), along the state boundary, from beneath the Nýznerov dislocation zone, the 'Brousek quartzites' (B1) occur. They are of a still unidentified age. Their appearance is close to that of the basal quartzites of the upper Branná subgroup (Skácel, 1989b), and their tectonic style is different from that of the underlying series of the Velké Vrbno dome.

The tectonic setting and development of the Staré Město paleorift zone

The dominant rocks of the Staré Město metaophiolite zone are amphibolites, the thickness of which reaches several hundred metres. Unlike the adjacent units, this zone contains no signs of the development of dome type structures. There is a dominant steep dip of the rock series to the west with a local northern deviation. Within the volcanites, one can observe a variation from coarse-grained amphibolite to laminated amphibolite schists, in places with intercalations of more acidic differentiates, which in turn pass laterally into paleorhyolites. The metabasites contain units of amphibole, biotite and two-mica gneisses with local intercalations of quartzites and mica schists, while the presence of crystalline limestones, between Vlčice and Uhelna, is a unique case. In the central part of this zone, lenses of serpentinites and of rocks closely related to eclogites also occur. Moreover, they accompany the Nýznerov dislocation zone, regarded by Skácel (1989b) as the boundary of the East and West Sudetes.

Here at the turn of the Cambrian and the Ordovician (~500 Ma) linear eruptions related to the development of the Staré Město paleorift formed the several tens of kilometres long zone. It is recognised as a continuous zone probably from the Niedźwiedź borehole near Paczków, on the Fore-Sudetic Block, to the transverse Bušin dislocation in the south, i.e. an approximately 70 km long section. The Zábřeh crystalline zone extends behind this dislocation. As regards lithology, it does not differ from the Staré Město paleorift zone. However, it cuts the paleorift in a similar manner to contemporary zones of transverse faults.

After the Caledonian consolidation, overthrusts formed in the Variscan orogeny along the Staré Město overthrust. In the final phase, faults also formed which were used by linear, syntectonic intrusions of the magma of the Variscan Staré Město granitoids ("Bialskie tonalites").

The Staré Město paleorift represents one of the major lineaments, not only of the Sudetes but of the whole of Central Europe.

The tectonic setting and evolution of the Śnieżnik metamorphic unit

The tectonic setting of the Śnieżnik metamorphic unit is based mainly on the interpretation of the compiled map and on direct macro- and mesostructural observations in the field.

The Śnieżnik metamorphic unit rock series are linearly stretched. This is most visible within the lithologically varied Stronie formation, where isoclinal folds dominate. In the Krowiarki, where this formation is dominant, the folds are – taking Krosnowice as our starting point – stretched towards the south-east and show recumbence to the south-west. On the Trzebieszowice–Waliszów transverse line, they begin to deviate and split in a fan forming two branches, the north and the south branch. This fan was already observed by Cloos (1922) and Bederke (1929). Teisseyre (1956) called it the Lądek virgation, caused by overthrusting of the West Sudetes with their prevailing "Sudetic" directions (north-west/south-east) onto the East Sudetes with their meridional structures (north-north-east/south-south-west).

The north branch of the Lądek virgation resembles a mild arc initially turning from the south-east to the east, then to the north-east and finally, near Złoty Stok, to the north-north-east, and even changing to north. The course of the structures in this branch is expressed near Ołdrzychowice in continuous outcrops of amphibolites and crystalline limestones, and in the Góry Złote Mts. mainly in leptite gneiss (paleorhyolite) outcrops. In this branch, called "Złoty Stok branch" (Don, 1964), the isoclinal folds are consequently recumbent to the outside of the arc, i.e. in the Krowiarki to the south-west, in the Góry Złote Mts. and the Rychlebské hory Mts. (on the Czech side) gradually to the south-east and east. Later, a crescent-shaped intrusion of the Kłodzko–Złoty Stok granitoids fits to this arc (Bederke, 1929).

The southern, "Śnieżnik" branch (Don, 1964), gradually turns from south-east near Nowy Waliszów to the south near Kamienna and Międzygórze. Its course is expressed both by continuous outcrops of crystalline limestones in the Krowiarki, and by the directions of tectonic structures in the Śnieżnik Massif (Fischer, 1936; Teisseyre, 1957). Isoclinal folds in this branch are consequently recumbent towards the centre of the arc, i.e. to the south-west in the Krowiarki, and gradually to the west in the southern part. The setting of this arc later influenced the shape of the Nysa Kłodzka graben (bent to the north-west), which was meridionally stretched over 45 km as far as Štity on the Czech side.

East of the Krowiarki, the regional tectonic elements form a fan-like setting (Don, 1964 – Fig. 3). From beneath the schists of the Stronie formation, which dominates in the Krowiarki, compact gneiss massifs of Międzygórze, Śnieżnik, Gierałtów, Radochów and Skrzynka emerge, and spread outside of the fan on the surface. Their occurrence on the surface is accompanied by the increased regional metamorphose degree, from mesozonal alterations in the Krowiarki, to catazonal alterations in the axes of these massifs.

The structural position of the gneisses in the massif of the central part of the Lądek virgation fan is a issue of some debate. There is no unanimity as to whether they occur in the axes of synclinorial structures (Kasza, 1964; Oberc, 1972; Paděra & Pouba, 1985; Dumicz, 1991), or anticlinorial structures (Fischer, 1936; Bederke, 1943; Skácel, 1963, 1995; Don, 1964, 1982a, 2001b). The arguments for the first option are the dips of the Stronie for-

Fig. 4. Overturned to SW fold F_3 of the crystalline limestone layer within the Stronie mica-schists. "Julianna" quarry on the S slope of the Krzyżnik Mt. near Stronie Śląskie (Photo by J. Don).

mation schists on several limbs of the massifs under the gneisses. The argument for the second option is the dipping of the gneisses together with the accompanying rodding lineation (L_2) in the zones of the periclinal bends of all the massifs, under the schists of this formation. Moreover, an argument for the second option is the presence of ultra-high-pressure (UHP) catazonal rocks, granulites and eclogites, in the axes of synclionorial structures underlain with series metamorphosed to a much lesser degree. There is no justification of this in papers on the Śnieżnik metamorphic unit. Measurements of the dip of lithological planes directed towards a fold axis do not necessarily indicate a synclinal structure; an example could be the 'mushroom-like' Kletno fold (Don, 1996).

