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LATE CRETACEOUS AGE OF THE ROCHOVCE GRANITE, WESTERN CARPATHIANS, CONSTRAINED BY U-Pb SINGLE-ZIRCON DATING IN COMBINATION WITH CATHODOLUMINESCENCE IMAGING

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Abstract: The Rochovce Granite — a subsurface intrusion in the southeastern part of the Veporic Unit, has been dated by means of the single zircon U-Pb method. The dated sample represents coarse-grained biotite monzogranite of the first intrusive phase. The morphology and composition of the zircon crystals were controlled by cathodoluminescence and electron microprobe analysis. The resulting U-Pb data plot on a discordia line with a lower intercept age of 75.6 ± 1.1 Ma, and an upper intercept age of 1203 ± 500 Ma. The lower intercept age is interpreted as the crystallization age of the Rochovce Granite. Cathodoluminescence imaging excludes the presence of inherited cores or disturbing inclusions in the dated zircons. The intrusion and emplacement of the Rochovce Granite were most likely accomplished by NE-dipping, low-angle extensional normal faults, developed along the NW-SE sector of the Lubeník line at the contact between the Veporicum and Gemericum. The new U-Pb single-zircon data prove the Late Cretaceous age of the Rochovce Granite and provide a further argument to recognize Cretaceous granite magmatism in the Western Carpathians.

Key words: Cretaceous orogeny, Western Carpathians, Rochovce Granite, single zircon U-Pb dating, cathodoluminescence imaging.

Introduction

The Rochovce Granite is a unique intrusion related to Alpine orogenic events in the Western Carpathians. This subsurface intrusion occurs in the southeastern part of the Veporic Unit along the contact with the overlying Gemeric Unit. The hidden granite body was discovered by the drill-hole KV-3 (Klinec et al. 1980), situated in the centre of a magnetic anomaly (Filo et al. 1974). Former geochronological investigations (Hraško et al. 1999) provided a Late Cretaceous (82 ± 1 Ma) age for the Rochovce Granite by conventional U-Pb dating of several zircon fractions. However, some authors (Cambel et al. 1989, 1990), also considered an older — Late Paleozoic age for this granite.

This contribution presents the first single zircon U-Pb data from the Rochovce Granite. To exclude possible contamination due to the presence of inherited components, morphology and composition of the investigated zircon crystals were controlled by cathodoluminescence (CL) and electron microprobe analysis. The resulting age determination supports Late Cretaceous crystallization of the Rochovce Granite that is discussed with regard to Cretaceous orogenic cycle in the Western Carpathians.

Geological background

The Rochovce Granite is subsurface intrusion in the southeastern part of the Veporic Unit along the contact with the overlying Gemeric Unit (Fig. 1). The contact between the Veporic and Gemeric units — the Lubeník line, was originally a Cretaceous overthrust fault. Its straight SW-NE trending segment was reactivated as a sinistral transpressional zone, while the NW-SE sector was reactivated as a NE-dipping low-angle extensional normal fault (Hók et al. 1993; Plašienka 1993; Madarás et al. 1996).

The SE part of the Veporic Unit (Figs. 1, 2) consists of pre-Alpine basement complexes assembled during the Variscan orogeny overlain by an Upper Paleozoic–Triassic sedimentary cover (Klinec 1966, 1976; Bajaník et al. 1984; Bezák et al. 1999). The polymetamorphic crystalline basement comprises mylonitized granitoids, migmatites, gneisses and diaphtoritic micaschists. Variscan ages (ca. 370–300 Ma) have been determined by U-Pb dating of zircons in granitoids, migmatites and orthogneisses (Bibikova et al. 1988, 1990; Cambel et al. 1990; Michalko et al. 1999). The A-type granites (Petrík et al. 1995) and subvolcanic felsic dykes show Permian to Triassic ages (278–216 Ma) according to U-Pb zircon dating (Kotov et al. 1996; Putiš et al. 2000). Fine-grained gneisses, mica schists and phyllites are mostly of sedimentary and volcanosedimentary Late Paleozoic protolith (Vozárová & Vozár 1988). These have been affected by Alpine medium-pressure regional metamorphism of greenschist to epidote amphibolite facies (Vrána 1964; Vozárová 1990; Plašienka et al. 1999; Lupták et al. 2000; Janák et al. 2001). Contact metamorphism related to the intrusion of the Rochovce Granite is manifested by the development of cordierite and andalusite in the metapelites (Korikovsky et al. 1986; Vozárová 1990).

