

# The $^{40}\text{Ar}/^{39}\text{Ar}$ cooling ages of white micas from the Jegłowa Beds (Strzelin Massif, Fore-Sudetic Block, SW Poland)

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**Abstract** The metamorphic rocks of the Strzelin Massif, in the Fore-Sudetic Block, underwent polyphase tectonothermal evolution terminating with late orogenic gravitational collapse. These rocks recorded Early Permian cooling ages in the range of 279–285 Ma, obtained on white mica concentrates derived from metasediments of the Jegłowa Beds. The obtained results correspond to the youngest group of ages presented by Maluski *et al.* (1995) from the northern part of the Jeseník Mts, the Moravo-Silesian Zone of the East Sudetes. They suggest very low exhumation rate.

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## INTRODUCTION

The Strzelin Massif emerges from beneath Cenozoic sediments in the northern Sudetic foreland, ca 40 km south of Wrocław. It forms an isolated outcrop of Variscan basement exposed directly north of a mountainous area of the East Sudetes. The ages of deformation and cooling of the crystalline complexes contained in the East Sudetic domain were already documented by Maluski *et al.* (1995). However, as yet no radiometric data on the timing of the metamorphism and subsequent cooling are available for the Strzelin Massif itself.

The purpose of this study was to investigate and de-

scribe the thermal history of the Strzelin Massif (Fig. 1), using  $^{40}\text{Ar}/^{39}\text{Ar}$  data for white micas derived from the Jegłowa Beds. The beds mainly comprise quartzites which are believed to be of Devonian age and to represent an equivalent to those from the Vrbno Group of the Czech East Sudetes. The obtained results indicate surprisingly young cooling ages for the studied rocks, and suggest that the Strzelin Massif underwent very slow exhumation after the final stages of deformation and regional metamorphism.

## GEOLOGICAL SETTING

The East Sudetes form part of a collision-related belt of deformation and metamorphism, nearly 50 km wide and 300 km long, which occupies the eastern margin of the Bohemian Massif. The belt is composed of nappe piles that crop out from below the upper plate of the collision zone, represented in its northern part by Central Sudetic rock complexes. The east Sudetic pile of nappes consist of medium-grade metamorphosed Neoproterozoic Cadomian crust, partly Variscan reworked, involved in nappe tectonics and folded together with its metamorphic Devonian and Lower Carboniferous cover (e.g. Misař, 1995). It is overridden from the west by the Orlica–Śnieżnik Massif and the Staré Město Belt, and exposed in a tectonic half-window. The East Sudetic nappes are referred to as the

Silesian units (Suess, 1912; 1926; Dudek, 1980), and usually described as a part of the larger Moravo-Silesian Zone (e.g. Franke & Żelaźniewicz, 2000), which includes, besides metamorphic complexes, an extensive Devonian–Carboniferous sedimentary basin situated more to the east.

The East Sudetic domain is usually expected to continue northward below the cover of Cenozoic sediments (e.g. Grocholski, 1976). Accordingly, the Strzelin Massif is often thought to represent an isolated outcrop of mostly concealed East Sudetic basement (e.g. Bederke, 1929; Grocholski, 1975; Skácel, 1989). However, alternative interpretations have also been presented, assuming a West Sudetic affinity for the Strzelin Massif (Oberc, 1966;

