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Permian single crystal U-Pb zircon age of the Rožňava Formation volcanites (Southern Gemeric Unit, Western Carpathians, Slovakia)

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Abstract: Zircon populations from the Rožňava Formation volcanic rock complex have been analysed. Euhedral zircons from the 1st volcanogenic horizon with fine oscillatory growth zoning, typical of magmatic origin, gave the average concordia age of 273.3 ± 2.8 Ma, with Th/U ratios in the range of 0.44–0.73. The Permian ages ranging from 266 to 284 Ma were identified in the wider, zoned or unzoned, central zircon parts, as well as in their fine-zoned oscillatory rims. The average concordia age of 275.3 ± 2.9 was obtained from the euhedral zircon population of the 2nd volcanogenic horizon of the Rožňava Formation. The analyses were performed on zoned magmatic zircons in the age interval from 267 to 287 Ma, with Th/U ratios in the range of 0.39–0.75. In the later zircon population two inherited zircon grains were dated giving the age of 842 ± 12 Ma (Neoproterozoic) and 456 ± 7 Ma (Late Ordovician). The magmatic zircon ages document the Kungurian age of Permian volcanic activity and contemporaneous establishment of the south-Gemeric basin. The time span of volcanic activity corresponds to the collapse of the Western Carpathian Variscan foreland which expanded southward.

Key words: Permian, Kungurian, post-Variscan rifting, synsedimentary volcanism, U-Pb magmatic zircon ages, inherited grains.

Introduction

An extensive rift system developed gradually within the foreland of the Western Carpathian part of the Variscan orogenic belt during the Carboniferous–Permian. These extensional events post-dated the main Late Devonian–Carboniferous and Serpukhovian-Bashkirian orogenic events (Vozárová 1998). Post-orogenic rifting also propagated across the entire Variscan orogen and its retro-arc continental basement part. Following the main phases of Variscan compression, thermal crust relaxation occurred in Late Pennsylvanian–Cisuralian times. This created rifts and grabens that allowed accumulation of the first stage of post-orogenic sedimentation. Within the post-orogenic basins mainly coarse-grained continental sedimentary formations were formed, associated with widespread calc-alkaline, bimodal and/or continental tholeiitic volcanism. The fragments of Upper Pennsylvanian-Permian sedimentary basin filling are preserved as part of the main Western Carpathian Alpine crustal-scale superunits (from the N to S: Tatricum, Northern and Southern Veporicum and Northern and Southern Gemericum) and several cover nappe systems (Fatric, Hronic, Turnaic and Bôrka Nappe; Vozárová & Vozár 1988).

Generally, the stratigraphic position as well as the correlation of these coarse-grained continental sedimentary formations is not easy to prove, due to lack of relevant faunal and plant remains. One of the best ways to resolve this problem is dating of the associated volcanic rocks, as they form good correlational horizons throughout widespread regional areas (McCann et al. 2008; Vozárová et al. 2009a). Thus, the post-tectonic coarse-grained volcano-sedimentary sequence of the Southern Gemeric Unit is no exception. The Permian age of this sequence is documented only by scarce biostratigraphic data. The problem studied here is focused on zircon single grain age determinations of the acid volcanic and volcaniclastic rocks. Such study enables dating of a principal stage of the Variscan post-tectonic extensional movements in the area of the Inner Western Carpathians as well as to specify the stratigraphic position of the associated Gočaltovo Group sediments.

Geological setting

Within the Southern Gemeric Unit, the post-orogenic overstep sequences are represented by the Permian continental to near-shore, lagoonal-sabkha formations of the Gočaltovo Group (Fig. 1). They unconformably overlap their basement, the Early Paleozoic Gelnica Terrane, consisting of the pre-Permian low-graded rock complexes of the Gelnica Group and Štós Formation (Vozárová & Vozár 1996). Generally, the sediments of the Gočaltovo Group represent the relic of rift-related sedimentary basin fillings, which originated with the initial stage of the post-Variscan extension and crustal relaxation. The whole sequence is subdivided into two lithostratigraphic units: the basal Rožňava Formation and the upper Štítnik Formation (Bajaník et al. 1981; Fig. 2). The studied volcanites are an integral part of the basal Rožňava Formation.

