Geologia Sudetica, 2005, 37: 35–51.

Cadomian versus younger deformations in the basement of the Moravo-Silesian Variscides, East Sudetes, SW Poland: U-Pb SHRIMP and Rb-Sr age data

Andrzej Żelaźniewicz[1, 2], Izabella Nowak[1], Robert Bachliński[3], Alexander N. Larionov[4] & Sergey A. Sergeev[4]

[1] *Instytut Nauk Geologicznych PAN, Podwale 75, 50-449 Wrocław, Poland; pansudet@pwr.wroc.pl*
[2] *Instytut Geologii, Uniwersytet Adama Mickiewicza, ul. Maków Polnych 16, 61-616 Poznań*
[3] *Instytut Nauk Geologicznych PAN, Twarda 51/55, 00-818 Warszawa, Poland*
[4] *Centre of Isotopic Research, All Russian Geological Research Institute, St. Petersburg, Russia*

Key words: Desná, Keprník, dome, zircon, tholeiite, pegmatite, muscovite, Vrbno Group, Rejvíz series, Bohemian Massif.

Abstract U-Pb SHRIMP dating of zircons from a metapegmatite vein which cross-cuts amphibolite facies paragneisses confirms ~580 Ma magmatism in the basement of the northern part of the Moravo-Silesian Zone (Jeseníky Mts.). Structures older than the felsic vein set are interpreted as a record of the Cadomian orogeny. This has been represented by N-trending, W-vergent folds followed by a top-to-the east shearing that occurred at T = 600°C and P = 5 kbar in the Neoproterozoic. The subsequent tectonic overprint led to folding and shearing of the pegmatite, which took place at similar P-T conditions but was associated with top-to-the west kinematics and shortening at a high angle to the foliation. This event likely developed during early stages of Variscan convergence when the Moravo-Silesian crust (Brunovistulia) was subducted and forced down below the approaching upper plate composed of terranes of the Bohemian Massif. Alternatively, it may have occurred around 500 Ma, related to crustal extensional (break-up of Gondwana margins in Cambrian times). Although the first option is favoured, presumably the two may have actually happened. The last ductile deformation was a top-to-the-east younger shearing localized in zones of various widths, assigned to the Variscan collision and reverse movement of the basement rocks. The latter two events occurred at temperatures that allowed in the metapegmatite for the crystal plastic deformation of quartz grains from which the strain was removed by subsequent static recrystallization, and that were high enough to reset the Rb-Sr system in this rock. Consequently, the obtained Rb-Sr isochron age of 290 Ma is considered to reflect the time of uplift. Such late regional uplift is characteristic of the northern part of the Moravo-Silesian Zone, which is the footwall to the Moldanubian Thrust, which separates the Bohemian Massif terranes from the Brunovistulia terrane. It follows from this study that in the East Sudetes basement rocks, structures which are often classified as Variscan may in fact be Cadomian and that the Cadomian record in these rocks is richer than previously assumed.

Manuscript received 10 August 2005, manuscript accepted 20 December 2005

INTRODUCTION

Since the mid-19th century discovery of Devonian fauna in the metasedimentary rocks in the Jeseníky Mts., Northern Moravia, it has been known that in the eastern part of the central European Variscides, in the Moravo-Silesian Zone, Devonian–Carboniferous metasediments overlie an older crystalline basement. Suess (1912), Kölbl (1929) and Bederke (1935) recognized that basement sheets were thrust over multiply deformed and metamorphosed Devonian rocks during an Alpine-type Variscan orogenic event. Later workers have assumed that the metamorphic foliation and migmatitic layering observed in the basement rocks are Proterozoic fabrics, while the other tectonic structures found in these rocks are said to be due to an extensive Variscan overprint under amphibolite and greenschist facies conditions (Cháb *et al.*, 1992; Testa & Gibbons, 1996; Schulmann & Gayer, 2000). However, such a simple distinction may be misleading; the pre-Variscan structures may be overlooked and misidentified as Variscan structures, leading to erroneous tectonic interpretations. The reasons for possible misidentifications stem from lithological similarities between the Precambrian and Devonian rocks, and, despite the 22 sites with Lower De-

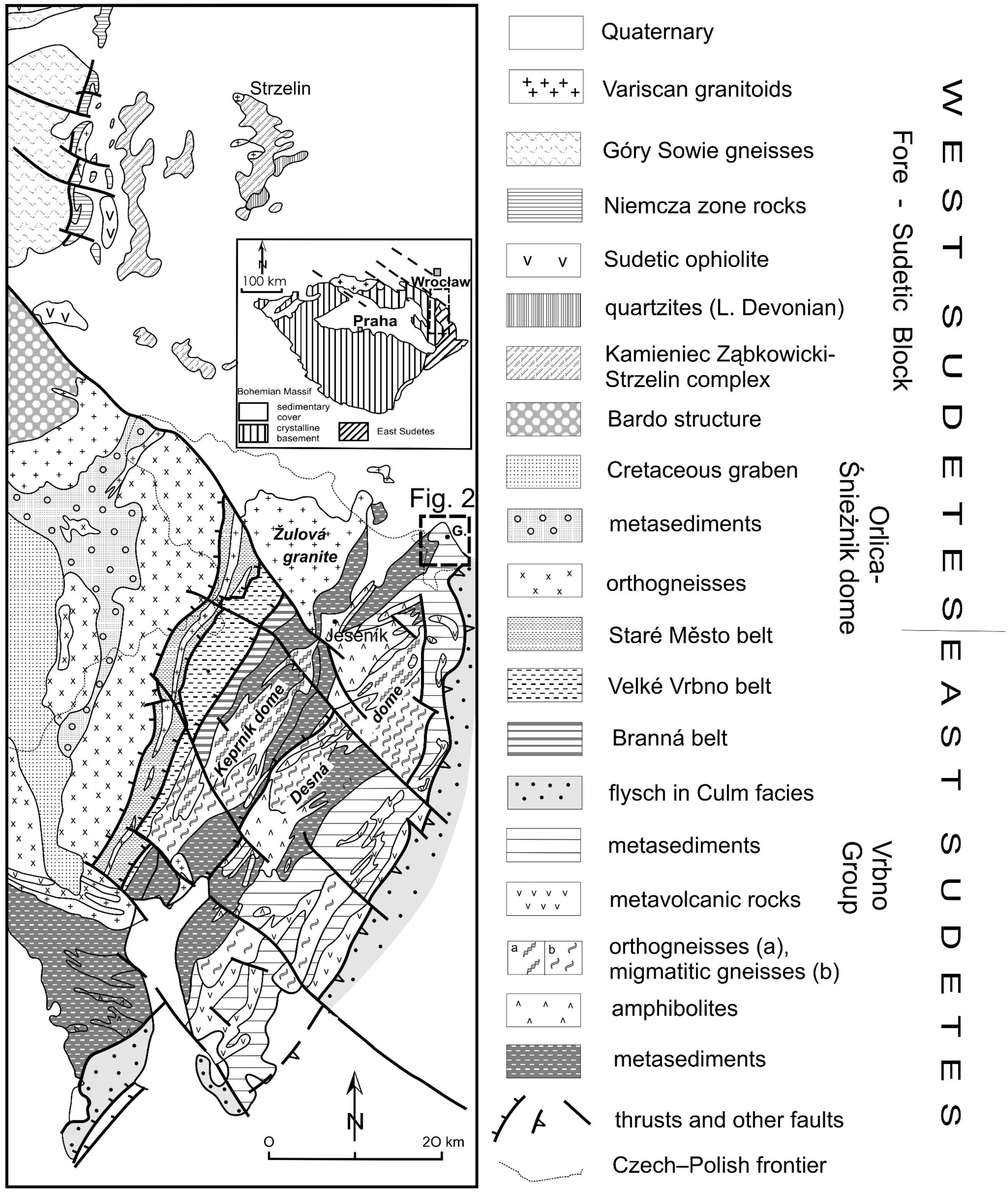


Fig. 1. Geological sketch of the East Sudetes and their continuation to the Fore–Sudetic Block, after the Geological Map of Czechoslovakia 1:500,000 (Kodym *et al.*, 1967) and Geological map for tourists – Jeseníky (ČGÚ), modified. Inset shows position of the region with respect to the Bohemian massif and location of the study area.

vonian fauna (Chlupáč, 1989), from the insuffcient age data, resulting in poor resolution of structures that developed at different times. Isotopic datings of cross-cutting igneous features usually help in such instances as similar problems apply to basement-cover relationships worldwide. In this paper, we report on discriminating between the Cadomian structures and Variscan overprint in a basement fragment at the northern termination of the Jeseníky Mts. in SW Poland.

REGIONAL SETTING

In the Jeseníky Mts., in the northern section of the Moravo-Silesian Zone exposed in the Czech Republic and SW Poland, there are two discernable antiformal domes in which basement orthogneisses are enveloped by medium- to high-grade metasediments (Fig. 1). The western unit is known as the Keprník dome and the eastern one as the Desná dome. Orthogneisses were isotpically dated (Sm-Nd, U-Pb, Pb-Pb), yielding ages between 684 Ma and 502 Ma in the Desná dome and 584 and 546 Ma in the Keprník dome. These were all interepreted as magmatic ages (van Breemen *et al.*, 1982; Hegner & Kröner, 2000; Kröner *et al.*, 2000). On the eastern flank of the Desná dome, there are quartzites, phyllites, mica schists, paragneisses, greenschists, amphibolites and limestones that have been distinguished for over a hundred years as the Vrbno series (beds) and assigned to the Lower Devonian on account of Rhenish-type fauna preserved in lowermost quartzite (Römer, 1865; Chlupač, 1989). To the northwest, at the periphery of the Desná dome, the Vrbno series is said to come along the Ondřejovice Fault (not shown, however, on most of the maps of this region) into contact with the Rejvíz series composed of unfossiliferous biotite paragneisses and mica schists accompanied by amphibolites and quartz-silicate rocks. The latter series has been treated either as an age equivalent of the Vrbno series (Chlupač, 1975), or as a unit that consists of older (Proterozoic) lower portion and of Devonian upper part which also embraces some quartzites (Skácel, 1958; Souček, 1978a,b). Because the quartzites of the Vrbno and Rejvíz series appear lithologically identical and contain identical Lower Devonian fauna assemblages, Chlupač (1975) concluded that they are identical in lithostratigraphic position and chronostratigraphic range.