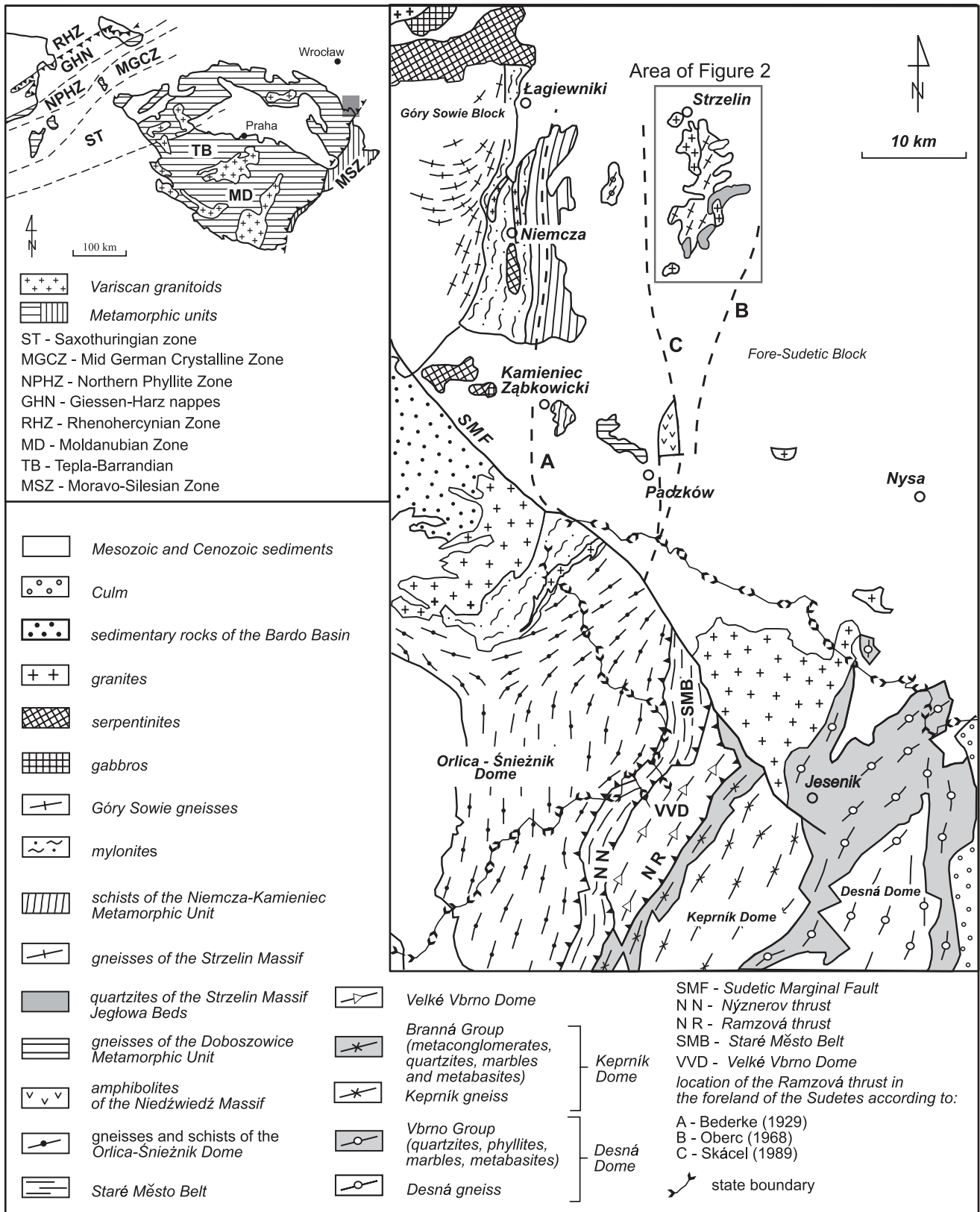


Fig. 1. Regional setting of the study area; the inset shows location of the study area on the sketch map of the Bohemian Massif after Puziewicz *et al.* (1999), slightly modified.

Oliver *et al.*, 1993; Cymerman *et al.*, 1997) or its tectonic setting on both sides of the East/West Sudetes contact zone (Franke & Żelaźniewicz, 2000; Oberc-Dziedzic, 2001). The inferred equivalence of the Strzelin Massif and the East Sudetic domain is mostly based on an apparent similarity of their lithological units. The Strzelin quartzite succession, although not yet paleontologically dated, closely corresponds to the Early/Middle Devonian quartzites of the Vrbno group in the Czech part of the east Sudetes (Bederke, 1931; Chlupač, 1989). At the same time, East Sudetic affinities for at least some of the Strzelin orthogneisses are documented by their Late Proterozoic U-Pb SHRIMP ages (Oberc-Dziedzic *et al.*, 2000). Furthermore, the structural record of the Strzelin Massif, with syn-collisional thrusting to the E or NE and subsequent bi-vergent NE- and SW-directed extensional collapse (Szczepański, 2001), is analogous to that known from the mountainous part of the East Sudetes (Cháb *et al.*, 1994; Schulmann & Gayer, 2000) and adjacent areas of Sudetic Foreland (Mazur & Józefiak, 1999).

$^{40}\text{Ar}/^{39}\text{Ar}$  dating of the East Sudetic rock complexes exposed in the Jeseník Mts yielded five groups of ages related to consecutive tectonothermal events (Maluski *et al.*, 1995). The oldest one was ascribed to a wide time span of 340–440 Ma. It was followed by younger events successively dated at: 320–340 Ma, 300–310 Ma and 279–290 Ma. The thermal evolution of the area was terminated by the 270–90 Ma episode (Maluski *et al.*, 1995). All the described thermal events were attributed by Maluski *et al.* (1995) to subsequent stages of metamorphism and deformation.