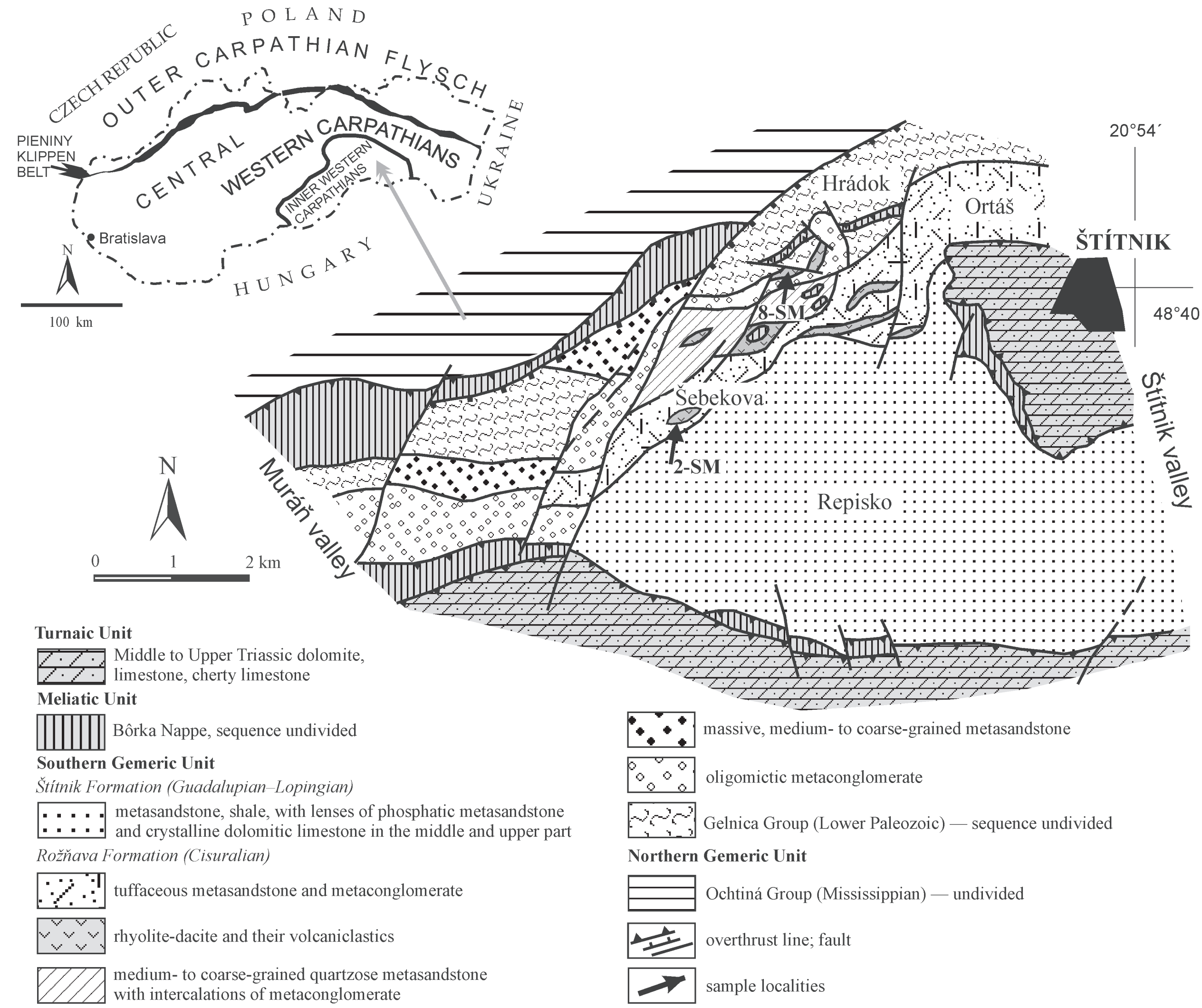

Fig. 1. Geological scheme of the Štítnik–Jelšava area with localization of samples (modified after Bajaník et al. 1984 and Mello et al. 1996).

The characteristic lithological feature of the Rožňava Formation is the high content of mature detritus, represented by the presence of the oligomictic quartzose conglomerates and sandstones, with indistinct stratification. The whole Rožňava sequence is vertically subdivided into two regional widespread larger cycles, with conglomerate strata at the base of each cycle and a shaly-sandstone member among them. Sedimentary structures supporting stream channel deposits are dominant, with a distinct unimodal transport system. Both conglomerate horizons were associated with the calc-alkaline rhyolite-dacite subaerial volcanism. Their relics are recently indicated as the 1st and 2nd volcanogenic horizons (Fig. 2).

The Cisuralian age of the Rožňava Formation is assumed on the basis of the poor microfloral assemblage, with the predominant species from the genera *Potonieisporites*, *Striatodisaccites*, *Vittatina* sp. and mainly the form *Triquitrites additus* Wilson et Hoffmeister, *Potonieisporites novicus* Bharadwaj, *Vittatina costabilis* Wilson, *Reticulatisporites reticulocingulum* (Planderová 1980).

Detailed petrological and geochemical investigations of the Rožňava Formation volcanites have not been done systematically up till now. All previous analytical data have been summarized by Vozárová (in Marsina et al. 1999 and references therein). According to this, the volcanites were classified as calc-alkaline rhyolites/rhyolite-dacites and they are markedly enriched in B, Zr and Rb and only slightly enriched in La and Y and depleted in Ba, Sr and V. Results based on zircon typology indicate the A-type high-temperature alkaline magma (Broska et al. 1993).

The Cisuralian age of the magmatic event at 276 ± 25 Ma has been, for the first time, determined for the Rožňava Formation volcanites by monazite dating (Vozárová et al. 2008). Isolated relics of Silurian age, 421 and 431 Ma, found within the Permian monazite cores were interpreted as the inherited relics from the source rocks, extracted from the Lower Paleozoic protolith.

Method of investigation

Zircon populations from two samples of the 1st and 2nd volcanogenic horizons of the Rožňava Formation rock complex

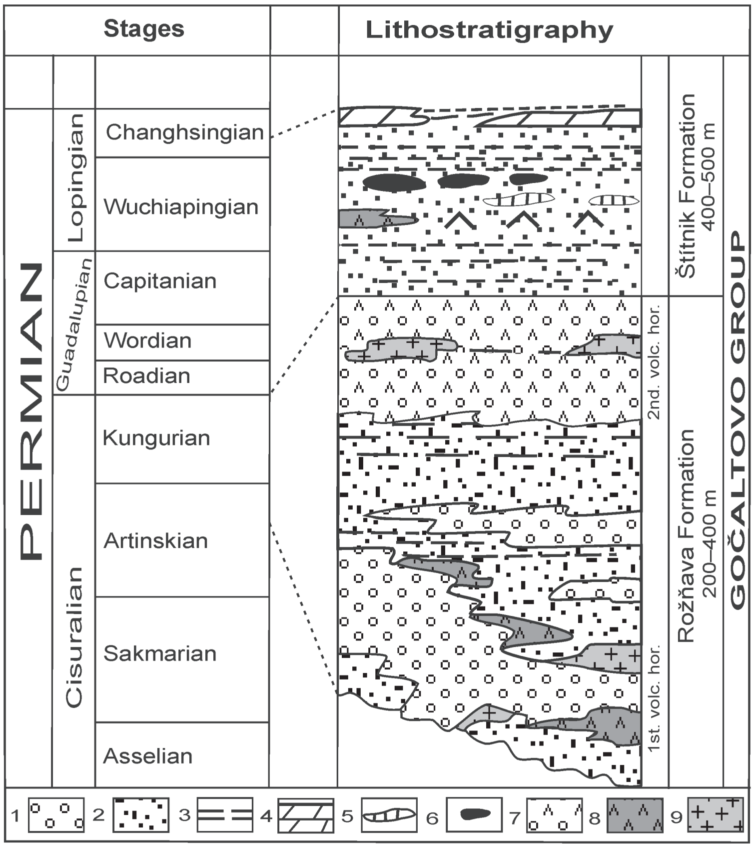

Fig. 2. Gočaltovo Group lithostratigraphic scheme (modified after Vozárová & Vozár 1988). Explanation: **1** — metaconglomerate; **2** — metasandstone; **3** — shale; **4** — crystalline dolomitic limestone; **5** — albitolite; **6** — phosphatic metasandstone; **7** — tuffaceous/sedimentary mixed rocks; **8** — rhyolite-dacite volcaniclastics; **9** — rhyolite-dacite.

have been analysed. The zircons have been separated from rocks by standard grinding, heavy liquid and magnetic separation analytical procedures. The internal zoning structures and shapes of the half-sectioned zircon crystals mounted in epoxy resin puck with chips of the TEMORA (Middledale Gabbroic Diorite, New South Wales, Australia) and 91500 (Geostandard zircon) reference zircons, were first imaged by BSE and CL, in order to reveal surface features for analytical spots positioning. *In situ* U-Pb analyses were performed on a SHRIMP-II in the Center for Isotopic Research (CIR) at VSEGEI in St.-Petersburg, Russia.