The distinguished gneiss massifs are separated by relatively narrow zones of supracrustal rocks, mainly by the Stronie formation, and in places also by the Młynowiec formation. From the interpretation of the map and the arguments presented so far it appears that they fill the synclinorial structures of Sienna–Morava, Kamienica, Stronie Śląskie, Lądek and Orłowiec, which at the meeting point of the Lądek virgation join in the strongly folded Krowiarki zone. The tectonic style of the Stronie formation is rather easy to reconstruct, due to its variegated, lithologically varied character. This style is well represented by a recumbent fold of the Krzyżnik crystalline limestones (Oberc, 1964; Don, 1976; Jastrzębski, 2002), uncovered to a great extent south of Stronie Śląskie in the "Biała", "Zielona Marianna" and "Julianna" quarries, all in operation (Fig. 4). The fold consists of a synclinal bend that dips to the north-north-east at a mean angle of 25° and of a superpositioned anticlinal bend with its axis dipping at an angle from 10 to 15° to the north-west. The fold was formed in a rotating field of compressive tensions acting on the east-west line in the initial phase (F_2), and on the north-east/south-west line in the final phase (F_3). The folds are accompanied by linear rodding structures (L_2 to L_3), passing into a superimposed gouffrage (L_3). In the Krowiarki, linear structures (L_3) related to the final phase of this deformation clearly dominate and mask the earlier linear structures (F_2). This is particularly visible in the Śnieżnik augen gneisses of the Góry Różane Mts. fold and Koleba south of Trzebieszowice (Don, 1972), the protolith magma of the orthogneisses intruded into the Stronie formation schists at the turn of the Cambrian and Ordovician in the form of a several tens to over 100 m thick sill. During the described deformations (D_2 to D_3), the sills were, together with the enveloping schists, folded into a structure resembling the Krzyżnik structure, composed of a predominant F_3 fold with an axis of 335/10° imposed on the F_2 fold with an axis of 355/10°–40°.

The Bzowiec fold, which has a similar style was also mapped in the Góry Złote Mts., in the Orłowiec synclinorium (Don, 1964; Cwojdziński, 1977a; Don & Gotowała, 1980). It contains leptite gneisses with the enveloping Stronie formation schists. The gneisses, together with paleorhyolites, are regarded as subvolcanic intrusions of the protolith magma of the Śnieżnik gneisses (Finckh *et al.*, 1938; Don, 1964, 2001a; Kröner *et al.*,1997; Kröner – personal communication).

Unlike the lithologically-varied Stronie formation, the tectonic setting of the monotonous Młynowiec formation is hard to map. As there are no key horizons, it is impossible to compare the tectonic styles of the two supracrustal series that fill the Lądek virgation synclinoria. A sharp and clearly defined boundary between them is marked by the bottom plane of the light basal quartzites of the Stronie formation (Vangerow, 1943; Don & Dowidar, 1988; Dumicz, 1975). Based on microproblematics, Gunia (1984a) determined their age as Late Proterozoic–Early Cambrian, and related the addition of heavy minerals to a paleo-beach environment. Dowidar (1990) used foliation diagrams to statistically obtain two distinct maxima from the Młynowiec formation, with only one of them from the light quartzites, and the same maximum from the other lithological varieties of the Stronie formation. These observations are rather in favour of the commencement of a new sedimentation cycle after the folding and erosional cutting of the initially flysch-like sediments of the Młynowiec formation, already postulated by

Fig. 5. Recumbant fold F_2 cut by by aplitic Gierałtów gneiss along the axial plane (S_2). Abandoned quarry of Stronie formation leptinites, amphibolites and mica-schists as relicts within the Gierałtów migmatites. Right bank of the Biała Lądecka river in Nowy Gierałtów (Photo by J. Don).

Fischer (1936). Should this suggestion be confirmed (e.g. by isotopic datings), then an earlier deformation should be added to the assumed sequence of deformations (D_1– D_4).

The macrofolds of Krzyżnik, the Góry Różane Mts. and Koleba and Bzowiec, described as examples illustrating the tectonic setting of the synclinal zones of the Lądek virgation, represent the second and third stages of the Śnieżnik metamorphic unit deformation. It has not proved possible to map similar macrofolds related to the first stage. The existence of this folding is confirmed by the frequent appearance of intrafolial mesofolds, and by metamorphic S_1 foliation planes folded in the second stage. Prior to the formation of the F_2 folds, these planes were used by the sill intrusions of the Śnieżnik gneiss protolith magma; thus their age is over 500 Ma. The contacts of the gneisses with the adjacent rocks are clear and sharp, and easy to trace during mapping work. The example of the Kletno fold granite-gneiss (Don, 1989a; Don & Opletal, 1996) illustrates the fact that their plane obliquely cuts (east of Stronie Śląskie) the basal quartzites of the Stronie formation and the underlying paragneisses of the Młynowiec formation near Stara Morawa, and near Kletno it borders the crystalline limestones altered by contact metamorphism in the Kamienica syncline to erlanes (J. Teisseyre, 1961).

Unlike those of the D_2 and D_3 deformations, the regional setting of the F_1 (Wojciechowska, 1972a, b) fold axes has not been determined. The folds were probably of a strongly isoclinal character, as the axial foliation planes in outcrops are in general concordant with the lithological planes of the Stronie formation; similarly to the situation with the boundary planes of the Śnieżnik unit granite-gneisses. Thus, the tectonic style (D_2 to D_3) of these gneisses and the corresponding paleorhyolites and leptite gneisses does not distinguish them very much within the Stronie formation, which was already folded before the Śnieżnik intrusion (D_1).