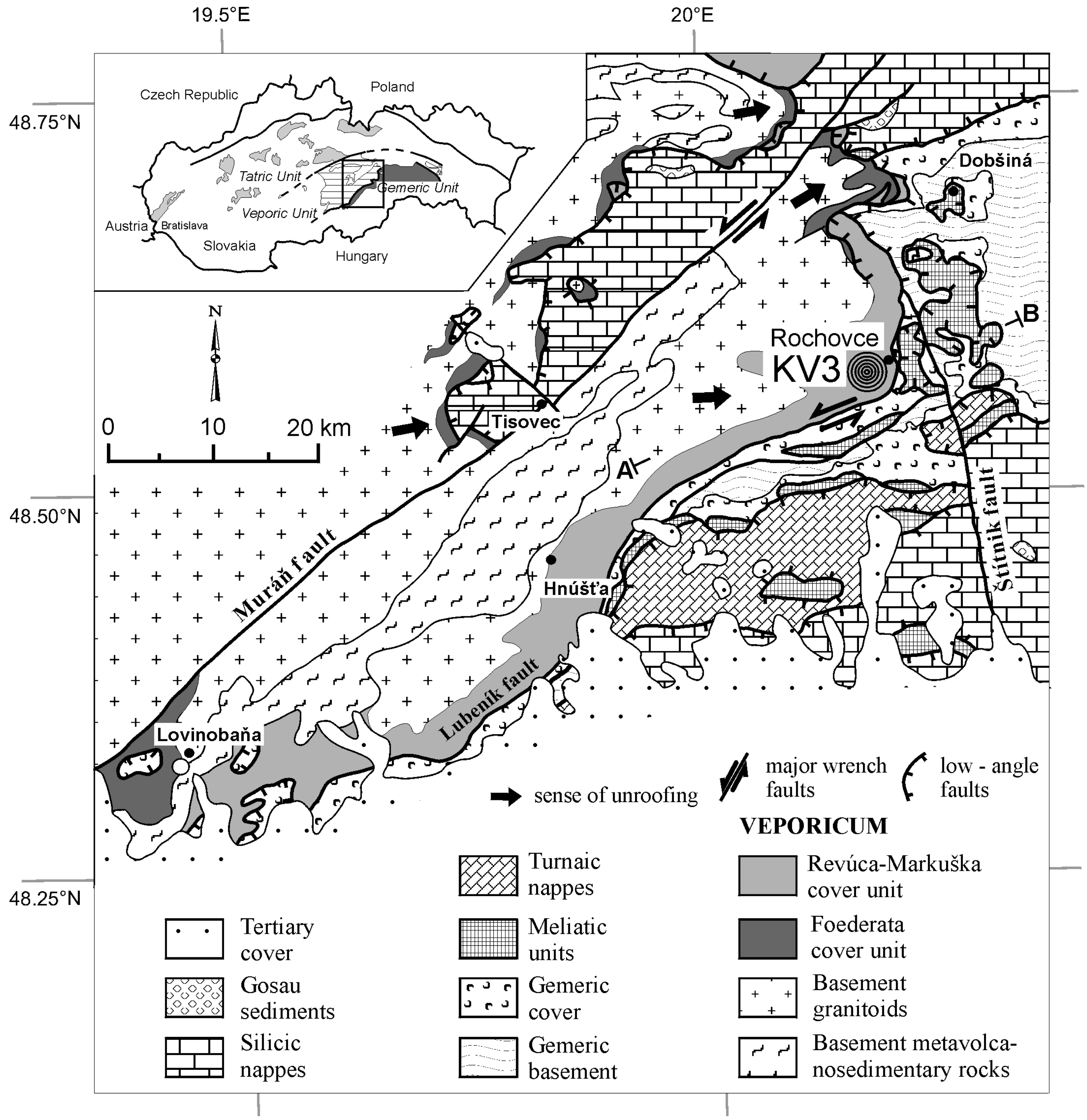

Fig. 1. Geological sketch map of the southeastern part of the Veporic Unit with the location of the borehole KV-3.