Chlupač (1989) proposed a lithostratigraphic scheme of rock units in the Hrubý Jeseník Mountains. In this subdivision, the Vrbno series is established as the Vrbno Group, with its lower part composed of the Basal Phyllite and the Drakov Quartzite. The Devonian Vrbno Group is underlain by the Desná Group metagranites and metasediments and overlain by the Andělska Hora Formation of Lower Carboniferous flysch sediments. A protolith of the plagioclase-mica schists in the Desná Group (dome), considered volcanic greywacke or tuff, was probably deposited around 600 Ma as judged from five analysed (Pb-Pb evaporation) idiomorphic zircons retrieved from these rocks (Kröner *et al.*, 2000). This data along with ~685–500 Ma metagranites confirmed earlier assumptions and proved Neoproterozoic age of the Desná Group.

In contrary to the Vrbno Group, no lithostratigraphic column for the Rejvíz series (Group) has been published, and its stratigraphy remains much unclear. Chlupač (1975) treats the two groups as strict equivalents, thus the quartzites in the Rejvíz series should also occur in its basal part as the Drakov Quartzite in the Vrbno Group. However, such a view directly contradicts stratigraphic solutions of Skácel (1958, 1972) who did a detailed mapping in the region and proposed that the quartzites equivalent to those of the Vrbno Group appear in the upper part of the Rejvíz series. In this case, the Rejvíz series obviously cannot be taken as a counterpart of the Vrbno series in which the quartzite occupies the basal part and the unfossiliferous paragneisses, mica schists and amphibolites of the lower portion of the Rejvíz series can hardly be assigned to the Devonian. Late Proterozoic age of parts or all of these rocks is then conceivable in line with earlier assignments of Skácel (1958, 1972). Other authors adhere to either Skácel's or Chlupač's views and do not discuss stratigraphic questions.

Following Kettner (1922), the older rocks have long been considered to be of Algonkian age by virtue of their lithological similarities to pre-Palaeozoic deposits in West and Central Bohemia, and with the advent of radiometric dating, they were established as and are commonly treated as part of the Cadomian basement. The detailed stratigraphic problems are beyond the scope of this paper and cannot be discussed basing on very limited data from the Polish territory. Nevertheless, it seems quite possible that the lower portion of the Rejvíz series may be compared and possibly correlated with Neoproterozoic metasediments of the Desná Group, while the upper portion of this series may be Devonian in age as suggested by Skácel (1958, 1972). It cannot be excluded that only the fossil-bearing quartzites in the Rejvíz series (equivalent of the Drakov quartzite) represent the Lower Devonian. Such an alternative applies to other occurrences in the Jeseníky Mts. where rocks assigned to the Devonian are deformed and metamorphosed together with its Proterozoic basement. Since the Precambrian and Devonian metasediments in the Jeseníky Mts. are strongly refolded, foliated, and tectonically shuffled, it is difficult to distinguish mica schists and paragneisses of different ages and assign them appropriately, which may lead to serious errors in regional lithostratigraphic and tectonic interpretations. Erroneous age

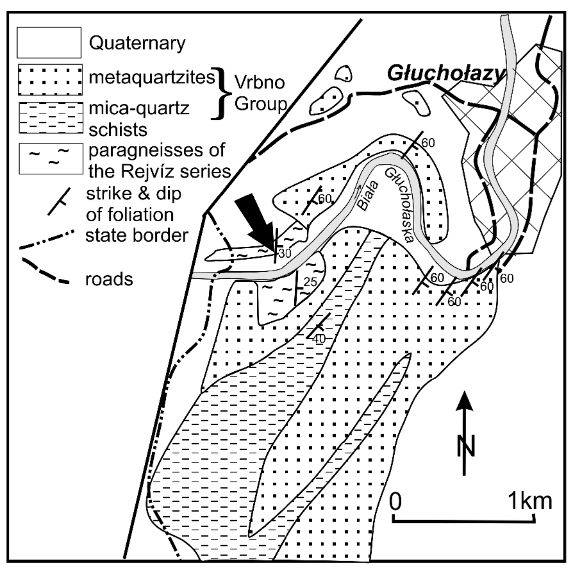


Fig. 2. Geological sketch of the Głuchołazy area after Majerowicz & Sawicki (1958), modified. Arrow indicates sampling site.

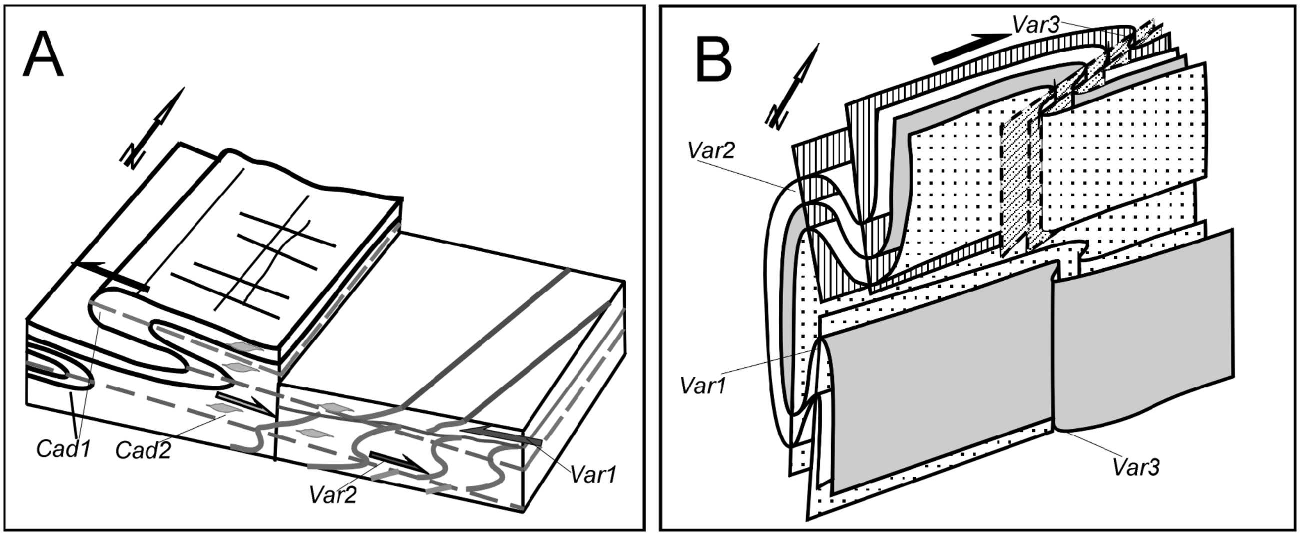


Fig. 3. Block diagrams summarizing structural features at the top of the Rejvíz series (**A**) and at the bottom part of the Vrbno Group (**B**) near Głuchołazy. Cad1, Cad2 – sequential Cadomian features; Var1, Var2, Var3 – sequential Variscan features.

assignments may also apply at least to (some) metabasites occurring among the rocks of the Rejvíz series which are all considered to have evolved from Lower Devonian protoliths (Souček, 1978a,b, 1981).

At the northern termination of the Hrubý Jeseník Mts. in the Głuchołazy area, East Sudetes, SW Poland, rocks of the Rejvíz series and the Vrbno Group are in contact (Fig. 2). To the west of the town of Głuchołazy, on both banks of the Biała Głuchołaska River, there are (1) outcrops of biotite paragneisses of the Rejvíz series, accompanied by minor layers of quartz-amphibole-epidote schists and amphibolite boudins, and (2) outcrops of quartzites and quartz-muscovite±staurolite schists of the Vrbno Group. The two units differ there significantly in terms of lithology and structures, but represent a similar grade of amphibolite-facies metamorphism.

LITHOLOGY

The Rejvíz series

The biotite paragneiss is a medium-grained, excellently foliated rock, composed of a biotite-plagioclase-quartz assemblage, with some garnet and muscovite (Si contents p.f.u. = 3.12), and accessory ilmenite and tourmaline. The plagioclase in the matrix has An contents of 27–33%, and shows reverse (An_{27} in the inner parts to An_{33} in the outer parts of grains) and normal zoning (Ca decreasing towards the rims). The plagioclase inclusions in the garnet have An contents varying between 6 and 25%. Almadine garnet, usually poikiloblastic, has a composition of Alm_{60-64}-Py_{9-12}-Grs_{3-6}- Sps_{2-19}, with Ca and Mn decreasing towards the rims. The recognized types of compositional zoning in both plagioclase and garnet point to prograde metamorphism. Using the garnet and biotite rim compositions in the grt-bi geothermometer of Ferry & Spear (1978), a peak temperature of T = 600°C (556–642°C) at P = 5 kbar (calculated for the amphibolites) was estimated for the paragneisses.

Amphibolites that originated as tholeiitic dolerite veins, occur in the study area as up to 40 cm thick, boudinaged layers in the paragneisses. They represent a medium-grained, moderately foliated rock, composed of tschermakitic amphibole and plagioclase (An_{35-45}), with minor rutile, quartz and ilmenite. The peak conditions of metamorphism were calculated by means of the plagioclase-amphibole geothermobarometer of Plyusnina (1982) for the An-richest plagioclase paired with the tschermakite grains which define the foliation. The estimates range between 560 and 610°C and 4 and 6 kbar, yielding a mean T = 590°C and P = 5 kbar, which fits the P-T data for the paragneisses well and hints at a common metamorphic history for both rocks. At their margins, the amphibolites are strongly schistose, turning to biotite schists which form borders with the host paragneisses. Compositionally, the studied amphibolites do not differ significantly from the amphibolites occurring within the Devonian series although the latter are richer in SiO_2 and contain actinolite as noted by earlier workers in the Głuchołazy area (Majerowicz & Sawicki, 1958; Muszyńska, 1989).

In the paragneisses, disrupted and folded layers and boudins of calc-silicate rocks can be observed. They are composed of alternating layers of which one consists of tschermakite-epidote-almandine-anorthite and the other of quartz-epidote-almandine-anorthite.

The felsic injections which cut the paragneiss, metatholeiite and calc-silicate layers range from up to 40-cm thick dykes of leucogranite and pegmatite down to < 1-cm quartzo-feldspathic veinlets. They are composed of K-feldspar-plagioclase-quartz-muscovite±garnet.