Each analysis consisted of 5 scans through the mass range, the diameter of each spot was about 25 μm, and primary beam intensity was about 6 nA. The data have been reduced in a manner similar to that described by Williams (1998, and references therein), using the SQUID Excel Macro of Ludwig (2000). The Pb/U ratios have been normalized relative to a value of 0.0668 for the $^{206}Pb/^{238}U$ ratio of the TEMORA reference zircons, equivalent to an age of 416.75 Ma (Black & Kamo 2003). Uncertainties given for individual analyses (ratios and ages) are at the 1σ level; but the uncertainties in calculated concordia ages are reported at 2σ levels. The Ahrens-Wetherill (1956) concordia plot has been prepared using ISOPLOT/EX (Ludwig 1999).

Petrography and geochemistry of volcanites

Rhyolites of the *1st volcanogenic horizon* are composed of the light coloured silicate, mainly potassium feldspars and less present sodium reach plagioclases. In texture they are classified as a fine-grained, primary aphanitic to microcrystalline in the matrix, with the evidence of small phenocrysts of β-quartz and alkali feldspars, mainly represented by soda-poor microcline or microcline-perthite (matrix/phenocrysts ratio = 1 : 3). A sanidine type of the alkali feldspar shape is evident in some samples. Occasionally, they contain besides alkali feldspars also phenocrysts of sodium rich plagioclases (An_{5-15}) and frequently associated with scarce biotite. These porphyritic textures indicate that crystallization of phenocrysts began prior to extrusion, when magma was deeper situated. Zircon, monazite, xenotime, apatite, rutile and Fe-Ti oxide are present as accessory minerals.

The 1st volcanogenic horizon acid volcanites are associated with volcaniclastics, frequently with textures indicating ignimbrite or welded tuffs, flattened lithic and glassy pumice mixed with vitric material, with relics of deformed "fiamè".

The *2nd volcanogenic horizon* acid volcanites have very fine-grained primary texture of vitric/or glassy appearance, which contains only small amounts of phenocrysts (maximum 5 % of the whole rock), consisting mainly of β-quartz. They frequently contain voids and recrystallized glassy fragments, as the evidence of having been formed in a surface environment with rapid cooling. Only pyroclastic ash-falls are associated with the 2nd volcanogenic horizon rhyolites. They have primary very fine-grained vitroclastic textures and are commonly interbedded and mixed with siliciclastic sediments, mostly conglomerates and sandstones.

Permian sequences of the Southern Gemeric Unit are deformed and recrystallized, within metamorphic grade attaining P-T conditions from anchizone to the low-temperature part of the greenschist facies (Šucha & Eberl 1992; Vozárová 1996; Vozárová & Rojkovič 2000). The newly formed metamorphic mineral assemblage is represented by the fine-grained aggregate of quartz + phengite + chlorite ± albite and/or microcline, associated with scarce biotite in some places. The multistage tectonothermal events in the south-Gemeric Permian metarhyolites, from the Late Jurassic–Early Cretaceous (167 ± 12 and 136 ± 10 Ma), were deduced from the electron microprobe monazite dating (Vozárová et al. 2008).

Six samples were selected for representative chemical analyses, three from the 1st volcanogenic horizon and three from the 2nd volcanogenic horizon. All samples were analysed for major and trace elements content including REE. Their chemical composition was determined by ICP/ICP SM Acme Laboratories Ltd. in Canada.

As they are only slight petrographic differences, the chemical composition of the Rožňava acid volcanites from the two volcanogenic horizons is practically identical. The representative chemical analyses of the studied samples are given in Table 1. As a consequence of metamorphic alteration that presumably modified their chemistry, particularly the content of fluid mobile elements such as K, Na, Si, Rb and Cs, the use of classification based on mobile elements (TAS) has been considered unreliable. Therefore, a diagram based on relatively immobile elements Nb/Y vs. Zr/TiO_2 (Winchester & Floyd 1977 modified according to Pearce 1996) was preferred for classification purposes (Fig. 3a). The two groups of volcanites are calc-alkaline and rhyolitic in character, with SiO_2 contents ranging from 68.03 to 76.77 wt. %, and fall into peraluminous suite (A/CNK = 1.35–2.64; A/NK = 1.33–2.45). Very high K_2O/Na_2O ratio is a result of secondary alteration processes. Volcanic rocks are generally characterized by extremely low CaO (0.01–0.03 wt. %), MgO (from 0.39 to 0.66 wt. %) and relative low Fe_2O_{3t} (from 0.73 to 2.46 wt. %) contents. The chondrite-normalized trace-elements variation diagram for the studied samples (Fig. 3b) reflects strong negative anomalies of Ba, Nb, Sr and Ti, and enrichment in Rb, Th, K, La, Ce, Nd, Hf and Y. These broadly indicate their A-type affinity. Similarly, based on the chondrite-normalized REE distribution (normalizing values after Taylor & McLennan 1985; Fig. 3c) the rhyolites are enriched in light REE, and have relatively unfractionated heavy REE with $\Sigma(La/Yb)_n = 3.5$ and $\Sigma(Gd/Lu)_n = 1.6$. These features, together with the distinct negative Eu-anomaly (Eu/Eu* = 0.48) are typical for A-type magmatites. Based on Y/Nb ratio, which ranges from 2.3 to 2.6 in all studied samples, the Rožňava rhyolites correspond to non-orogenic A_2-subtype, which could indicate the post-collisional magmatic environment (Eby 1992). According to Eby's interpretation this magmatic subtype consists of granites emplaced in a variety of tectonic environments, including post-collisional, post-orogenic and anorogenic settings. Negative Nb anomalies are a common feature of igneous rocks formed in destructive margin settings and derived from arc crust (Whalen et al. 1996). The origin of magma of the Rožňava felsic volcanites was probably connected with crustal melting associated with regional post-Variscan extension and thermal relaxation. Its composition presumably reflects source characteristics — the metasediments and metavolcanites of the Lower Paleozoic Gelnica Group. A non-orogenic geotectonic interpretation may also be derived from the Nb/Y (Fig. 3d) and Rb/(Yb+Ta) ratios and Rb/10:Hf:Tax3 referred to Pearce et al. (1984) and Harris et al. (1986) discrimination diagrams. The relative enrichment of Ce, Zr and Y is indicative for their compatibility with crustal components in the melt. Negative Ti, Sr, Ba and Eu indicate retention of plagioclases and accessory minerals during partial melting (Collins et al. 1982; Pearce et al. 1984; Whalen et al. 1996).