The described synclinoria of the Lądek virgation, filled with old formations (Pt_3-Cm_{1+2}) of the Śnieżnik metamorphic unit, form a characteristic fan setting together with the aforementioned compact gneiss massifs. This setting is markedly reconstructed in the eastern part of the described unit, i.e. in the Bialskie Góry and Rychlebské hory Mts. The reconstruction is related to an east-south-easterly clearer and clearer fitting of the tectonics of this part of the Śnieżnik metamorphic unit to the style of the structure of the East Sudetes. In this direction, an inversion occurred of the vergence of folds in the Śnieżnik branch of the Lądek virgation, connected with the development of "mushroom-like" folds (Don & Opletal, 1996) and with the first signs of regional scale overthrusts (Don, 1991b) so typical in the boundary zone of the West and East Sudetes (Skácel, 1989b). However, the major result of the reconstruction was the process of the regional Gierałtów migmatization, which mainly covered the eastern part of the Lądek virgation fan. A typical example is the oblique to the Kletno mushroom-like fold, the Gierałtów migmatization front (Don, 1991a). In the Góry Bialskie Mts., this migmatization (~340 M) included the Młynowiec paragneisses (Fischer, 1936), the schists of the variegated Stronie formation (Fig. 5) and the Śnieżnik granite-gneisses with the paleorhyolites of corresponding age (Don, 2001a). Here, numerous preserved relicts of these rocks follow the old structural plan of the Lądek virgation. The effects of the migmatization process gradually vanish to the west across transition zones several hundreds of metres wide (Teisseyre, 1957, 1973; Don, 1977, 1982b). The result of the increase in the volume of the migmatised rock series was the development of brachyantyclinal structures of a dome type, dividing the synclinoria described earlier. In the axial zones of these domes, within the Gierałtów migmatites, the earlier mentioned granulites and eclogites occur (340–350 Ma), i.e. ultra-high pressure rocks (Bakun-Czubarow, 1991, 1992, 2002). And here we reach the ongoing dispute connected with the age of the Gierałtów gneisses and migmatites. On the basis of their migmatic nature (resembling that of the Sowie Góry migmatites, regarded earlier as Archean) and their posi-tion in the anticlinal structure axes, Fischer (1936) regarded them as the oldest infracrustal complex in the Śnieżnik metamorphic unit and ascribed them an undefined Archean age. On the other hand, Smulikowski (1957, 1973, 1979) related them to one cycle of metasomatic granitization of the Stronie formation finished with the development of the Śnieżnik augen gneisses, probably of Assyntian age. Don (1963, 1964) started with the same assumptions as Fischer (1936), but he reversed their sequence assuming a thesis that, unlike in the supracrustal formations, the subsequent infracrustal complexes were added in the root zone of the orogen during their uplift. Thus, the younger ones now occur at greater depth, i.e. in the axes of the anticlinal structures. Thus, he related the Stronie and Młynowiec formations schists that fill the synclinoria and the Śnieżnik granite-gneisses of the dome limbs (rocks that had been folded together) to the Assyntian orogeny. The Gierałtów gneisses and migmatities, which lie in the axes of the anticlinoria, were assigned to the Caledonian orogeny, and the granitoids underlying the metamorphic bodies to the Variscan orogeny. After the Early Cambrian age of the quartzites, schists and crystalline limestones was documented (Gunia, 1984a, b), Don (1982a) related the first folding (F_1) of the Stronie formation to the old Caledonian movements (Cm/O), which ended with the intrusion of the Śnieżnik granitoid magma. Those granitoids were dynamically altered into augen gneisses (Don, 1977, 1982b) as late as in the young Caledonian or old Variscan orogeny (before the Late Devonian). The assumption of a pre-Late Devonian process of metamorphism of the Śnieżnik rock series was based on Bederke's (1924) discovery of the position of Frasnian and Famenian conglomerates and limestones on folded and epizonally altered and erosionally cut series of the nearby Kłodzko metamorphic unit. This was supported by the discovery of conglomerates in the adits of the Kletno mines, the age of which was indirectly estimated as Late Devonian or Early Carboniferous (Kasza, 1964). New isotopic datings of the metamorphic process in the Śnieżnik area, giving ages from 350–330 Ma, show the need to reassess the age of the Kletno conglomerates, and also indicate a diachronic evolution of this process towards the meridionally-stretched boundary zone of the West and the East Sudetes, accompanied by the formation of ultra-high pressure and temperature (UHP) rocks. In this zone, the end of the metamorphic processes may be associated with the Sudetic Phase of the Variscan orogeny at the turn of the Early and Late Carboniferous. In such a convention, this phase would end the evolution of the Gierałtów gneisses and migmatites, a concept supported by the quoted interpretation of the geological maps and by mesostructural observations (Don, 1977, 1982, 2001).

On the basis of mesostructural investigations, mainly performed in the zones of transition and mixed gneisses, Dumicz (1989) came to a conclusion on the development of the two types of Gierałtów gneisses and migmatites of different ages, with each phase ending with the intrusion of Śnieżnik-type granite-gneisses. He related the first evolutionary cycle of these gneisses to the old-Variscan folding of the Reuss phase (D_2/D_3), and the second one to the middle-Variscan folding of the Sudetic Phase (C_1/C_2). Żelaźniewicz (1988), on the other hand, continually questions the need to distinguish gneisses of various age in the Orlica–Śnieżnik dome metamorphic unit. According to him, the Gierałtów and the Śnieżnik gneisses represent different facial varieties of the same granitoid intrusion ($\sim$500 Ma). These differences increased during the dynamometamorphic alteration of the granitoid protolith of these gneisses. He suggests resigning from the previously-used regional names to embrace a structural nomenclature. Setting aside the difference in views on the character of the granitoids' evolution, the concept put forward by Żelaźniewicz is close to Smulikowski's point of view (1957, 1979). Another author supporting the non-division of the aforementioned gneiss assemblages by age is Cymerman (1997). He also questions the appropriateness of distinguishing the evolution of separate deformational phase sequences comprising tectonic events from old Caledonian to middle Variscan movements in the Śnież- nik metamorphic unit. On the basis of structural-kinema- tic analysis, mainly taking into account penetrative ductile shear zones, he put forward the suggestion that the main stage of the evolution of the Śnieżnik metamorphic unit (and of the Orlica–Śnieżnik dome in a broader sense) was a progressive Variscan deformation. In order to prove this thesis, he presented a model of a dextral transpression within the Orlica–Śnieżnik dome with the tectonic transport directed mainly to the north and with a shortening in the east-west direction. According to Cymerman (1997), the cause of such a deformation was an oblique collision between the Moldanubian and the Moravian terrane along the Nýznerov zone. The continuous deformation process of the Śnieżnik granite in turn: augengneisses – laminated mylonites – syn-or late kinematic migmatites of the Gierałtów type (Don, 1982b) was for the first time dated by Lange *et al.* (2001, 2002). Phengite and biotite whole rock pairs of the different gneiss varieties yielded constant Rb-Sr cooling mean ages respectively 337 Ma and 329 Ma independent of the deformation degree, indicating a rapid tectonic uplift after thermal peak within the Variscan times.