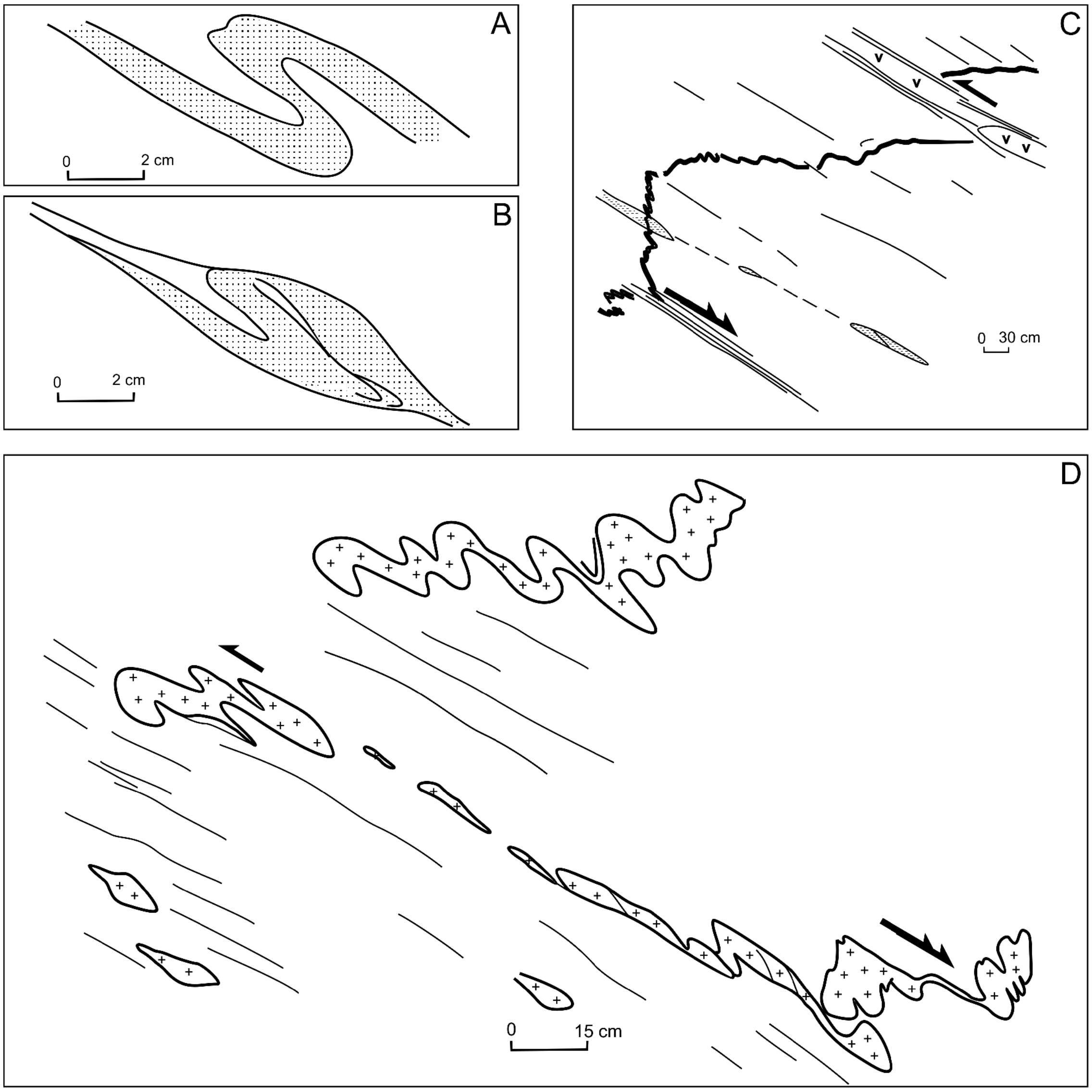


Fig. 4. Structural sequence observed in the biotite paragneisses of the Rejvíz series. **A** – N–trending, W–vergent fold in an early quartz segregation (stippled) in the biotite paragneiss. **B** – associated shearing turned fold A into a rootless intrafolial fold, then the structure was amplified by early (Neoproterozoic) E–vergent shearing (drawing from a photograph, see Fig. 5). **C** – paragneisses embrace: (1) extended and boudinaged calc–silicate rocks (ornamented) during early shearings, finally with top-to-the-east kinematics (Neoproterozoic); (2) metabasic vein (ticks), also boudinaged due to the same E–vergent shearing (Neoproterozoic); and (3) felsic vein (thick black line, ~580 Ma) cross-cutting both calc–silicate and metabasite layers, which was folded and sheared (Devonian/Carboniferous, earlier possibly in Cambrian) in a rotational regime with top-to-the-west kinematics (single headed arrow; see Fig. 5), with shearing often localized at the rheologically contrasting boundaries (basite–paragneiss), displacing the felsic veins with the same kinematics (drawing from a photograph). D – later superposed (younger, Carboniferous) ductile shearing (double-headed arrow) which zonally displaced the folded vein owing to a top-to-the-east movement (drawing from a photograph; see Fig. 11, 12). A and B are pre-580 Ma structures, C and D depict mostly post-580 Ma structures.

The quartzites and schists of the Vrbno Group

The quartzites are arenites, with quartz strongly dominating over feldspars. The quartzite layers can be 0.2 m to 5 m thick. They alternate with thinner muscovite-quartz schists with accessory feldspar ± staurolite ± biotite ± almandine ± magnetite ± sillimanite occurring in occasional banded concentrations. The schist layers are 0.01 to ~5 m thick. These rocks developed from a sandstone-mudstone series.

STRUCTURAL DATA

The Rejvíz series

The foliation planes in the biotite paragneisses dip gently to the east (Fig. 3A). On the foliation, biotite flakes are arranged in one direction defining a mineral lineation plunging gently E-ward (parallel to a weak corrugation lineation related to late kink folds). In sections parallel to the lineation and perpendicular to the foliation, asymmetric pods and sigma clasts derived from the foliation-parallel quartz segregations show variable senses of movement: top-to-the-E and top-to-the-W. In thin sections, a similar varying kinematics is shown by disrupted, foliation-parallel quartz segregations, and by garnet and occasional plagioclase porphyroclasts.

The presence of the cross-cutting leucogranitic to pegmatitic veins is critical for the study of the area, as it allows the differentiation of the history of the paragneisses into two stages: before and after the felsic injections. The pre-injection event probably consisted of more than one deformation episode (Fig. 4A, B). The intersection relationships yield evidence that prior to the felsic injections in the gneisses: (1) the quartz segregations were folded, with the formation of rootless intrafolial folds (Fig. 5), (2) the calc-silicate schists were also folded and disrupted by shearing parallel to the penetrative axial planar foliation (Fig. 6), and (3) the tholeiitic veins became metamorphosed and boudinaged. The earliest, N-trending asymmetric rootless folds in the paragneisses and in the calc-silicate schists in the study area seem to show predominantly westerly vergence, but the superposed shearing and formation of asymmetric boudins, pods and porphyroclasts occurred in a regime with the top-to-the-E kinematics (Figs 3A, 4, 7). Thus, the evidence of E-ward transport seen in these rocks is taken as a characteristic of the pre-injection event.

The felsic injections are variably discordant to concordant (Fig. 8). The thick veins (~30–40 cm) remain almost unfolded; however, thinner veins (0.5–4 cm) are deformed in open asymmetric to tight folds (Fig. 9). The thic- kness of the veins controlled their ability to fold. During folding, the veins were clearly more competent than the schistose paragneiss host. Folds of meter-scale amplitude developed "**Z**-type" and "**S**-type" second order folds in their opposite limbs, testifying to buckling and flexure; these were then amplified by shearing. The asymmetry of the larger folds indicates a westerly vergence (Figs 4C, D, 11).

The deformed veins allow us to infer the orientation of the strain ellipse and relate to it the folded and elongate vein sections, the latter being at a low angle to the pre-existing foliation in the host paragneisses. Furthemore, sectors in the strain ellipse which comprise the shortened and elongated lines (the radii of the ellipse) can be shown (Fig.

Fig. 5. W-vergent fold in the quartz segragation transformed to an intrafolial fold during superposed foliation–parallel shearings (see Fig. 4A, B). This and all other photographs represent W–E (right side) sections parallel to the lineation and perpendicular to the foliation (= XZ section of the strain ellipsoid).

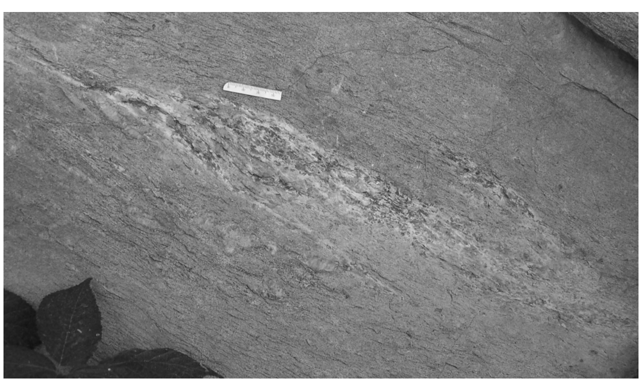


Fig. 6. Calc-silicate layer deformed by an early, pre–580 Ma, top-to-the-east shearing.

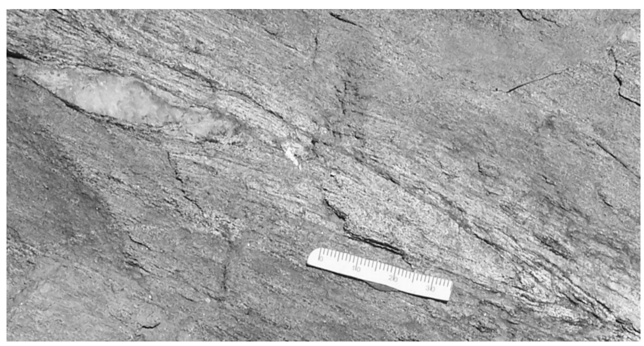


Fig. 7. Oblique fabric in paragneisses imparted by an early top-to-the-east shearing.

Fig. 8. A pegmatite dyke in paragneisses. Felsic (leucogranitic to pegmatitic) vein set with interconnecting off-sets intersects paragneisses. Relatively thick veins show folds only at their margins; the foliation, defined by parallel arranged muscovites and elongate/flattened quartz grains, is a penetrative feature.