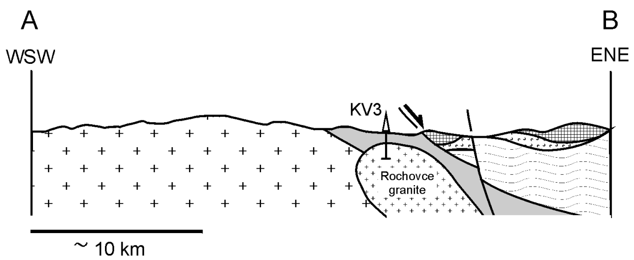

Fig. 2. Structural cross-section of the eastern part of the Veporic Unit, showing the inferred position of the Rochovce Granite. The explanations as in the Fig. 1.

Characterization of the Rochovce Granite

As revealed by the borehole KV-3, the Rochovce Granite occurs at the depth of 702 to 1600 m (Klinec 1980). The surrounding rocks are mostly metapelitic to psammitic micaschists and phyllites. Metabasites-metagabbros are less abundant, a larger body has been drilled in the depth of 607–702 m (Korikovsky et al. 1986, 1988; Krist et al. 1988).

The petrographic, mineralogical and geochemical features of the Rochovce Granite were described by Klinec et al. (1980), Határ et al. (1989) and Hraško et al. (1998). Two basic granitic phases have been recognized: (1) coarse-grained porphyritic biotite granite, locally with granite-porphyries and mafic magmatic enclaves, and (2) leucogranite porphyries, fine- to medium-grained and aplitic granites.

The Rochovce Granite shows high magnetic susceptibility (Gregor et al. 1992) and belongs to magnetite series according to Ishihara (1977). Measurements of magnetic susceptibility anisotropy indicate subhorizontal planar fabric attributed to both adjustment during solidification and partly to tectonic flattening after solidification (Gregor et al. 1992). However, there is no obvious deformation fabric present in our samples.

On the basis of the high sum of alkalies (Na_2O+K_2O = 7–9) and the Peacock's index (approximately 61–62), both intrusive phases of the Rochovce Granite correspond to the calc-alkaline or transition between the calc-alkaline and calcic magmatic series (Határ et al. 1989). They are enriched in Mg, K, Rb, REE's, Cr, Th, U, Nb, Mo a W (Határ et al. 1989). The porphyric biotite granites to granodiorites of the first intrusive phase are subaluminous, with A/CNK = 0.9–1.1, while leucogranitic fine- to medium-grained and aplitic granites of the second intrusive phase are rather peraluminous, with A/CNK ratio from 1.05 to 1.55. The second intrusive phase granites are accompanied by disseminated and vein mineralization containing molybdenite (± quartz, pyrite, ferberite and scheelite). This mineralization can be compared with that of the calc-alkaline Mo-stockwork deposits (Határ et al. 1989).

Geochemical and mineralogical features (e.g. allanite-magnetite-titanite accessory assemblage) as well as the presence and origin of mafic magmatic enclaves (Hraško et al. 1998) indicate an I-type character for the Rochovce Granites, involving the lower crust as the principal source of granite and mixing/mingling with more basic — dioritic magma.

The dated sample represents coarse-grained biotite monzogranite of the first intrusive phase, composed of quartz, K-feldspar, plagioclase and biotite. Accessory minerals represent mainly magnetite, titanite, allanite-(Ce), epidote, apatite and zircon. Quartz occurs as bipyramidal, euhedral (Qtz I) to anhedral (Otz II) grains. Pinkish K-feldspar forms large phenocrysts of up to 3 cm size or younger, intersticial and anhedral grains. Plagioclase of two generations (An_{36-45} and An_{15-22}) occurs mainly as subhedral crystals or twins after albite, Carlsbad, and pericline law. Biotite crystals are lath-shaped and subhedral, their compositions vary with respect to Fe/(Fe + Mg) ratio from 0.38–0.45 (Határ et al. 1989).

Analytical techniques

The cathodoluminescence imaging was performed at the Max-Planck Institute of Chemistry in Mainz using a Hitachi S450 scanning electron microscope with connected panchromatic CL detector. Prior to analysis the zircons were picked into a mount, polished and coated with carbon following the procedure for CLC-dating method (Poller et al. 1997; Poller 2000).