The Strzelin Massif (Fig. 2) comprises four distinct rock complexes. These are: (1) orthogneisses, (2) a schist series, (3) the Jegłowa Beds and (4) Variscan granitoids. The orthogneisses occur in two main varieties: the Strzelin gneiss in the north and the Nowolesie gneiss in the south of the studied area. U-Pb SHRIMP zircon dating of the Strzelin orthogneisses yielded values of 568–600 Ma, interpreted as the protolith age (Oberc-Dziedzic *et al.*, 2000). The locally exposed supracrustal schist series is composed of mica schists, paragneisses, calc-silicate rocks and amphibolites. The schist complex, which originally must have been the supracrustal envelope intruded by the protolith of gneisses, is believed to be of Neoproterozoic age (Oberc, 1966). Several thrust sheets of Devonian quartzites, the so called Jegłowa Beds, are tectonically interleaved with the orthogneiss and schist complexes. The protolith of the Jegłowa Beds probably consist of quartz sandstones with minor intercalations of arkosic and lithic varieties (Patočka & Szczepański, 1997). The metamorphic rocks of the Strzelin Massif are intruded by Variscan granitoids, dated at  $330 \pm 6$  and  $347 \pm 12$  Ma using the Rb-Sr whole rock method (Oberc-Dziedzic *et al.*, 1996).

The Jegłowa Beds recorded three metamorphic episodes (Szczepański, 1999; Szczepański & Józefiak, 1999) correlated with three deformation events (Szczepański, 2001). The conditions of the  $M_1$  episode were established as corresponding to the greenschist facies ( $T = 500^\circ\text{C}$  and  $p = 6$  kbar). It was presumably related to the E or NE-vergent nappe transport initiated in response to the Variscan collision. The second metamorphic event  $M_2$  involved

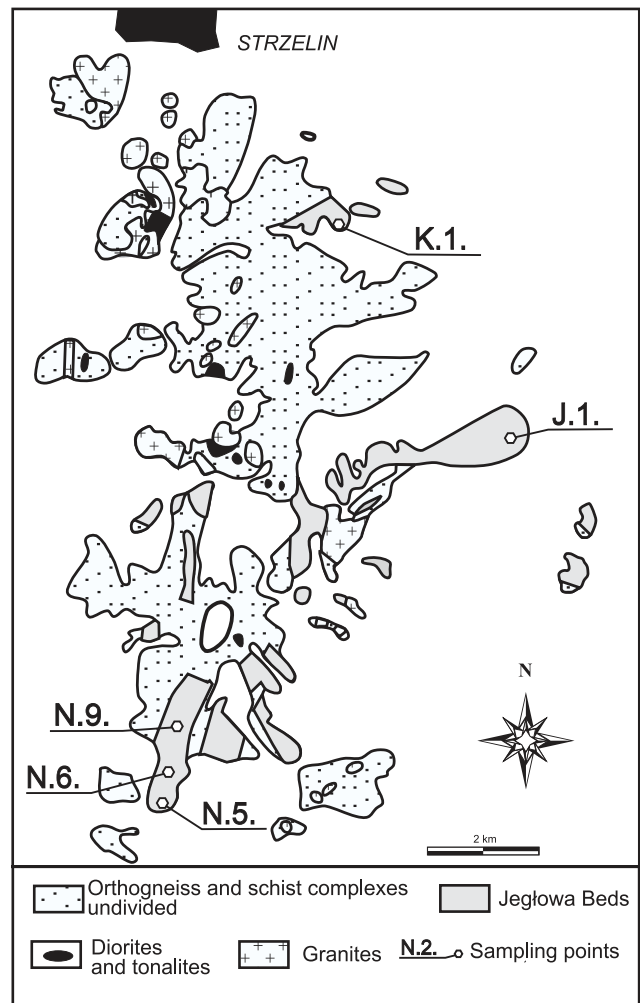


Fig. 2. Geological sketch map of the Strzelin Massif after Oberc *et al.* (1988).

a change in the PT conditions, with values decreasing from maximum of 6 kbar and  $500^\circ\text{C}$ . Simultaneously, the Jegłowa Beds underwent progressive folding. During the  $M_3$  event the rocks experienced HT/LP metamorphism ( $\sim 3.8$  kbar and  $\sim 630^\circ\text{C}$ ) associated with late orogenic gravitational collapse. The high geothermal gradient during the  $M_3$  event ( $\sim 45^\circ\text{C}/\text{km}$ ) was most probably related to numerous late orogenic granitoid intrusions. Moreover, the granites, cutting the metamorphic rocks discordantly, exhibit a magnetic fabric parallel to deformation structures originated during the  $D_3$  episode (Szczepański *et al.*, 2000). Consequently, emplacement of the granites was probably related to a late phase of the  $D_3$  event.