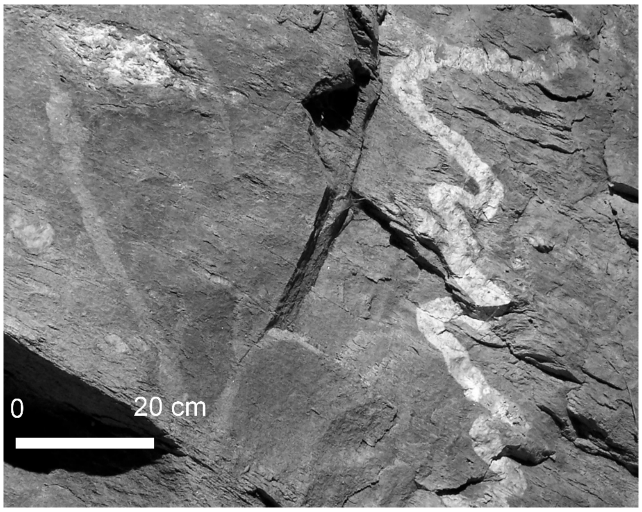


Fig. 9. Buckled felsic vein with "z"-shaped minor folds of the shorter limb. Note a single pod (upper left corner) of the dismembered calc-silicate layer due to pre–580 Ma top-to-the-east shearing.

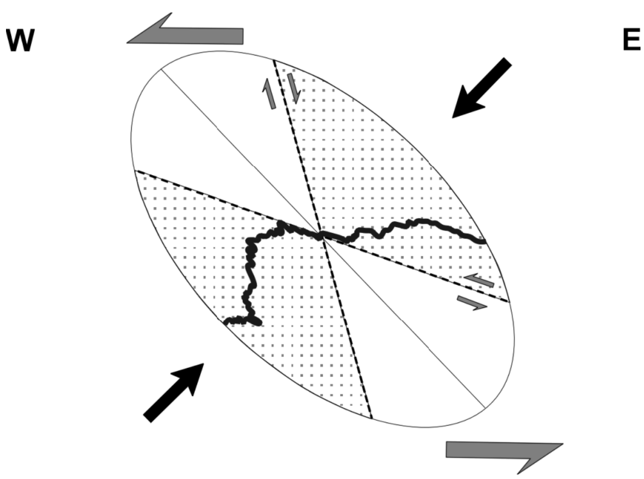


Fig. 10. Strain ellipse showing the orientation of structural elements during the folding of the felsic vein (thick black line, see Fig. 4C).

10). The inferred strain ellipse explains the geometry of the folds and confirms an overall top-to-the-W kinematics and the roughly foliation-normal shortening during the ductile folding and associated shearing of the felsic veins (Fig. 4C).

The last recognizable ductile event in the rocks of the Rejvíz series was identified as top-to-the-E shearing, a post-injection event that is well marked by the deformed felsic veins. The amount of transport due to this late ductile shearing along the rejuvenated foliation planes in the gneisses can be quantified by direct observations of the displacements of the folded veins. Fragments that once adhered to each other may now be up to 70 cm apart due to the E-directed movement in the localized shear zones (Figs 11, 12). Such strain zones are heterogeneously distributed with spacing of 15 to 150 cm (and above). They obviously added to the considerable to total eastward tectonic displacement experienced by the studied rock complex; however, this contribution was difficult to assess in the limited study

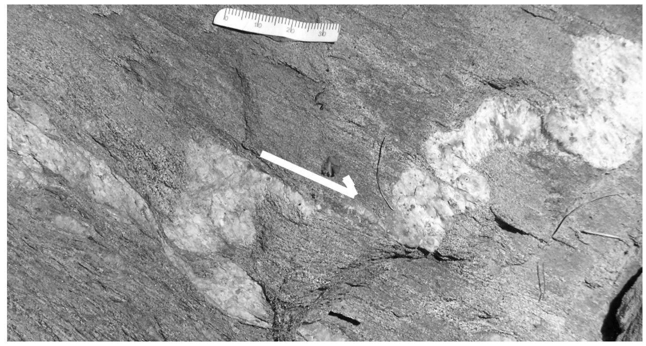


Fig. 11. A fragment of the folded felsic vein (crossed) subjected to top top-to-the-west (left) and then top-to-the-east (centre right) shearing. Note the mullion-type folds (right) with characteristic cuspate entrants of the less competent paragneiss into the more competent leucogranitic vein. In mullions, the sharp contact always points towards the competent unit. Such structures develop due to layer-parallel shortening (in this case parallel to the vein and perpendicular to the foliation in the country paragneiss, see Fig. 10).

Fig. 12. A folded felsic vein subjected to younger top-to-the-east shearing which is localized in zones of more intense shear strain. In such zones (there are three on the photo seen in its upper, middle and lower parts), the vein may be completely sheared out and vanish. In the intervening low strain zones, the folded vein managed to retain its earlier geometry acquired during folding. Note that the vein cuts the older quartz segregation. White scale-bar in the middle is 3.5 cm long.

area. The intervening areas between the post-injection E-vergent shear zones conserve the earlier folded (buckled) veins which became strongly sheared and even almost totally desintegrated inside the shear zones themselves (Fig. 12). Both of the post-injection shear events in the Rejvíz rocks, the W-vergent and the E-vergent one, availed of the contrasting rheological boundaries, i.e. gneisses and the marginally schistose amphibolites (Fig. 4C).

The quartzites and schists of the Vrbno Group

West of Głuchołazy, the paragneisses of the Rejvíz series are in contact with thick-bedded, massive quartzites (the Drakov quartzite) of the Vrbno Group. The Basal Phyllite has not been detected (if originally present there, it could be tectonically reduced by later shearing). Bedding-parallel foliation in the quartiztes is dipping monoclinally to the ESE at an angle of 55–60°. Several tens meters away of the contact, the quartzites become interbedded with micaceous quartzites and mica schists (stratigraphically higher in the Vrbno Group). The schists underwent multiple ductile deformation and developed three sets of mesoscopic folds accompanied by the axial planar foliations and shearing (Fig. 3B). Folds of the two older sets have subhorizontal NE-trending axes which are almost parallel or plunge at slightly different angles, being associated with composite intersection and mineral lineations. Observed in a single foliation plane, the earliest folds which display S-type geometry and top-to-the NW kinematics became refolded by folds displaying Z-type geometry and top-to the SE kinematics. Then the two sets were folded by folds subvertical or steeply plunging to the NE, with more localized axial planar foliation. Their asymmetry is evidence of a dextral strike-slip (oblique) regime (Fig. 3B).

Relationships between the Rejvíz series and the Vrbno Group near Głuchołazy

Unfortunately, no interface between the paragneisses of the Rejvíz series and the quartzites of the Vrbno Group is exposed at the studied site. The foliation planes in the biotite paragneisses strike N–S, dipping at an angle of 20–30° to the E, whereas the quartzite beds dip at an angle of 40–65° to the ESE/SE, which is by 25–35° higher and allows to infer an originally disconformable contact of the two rock units. Such a contact was likely later tectonically reworked, although not necessarily by the northern continuation of the Ondřejovice fault whose presence along the studied contact sector cannot be confirmed.The sequence of structures observed in the two lithostratigraphic units across the border area near Głuchołazy differs significantly (Fig. 2 and 3), which testifies to their different structural histories. Therefore, we expect that the biotite paragneisses and quartzites also differ in their protolith age as suggested by Skácel (1958, 1972) and the plausible original unconformity was masked during the superposed tectonic events when the Devonian rocks must have been depressed down to a depth of amphibolite facies conditions, which allowed for their progressive metamorphism. Since the paragneisses of the Rejvíz series were already deformed and metamorphosed, the metamorphic overprint at roughly the same P-T conditions may have passed unnoticed. In other places and on the regional scale, contacts usually appear secondary due to later tectonic adjustment by the superposed shearing. Cháb *et al.* (1990, 1992) even claim a wholesale decollément between the Cadomian basement and Devonian cover. The Rejvíz series/Vrbno Group contact may possibly be entirely tectonic, being a shear zone localized in the Basal Phyllite which may have become greatly reduced in thickness. Quite a similar relationship may be expected to occur between the quartzites and other lithologies distinguished as the Rejvíz series, then the quartzites would represent an allochthonous unit stratigraphically belonging to the Vrbno Group and tectonically displaced over older rocks in the Hrubý Jeseník Mountains.

ISOTOPIC STUDIES

Previous data

Several isotopic age numbers (Sm-Nd, Pb-Pb, U-Pb) obtained by Hegner & Kröner (2000) and Kröner *et al.* (2000) display a wide interval of dates between 684 Ma and 502 Ma for the Desná dome orthogneisses (_Nd$_{(t)}$ +0.5 to –4), and between 584 Ma and 555 Ma for the Keprník dome orthogneisses (_Nd$_{580}$ –3 to –7), and around 600 Ma for the volcanic greywacke/tuff protolith of the (Desná Group) plagioclase-mica schists (_Nd$_{600}$ –3 to –7). Van Breemen *et al.* (1982) studied the U-Pb systematics of zircons from the Keprník gneisses which gave an upper intercept age of 1422+191/–177 Ma and a lower intercept age of 547+6/–8 Ma, but they noted that the latter is probably too low. Referring to this note and based on their own data, Kröner *et al.* (2000) suggest that the igneous precursors of these gneisses intruded at ~583 Ma and at ~555 Ma, and represent a Cadomian basement. A similar protolith age of ~574 Ma was also determined by them for the (Velké Vrbno) orthogneisses occurring to the W of the Keprník dome. The time of gneissification remained unconstrained in that study.

In the Desná dome, the granitic protoliths of the different gneiss variants were emplaced at ~684 Ma, ~517 Ma and 507–502 Ma, and became foliated in the latter period (Kröner *et al.*, 2000). No particular account of the regional geological significance of these age groups was offered.

Material sampled for this study

To place some time constrains on the features recognized by us in the Głuchołazy area, it is essential to know when the felsic veins intruded the paragneisses. For this purpose, zircons for U-Pb analyses and muscovites for Rb-Sr studies were retrieved from the foliated pegmatitic to leucogranitic vein exposed in an old quarry on the left bank of Biała Głuchołaska (Figs 2, 13).