Electron microprobe analyses (EMPA) of separated and polished zircon crystals were performed in the WDS mode, using a Cameca SX50 instrument at the Department of Geological Sciences, University of Manitoba in Winnipeg, Canada. The beam diameter was 1–2 μm. An accelerating potential of 15 kV, beam current of 20 nA and counting time of 20 s were set for Si, Zr, Hf and Y; 20 kV, 30 nA and 40 s for Th and U. The following standards were used: zircon (Si Ka, Zr La), metallic Hf (Hf Ma), YAG (Y La), ThO_2 (Th Ma) and UO_2 (U Mb). The data were reduced according to the PAP routine.

The isotopic measurements were performed on single zircon grains of less than 10 μg using the vapor digestion method (Wendt & Todt 1991). The zircons were placed in a special teflon bomb with small holes for each individual grain. A ^{205}Pb-^{233}U mixed spike and 28N HF were added to each hole and the bomb was placed in an oven at 200 °C for 5 days. After complete dissolution, the samples were dried and 6N HCl was added, and then they were kept for 1-day in the oven at the same temperature. Following this step the zircons were completely dissolved, homogenized with the spike and ready for measurement. The samples were loaded on Re single filaments with a mixture of silica gel and H_3PO_4. The Pb isotopes were measured using a MAT 261 mass spectrometer in peak-jumping mode, using a secondary electron multiplier. The Pb blank was analyzed together with the samples. The total amount of Pb blank was 3 pg and the following iotopic ratios were used for the Pb blank correction: $^{206}Pb/^{204}Pb$ = 18.89, $^{207}Pb/^{204}Pb$ = 15.30. This isotopic composition of the blank was determined by parallel blank measurements. For the common Pb correction, cogenetic feldspar and associated galena crystals from the Rochovce area were measured. The resulting values for correction were $^{206}Pb/^{204}Pb$ = 18.57 and $^{207}Pb/^{204}Pb$ = 15.68. All the ratios were corrected for fractionation using the NBS 982 standard as reference (Todt et al. 1996) and those for U using a "U nat" standard solution. The analyses were corrected with parallel determined fractionation values, scattering between 2.9 ‰ and 3.1 ‰ per Δ amu for Pb, during the period of measurements (Loveridge 1986). Due to the very low weight of the zircons (estimated to be 1–3 μg) no exact determination of their weight was possible. Consequently, concentrations for U, radiogenic Pb and common Pb cannot be given. The error correlations are based on Monte-Carlo calculations resulting the following values: 0.22 (KV3-a), 0.44 (KV3-e) and 0.39 (KV3-f). The U-Pb age calculations are based on ISOPLOT program of Ludwig (1992), the 2.01 version of May 27, 1999. All errors are 2σ and refer to the 2σ deviation of the weighted mean of 2 to 6 blocks.

Zircon characteristics

Zircon occurs as euhedral crystals of 0.1 to 0.4 mm in size enclosed by biotite, rarely by plagioclase or quartz. The zircon crystals are transparent, rarely semitransparent with pale pink, glassy to adamantine luster. According to zircon typology (Pupin 1980), the investigated zircons correspond mainly to the P_3-P_1 subtypes, which indicates medium temperature and a high (Na + K)/Al ratio in the magma during zircon crystallization.

Cathodoluminescence (CL) and back-scattered electron images (BSE) of zircon crystals show distinct oscillatory zoning, (Fig. 3). The central parts show diffuse structures