Table 1: Rock chemical analyses of the Rožňava Formation 1st and 2nd volcanogenic horizons acid metavolcanites.

	1st volcanogenic horizon			2nd volcanogenic horizon		
Locality Sample	**Hrádok 04-SM**	**Hrádok 06-SM**	**Hrádok 08-SM**	**Šebeková 01-SM**	**Šebeková 02-SM**	**Šebeková 05-SM**
	wt. (%)	wt. (%)	wt. (%)	wt. (%)	wt. (%)	wt. (%)
SiO_2	74.38	74.53	76.77	74.82	74.83	68.03
Al_2O_3	13.47	12.86	12.95	14.25	14.47	17.49
Fe_2O_3	2.46	0.73	2.00	2.32	0.84	1.61
MgO	0.58	0.23	0.47	0.66	0.39	0.56
CaO	0.01	0.03	0.02	0.01	0.01	0.02
Na_2O	0.09	0.16	0.05	0.04	0.13	0.11
K_2O	7.08	8.68	4.64	5.41	7.71	8.31
TiO_2	0.23	0.18	0.17	0.19	0.19	0.28
P_2O_5	0.03	0.03	0.03	0.04	0.03	0.02
MnO	0.03	<0.01	<0.01	0.01	0.01	<0.01
Cr_2O_3	0.00	<0.002	<0.002	0.00	0.00	<0.002
LOI	1.80	2.50	2.90	2.40	1.60	3.60
Total	**100.16**	**99.93**	**100.00**	**100.15**	**100.21**	**100.03**
	ppm	ppm	ppm	ppm	ppm	ppm
Hf	10.1	9.2	9.1	9.9	9.5	13.1
Nb	20.5	18.5	19.6	21.2	21.6	31
Rb	150.4	99.8	111	108.7	112.5	128.8
Sn	4	4	4	5	5	7
Sr	9	7.9	1.5	2.3	5.8	4.6
Ta	1.7	1.3	1.4	1.5	1.6	1.7
Th	21.6	24.3	23.8	20.7	20.1	28.9
U	4.7	6	6.3	4.1	3.7	5.7
V	14	<8	<8	5	5	<8
W	3.2	3.4	2.7	3.2	2.7	4.2
Zr	323.6	323	268	310.4	306.9	446.6
Y	49.9	48.6	54.1	55.1	50.8	41.4
La	62.5	51.5	58.4	52.7	53.9	53.9
Ce	136.7	105.3	114.7	109.3	104	113.4
Pr	16.23	13.11	14.07	13.77	13.52	15.49
Nd	61.5	48.7	50.8	52.9	50.3	59.1
Sm	11.3	9.21	9.16	9.8	9.2	11.01
Eu	0.78	0.76	0.6	0.71	0.66	1.08
Gd	9.89	8.33	8.34	8.97	8.44	8.93
Tb		1.39	1.43			1.39
Dy	8.92	7.84	8.59	9.3	8.89	7.53
Ho	1.7	1.67	1.84	1.77	1.69	1.47
Er	5.02	4.82	5.32	5.29	5.29	4.3
Tm	0.8	0.75	0.86	0.79	0.78	0.72
Yb	4.76	4.54	5.07	5.04	4.93	4.55
Lu	0.7	0.72	0.76	0.71	0.71	0.69

Zircon characteristics

Zircon characteristics are supplemented by electron microprobe analyses, in addition to U-Th-Pb ion microprobe analyses performed on a SHRIMP-II in the Center for Isotopic Research (CIR) at VSEGEI in St.-Petersburg, Russia. CAMECA SX-100 electron microprobe at Slovak Geological Survey, Bratislava was used for element concentration analyses. Si and Zr together with elements such as Hf, Y, U, Th, P and REE have been analysed (Table 2). La was below the detection limits. The operating conditions were as follows: 15 kV accelerating voltage, 40 nA beam current, beam diameter 1–5 μm; standards — zircon (Zr, Si), HfO_2 (Hf), apatite (P), $YbPO_4$ (Yb), wollastonite (Ca), $CePO_4$ (Ce), ThO_2 (Th), YPO_4 (Y), Gd_2O_3 (Gd); connecting period at 30 s (Si, Zr), 50 s (Hf), 110 s (Y) and 140 s (U, Th).

The analysed zircons exhibit composition zonation trends of increasing HfO_2 and ($UO_2 + ThO_2$) concentrations and decreasing ZrO_2/HfO_2 ratios from the core to the rim of the crystals (Table 2). The HfO_2