The zircons are mostly 150–200 –μm long, euhedral and prismatic, with a low aspect ratio of 1:2 to 1:3, and oscillatory zoning characteristic of igneous rocks (Fig. 14). Some of these grains have dark (richer in U) cores (1 and 2), while others have an evidently different growth pattern (6). Zircons with simple sector zoning are rare (11). Only a few grains represent rounded anhedral fragments of larger crystals with simple zoning (10), and this minority may be detrital.

Muscovite grains retrieved from the sampled rocks range in size from 0.1 to 20 mm, the latter occurring in the pegmatitic portion of the felsic vein.

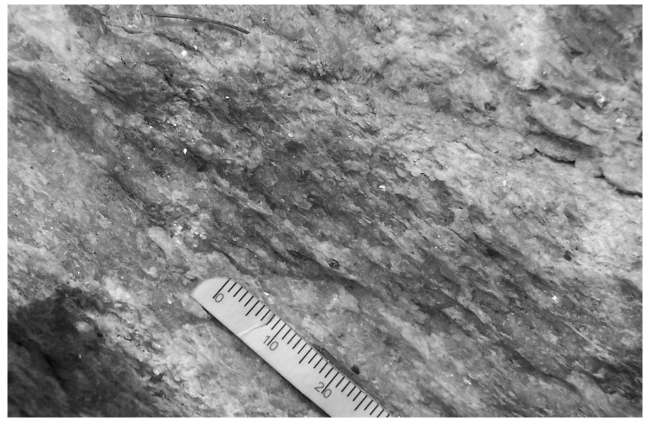


Fig. 13. A close-up of the sampled pegmatitic vein; note the pervasive foliation.

METHODS

U-Pb analysis

After a standard heavy liquid and magnetic separation procedure, zircons were handpicked under a microscope, mounted in epoxy and polished. Transmitted and reflected light photomicrographs and CL images were made in order to select grains and choose sites for analyses omitting cracks and inclusions. The Sensitive High-Resolution Ion Microprobe (SHRIMP II) at the Center of Isotopic Research (CIR) of the All-Russian Geological Research Institute (VSEGEI), St. Petersburg, was used to perform *in situ* U-Pb analyses by applying a secondary electron multiplier in a peak-jumping mode following the procedure described in Williams (1998) or Larionov *et al.* (2004). A primary beam of molecular oxygen was employed to bombard the zircon in order to sputter secondary ions. The elliptical analytical spots were c. 27 × 20 μm, and the corresponding ion current was c. 4 nA. The sputtered secondary ions were extracted at 10 kV. The 80-μm wide slit of the secondary ion source, in combination with a 100-–μm multiplier slit, allowed a mass-resolution of M/ΔM 5000 (1% valley), so that all the possible isobaric interferences were resolved. One-minute rastering over a rectangular area of c. 60 × 50 μm was employed before each analysis in order to remove the gold coating and possible surface contamination with common Pb.

The following ion species were measured in sequence: $^{196}(Zr_2O)$-^{204}Pb-background (c. ^{204} AMU)-^{206}Pb-^{207}Pb-^{208}Pb-^{238}U-^{248}ThO-^{254}UO, with an integration time ranging from 2 to 20 seconds. Four cycles for each spot analyzed were acquired. Every fifth measurement was carried out on the zircon Pb/U standard TEMORA (Black et al., 2003) with an accepted 206Pb/238U age of 416.75±0.24 Ma. The 91500 zircon with a U concentration of 81.2 ppm and a

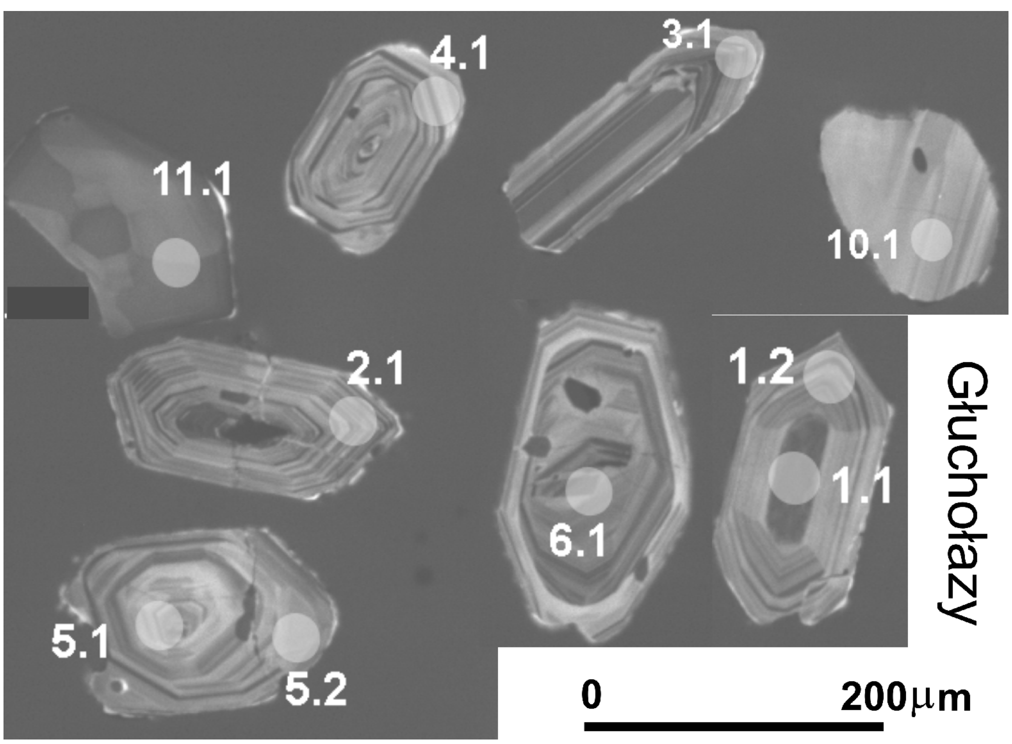


Fig. 14. Examples of the analysed zircons in CL images.

U–Pb isotopic results

Spot	% $^{206}Pb_c$	$^{204}Pb/^{206}Pb$	ppm U	ppm Th	$^{232}Th/^{238}U$	ppm $^{206}Pb^{*}$	(1) $^{206}Pb/^{238}U$ Age		(1) $^{207}Pb/^{235}U$ Age	(1) $^{207}Pb/^{206}Pb$ Age	
GLUCH.6.1	0.04	0.00002	256	52	0.21	20.3	569	4	573	589	44
GLUCH.13.1	–	–	273	92	0.35	21.8	573	36	573	571	32
GLUCH.7.1	0.02	0.00001	308	72	0.24	25.0	581	4	582	586	31
GLUCH.12.1	–	–	130	23	0.19	10.6	584	5	602	667	43
GLUCH.3.1	0.04	0.00002	677	239	0.36	56.7	599	3	588	548	22
GLUCH.2.1	0.02	0.00001	315	120	0.39	27.0	613	4	610	596	30
GLUCH.11.1	0.02	0.00001	280	259	0.96	24.0	614	4	615	618	42
GLUCH.8.1	--	--	103	53	0.53	8.9	615	7	626	663	56
GLUCH.4.1	0.01	0.00001	254	190	0.77	22.0	618	4	616	612	29
GLUCH.1.2	0.16	0.00009	310	117	0.39	27.6	634	4	645	684	44
GLUCH.9.1	0.07	0.00004	400	336	0.87	35.7	637	4	648	688	26
GLUCH.1.1	--	--	798	324	0.42	74.7	667	4	661	640	31
GLUCH.5.2	0.01	0.00000	174	41	0.24	36.6	1409	9	1417	1429	17
GLUCH.10.1	0.10	0.00006	83	36	0.45	17.6	1426	12	1423	1419	31
GLUCH.5.1	--	--	147	83	0.59	31.3	1431	11	1442	1459	25

Errors are 1-sigma; Pb and Pb indicate the common and radiogenic portions, respectively.
Error in Standard calibration was 0.35%.
(1) Common Pb corrected using measured Pb

206Pb/238U age of 1062±Ma (Wiedenbeck *et al.*, 1995) was applied as a "U-concentration" standard. The collected results were then processed with the SQUID v. 1.12 (Ludwig, 2005a) and ISOPLOT/Ex 3.22 (Ludwig, 2005b) software, using the decay constants of Steiger & Jäger (1977). The common lead correction was done using measured 204Pb according to the model of Stacey & Kramers (1975).

Rb-Sr analysis

From the metapegmatite fragments of a whole rock, 4 size fractions of muscovites (>2; 4–2; 0.7; 0.12 mm) and 3 single large muscovites were taken as samples for isotopic study in the Geochronological Laboratory of the Institute of Geological Sciences, Polish Academy of Sciences, Warsaw. The material was prepared according to a standard chemical procedure described by Bachliński & Smulikowski (2001). All the sampled materials were powdered in an agate mortar. About 100 mg of powder of every sample was split into two like parts – one for measuring the $^{87}Sr/^{86}Sr$ isotopic ratio (called natural strontium) and the other for measuring Rb and Sr concentrations using the isotopic dilution method (ID). The second series was mixed with a ^{87}Rb (50.4 ppm) + ^{84}Sr (0.8 ppm) spike. Each sample part was dissolved in 1 ml 65% HNO_3 teflon-distilled (TD) and 5 ml 40% HF TD acids for 3 days in PTFE beakers. After this time, all the sample parts were evaporated and dissolved for 24 hours in 5 ml 6 M HCl TD acid. Next, the samples were centrifuged for 15 min at 4000 rpm, and the solutions were evaporated to dryness. Then, each sample part was dissolved in 2 ml 2.5 M HCl TD. 1 ml of solution was run on a chromatographic column filled with AG 50W-X8 (200–400 mesh) cation resin (made by Bio-Rad Laboratories, US). Rb and Sr were collected in a stepwise evaluation process. The $^{87}Sr/^{86}Sr$ isotopic ratios and Rb and Sr concentrations were measured with a VG Sector 54 mass spectrometer in multi-collector dynamic mode. All the results were normalized to $^{86}Sr/^{88}Sr = 0.1194$ to correct for machine fractionation. Replicate analyses of the NBS SRM 987 standard gave an average normalized $^{87}Sr/^{86}Sr$ ratio of 0.710252 ± 0.000020 (2σ, n = 22). The $^{87}Rb/^{86}Sr$ isotopic ratios and ages were calculated by Isoplot (Ludwig, 2000).