The age of the infracrustal complexes – in particular that of the Gierałtów gneisses and migmatites, along with their relation to the Śnieżnik gneisses – is still an open issue. Its solution would facilitate the understanding of the Śnieżnik crystalline massif's evolution involved in both the Caledonian and the Variscan folding.

BLOCK TECTONICS

Starting in the Permo-Carboniferous more and more signs of block tectonics connected with large-radius distortions appeared in the area under study. In the Early Permian (290–270 Ma), the western part of the Śnieżnik metamorphic unit was covered with the molasse-type red desert sediments of the Intra-Sudetic Basin (D_3-C_1-C_2-P-T_1/K_2). Almost throughout the whole Mesozoic, the area of the Kłodzko Region region and the adjacent part of the East Sudetes formed a land that was gradually more and more strongly peneplained. Thus, over approximately 200 Ma, the Caledonian-Variscan orogen of the pre-Sudetes vanished from the face of Central Europe, and the Late Cretaceous (~97 Ma) sea transgressing from the west in the Cenomanian encountered a deeply-eroded and smoothed area. Denivelations did not exceed several tens of metres, as suggested by the regionally stable and relatively small thickness of the Cenomanian and Turonian sediments encroaching eastward on the East Sudetic–Wrocław island.

Due to the scarcity of Cainozoic sediments, the well-dated and smoothed plane of the Cenomanian–Turonian transgression is of an exceptional character. Therefore, it forms an underestimated horizon with a significance as a reference point in considerations of the tectonic evolution and intensity of the Late Cretaceous and Cainozoic block movements in particular.

The tectonic quiescence after the Variscan movements was quite abruptly broken in the Coniacian, i.e. 89 Ma ago. On the meridional Štity–Kraliky–Międzylesie–Idzików–Waliszów line, a relatively narrow furrow of the Late Cretaceous sea began to deepen. The clays filling it reached over 600 m in thickness, many times more than in the Intra-Sudetic Basin (Don & Don, 1960). At the end of the Coniacian, along the eastern flexure of this furrow, the Śnieżnik massif appeared from the Cretaceous sea. This moment is documented by the Idzików conglomerate beds, which quickly thin out to the west, and in which pebbles of the eroded crystalline basement dominate. At the same time, the Cretaceous sea receded gradually to the south towards the fore-Carpathian depression. The movements which caused its regression were not by any means small, as the amplitude of the displacement of both blocks exceeded the total thickness of the Cretaceous sediments of the sinking furrow, i.e. approximately 660 m. Then, a meridionally stretched asymmetric half graben, open to the west, formed. Its formation was related to tensional stresses in the axial zone of the Orlica–Śnieżnik dome, which was being uplifted in a large-radius manner at that time (Cloos, 1936; Don & Don, 1960). Such an origin for the first stage of the Nysa graben's development was also confirmed by macro- and mesostructural observations.

In the second stage, the graben's evolution took place in a regional compression field, oblique in relation to the meridionally stretched semi-graben. At that time, thrust faults formed, directed symmetrically to the new axis of the graben, i.e. north-west/south-east. The faults extend into the area of the Śnieżnik metamorphic unit and the Staré Město paleorift, gradually becoming less intensive. The greatest of them include: the renewed Sudetic-Marginal Fault, the Bielice–Stronie Śląskie Fault (Kasza 1964), the Staré Město–Kletno–Marcinków–Waliszów fault (Don, 1982a; Don & Opletal, 1996) and the Bušin fault. They also include the marginal fault of the Krowiarki in the extension of the Staré Město–Kletno–Marcinków fault and the step-like faults of the Góry Bystrzyckie Mts. Their inversional character – with overthrusts of the metamorphic basement rocks onto Cretaceous sediments – was confirmed in drillings in Młoty and Nowy Waliszów. The age of the second stage of development of the Krowiarki, the Góry Bystrzyckie Mts. and the Góry Orlickie Mts. is difficult to determine; however, from regional comparisons, it appears that this process was most probably related to the Laramian movements at the turn of the Cretaceous and the Tertiary (~66 Ma) during which, for example, the Central Polish anticlinorium was formed. The Międzygórze–Staré Město north-west/south-east stretched elevation (discovered by Kasza, 1964)) is related with the Laramian compression. It manifests by plunging to the outside of L_2 rodding lineation structures (the so-called "Śnieżnik" lineation). The elevation extends to the area of the Nysa Kłodzka graben and, along the Domaszków–Długopole Zdrój line, it separates the Idzików brachysyncline from the Międzylesie–Pisary syncline (Don, in preparation).

As a result of the Cretaceous–Tertiary movements of the first and second stages, the present outline of the Nysa Kłodzka graben took shape, and the Coniacian displacements (the Idzików conglomerates) were the first well-dated repercussion of the Sudetes block uplift. The process took place in the subsequent phases and gradually covered their whole area, reaching its peak in the third stage in the early Cainozoic. In the Śnieżnik Massif area, this is confirmed by progressively younger peneplains situated at various elevations from 1400 to 400 m a.s.l. (Jahn, 1980; Walczak, 1980; Don, 1989a). A particularly large extent is occupied by an old morphological plain preserved at 820–890 m a.s.l. and correlated with the development of the Miocene sediments of the Sudetic foreland. The second, very important plain relates to the setting of the major valleys of the Śnieżnik metamorphic massif and prevails at average elevations of approximately 570 m a.s.l.. It is accompanied by deeply weathered and eroded rocks of the metamorphic basement, in places covered with Eopleistocene or Pliocene sediments (Jahn, 1980). This plain is correlated with Pliocene sediments widespread on the Sudetic foreland (Dyjor, 1979), and in the Czech Republic with Miopliocene sediments.

The total amplitude of the following block displacements, counted from the sub-Cenomanian plane of the Nysa Kłodzka graben to the nearby peak of Czarna Góra (1205 m a.s.l.) in the Śnieżnik metamorphic unit exceeds 1700 m.