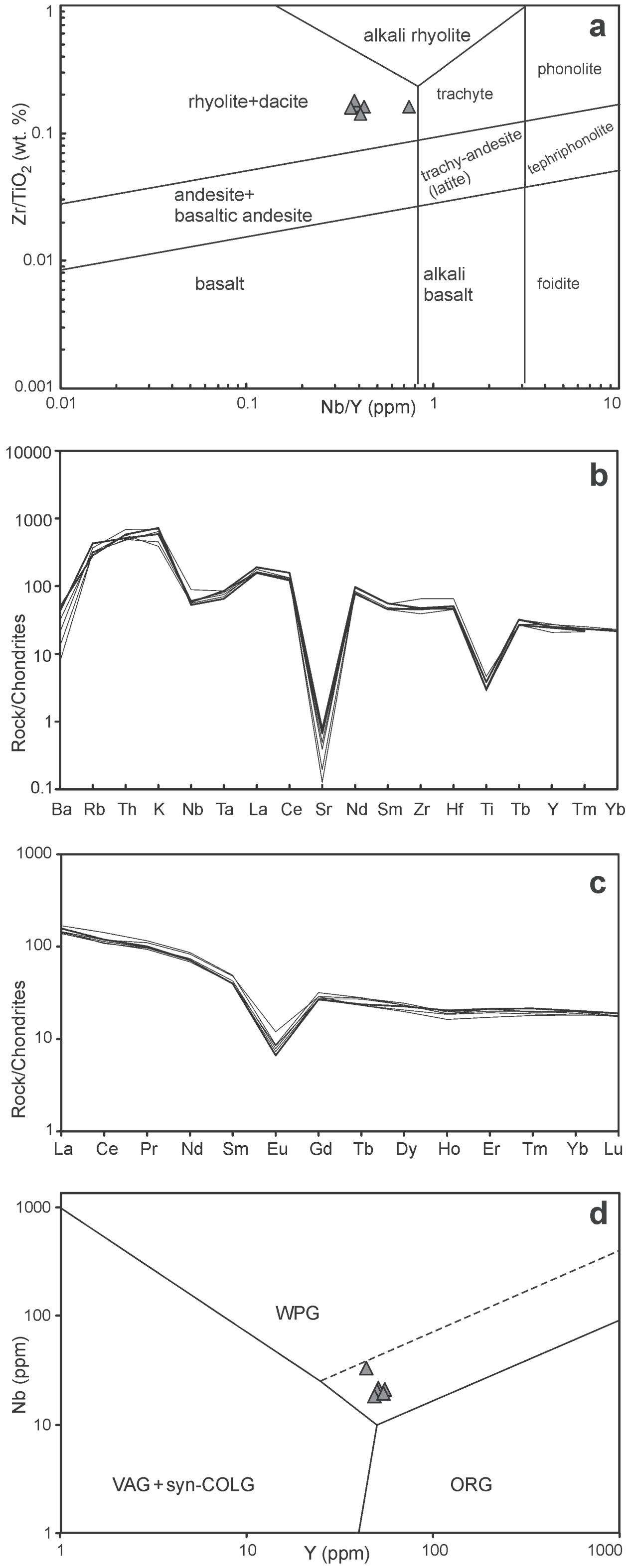

Fig. 3. Rožnava Formation acid volcanite characteristics based on the chemical composition. **a** — Zr/TiO_2 (wt. %) vs. Nb/Y (ppm) diagram after Winchester & Floyd (1977) modified by Pearce (1996). **b** — Chondrite normalized (Thompson 1982) trace elements abundances. **c** — Chondrite normalized REE patterns. Normalizing values are after Taylor & McLennan (1985). **d** — Variation Nb (ppm) vs. Y (ppm) with indication of tectonic settings after Pearce et al. (1984).

Table 2: Representative magmatic zircon analyses of the Rožňava Formation metarhyolites.

	1st volcanogenic horizon											2nd volcanogenic horizon					
Sample	**4-SM**	**4-SM**	**4-SM**	**4-SM**	**4-SM**	**4-SM**	**4-SM**	**4-SM**	**4-SM**	**4-SM**	**4-SM**	**2-SM**	**2-SM**	**2-SM**	**2-SM**	**2-SM**	**2-SM**
Analyses	ana1	ana2	ana3	ana4	ana5	ana6	ana7	ana9	ana10	ana11	ana12	ana4	ana5	ana6	ana7	ana8	ana9
Comment	zircon 1	zircon 2 bright zone	zircon 2 dark zone	zircon 3 bright core	zircon 3 dark rim	zircon 4 bright core	zircon 4 dark rim	zircon 5	zircon 6	zircon 7 core	zircon 7 rim	zircon 3 bright core	zircon 3 dark rim	zircon 4 dark rim	zircon 4 bright core	zircon 5 middle	zircon 5 rim
	(wt. %)	(wt. %)	(wt. %)	(wt. %)	(wt. %)	(wt. %)	(wt. %)	(wt. %)	(wt. %)	(wt. %)	(wt. %)	(wt. %)	(wt. %)	(wt. %)	(wt. %)	(wt. %)	(wt. %)
SiO_2	32.81	32.80	32.73	32.88	32.81	32.81	33.02	32.95	33.05	32.28	32.93	32.47	32.90	32.43	32.31	32.39	32.29
ZrO_2	66.00	66.01	66.29	66.81	67.14	65.57	66.48	66.55	65.60	63.45	65.87	63.33	64.98	64.72	63.47	65.68	65.80
Y_2O_3		0.46	0.20	0.71	0.08	0.46	0.30	0.12	0.30	1.89	0.15	0.79	0.21	0.36	0.55	0.15	0.15
UO_2		0.03		0.03		0.15	0.04		0.01	0.20	0.03	0.17			0.39		
ThO_2	0.04	0.06	0.02	0.06		0.15	0.02	0.04	0.03	0.24	0.01	0.29		0.04	0.21	0.01	
P_2O_5	0.21	0.16	0.22	0.14	0.10	0.24	0.15	0.17	0.10	0.38	0.09	0.42	0.13	0.32	0.36	0.19	0.13
CaO	0.01		0.00	0.00		0.00		0.00		0.00			0.01	0.01	0.01	0.01	0.01
HfO_2	1.09	1.45	1.43	0.77	0.85	1.43	1.46	0.82	1.45	1.17	1.54	1.12	1.20	1.41	2.04	1.33	1.31
Ce_2O_3			0.01	0.07	0.07			0.05		0.01				0.07	0.03	0.01	0.01
Gd_2O_3	0.01				0.07	0.03	0.08	0.09	0.10	0.14	0.07		0.00	0.00	0.13	0.13	0.02
Tb_2O_3	0.10	0.02	0.04	0.02	0.02		0.08	0.08		0.04	0.03		0.01	0.01	0.06		0.02
Dy_2O_3	0.11	0.08	0.03	0.19		0.13	0.16	0.19		0.07	0.14				0.06	0.05	0.05
Ho_2O_3	0.37	0.03	0.05	0.09	0.02	0.19	0.36	0.02		0.13	0.17		0.34		0.10		0.05
Er_2O_3	0.25	0.23		0.25			0.06		0.08	0.10		0.15	0.55	0.07		0.22	
Tm_2O_3	0.01	0.02	0.01	0.00		0.04	0.13	0.06		0.04	0.04	0.14				0.02	
Yb_2O_3	0.30	0.23	0.11	0.23		0.27	0.04	0.02	0.09	0.13		0.32	0.08	0.25	0.40	0.29	
Lu_2O_3			0.00	0.02	0.40		0.40		0.28		0.52	0.18		0.21			0.02
Total	**101.72**	**101.55**	**101.13**	**102.27**	**101.56**	**101.47**	**102.77**	**101.15**	**101.08**	**100.25**	**101.58**	**99.37**	**100.41**	**99.91**	**100.09**	**100.48**	**99.84**

abundance of these zircons range from 0.77 to 2.03 wt. % and the mean of 1.29 wt. % falls in the field of Hf (wt. %) variation in the zircon associations of acid magmatic rocks (Wark & Miller 1993; Hoskin & Ireland 2000; Hoskin & Schaltegger 2003 and references therein). The variation of the ZrO_2/HfO_2 ratios in the zircon assemblage ranges from 86 to 57 in the core and from 78 to 42 in the rim. The Th/U ratios are high, ranging from 0.42 to 0.89, typical for magmatic rocks. Based on chemical composition of studied zircons, the dominant substitution was probably the simple mechanism ($Hf^{4+}=Zr^{4+}$) combined with coupled substitution "xenotime" mechanism [$(Y, REE)^{3+}+P^{5+}=Zr^{4+}+Si^{4+}$] (Speer 1982), which is reflected in variations of Y contents (from 0.1 to 0.8 wt. %) and ΣREE abundance (0.15–1.31 wt. %).