RESULTS

Zircons

The results of the zircon analyses are shown in Table 1 and in Figure 15. They revealed that the zircons have a typical magmatic Th/U ratio of 0.2–0.9 (Table 1), which is consistent with their mostly euhedral shapes and oscillatory zoning. On the concordia diagram, 2 discrete groups of concordant (within 2%) U-Pb ages occur at ~1400 Ma and at ~600 Ma (Fig. 15). The three oldest analyses (grains 5 and 10) yield a mean concordant age of 1423±11 Ma, and they certainly represent an inheritance from a Mesoproterozic crust (Fig. 15A). The other group actually consists of two clusters, with the older one represented by 4 nearly concordant analyses yielding a mean concordia age of 615±5 Ma and the younger represented by another 4 almost concordant analyses yielding a mean concordia age of 578±5 Ma (Fig. 15B). As most of the zircons are euhedral,

Table 1

of zircon analyses

(1) $^{208}Pb/^{232}Th$ Age		% Discordant	Total $^{238}U/^{206}Pb$ ±%		Total $^{207}Pb/^{206}Pb$ %±		(1) $^{238}U/^{206}Pb^*$ ±%		(1) $^{207}Pb^*/^{206}Pb^*$ ±%	
598	19	4	10.83	0.8	0.0600	1.8	10.83	0.81	0.060	2.0
541	37	0	10.76	6.6	0.0586	1.3	10.76	6.58	0.059	1.5
608	14	1	10.59	0.8	0.0597	1.3	10.60	0.76	0.060	1.4
688	25	14	10.54	0.9	0.0615	2.0	10.54	0.91	0.062	2.0
627	8	–9	10.27	0.6	0.0588	0.8	10.27	0.59	0.058	1.0
639	22	–3	10.02	0.7	0.0600	1.2	10.02	0.69	0.060	1.4
646	8	1	10.01	0.7	0.0606	1.7	10.01	0.71	0.060	1.9
661	20	8	10.00	1.1	0.0601	2.2	9.98	1.11	0.062	2.6
641	9	–1	9.94	0.7	0.0603	1.3	9.94	0.72	0.060	1.4
673	18	8	9.65	0.7	0.0636	1.2	9.67	0.71	0.062	2.1
693	8	8	9.63	0.7	0.0630	1.0	9.63	0.65	0.062	1.2
713	29	–4	9.18	0.6	0.0608	1.4	9.18	0.62	0.061	1.4
1507	27	1	4.09	0.7	0.0902	0.9	4.09	0.72	0.090	0.9
1527	37	0	4.04	0.9	0.0905	1.3	4.04	0.92	0.090	1.6
1560	28	2	4.03	0.8	0.0899	1.0	4.02	0.84	0.092	1.3

have oscillatory zoning and display no systematic difference between grains of various ages, the zircons of 615±5 Ma are interpreted as evidence of granitic magma formation in the crust. The zircons of 578±5 Ma age are taken to reflect the time of intrusion of the pegmatite dyke, probably towards the end of the Cadomian magmatic activity. Alternatively, the youngest zircons could suffer some Pb loss during later events, thus becoming slightly discordant. Using the age of 615±5 Ma as an anchored U-Pb concordia upper intercept, the discordia was constructed with a lower intercept at 350±5 Ma, which would indicate an early Variscan overprint.

Muscovites

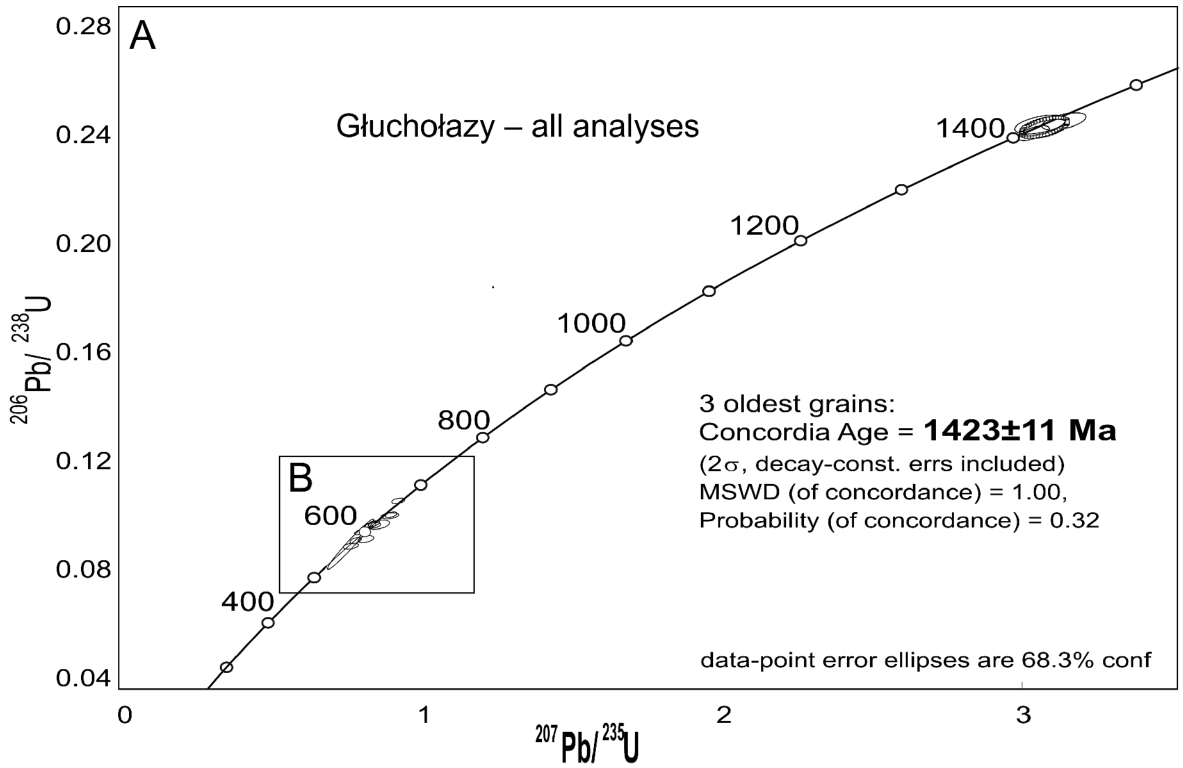
The results of Rb-Sr analyses are shown in Table 2. Maximum concentrations of Rb (about 1300 ppm) are found in large grains of muscovites. A linear relationship is observed between the grain-size and Rb contents, the bigger grain – the larger Rb concentration and the lower content of Sr (Table 2). Moreover, single, large grains of muscovites are characterized by high values of $^{87}Sr/^{86}Sr$ isotope ratios (about 3.00). These values and low concentrations of Sr may reflect very large participation of radiogenic strontium as effect of radioactive decay of rubidium, according to the scheme: ^{87}Rb $^{87}Sr + \beta^- + \nu^- + Q$, where β^- is negative beta particle, ν^- is an antineutrino, and Q is the decay energy (Faure, 1986). The calculated $^{87}Rb/^{86}Sr$ isotope ratios are very high too (about 500), which is of great significance for the obtained isochron age. The distribution of points on the isochron is very even because grain-size fractions were utilized in the isotope analyses, and the calculated error is less than 1%. The Rb-Sr isotopic measurements allowed the construction of an isochron based on 8 points (one whole rock, 4 grain-size fractions of muscovite and 3 single large muscovite grains), yielding an age of 288.7±2.4 Ma and an initial ratio of $^{87}Sr/^{86}Sr_i$ = 0.7100±0.0014 (Fig. 16). The data reflects the time of the passage through the blocking temperature of the Rb-Sr system in the muscovite. This temperature was 550±50°C (Rollinson, 1993), and it may have been even higher (600–650°C) in the large muscovite flakes in the pegmatites, and thus close to crystallization temperature (Cliff, 1985). The U-Pb

Table 2

Rb-Sr isotopic data of whole–rock and separated muscovites

	Sample*	87Sr/86Sr	error [2s]	Sr [ppm]	Rb [ppm]	87Rb/86Sr	error [2s]
1.	Gl-4 WR	0.773404	±0.000011	25.00	133.62	15.5621	±0.3112
2.	Gl-4 (>2)	1.684270	±0.000029	12.00	900.35	237.8377	±4.7567
3.	Gl-4 (4-2)	1.723538	±0.000019	11.91	936.21	250.0105	±5.0002
4.	Gl-4 (0.7)	1.173792	±0.000015	13.91	516.92	112.4215	±2.2484
5.	Gl-4 (0.12)	0.863620	±0.000013	23.34	291.23	36.6498	±0.7330
6.	Gl-4-1	2.864774	±0.000046	8.69	1294.04	521.5731	±10.3415
7.	Gl-4-2	2.697532	±0.000078	7.84	1301.40	481.2105	±9.6242
8.	Gl-4-3	3.064365	±0.000028	7.86	1282.49	580.6245	±11.6125

* WR – whole rock; (>2; 4-2; 0.7; 0.12) – fractions (in mm) of separated muscovites; Gl-4-1, 2, 3 – coarse, single muscovite grains