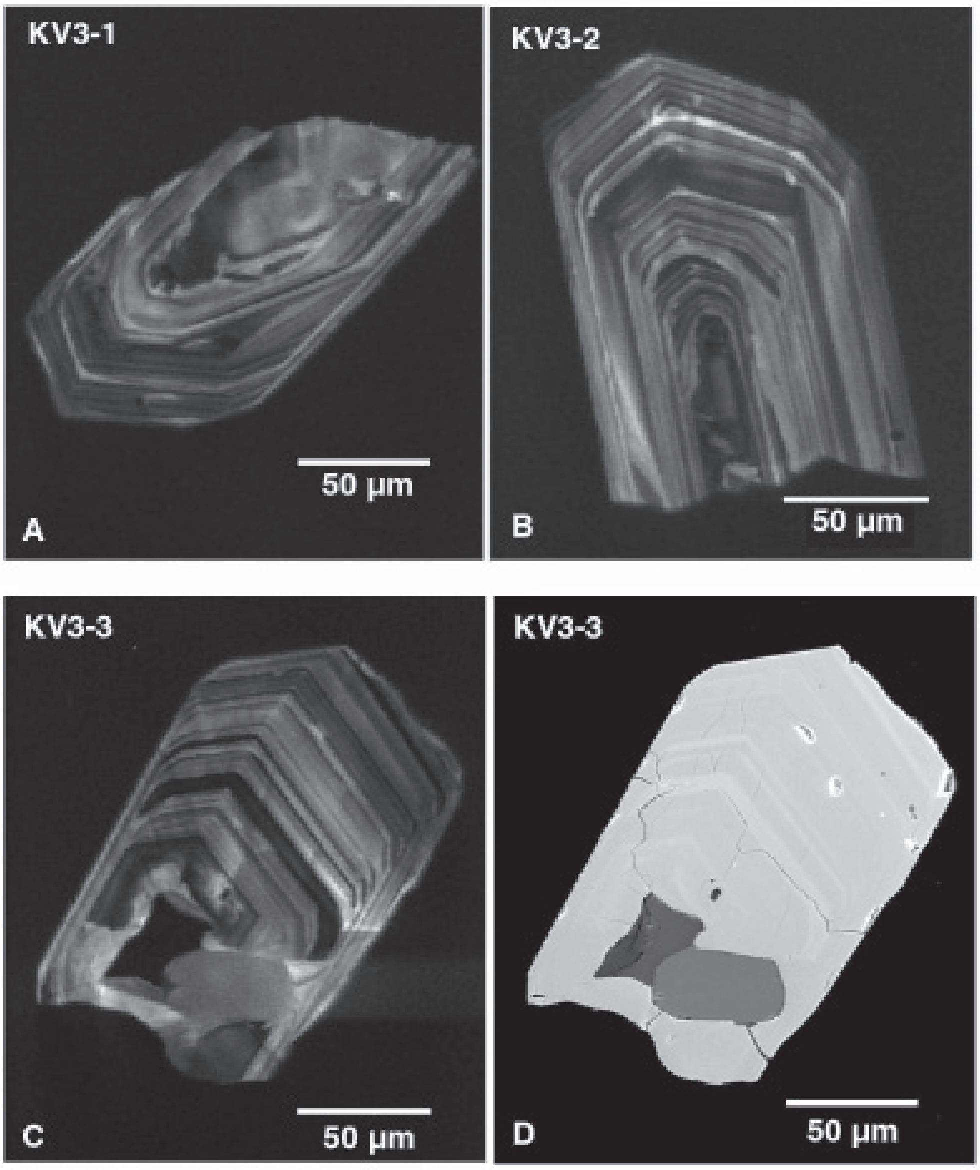

Fig. 3. Cathodoluminescence (A, B, C) and back-scattered electron (D) images of zircons from the Rochovce Granite. Images (C) and (D) show the inclusions of quartz (black) and feldspar (grey) in the zircon grain KV3-3.

(Fig. 3a) and locally even several different luminescent areas. Nevertheless, the inner parts have a regular outer shape and their uniform habit corresponds to the outer zones of crystals. No significant amounts of old, inherited components were detected either by the cathodoluminescence (Fig. 3b), or the U-Pb measurements. Consequently, analysed zircons seem to be grown during a single event. Sporadically, inclusions of quartz and feldspar have been found in some zircons (Fig. 3c and 3d). They contain a large amount of common Pb contaminating zircons and analyses of such zircons may fail due to low $^{206}Pb/^{204}Pb$ ratios and too large corrections.

The electron-microprobe analyses of zircons (Table l) show slight compositional zoning with respect to the HfO_2 contents (0.9–1.4 wt. %). The Hf/(Hf + Zr) ratio is similar to that in zircons from crustal, orogenic calc-alkaline granites (cf. Pupin 1992). The concentrations of U, Th, Y, REE and other trace elements are rather low and often below the detection limit (< 0.4 wt. %). Nevertheless, the compositions of the zircons indicate the crustal origin of the Rochovce Granite.