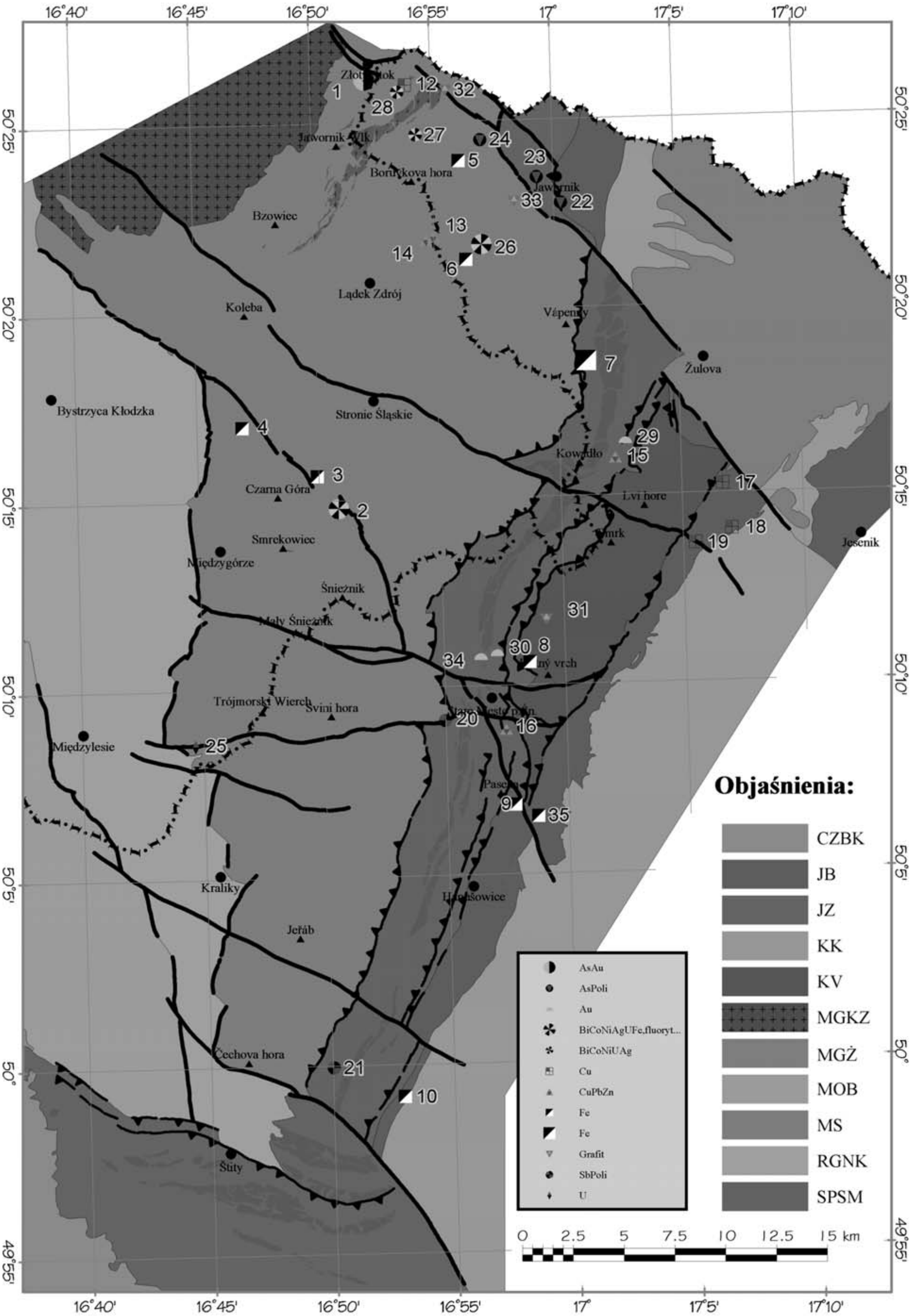

Fig. 6. Distribution of mineral depositions in the geological units of the East- and West Sudetes border zone.

DEPOSITS AND TRACES OF METALLIFEROUS AND NON-METALLIFEROUS MINERALS (*Jaroslav Skácel*)

In the eastern part of the Orlica–Śnieżnik dome, and in the adjacent geological units, ores have been exploited for many centuries on both sides of the border (Fig. 6). All in all, 25 small and medium size deposits and occurrences are known on which at various times mining works for ores or rocks were carried out (Banaś, 1965; Dziedzic *et al.*, 1979; Fojt et al., 1976; Kruťa, 1973; Lis & Sylwestrzak, 1986; Skácel, 1979b, 1989c). Their location, numbered compliant with the description presented below, is marked on a general sketch map of the tectonic units. Periods of intensive exploitation alternated with times of lesser interest in the minerals. The peak of exploitation occurred in the 19th and 20th centuries, whereas now it is limited to just a few marble and graphite mines.

The oldest mining work was carried out on the gold-bearing deposit of arsene in Złoty Stok (1). Work went on there almost continuously from the 7th century, and in total over 16.5 t of metallic (pure) gold was exploited, i.e. the greatest amount anywhere in the whole Bohemian Massif (Domaszewska, 1964; Morávek *et al.*, 1992). These deposits occur in metamorphic rocks in the form of lensoidal impregnations within serpentinised marbles. Submicroscopic inclusions in löllingite and arsenopyrite are also encountered in amounts of 30–35 g Au/t. No gold in its free form has been found here; therefore, it does not occur in placers in the alluvia in secondary deposits. In the ore zones, it occurs together with magnetite, rarely with antimonite, polymetallic sulphides, cobalt, smaltite, etc. The mineralization is polygenetic, polyphase, and related to the Variscan metasomatosis.

In the lithologically variegated Stronie formation, small deposits and traces of iron ores occur, mostly of magnetite. They form concordant occurrences mainly along the contacts of crystalline limestones with amphibolites, suggesting their pre-Devonian volcanic-sedimentary origin. They were involved in processes of the regional metamorphism similar to those of the adjacent rocks. Similar traces of Fe mineralization were also encountered in the Velké Vrbno and the Staré Město formations.

In Kletno (2), magnetite-hematite mineralization occurs in crystalline limestones in deeper adits of the fluorite mine (Banaś, 1965). In this structural position, it progresses to the north-west to Janowa Góra (3) and farther to Marcinków (4) and along the south-west slopes of the Krowiarki (the Góry Żelazne Mts.). The main mineral in the Kletno deposit is a younger fluorite, occurring with quartz in decimetre- to a metre-thick veins and stockworks. The veins are accompanied by barite, calcite and mineralogically-rich associations of silver-bearing sulphides, arsenides, selenides and other metals. Gold was also identified in the vein quartz. After the Second World War, in the 1950s, radioactive minerals were intensively mined in Kletno, and a rich accumulation of magnetite was discovered also in a long zone of marbles between Kletno and Janowa Góra (3).