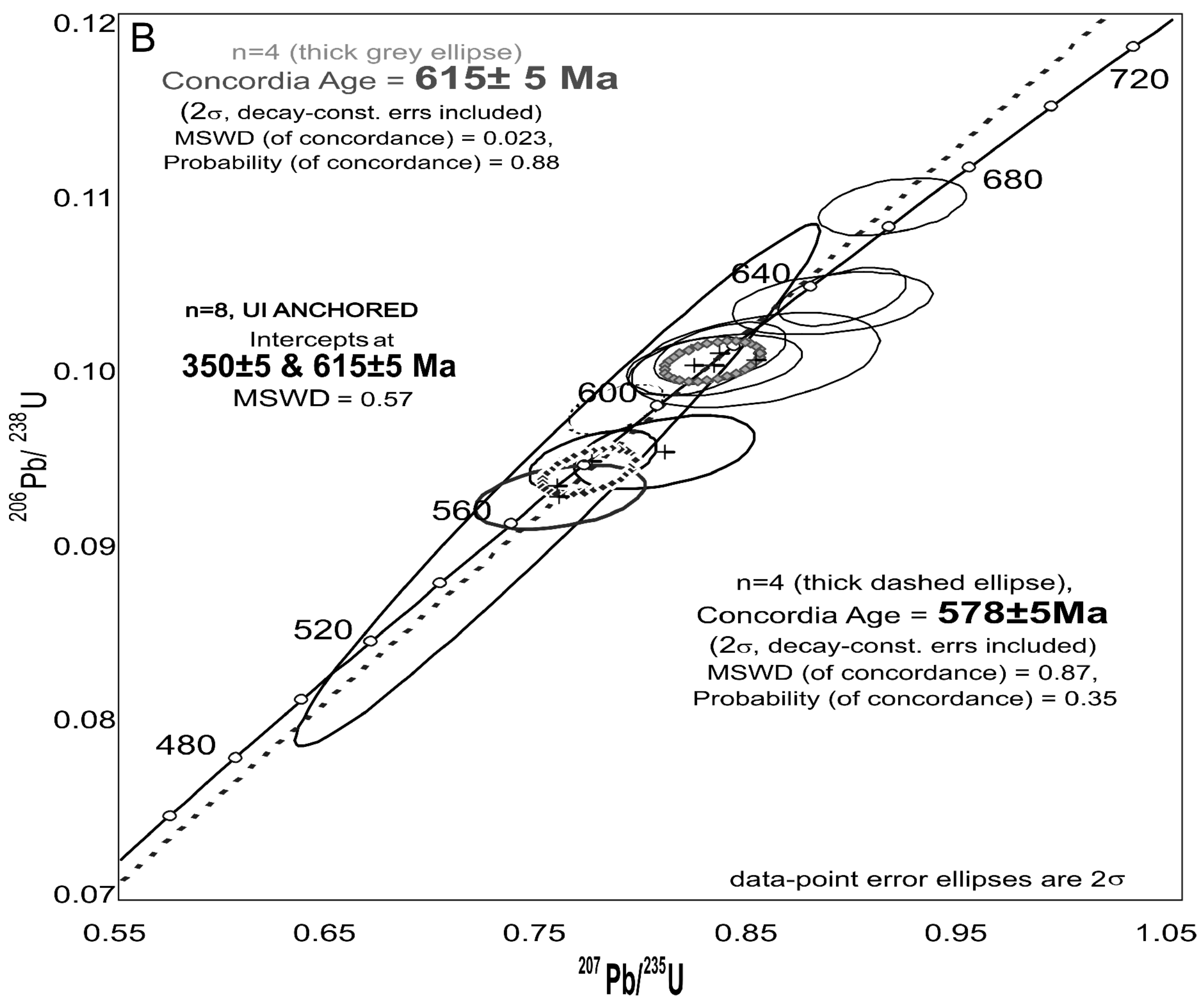


Fig. 15. U-Pb concordia plots. See text for further explanation.

zircon data for the studied pegmatite unambiguously excludes such a young crystallization age. Since the pegmatite became deformed and metamorphosed, our Rb-Sr data may match metamorphism or just cooling. The Sr in our sample must have been totally isotopically reequilibrated during the time that elapsed from the intrusion at ~580 Ma until cooling at ~289 Ma. As no retrogression is visible accompanying the deformation and metamorphism of the pegmatite, the W-vergent shearing responsible for the transformations must have occurred under amphibolite facies conditions. The flattened quartz which defines the foliation in this rock jointly with the reoriented muscovite became statically recrystallized (annealed) to optically strain-free grains, indicating that strain effects were removed (Fig. 17). Such removal requires temperature and time, the two factors which were necessary for the Rb-Sr system to reset. Therefore, the obtained Rb-Sr age of 288.7±2.4 Ma is taken to reflect cooling.

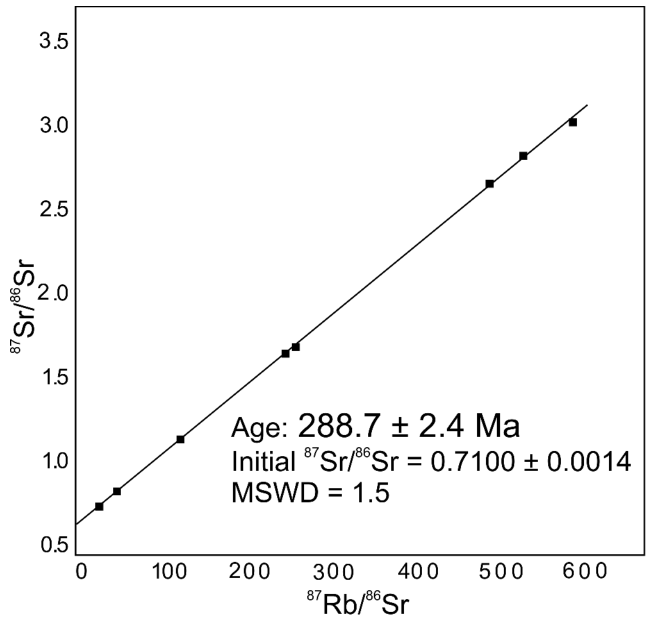


Fig. 16. Rb-Sr isochron diagram. See text for further explanation.

DISCUSSION

The dating of the pegmatite dyke places important constraints on the deformation recognized in paragneisses of the the Rejvíz series near Głuchołazy. The pre-injection folding on the N–S axes and subsequent penetrative shearing with top-to-the-E kinematics (normal regime at the present-day orientation of the foliation) unambiguously occurred in these rocks in Neoproterozoic times. These events are taken as an effect of the Cadomian orogenesis. It is suggested that a remarkable share of the mylonitic features observed in the basement rocks of the Hrubý Jeseník Mts. and attributed to the Variscan orogeny are actually Cadomian. The 578±5 Ma age is interpreted as the time of pegmatite injection in a late magmatic stage that followed the orogenic climax, with the main magmatic pulse at ~615 Ma involving partial melting of ~1420 Ma old Mesoproterozoic crust. Our data is identical, within the error limit, with the lower intercept U-Pb zircon age of 584±8 Ma obtained for the Keprník gneiss by Kröner *et al.* (2000) and consistent with the assignment of the Jeseníky Mts. basement (at least some part of it) to the Cadomian orogen. Magmatism at ~616–570 Ma has been frequently reported for various terrane fragments of this orogen, e.g. the Armorican massif and Iberia (Quesada, 1990; Miller *et al.*, 2001).

Our results are also consistent with SHRIMP zircon data for the Bittesch gneiss in the Thaya window, Southern Moravia, which have a protolith age of 586±7 Ma and inherited cores 1377±10 Ma old (Friedl *et al.*, 2000), with U-Pb zircon data for the Keprník gneiss obtained by van Breemen *et al.* (1982), yielding an upper intercept age of 1422+191/−177 Ma and a lower intercept age of 547+6/−8 Ma (considered too low), and with U-Pb SHRIMP zircon ages between 600±7 Ma and 568±7 Ma (with 1.9–1.2 Ga inherited xenocrysts) reported for a selection of orthogneisses (Oberc-Dziedzic *et al.*, 2003) in the Strzelin region of the Fore-Sudetic Block (Fig. 2). This data suggests that both South (Thaya) and North Moravia (Keprník, Głuchołazy) were formed as parts of the Cadomian orogen through the reworking of ~1.4–1.2 Ga old crust. A number of pegmatitic veins similar to that dated in this study occur in the Rejviz series further SW of Głuchołazy, between Mikulovice and Jeseník (Cháb & Žáček, 1994). We expect that at least part of them are of the same age as the Głuchołazy dyke, and that together, they represent quite an extensive Neoproterozoic magmatism. The presence of ~1.4 Ga Ma old zircons denies the derivation of the Moravo-Silesian crustal pieces from the West Africa Craton, where evidence for thermal events between 2.0 Ga and 0.9 Ga is lacking.

The timing of the turning of the granitic protoliths to gneisses is unclear. The age of 507–502 Ma suggested by Kröner *et al.* (2000) for the foliation development in some Desná gneisses may not be valid for other gneiss variants, but it fits the natural expectation that not all shearing visible in the pre-Devonian rocks has to be from a Variscan overprint. As our zircon data could not determine the time when the axial planar quartz-muscovite foliation was formed in the folded Głuchołazy pegmatite dyke, the rock was subjected to a Rb-Sr study in the hope of constraining this deformation.

As a result of the Rb-Sr study, a whole-rock-muscovite fraction isochron age of 289±2 Ma was obtained, indicating the time when the pegmatite passed through an isotherm of 500±50°C during uplift (Fig. 16). In view of the U-Pb zircon data and the presence of the metamorphic foliation in the pegmatite, the obtained early Permian age is certainly too young to reflect the time of crystallization and pegmatite intrusion. After intrusion and prior to uplift, the pegmatite vein underwent folding and two shearing episodes. These episodes were accompanied by no significant changes in the mineral assemblages of the rocks involved. The ductile deformation of the dated pegmatite probably occurred at a temperature exceeding the closure

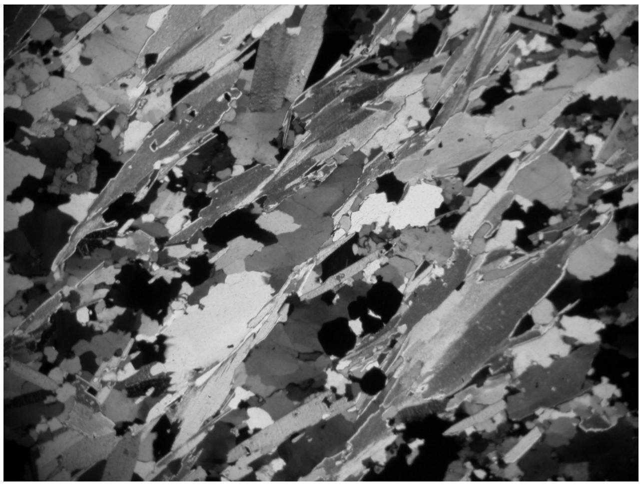


Fig. 17. Microphotograph showing the internal fabric of the deformed pegmatite with quartz grains free of strain, which was removed during static recrystallization. Field of view is 3 mm wide.

temperature promoting the diffusion of Sr ions through the muscovite crystal lattice and across the grain boundaries. Therefore, the obtained muscovite age cannot be interpreted as the deformation age. The Rb-Sr system in the analyzed micas must have been totally reset in the Palaeozoic, and thus yielded only cooling information. Such complete resetting could be accomplished in temperatures higher than ~500°C. The removal of strain from the quartz grains once flattened/elongated by crystal plastic deformation suggests that the process might have had a relatively long duration still under the high temperatures of the post-deformational conditions. This would explain how the quartz grains in the metapegmatite managed to recrystallize statically after deformation (Fig. 17). The process may have taken place at any time between the Precambrian and the Carboniferous. It cannot be excluded that the Neoproterozoic basement series stayed in the middle/lower crust at a depth below the isotherm of 500°C for more than 250 m.y. On the other hand, it is obvious that the Devonian rocks in the Hrubý Jeseník Mts. were buried during the Variscan orogeny to depths yielding the amphibolite facies conditions. The increase of temperature necessary for ion diffusion in muscovites was connected either with the ~507–502 Ma event recorded by the Desná dome rocks (Kröner *et al.*, 2000), or with the Variscan event at ca. 350±5 Ma indicated by our zircon data and by the suggested lower intercept of the concordia (Fig. 15B). The most likely situation is that the two events contributed.