During the Late Carboniferous, the Strzelin Massif must have been exposed at the surface since it supplied clastic material to the Laskowice graben (Kiersnowski, 1983; 1995). The graben, situated on the north-eastern periphery of the Strzelin Massif, was initiated during the latest Carboniferous (Kiersnowski, 1983; 1995).

## METHODS OF INVESTIGATION AND SAMPLING

Five white mica concentrates were selected for the isotopic study (Fig. 2). 30 mg concentrates were irradiated using fast neutrons ( $\sim 10^{12}$  neutrons/cm<sup>2</sup>) in the nuclear reactor of the Laboratory of Nuclear Energy in Świerk. An assessment of Ar isotopes within the investigated samples was performed using a modified mass spectrometer MS-10, in the Institute of Physics of the Marie Curie-Skłodowska University in Lublin. The results of the isotopic investigations are shown in Tab. 1. The concentrates were examined using the stepwise heating method (Merrill & Turner, 1966) at the max. of 10 determination steps (apart from sample K1) and 100°C increments of temperature.

A thin section examination of each of samples collected for geochronological analysis was carried out as the preliminary step. It was possible to reject those which were too fine-grained, contained mineral inclusions or showed alteration effects. Furthermore, the selected samples contained only one generation of white mica, expected to have recorded only one particular tectonometamorphic event. The samples taken from the northern part of the massif (J1 and K1) only contained the generation of white mica developed during the M<sub>2</sub> episode. On the other hand, the samples collected in the southern part of the massif (N5, N6 and N9) almost exclusively had micas which crystallised during the M<sub>3</sub> episode. Nevertheless, removal of small admixtures of white micas that had originated during other metamorphic events was not entirely possible. The samples were crushed and sieved to a 0.5–0.125 mm size fraction and the white micas were separated using the standard magnetic technique. The final purification of the concentrates was achieved by hand picking.

## ISOTOPIC DATA

The results are discussed collectively for the whole Strzelin Massif. The apparent ages are presented as classical age spectra (Fig. 3), where the age is plotted against the cumulative <sup>39</sup>Ar isotope released during each increment of temperature. Inversed correlation diagrams were also used (Fig. 3). 100°C increments of temperature were applied during the analyses, starting from 450°C (or 500°C in the case of sample K1) and finishing at 1350°C (or 1300°C in the case of sample K1).

All the obtained age spectra are very regular, displaying a well-developed plateau. The first two temperature increments (and for samples N6 and N9, also the third increment) show younger ages than those for the remaining part of the released portion of <sup>39</sup>Ar. It does not exceed the first 10% (20% in the case of samples N6 and N9) of the released <sup>39</sup>Ar. In fact, this first portion of <sup>39</sup>Ar released in the low temperature range (500–700°C) corresponds to ages of 193–226 Ma. The remaining part of the released <sup>39</sup>Ar define a plateau which is interpreted as the closure time of the isotopic system. The obtained ages are between