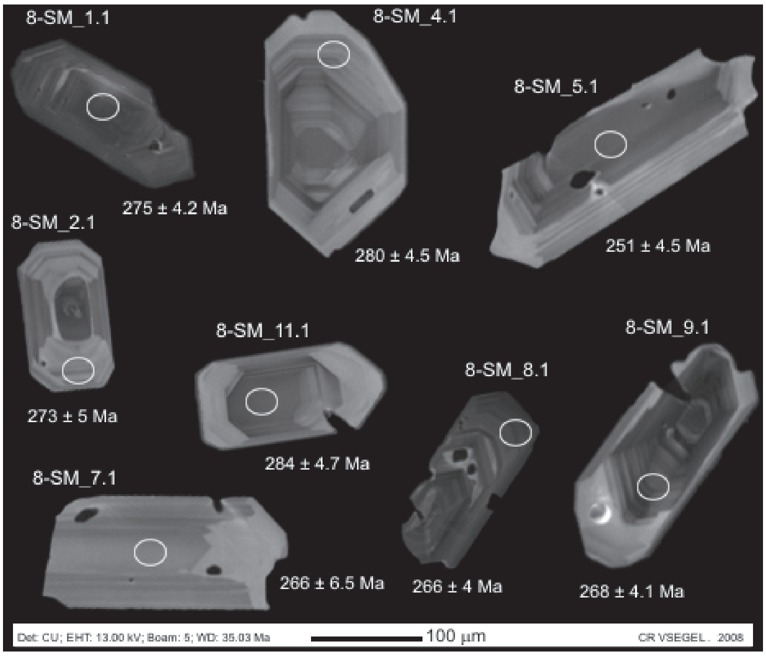

Fig. 4. Selected CL zircon images from the Rožňava Formation 1st horizon metavolcanites (sample no. 8-SM) and age data based on $^{206}Pb/^{238}U$ ratios with indication of measurement points.

SHRIMP ages

Samples 8-SM and 2-SM from the 1st and the 2nd volcanogenic horizons were dated from the Rožňava Formation volcanic rock suite.

Sample 8-SM: Loc.: West of Štítnik town, forest road 550 m SW from the Hrádok Hill (810 m altitude). Coordinates: N 48°92′020″, E 20°48′165″; 750 m above sea level.

A typical feature of the majority of the studied 8-SM zircon population is the presence of well developed growth zoning. It is quite commonly observed that regular growth zoning is interrupted by textural discontinuities along which the original zoning is resorbed and succeeded by the growth of a newly-zoned zircon. These resorption events probably reflect interference periods of Zr undersaturation in the magma. Some zircon crystals with bipyramidal sector zoning occur. The development of sector zoning has been attributed to kinetic factors and changes in the magmatic environment during crystal growth (Paterson & Stephens 1992) or to the relation between growth rates and lattice diffusivity (Watson & Liang 1995). Vavra et al. (1996) referred sector zoning to rapidly fluctuating and unequal growth rates related to the roughness of the growth surface and degree of saturation of the growth medium.

Euhedral zircons with fine oscillatory zoning, typical of magmatic origin (Fig. 4), gave an average concordia age of 273.3±2.8 Ma (Probability of concordance=0.90; MSWD of concordance=0.016; n=10; Fig. 5), with Th/U ratios within the range of 0.44–0.73 (Table 3). The Permian ages ranging from 266 to 284 Ma were determined in the wider zoned or unzoned central parts of the zircon crystals, as well as in their fine growth oscillation zoned rims.

Sample 2-SM: Loc.: West of Gočaltovo village, 50 m N of the Šebeková Hill (643 m altitude). Coordinates: N 48°92′180″, E 20°48′020″; 630 m above sea level.

Zircon population from the sample 2-SM contains crystals with fine oscillatory growth zoning and less with sector zoning (Fig. 6). A special case is local modification of magmatic zircon by the magmatic phenomena, which tend to disrupt the concentric oscillatory zoning and to develop irregular domains in zircon, thus cutting discordantly growth zoned domains.

The occurrence of xenocrystic zircons is a common feature in sample 2-SM. Zircon xenocrysts occur as cores mantled by newly grown magmatic zircons (Fig. 6). Xenocrystic cores are recognized from their rims by geometrically irregular surfaces, which truncate internal zoning or separate sub-rounded unzoned or chaotically zoned cores.

The average concordia age of 275.3±2.9 (Probability of concordance=0.85; MSWD of concordance=0.035; n=10) was obtained from the euhedral zircon population of the sample 2-SM (Fig. 7). The analyses were performed from oscillatory zoned magmatic zircons in the age interval from 267 to 287 Ma, with Th/U ratios within the range of 0.39–0.75 (Table 3).

From the studied zircon population, two inherited zircon grains were dated, which gave 842±12 Ma (Neoproterozoic) and 456±7 Ma (Late Ordovician) age (Table 3). They could be either supracrustal and/or magmatic in origin. Presumably they were incorporated in the Permian magmatic event from the underlying south-Gemeric basement, in which the Upper Ordovician metavolcanites of the Bystrý potok Formation (the Gelnica Group) contain Neoproterozoic inherited zircon cores (Vozárová et al. 2009b).

Discussion and conclusions

The obtained *in situ* U-Pb (SHRIMP) zircon ages clearly document the timing of post-Variscan extensional rifting in the internal zone of the Variscan Western Carpathians. The

Table 3: Rožňava Formation metavolcanites ion microprobe zircon data.