Results of the U-Pb dating

Results of the U-Pb single zircon measurements from the Rochovce Granite are shown in the Table 2 and Fig. 4. Although six zircon grains were analysed, due to incorporated common Pb and extremely low contents of radiogenic Pb (estimated to be below 10 ppm) and U, only three analyses gave reasonable data points (Fig. 4). Two zircons (KV3-758e and KV3-758f) are concordant near 75 Ma; grain KV3-758a is slightly discordant. Altogether, they plot on a discordia line with a lower intercept age of 75.6 ± 1.1 Ma and an upper intercept age of 1203 ± 500 Ma. The large error in the upper

Table 1: Representative microprobe compositions of zircon from the Rochovce Granite (in wt. %).

grain/position	1core	1rim	2core	2rim
SiO_2	32.09	31.62	31.75	32.13
ZrO_2	66.17	64.40	63.33	65.60
HfO_2	1.35	1.39	0.91	1.24
ThO_2	0.00	0.00	0.44	0.00
UO_2	0.04	0.09	0.37	0.13
Y_2O_3	0.03	0.00	0.37	0.00
Total	99.68	97.50	97.17	99.10
Formulae based on 16 anions				
Si	3.964	3.987	4.018	3.985
Zr	3.986	3.960	3.908	3.967
Hf	0.048	0.050	0.033	0.044
Th	0.000	0.000	0.013	0.000
U	0.001	0.003	0.010	0.004
Y	0.002	0.000	0.025	0.000
Total	8.001	8.000	8.007	8.000
Hf/(Hf+Zr)	0.012	0.012	0.008	0.011

Table 2: U-Pb data of the single zircon analyses by TIMS (thermal ionization mass spectrometer).

	KV3-a	KV3-e	KV3-f
measured ratios $^{a)}$			
U/Pb*	68.81	72.99	71.64
^{206}**Pb/**^{204}**Pb**	658.81	369.87	1046.63
atomic ratios $^{b)}$			
$^{206}Pb^*/^{238}U$	0.01208	0.01141	0.01162
± $^{206}Pb^*/^{238}U$	0.00006	0.00007	0.00007
$^{207}Pb^*/^{235}U$	0.08066	0.07383	0.07466
± $^{207}Pb^*/^{235}U$	0.00118	0.00212	0.00137
$^{207}Pb^*/^{206}Pb^*$	0.04843	0.04695	0.04660
± $^{207}Pb^*/^{206}Pb^*$	0.00047	0.00111	0.00057
ages (Ma) $^{b)}$			
$^{206}Pb^*/^{238}U$	77.4	73.1	74.5
± $^{206}Pb^*/^{238}U$	0.4	0.4	0.4
$^{207}Pb^*/^{235}U$	78.8	72.3	73.1
± $^{207}Pb^*/^{235}U$	1.1	2.0	1.3
$^{207}Pb^*/^{206}Pb^*$	120.5	46.7	28.5
± $^{207}Pb^*/^{206}Pb^*$	22.8	50.0	29.5

a) corrected for fractionation
b) corrected for blank, spike and common Pb
* radiogenic Pb
2σ mean errors refer to 2σ deviation of the weighted mean of 2–6 blocks.

intercept can be attributed to the absence of larger inherited components. The lower intercept age is interpreted as the crystallization age of the Rochovce Granite.

Discussion

Cretaceous orogeny and granite magmatism in the Western Carpathians

The Austroalpine units of the Eastern Alps and the Slovakocarpathian units of the Western Carpathians exhibit a Cretaceous nappe structure that originated from collisional crustal stacking of the lower plate after closure of the Meliata-Hallstatt oceanic domain (e.g. Dallmeyer et al. 1996; Plašienka 1997; Willingshofer et al. 1999). Considerable crustal thickening during this collisional event is indicated by the amphibolite, in places also eclogite facies metamorphism (e.g. Thöni & Jagoutz 1992; Hoinkes et al. 1999) in the southern Austroalpine units (Ötztal region, Kreutzek area, Gleinalm, Koralm and Saualm domes, Sieggraben unit). Cretaceous metamorphism in the Veporic Unit reached middle amphibolite facies at *P-T* conditions of ca. 600 °C and 10 kbar (Plašienka et al. 1999; Janák et al. 2001). Late Cretaceous exhumation of these metamorphic terrains is interpreted in terms of post-collisional, orogen-parallel extension and unroofing along low-angle detachment faults (Neubauer et al. 1995; Hoke 1988; Plašienka et al. 1999). Such a tectonic situation is favourable for melting of the lower crust and intrusions of early post-orogenic granite bodies. However, only minor aplite and pegmatite veins are reported to accompany Cretaceous metamorphism in the Alps.