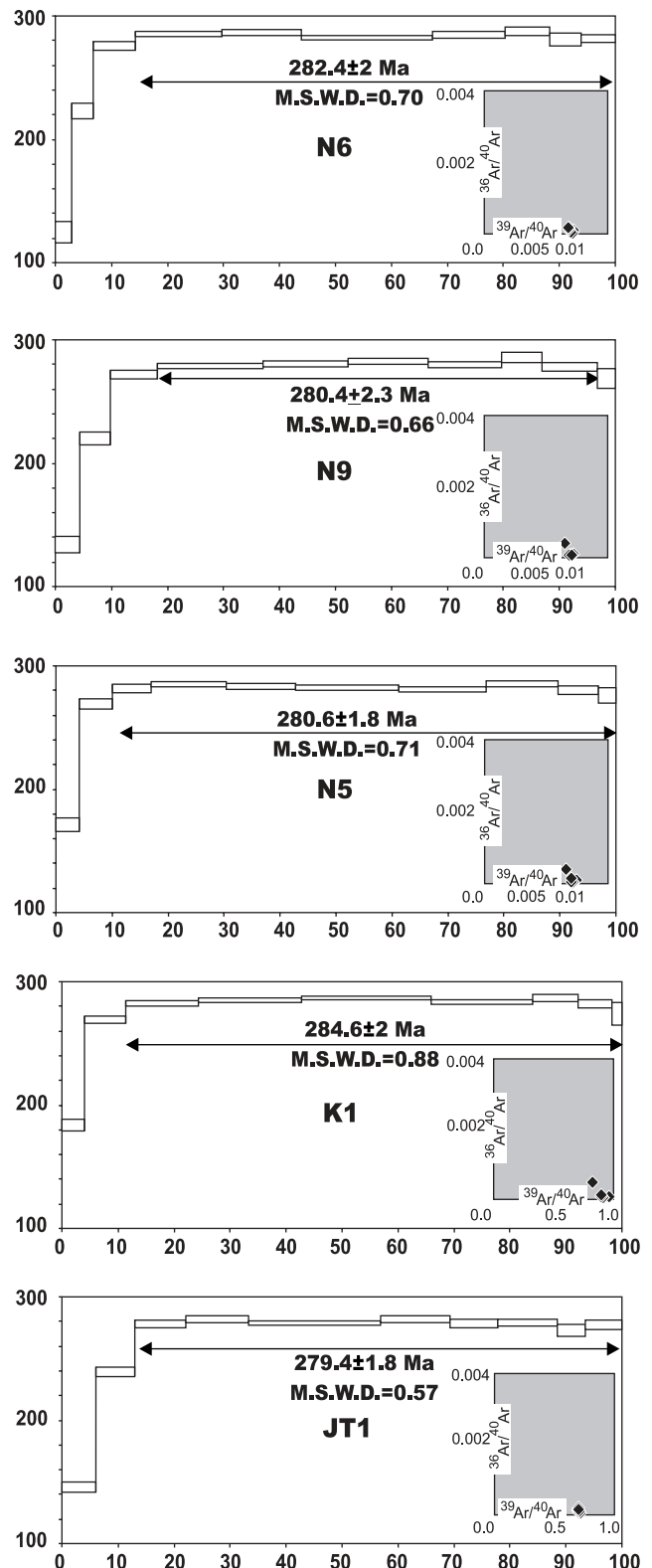


Fig. 3. Age spectra of the analysed white mica concentrates. Reversed isochron diagrams corresponding to the particular white mica concentrate are shown to the left of each age spectrum.

279–285 Ma. Moreover, a very well-defined plateau (MSDW is in the range between 0.57–0.88) suggests quite a simple thermal history for the analysed samples.