Gemeric Unit Gočaltovo Group Rožňava Formation	% $^{206}Pb_c$	ppm U	ppm Th	$^{232}Th/^{238}U$	ppm $^{206}Pb^*$	$^{206}Pb/^{238}U$ Age (Ma)	±	$^{207}Pb/^{206}Pb$ Age (Ma)	±	% Discor-dant
8-SM_1.1(core)	0.03	614	310	0.52	23	274.6	±4.2	287	±37	4
8-SM_2.1(rim)	0.00	135	57	0.44	5	272.6	±5	288	±76	5
8-SM_3.1(rim)	0.23	541	245	0.47	20.1	272.9	±4.1	269	±57	–1
8-SM_4.1(rim)	0.42	253	178	0.73	9.69	280.2	±4.5	271	±87	–3
8-SM_5.1(core)	0.11	151	89	0.61	5.17	250.9	±4.5	250	±83	0
8-SM_6.1(core)	0.16	710	341	0.50	26.5	273.1	±4.2	262	±68	–4
8-SM_7.1(core)	0.00	33	14	0.44	1.21	265.8	±6.5	292	±150	10
8-SM_8.1(core)	0.26	741	375	0.52	26.8	265.5	±4	255	±49	–4
8-SM_9.1(core)	0.21	463	310	0.69	16.9	268	±4.1	265	±61	–1
8-SM_10.1(core)	0.17	379	256	0.70	14.3	275.7	±4.3	252	±76	–9
8-SM_11.1(core)	0.25	204	123	0.62	7.92	284.1	±4.7	264	±95	–7
2-SM_1.1(rim)	--	140	64	0.47	5.36	281.1	±4.8	350	±110	25
2-SM_2.1(rim)	--	164	82	0.52	6.26	280.8	±4.9	290	±68	3
2-SM_3.1(rim)	0.06	40	15	0.39	1.51	279.1	±6.4	219	±150	–22
2-SM_4.1(rim)	--	169	81	0.50	6.24	272.1	±4.6	344	±77	26
2-SM_5.1(core)	0.16	447	398	0.92	16.8	275.9	±4.2	228	±62	–17
2-SM_6.1(core)	0.10	445	505	1.17	53.4	842	±12	835	±23	–1
2-SM_6.2(rim)	--	174	92	0.54	6.68	281.9	±4.7	300	±68	6
2-SM_7.1(core)	0.03	170	75	0.46	10.7	455.9	±7.2	422	±68	–7
2-SM_7.2(rim)	0.09	368	190	0.54	13.7	272.8	±4.2	284	±50	4
2-SM_8.1(rim)	0.10	251	183	0.75	9.01	263.4	±4.4	239	±68	–9
2-SM_9.1(rim)	0.18	289	209	0.75	10.5	267.2	±4.2	225	±66	–16
2-SM_10.1(rim)	0.46	188	117	0.64	7.37	286.9	±4.8	282	±120	–2

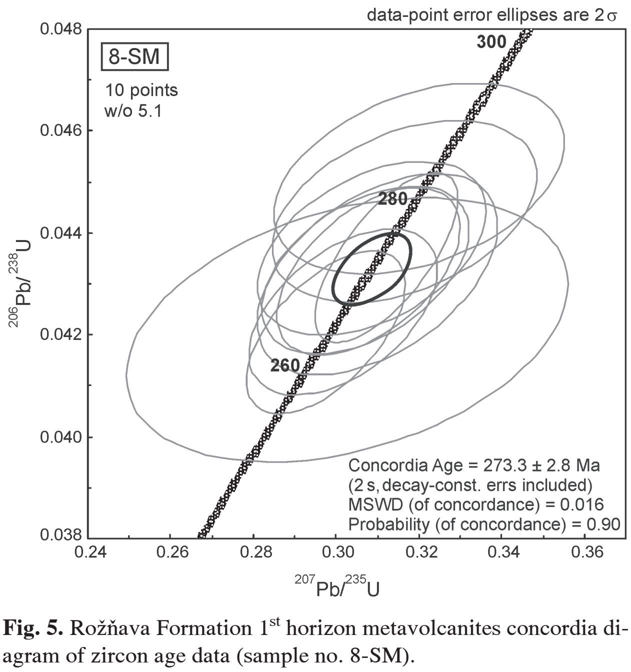

Fig. 5. Rožňava Formation 1st horizon metavolcanites concordia diagram of zircon age data (sample no. 8-SM).

average concordia ages of 273 ± 2.8 or 275 ± 2.9 Ma correspond to the Kungurian (the latest Cisuralian according to the International Stratigraphic Chart, Gradstein et al. 2004). This magmatism coincided with evolution of the Cisuralian rift system, post-dating the Devonian-Mississippian accretion of the Neoproterozoic/Early Paleozoic peri-Gondwana derived microplates (Gotic Terrane — Stampfli et al. 2001a; Hun Terrane — Stampfli et al. 2002; Galatian Terrane — von Raumer & Stampfli 2008), with polyphase colliding into the southern margin of Laurussia. The Western Carpathian Variscides, as an easterly continuation of the Austro-Alpine Domain of the Alps, were a part of this geodynamic system. The final stage of the Variscan collision shifted crustal blocks of the Central Western Carpathian Crystalline Zone on to the terranes of the Northern Gemeric Zone, where tectonically squeezed out relics of island arc and oceanic crustal fragments were preserved, on the Cambrian-Ordovician Gelnica Terrane margin (Vozárová 1998).

The change of regional stress patterns was coincident with termination of orogenic activity in the Variscan orogenic belt and was followed by major dextral translation between Gondwana and Laurussia (Ziegler 1990; Ziegler & Cloetingh 2004). The Variscan orogenic belt of the Western Carpathians during the post-Variscan evolution was deeply truncated with its superimposed system of the Pennsylvanian-Permian wrench-induced troughs. The Pennsylvanian-Cisuralian collapse of the Western Carpathian Variscan internides, of which relics are preserved in the Alpine tectonic superunits: Tatricum, Veporicum, Zemplinicum and Hronicum, is documented to have expanded southward over time (Vozárová 1996, 1998). The Cisuralian collapse of the southern foreland is reflected within the Permian sequence of the Southern Gemeric Unit.

Rifting, after rapid sedimentation of coarse-grained mature sediments, was associated with synsedimentary magmatic activity. It is well documented in the lithostratigraphic sequence of the Gočaltovo Group (Fig. 2). Polystage regional uplift coincided with regional cyclic sedimentation, as well as with the polyphase volcanic activity in the context of the 1st and 2nd volcanogenic horizons (Vozárová 1977). This uplift was probably induced by a complex combination of wrench-related lithospheric deformation and magmatic inflation of the lithosphere.