On the Czech part of the map, several small occurrences of iron ores disseminated through all the geological units are known. Within the Stronie formation, magnetite was exploited in the Hoštický potok valley, south of Horni Hoštice (5), as early as in the mid-16th century. Fine-grained magnetite forms a number of decimetre-thick intercalations there, on the contact of the marble with the amphibolite (Skácel & Skácelova, 1993). Magnetites were later exploited to the south of Zalesi (6) from nests in basite rocks and on the contact of the amphibolite with the crystalline limestones and mica schists and mica-garnet schists in the upper part of the Stronie formation.

The largest magnetite-hematite deposit was located in Hranična, south-west of Vojtovice (7). It was exploited in the mid-19th century, and studied again in 1952–1958. Its documented resources were estimated at 500,000 t. The ores were exploited until 1967, and used as a filler charge. The deposit had elevated concentrations of Pb and Zn sulphides, and inclusions of spinels were encountered in the magnetite (hercynite, franklinite, gahnite). The two main seams of the magnetite-hematite ore, up to 2 m thick, occur in the crystalline limestones and erlanes of the "autonomous series of Hranična", assigned earlier to the Staré Město crystalline unit, and now to the Stronie formation. Magnetite dominates over hematite in this deposit at a ratio of 4:1. Apart from sulphides (pyrite, pyrrhotite, galenite and sphalerite), molybdenite and fluorite occur in minor amounts. To the north and south, the mineralization in the crystalline limestones is represented solely by inclusions of galenite, with the oldest isotopic dating in the Bohemian Massif being Ordovician (Legierski, 1973). At the bottom and the top of the deposit, the sulphide concentration increases, and the mica paragneisses were in part turned to cherts, while the marbles were altered to erlanes. The ore mineralization's origin is a matter of dispute (Fojt *et al.*, 1976).

Another iron ore deposit on the Czech side of the border is Male Vrbno (8). Fine-grained magnetite forms concordant seams there at the contact of the marbles with the amphibolites, or with the paragneisses partially altered to cherts and with the cherts, belonging to the upper member of the Velké Vrbno dome. Mining on this deposit is mentioned in documents from the 14th century. Attempts to exploit this resource were made in the 19th century, and modern investigations were carried out in 1958 (Skácel, 1959).

Limonite weathering ores were locally exploited in the 18th and 19th centuries near Rudkov, Pleče and Habartice (9) north of Hanušovice, and in karst pockets of limestones of the Branná sub-group near Ruda nad Moravou (10).

Significant numbers of veins with polymetallic sulphides occur close to the Sudetic Marginal Fault. However, these are small occurrences, known from old mining excavations. In some of them, Cu ores dominate, while in others, sulphides of Pb and Zn with pyrite within vein quartz or in the quartz-calcareous mass are dominant. On the Polish side, occurrences of this type are known above all from Mąkolno (11) west of Złoty Stok, and on the Czech side from Bila Voda near Karlov farm (12) mainly with Cu ores (Krut'a 1973), and in Travna (13) with Cu, Pb and Zn sulphides in an adit running towards the Polish border, where an analogical occurrence was described by Muszer (1995) in Lutynia (14).

Surface mining uncovered a quartz vein with chalcopyrite and minor galenite, sphalerite and barite on the "Stříbrník" hill near Nýznerov (15). A several tens of metres long vein structure is located there in the contact zone of blastomylonite schists with metagabbros of the Nýznerov dislocation zone. In the Stříbrny stream valley, old placers with traces of gold were preserved below the deposit.

A vein deposit in Šléglov (16) occurs in a similar position. It is situated about 2 km south-east of Staré Město, where at a left tributary of the Krupa river, mining was carried out in the past (Skácel & Pecina, 1990). In the dynamically deformed rocks of the Nýznerov dislocation zone a quartz vein with galenite and sphalerite occurs. According to archival sources, mining there dates back to 1783, and had been commenced in older excavations from the mid-14th century.

In the upper Branná sub-group, there are known occurrences with Cu mineralization in Lesní Čtvrť u Vapenne (17), Na Pomezi over Dolni Lipova (18) and on the southern slope of "Kopřivnik" over Horni Lipova (19).

Of interest are the veins in which, apart from galenite, sphalerite and chalcopyrite, antimonite or arsenopyrite occurs. Two antimonite veins were exploited during the First World War (Fojt *et al.*, 1977) in the Staré Město crystalline unit: one in Hynčice pod Sušinou (20) and the second in Jakubovice (21). In Poland, antimony associations were found in the Góry Bardzkie Mts. (outside of the map's area), near Boguszyn, Dębowina and Bardo. Polymetallic veins with arsenopyrite and traces of Au and Ag were exploited near Javornik, mainly in the "Boťí poťehnání" mine with the "Melchior" adit from the mid-19th century, which cuts the phyllites of the upper Branná sub-group of the eastern part of the Javornik scale near Horni Fořt south of Javornik (22). In the Staré Město crystalline unit of the western part of the Javornik scale, there is a quartz vein with arsenopyrite and polymetals at the so called 'Totenkoppe' north of Javornik (23). The third occurrence is in the Śnieżnik gneisses near Horni Hoštice (24). On the basis of the lead isotope ratio, their age was estimated as Jurassic (Legierski, 1973).

The radioactive ore mineralization also belongs to the younger metallogeny. In the 1950s, such ores were mainly