In order to determine the composition of the initial

Table 1

A summary of the isotopic analysis results

Sample	T [°C]	% $^{39}\text{Ar}$	% $^{40}\text{Ar}^*$	Age [Ma]	Sigma [Ma]	$^{36}\text{Ar}/^{39}\text{Ar}$	$^{40}\text{Ar}/^{39}\text{Ar}$
<b>Sample K1</b>							
1	500	4.0	82.6	183.8	4.5	0.04199	71.1911
2	600	7.3	97.8	269.2	2.8	0.00664	90.1285
3	700	13.0	98.0	282.6	2.1	0.00660	94.8864
4	800	18.4	98.5	284.8	1.9	0.00500	95.1751
5	900	23.2	98.8	286.8	1.8	0.00379	95.5532
6	1000	18.1	98.3	283.6	1.9	0.00551	94.9256
7	1100	8.2	97.4	286.9	2.7	0.00840	96.9510
8	1200	6.0	96.1	282.1	3.3	0.01286	96.5595
9	1300	1.8	85.4	274.0	9.4	0.05194	105.2234
<b>Sample JT1</b>							
1	450	6.1	83.8	146.6	4.1	0.03041	55.3521
2	550	6.8	94.1	239.4	3.8	0.01640	82.6032
3	650	9.2	95.2	277.9	3.1	0.01542	95.8092
4	750	11.2	96.6	281.9	2.7	0.01113	95.9528
5	850	23.6	98.2	279.0	1.9	0.00574	93.3431
6	950	12.3	97.6	281.9	2.6	0.00767	94.9477
7	1050	8.6	96.2	278.5	3.2	0.01224	95.0724
8	1150	10.6	97.0	279.5	2.8	0.00962	94.6405
9	1250	4.9	93.9	273.0	5.0	0.01961	95.3015
10	1350	6.7	95.7	277.7	3.9	0.01406	95.3173
<b>Sample N9</b>							
1	450	4.4	69.8	134.7	6.4	0.06221	60.8599
2	550	5.4	89.3	220.5	5.3	0.02878	79.7287
3	650	8.5	96.4	271.8	3.6	0.01143	92.4761
4	750	18.7	97.7	278.8	2.2	0.00724	93.6888
5	850	15.2	97.4	280.6	2.5	0.00832	94.6545
6	950	14.3	97.9	282.3	2.5	0.00676	94.8036
7	1050	13.1	97.7	279.7	2.7	0.00738	94.0716
8	1150	7.1	97.4	285.6	4.2	0.00849	96.5113
9	1250	9.9	97.3	278.0	3.2	0.00858	93.8232
10	1350	3.4	86.2	268.4	8.0	0.04782	102.0302
<b>Sample N6</b>							
1	450	2.9	65.7	124.3	8.5	0.06911	59.5070
2	550	3.8	94.9	221.4	6.2	0.01294	75.3515
3	650	7.6	97.2	273.8	3.5	0.00871	92.3879
4	750	15.3	98.7	283.4	2.3	0.00431	94.4847
5	850	14.1	98.5	284.7	2.4	0.00470	95.0551
6	950	23.4	99.1	280.4	1.9	0.00282	92.9547
7	1050	13.0	98.2	282.8	2.5	0.00574	94.6821
8	1150	7.8	96.7	285.5	3.4	0.01102	97.2156
9	1250	5.7	94.5	278.2	4.4	0.01798	96.6617
10	1350	6.4	94.6	280.5	3.9	0.01788	97.4492
<b>Sample N5</b>							
1	450	4.3	82.4	170.5	5.2	0.03921	65.9107
2	550	5.8	97.4	267.1	4.0	0.00791	89.7608
3	650	6.9	97.5	279.2	3.5	0.00809	94.0927
4	750	13.3	98.9	282.8	2.3	0.00354	94.0314
5	850	12.3	98.9	281.3	2.4	0.00345	93.4739
6	950	18.4	99.1	280.0	2.0	0.00289	92.8451
7	1050	15.6	98.6	278.9	2.2	0.00446	92.9348
8	1150	12.7	98.4	283.4	2.4	0.00524	94.7605
9	1250	7.2	95.9	277.9	3.4	0.01313	95.1435
10	1350	3.5	88.5	274.0	6.2	0.03950	101.5311

Ar, inverted  $^{36}\text{Ar}/^{40}\text{Ar}$ – $^{39}\text{Ar}/^{40}\text{Ar}$  isochron diagrams were used. Taking into account the very low proportion of  $^{36}\text{Ar}/^{40}\text{Ar}$ , the projection points of the analysed white mica concentrates are located within the lower part of the diagram. This implies that the Ar enclosed in the white

mica plates almost exclusively originated from radiogenic  $^{40}\text{K}$  decay. The remaining non-radiogenic component, which in this case is negligible in amount, is probably that derived from the atmosphere.

## INTERPRETATION

The obtained isotopic data show two essential features which are: plateau ages very young, less than 284 Ma and a lack of a difference between the plateau ages of white micas collected in different parts of the study area. This implies that the presented results correspond to cooling ages related to the exhumation of the Strzelin Massif, rather than representing a record of any tectonometamorphic event. In the latter case, the results would differ in various parts of the massif, as the investigated rocks preserved micas originated during different tectonometamorphic events. The closing temperatures for the white micas suggested by most workers are in the range of 330–430°C (McDougall & Harrison, 1988). Thus, the obtained cooling ages were associated with a medial phase of the exhumation, when the rocks passed the isotherms of 330 to 430°C. The youngest obtained ages (in the range between 193 to 226 Ma) were calculated based on the first portion of the released  $^{39}\text{Ar}$ , and may have resulted from a partial loss of Ar due to a younger thermal episode. It is however more probable that they reflect the influence of small mineral inclusions degassed in the low temperature range of the experiments.

The very young cooling ages presented in this paper correspond to the youngest of those reported by Maluski *et al.* (1995) from the Jeseník Mts. Maluski *et al.* (1995) interpreted these youngest ages as related to the reactivation of the Bela and Ramzova fault zones. These zones would have played a role of channels transporting heat from the Žulová granitoid intrusion. However, this interpretation is not consistent with the age of the Žulová pluton, recently dated at 340 Ma (Jedlička, 1995). Therefore, it seems more likely that the youngest Variscan ages reported in this paper and obtained by Maluski & co-authors (Maluski *et al.* 1995) represent the time of cooling and passing of the massifs through the 330–430°C isotherms.

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