Permian Basin-and-Range basin type rifting was postulated for the Central Western Carpathians by Dostal et al. (2003)

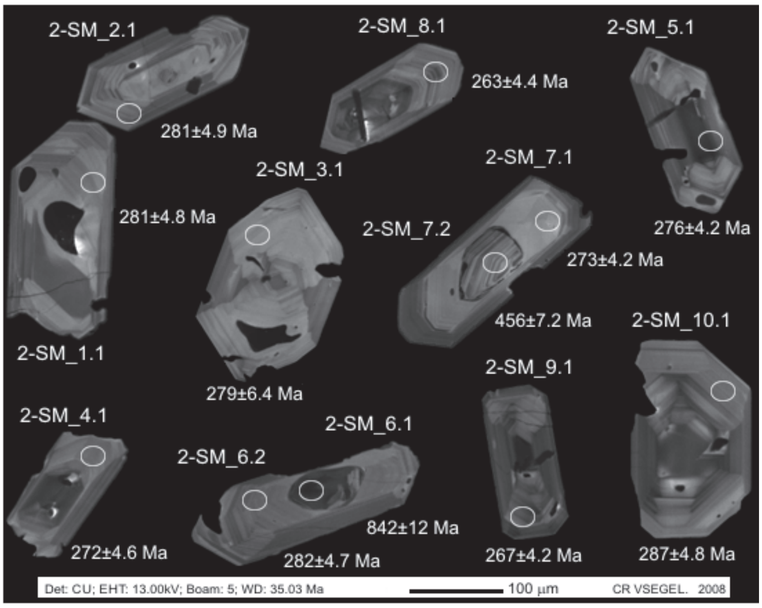

Fig. 6. Selected CL zircon images from the Rožňava Formation 2[nd] horizon (sample no. 2-SM) metavolcanites and age data based on $^{206}Pb/^{238}U$ ratios with indication of measurement points.

in the Hronic Unit. According to their interpretation this rifting followed the collision of the Paleo-Tethys ridge with the trench bordering the southern margin of Laurussia (in the sense of tectonic model of Stampfli 2001a,b). The south-Gemeric Rožňava Formation acid metavolcanites do not appear to be directly related to the mafic rocks. They were connected with crustal melting, but is not excluded that the melting was triggered by an elevated temperature gradient caused by ascending basaltic magma, as is supposed by Dostal et al. (2003).

The approximately equal zircon ages of the two volcanogenic horizons remain an open question, since it could be presupposed that in the case of normal lithostratigraphic sequence, the 2[nd] horizon volcanites might be younger then the 1[st] ones. The presented SHRIMP zircon ages show reverse trend, that means 273 ± 2.8 Ma concordia age for the 1[st] horizon volcanites and 275 ± 2.9 Ma zircon age for the 2[nd] one. Both correspond to the Kungurian age and the age difference is within the calculated standard deviation and standard analytical error.

Considering these age data, the Permian development of the south-Gemeric sedimentary basin was rapidly pulsating in extensional stages, following cyclicity in sedimentation and synsedimentary volcanic activity. The Rožňava Formation sedimentary sequence could have been formed in a relatively short lived transtensional event, within the Kungurian time span, not more than five and half million years long. A rapid subsidence coincides with the pulsating stage of extensional movements and was associated with synsedimentary volcanic activity. Referring to recent thickness of the Rožňava Formation rock sequence with calculation its diminishing due to diagenetic and metamorphic changes, the presumed sedimentation rate was relatively high, between 7 and 10 cm/yr. After the initial rapid sedimentation and synsedimentary tectonic activity, the Permian (Guadalupian-Lopingian) sedimentary evolution of the south-Gemeric basin had significantly less dynamic conditions. This is reflected in the absence of volcanic activity and coarse-grained sediments within the sedimentary sequence of the Štítnik Formation.

Two inherited grains were dated within the cores of the magmatic zircons from the sample 2-SM (Fig. 6). Both were presumably derived from the melted south-Gemeric basement rocks. The age of the Neoproterozoic inherited grain (842 ± 12 Ma) fully corresponds to the dominant detrital zircon ages coming from the Gelnica Group metasediments (unpublished results). Similarly, the majority of the inherited grains within the magmatic zircon cores of the Cambrian/Ordovician Gelnica Group metavolcanites confirm the same age (Vozárová et al. 2009b). The second inherited grain of the Middle/Late Ordovician age (456 ± 7 Ma) corresponds well to the youngest *in situ* U-Pb zircon ages of the metavolcanites of the Gelnica Group (Vozárová et al. 2009b).

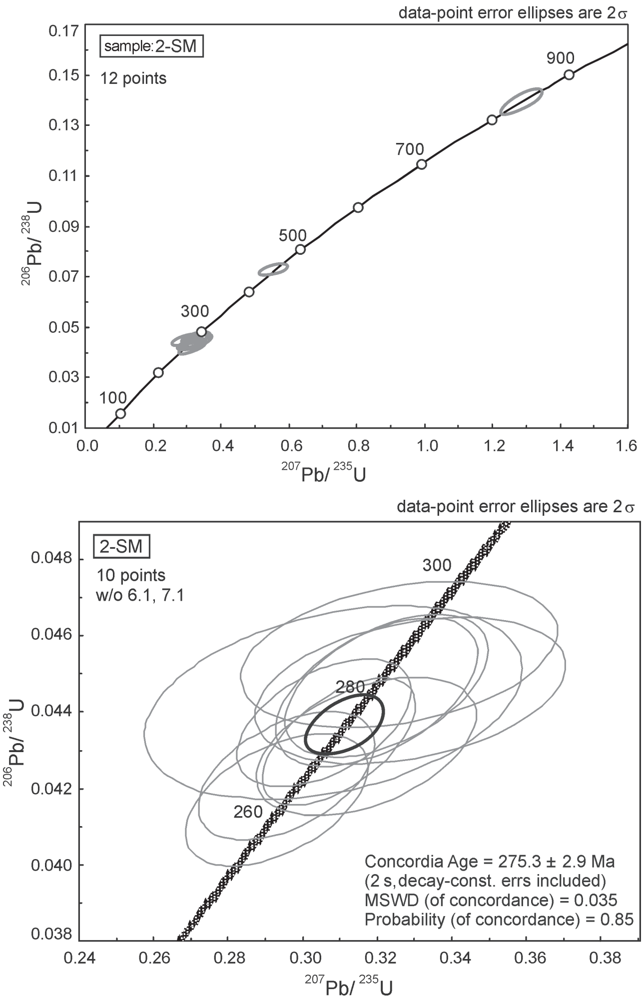

Fig. 7. Concordia diagrams of zircon age data from the Rožňava Formation 2[nd] horizon metavolcanites (sample no. 2-SM).

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