The first option is consistent with the presence of an undated W/WSW-trending stretching lineation in the Keprník dome and its western surroundings (Cháb *et al.*, 1994) compatible with that in the Głuchołazy area (the present-day easterly plunge is due to later doming; this study). By contrast with the explanation proposed by Cháb *et al.* (1994), the W-trending lineation is reinterpreted by us as a record of extensional tectonics related to Cambro-Ordovician (Middle Cambrian here) extension of the Cadomian crust and rifting. In the West Sudetes, granite magmatism at ~500 Ma is usually interpreted as concomittant with overall extensional tectonics and break-up at the northern peripheries of Gondwana (Żelaźniewicz *et al.*, 2003; Oberc-Dziedzic *et al.*, 2005).

The second option refers to a late manifestation of the Variscan orogeny in the Hrubý Jeseník Mts. provided by the Žulová granite pluton emplaced at ~340 Ma (Jedličká, 1995). Further to the north, in the Fore-Sudetic Block, the late-orogenic Strzelin granites intruded between 347±7 Ma and 330±6 (Oberc-Dziedzic *et al.*, 1996), i.e. concurrently within the error limit. One may speculate that rocks in these regions started to be heated up to around 600°C at ~350 Ma and cooled below 500±50°C at ~290 Ma. This over 50 Ma long period of increased temperature would provide heat to reset the Rb-Sr system and anneal the quartz in the Głuchołazy pegmatite. In fact, it is quite possible that the two options were sequentially realized, so that the observed structures and rock fabrics are composite products of thermotectonic events occurring in the region during Neoproterozoic and Palaeozoic (Cambrian, Carboniferous) times.

Late Carboniferous–early Permian regional uplift in the Jeseníky Mts. and in the Kamieniec-Strzelin metamorphic unit (Fig. 1) was already ascertained in other studies, the results of which fit our Rb-Sr data. Ar-Ar cooling ages of ~290 Ma were obtained for the amphiboles and micas from the Žulová granite, and of 315–274 Ma for amphibolite-facies rocks in the Keprník and Desná domes (Maluski *et al.*, 1995). Similar Ar-Ar cooling ages of 285–279 Ma were obtained for the white micas from the Devonian quartz-mica schists (Jegłowa Beds) further north, in the envelope of the Strzelin Granite (Szczepański, 2002). In the Strzelin Granite (tonalite), a Rb-Sr analysis of biotite and plagioclase crystals yielded too an age of 294 Ma (Pietranik & Waight, 2005), which may also represent Permian cooling of the granite rather than its crystallization. These regions represent the Variscan foreland and the footwall to the Moldanubian Thrust. The late deformational increament along the thrust zone was accomplished in a dextral transpressional regime on the NE-trending planes around 325 Ma (Franke & Żelaźniewicz, 2002). The transpression gave rise to a stack of thrust sheets piled over the depressed foreland (Achramowicz, 1999). These were effectively removed by erosion at the latest during Carboniferous–earliest Permian times (Szczepański, 2002).

Our structural observations in the Vrbno quartzites and mica-quartz schists next to the Rejviz series near Głuchołazy indicate an early contractional deformation with ~NW-vergent folding and thrusting followed by ~SE-vergent folding and then by dextral transpressional deformation which gave rise to moderately to steeply plunging folds. These observations do not fit the scheme of Carboniferous deformation in the Jeseníky Mts. proposed by Schulmann & Gayer (2000), who assumed a top-to-the-NE thrust movement (D2) and dextral transpressional shearing (D3) in narrow, steeply dipping NE-trending shear zones. Neither do they fit the Carboniferous template described by Żaba *et al.* (2005) from the northern continuation of the Vrbno Group to Poland, which comprises: E- or SE-vergent intrafolial folds (*D1*), WNW/

NW-trending folds with predominantly SSW vergence (*D2*), NE-trending folds with NW vergence (*D3*), and NW-trending folds with NE vergence (*D4*). Cháb *et al.* (1992) claimed to recognize 6 deformational and 4 metamorphic events in the Silesian units of the Hrubý Jeseník Mts., all thought to have occurred in the Late Carboniferous. The earliest recognizable structures, highly obscured during subsequent episodes, were attributed by them to an eastward overthrusting, while the second event produced a westward back-thrusting; the two events were to affect both the Carboni- ferous flysch and the crystalline basement units. Of the three models, only that of Cháb *et al.* (1992) may agree in terms of the early kinematics and sequence of structures with our observations in the paragneisses of the Rejvíz series, and thus it might be capable of explaining the deformation in the basement rocks, provided the necessary time correction was introduced.

In the basement rocks, the 578 ± 5 Ma age of pegmatite injection allows for distinction between the early E-vergent Neoproterozoic structures and later deformation features which comprise the W-vergent and then the younger E-vergent structures described in this paper. These may be Variscan events because they are kinematically compatible with the sequence of the WNW-vergent **S**-type folds and the ESE-vergent **Z**-type folds recognized by us in the Lower Devonian quartzitic and mica schists of the Vrbno Group.

Taking into account our new age and structural data and utilizing Cháb *et al.* (1992, 1994), specifically their D0 to D2 events, we propose that: (1) the formation of the older E-vergent structures in the basement metasediments occurred in Neoproterozoic times (pre-580 Ma) and matched a Cadomian episode; whereas (2) the W-vergent structures (post-580 Ma) probably developed during early Variscan convergence when Palaeozoic foreland sediments were depressed down, buried, and metamorphosed; and (3) the younger E-vergent structures were presumably connected with an inversion and reverse shearing that reflected the progressive collision between the Brunovistulian block (terrane) in the foreland and the Bohemian Massif terranes in the hinterland, with subsequent dextral transpressional component.

Alternatively, (2) the W-vergent structures (post-580 Ma) may have developed during Cambrian crustal extension and were reworked with the same kinematics in the course of Variscan back-thrusting; and (3) the latter and the subsequent E-vergent shearing were related to early Variscan deformation (i.e. burial) that reflected the collision between the Brunovistulian foreland and the Bohemian Massif hinterland, and the resultant doming.

In the overall tectonic scheme of the Hrubý Jeseník Mts., the Głuchołazy area represents the northern peripheral closure of the Desná dome (Fig. 1) which is considered a parautochthon (Cháb *et al.*, 1984; Schulmann & Gayer, 2000). Cháb *et al.* (1994) expected a significant detachment between the Precambrian basement and the Devonian–Carboniferous cover units, which is plausible. In 3 boreholes located along the eastern outcrop limit of the Vrbno Group, Cháb (1990) was able to confirm the existence of a W-vergent thrust (the Andělská hora thrust) which brought the Carboniferous Andělská hora phyllitized flysch westward back over the Vrbno Group. No effect of this backthrusting was observed in the Neoproterozoic and Lower Devonian rocks near Głuchołazy.

Since the dated metapegmatite cross-cuts the metatholeiite sill, it is apparent that a part of the metabasites in the western Hrubý Jeseník Mts. must be Neoproterozoic in age. This casts some doubts on the commonly assumed Devonian age of the nearest Jeseník massif amphibolites, which may actually be older, and may have undergone metamorphism and deformation together with the basement orthogneisses and metasediments like the described Głuchołazy metabasite.

CONCLUSIONS

1. New U-Pb SHRIMP data on zircons confirms Neoproterozoic magmatism (~615–580 Ma) in the northern part of the Moravo-Silesian Zone which translates to the Brunovistulian terrane.

2. Dating of the folded metapegmatite vein which cross-cuts amphibolite facies paragneisses of the Rejvíz series has allowed us to discern Neoproterozoic structures (pre-580 Ma) interepreted as a record of the Cadomian orogeny at the northern periphery of Gondwana. In present-day co-ordinates, they are represented by N-trending, W-vergent folds and subsequent top-to-the-east shearing occurring at T = 600°C and P = 5 kbar.

3. A further tectonic overprint which affected both the paragneisses and metapegmatite occurred under similar P-T conditions (post-580 Ma) and was associated with a top-to-the-west kinematics inducing shortening at a high angle to the foliation. This probably took place during Variscan convergence when rocks were progressively depressed in the subduction zone. Alternatively, this event may have occurred around 500 Ma in relation to crustal extension and the break-up of the Gondwana margins in Cambrian times.

4. Later (younger) E-vergent inverse shearing zonally deformed and displaced structures formed in the earlier events and was achieved during the Variscan collision between Brunovistulia and the Bohemian Massif terranes.

5. Both the post-580 Ma, W-vergent and E-vergent events occurred under amphibolite facies conditions that allowed for crystal plastic deformation of quartz grains in the metapegmatite and then for the removal of strain by static recrystallization. The temperatures were high enough to reset the Rb-Sr system in the pegmatite

6. A Rb-Sr isochron age of 290 Ma reflects the time of late regional uplift which characterizes the footwall units of the Moldanubian Thrust.

7. Caution should be exerted while identifying and in-

terpreting structural sequences and assigning deformation to orogenic event(s) in the Variscan belt. Structures classified as Variscan may be Cadomian or contain more Cadomian elements than inferred from field observations with no age control.

Acknowledgements

Teresa Oberc-Dziedzic is thanked for the very useful comments and discussion over the intricacies of the stratigraphic subdivisions in the Jesníky Mts.

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