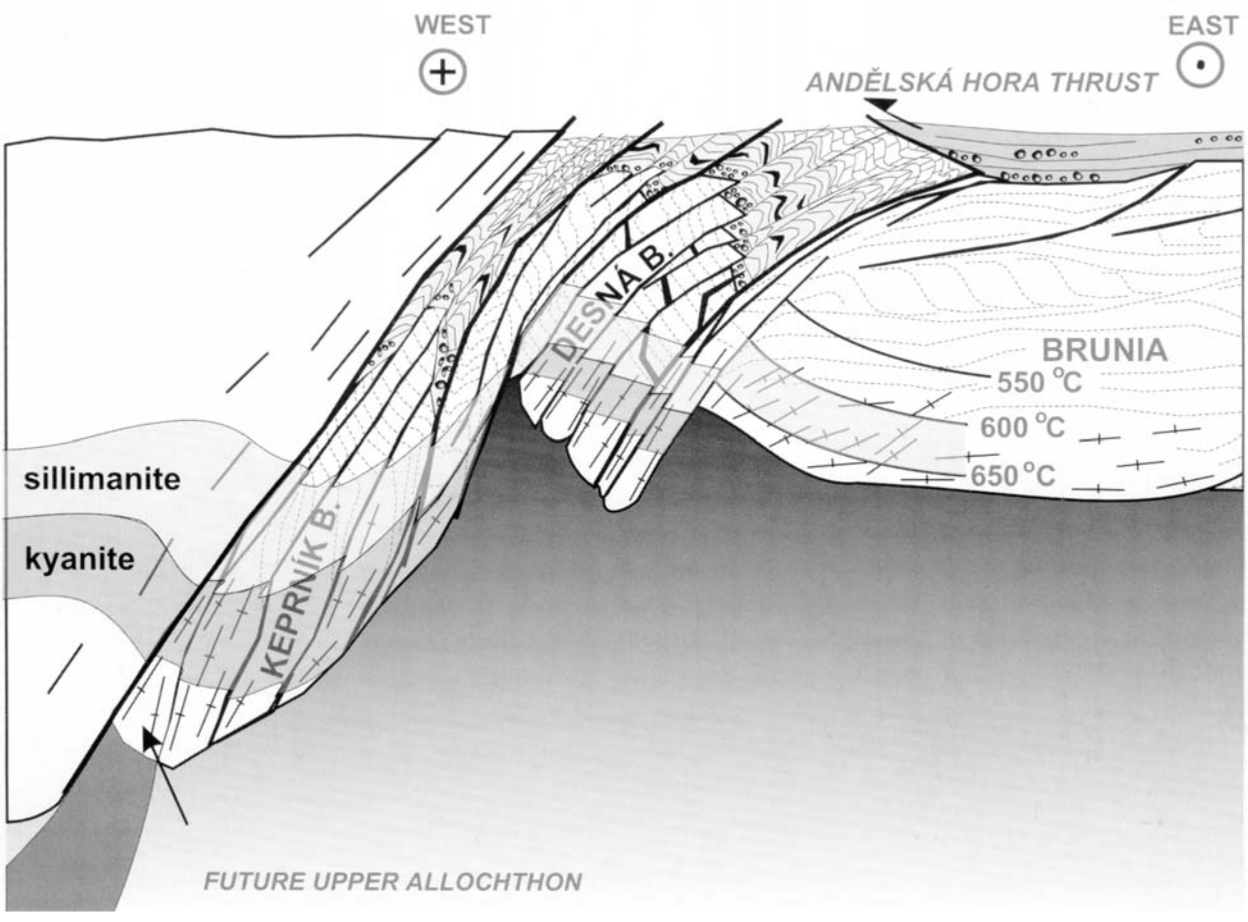

Fig. 7. Schematic section across the collision border zone between the Eastern - and Western Sudetes. After Schulmann & Gayer (2000).

exploited in Kletno (2) and nearby Janowa Góra (3), and on the slopes of Kopalniana Góra Mt. near Potoczek (25), east of Międzylesie. Primary and secondary uranium mineralization was also encountered in Mały Lej on the eastern slope of Śnieżnik Mt. (Lis & Sylwestrzak, 1986).

On the Czech side, a radioactive mineralization of the Jachymov type was discovered in Zalesi (26). In 1955 and the following years, these ores were exploited.

A number of mineralised quartz veins, locally with hematite, cut the variegated Stronie formation. In the limestones and erlanes of this formation, chaotically-disseminated nests of a five-element (Bi, Co, Ni, Ag and U) mineralization formed. Smaller traces of this mineralization were found during mining work on "Jelen" mountain, south-west of Horni Hoštice (27) and near Bila Voda-Ves (28).

Placer deposits of gold were exploited in the gravels of the Stříbrný potok stream near Nýznerov (29). Such deposits are also known from the Staré Město region on the Krupa river on the north and south sides of the town, and on the Bystřina stream between Staré Město and Male Vrbno (30).

Of industrial significance are the graphite deposits, particularly the "Konstantin" deposit in the Velké Vrbno (31), representing the tectonically thickened part of the graphite member of the Velké Vrbno dome. Since the second half of the 19th century, graphite has been exploited here in numerous locations along the elliptic outline of the outcrops of this member near Šleglov, Malé and Velké Vrbno, Petřikov, Adamov, Kronfelzov, and west of Branná. In the "Barbara" deposit, on the west side of Petřikov, the main exploited minerals were pyrite and pyrrhotite in crystalline dolomitic limestones.

There are various traces of old exploitations of graphite in the Stronie formation in Kamenička near Bila Voda (32) and in the valley between Javornik and Travna (33). The traces of graphite on the Polish side of the border have a rather mineralogical character, and were only exploited near Strachocin.

Marbles have been exploited for a long time in numerous quarries for building, decorative and metallurgical purposes, both from intercalations in the Stronie formation and from the upper Branná sub-group, mainly in Krowiarki (Żelazno, Romanów, Waliszów, Stronie Śląskie and Kletno) on the Polish side of the border; on the Czech side, near Vápenna, Na Pomezi, near Horni Lipová and Bohdikov.

FINAL REMARKS AND CONCLUSIONS

The interpretation of the map, compiled using uniform criteria, comprising the whole Śnieżnik metamorphic unit, the Staré Město paleorift zone, the Velké Vrbno dome and the Devonian Branná sub-group, required the authors to take thorough consideration of the issues connected with the evolution of the described geological units. These issues mainly concerned the facies-structural correlation of the units' evolutions, and their interactions and role in the super-regional structures. Therefore, this overall interpretation differs in several aspects from conclusions drawn on the basis of local or fragmentary studies, concerning selected issues solved with the use of methodology limited to the scope of said issues. Examples of this are isotopic dating results, which are frequently stripped of reference to the regional relationships of the analysed series, or conclusions drawn from geochemical studies.

The differences between the interpretations of the boundary zone of the two main parts of the Sudetes are well-illustrated on the schematic geological cross-section (Fig. 7), published by Schulmann & Gayer (2000) and used on the front page of the issue of "GeoLines" (vol. 14) devoted to a field conference of the Czech Tectonic Group in Żelazno near Kłodzko (9–12.05.2002). In this cross-section, not only was the presence of the Velké Vrbno dome omitted, but also the presence of the Staré Město paleorift and the accompanying Nýznerov dislocation zone (Skácel, 1989a, b), so important for the early Paleozoic evolution of this part of Europe. The Variscan reworking of this zone was reflected in the eastern part of the Ramzova thrust, and this process had repercussions on the Śnieżnik metamorphic unit area. This reworking was also accompanied by the evolution of the Gierałtów migmatites. This process in turn took in the previously folded rocks not only of the Młynowiec monotonous series (Fischer, 1936), but also the variegated schists of the Stronie series and the Śnieżnik augen orthogneisses that are folded together with them (Don, 1964, 1972, 2001a).