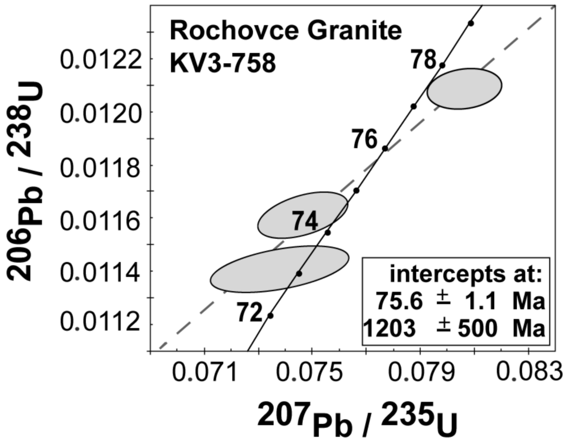

Fig. 4. $^{207}Pb/^{235}U$ vs. $^{206}Pb/^{238}U$ discordia plot for the Rochovce Granite.

In the southernmost part of the Veporic Unit, the quartzo-feldspathic veins frequently crosscut the Alpine metamorphic foliation in both the pre-Alpine basement and Late Paleozoic–Mesozoic cover sequences. Seemingly these veins are related to some larger granitoid bodies, whose Alpine age was inferred by some authors (e.g. Vozárová & Vozár 1988). The Rochovce Granite, as encountered in the well KV-3, is devoid of the penetrative Alpine deformation present in the country rocks. Its contact metamorphism clearly postdates Alpine regional metamorphic assemblages. Therefore, zircon dated by both conventional (Hraško et al. 1999) and single-grain methods presented above, definitely confirms the Alpine age of the Rochovce Granite, constraining its crystallization in Late Cretaceous time (82–75 Ma). Consequently, the existence of inferred Cretaceous granitoids in the southern Veporicum needs to be proved also on the surface.

On the basis of the general Mesozoic geodynamic development of the Western Carpathians (Plašienka 1997; Plašienka et al. 1997), the following scenario for the generation and emplacement of the Rochovce Granite can be inferred. (1) In the Late Jurassic–Early Cretaceous, continental collision and crustal stacking followed the closure of the Meliata ocean. The Veporic Unit, occupying the lower plate position was deeply buried below higher tectonic units (Gemeric, Meliatic, and Turnaic). Crustal thickening together with some heat input from the mantle might have triggered partial melting and the generation of granite in the lower crust. (2) In mid-Cretaceous times, shortening and crustal stacking continued and prograded outwards. The Veporic Unit was underplated by the buoyant continental Fatric crust. Shortening in the rear of the Veporic wedge triggered its exhumation and orogen-parallel extension. (3) During the final stages of exhumation, the Rochovce Granite was emplaced into the extensional shear zones. The sources of granitic melts could be in the lower crustal root, not exposed on the surface.

The relative scarcity of Cretaceous granites, especially in the Alps, could be ascribed to the comparatively steep metamorphic isotherms. Accordingly, the Cretaceous mountain root of the Alpine-Carpathian orogen was probably not hot enough to produce voluminous granitic melts as commonly happens in orogens collapsing due to the removal of the lithospheric root.

Conclusions

1 — Single zircon U-Pb dating of the Rochovce Granite yields an age of 75.6 ± 1.1 Ma. This is interpreted as the age of crystallization of the Rochovce Granite.

2 — Cathodoluminescence imaging excludes the presence of inherited cores or disturbing inclusions in the dated zircons.

3 — Single zircon data prove the Late Cretaceous age of the Rochovce Granite as determined also by the conventional U-Pb dating (82 ± 1 Ma; Hraško et al. 1999).

4 — The results of single zircon U-Pb dating provide a further argument to recognize the granite magmatism related to the Cretaceous orogenic cycle in the Western Carpathians.

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