Since the paper published by Fischer (1936), the position of the Gierałtów migmatites in the lithostratigraphic profile of the Śnieżnik metamorphic unit has been a matter of discussion. Apart from this, the age issue of the Haniak gneisses has not been explicitly solved. They migmatised the monotonous paragneisses of the Młynowiec type in the Góry Złote Mts. and mylonitised schists of the Stronie series in the Złoty Stok–Skrzynka zone (Don, 1964; Kozłowska-Koch, 1973). These gneisses were regarded by the authors of the detailed geological maps of the area (Finckh *et al.*, 1942) as the youngest member of the Śnieżnik metamorphic unit, and were compared by Don (1964) with the Gierałtów migmatites. They have not yet been isotopically dated.

A similar problem concerns amphibolites, since the paper by Vangerov (1943) included as part of the top of the variegated Stronie series. The latest studies indicate that they are petrographically and structurally varied (Nowak & Żelaźniewicz, 2002). On the maps published so far, however, and on the present map, they were not divided out. As they in part accompany the metarhyolites with an isotopic age of around 500 Ma, they were connected in this interpretation into one old Caledonian magmatic cycle preceded by the folding (F_1) of the Stronie series. On the contacts with crystalline limestones and erlanes, this folding is accompanied by magnetite-hematite mineralization (Skácel, previous chapter). Their analogical age in the Staré Město paleorift zone speaks in favour of the exclusion of some amphibolites from this series. However, the differentiation of the amphibolites, determined by the quoted authors, into massive varieties of hypabyssal origin and laminated ones representing earlier stages of pyroclastic volcanism, rather suggest a relationship of the latter with the Stronie series. The proposed temporal differentiation of the described varieties would require confirmation by isotopic datings.

Further doubts concern the age of the light quartzites in the Velké Vrbno dome. There is no unanimity as to whether they belong to one tectonically-repeated member, or to two members of various age, the younger of which is correlated with the basal quartzites of the Devonian Branná sub-group (Skácel, 1989b).

There are also doubts concerning the Variscan age of the uranium-fluorite veins in Kletno. One of the largest veins almost perpendicularly cuts the regional Staré Mesto–Kletno–Marcinków–Waliszów dislocation zone stretching on the Krowiarki section to the north-west into the marginal fault of the upper Cretaceous graben of the Nysa Kłodzka (Don, 1988, 1989a). The vein bears no marks of tectonic involvement or displacement on this fault. These observations point to a rather younger Tertiary age for the uranium-fluorite mineralization in the Śnieżnik metamorphic unit, alike the age of the fluorite veins near Jilová in the northen part of the Czech Republic (Štemprok & Vejnar, 1958).

Apart from issues concerning the ages of rock series in question, there are unsolved problems of a regional nature:

1. The relationship of the mesozonally-altered rocks of the Śnieżnik metamorphic unit to the epizonally-metamorphosed rocks of the Kłodzko metamorphic unit.

2. The issue of the course of the Staré Město paleorift outside of the mountainous part of the Sudetes, i.e. on the Fore-Sudetic Block and to the south towards the dislocation zone of the Moldanubicum and the Moravicum.

Ad 1. Both units mentioned here are separated by the granitoids of the Kłodzko–Złoty Stok massif, covered with Rotliegendes and Late Cretaceous sediments on the slopes of Czerwonak (397 m a.s.l.) in Krosnowice, and with Cainozoic sediments in the wide valley of the Nysa south of Kłodzko. In Jaszkowa and east of Kłodzko, these granites have a direct boundary with the Kłodzko metamorphic unit rocks and farther to the north-east with the Bardo structure sediments (O_3 – S – D - C_1), which are not only thermally metamorphosed in the contact zone, but were also regional metamorphosed in the vicinity of Podzamek in the SE part of the Bardo Mts. (Wojciechowska, 1975). In the northern part of Kłodzko, on the folded and erosionally cut rocks of the Kłodzko metamorphic unit (?Cm-?O-S–D_{1-2}) lie transgressively unmetamorphosed limestones of the Late Devonian, underlain with basal conglomerates (Bederke, 1924). Regarding the described situation, there is no direct information regarding sedimentary continuity or a gap and the possible existence of a discordance, or a gradient of the level of metamorphism between the sedimentary series of the both units. Only on the basis of comparisons with a similarly-developed lithostratigraphic profile of the South Karkonosze Mts. (Pt_3-Cm // O_3 – S - D_1 // D_3) may one draw indirect conclusions on the existence of such a gap between the Late Cambrian and the Ordovician, connected with a gradient of metamorphism. Both in the Karko- nosze Mts. and in the Ziemia Kłodzka District area, granitoid magmas intruded at that time (~500 Ma). These were later metamorphosed during folding prior to the Late Devonian (or in the Early Carboniferous) into the Izera and the Śnieżnik augen gneisses. In the Ziemia Kłodzka region the upper age boundary of this dynamometamorphism is probably diachronous. Near Kłodzko, this process ended before the Late Devonian, while in the area of the Śnieżnik metamorphic unit before the Late Carboniferous, which is indicated by numerous isotopic datings, falling within a mean range of 340–330 Ma.

Ad 2. A continuous belt of outcrops of the Staré Město paleorift metabasites ends on the marginal faults of the mountain part of the Sudetes. On the Fore-Sudetic Block, the metabasites were encountered in the borehole Niedźwiedź IG-2 (Cymerman 1986). At a depth of 1694 m, they are underlain by blastomylonites of the Nýznerov dislocation zone. On the basis of data collected from magnetic and gravimetric surveys, it was determined that these metabasites stretch to the north as far as Ziębice. Much less information exists on the continuation of the Staré Město paleorift to the south outside of the Bušin fault. As it forms a relatively narrow zone, it may be hidden entirely under Variscan thrusts of the Moldanubicum onto the Moravicum structures.

The digital version of the map on CD is available at the Institute of Geological Sciences, Wrocław University, pl. M. Borna 9, 50-204 Wrocław. Contact with Roman Gotowała, e-mail: romgot@ing.uni.wroc.pl

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