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U-Pb, Rb-Sr AND K-Ar DATING OF SIHLA TONALITES OF VEPOR PLUTON (WESTERN CARPATHIAN MTS.)

(2 Figs., 4 Tabs.)



Abstract: The authors present in the paper new results of isotopic datings of Sihla tonalites of the Vepor Pluton in Western Carpathians. U-Pb dating on zircons from 2 samples gave a concordant age of magmatic zircons – 303 ± 2 m.y., corresponding to the age of crystallization of the melt. At the same time, Rb-Sr model age of biotites from the same samples is 88–98 m.y. and K-Ar age 236–278 m.y. The paradoxical relation of Rb-Sr and K-Ar ages of micas can be explained by the suggestion that Alpine radiologic rejuvenation (94 m.y.) was of hydrothermal character (with migration of radiogenic Sr and Rb) at a temperature below 300 °C. In this case the loss of radiogenic Ar from micas would have been, minimal, as a result of which biotites could preserve higher values of K-Ar age nearer to the age of melt crystallization than to the age of Alpine rejuvenation.

Резюме: Проведено изотопное датирование тоналитов Сигла Вепорского плутона в Западных Карпатах. U-Pb методом по цирконам из 2 проб получено конкордантное значение возраста магматических цирконов 303 ± 2 млн. лет, что соответствует времени кристаллизации расплава. В то же время Rb-Sr модельный возраст биотитов из тех же проб оказался равным 88–98 млн. лет, а K-Ar – 236–278 млн. лет. Парадоксальное соотношение Rb-Sr и K-Ar возрастов слюд объясняется тем, предположением что альпийское радиологическое омоложение (~ 94 млн. лет) имело гидротермальный характер (с миграцией радиогенного Sr и Rb) при температуре ниже 300 °C. В этом случае потеря радиогенного Ar слюдами будет минимально, вследствие чего биотиты сохраняют древнее K-Ar значение возраста, более близкое ко времени кристаллизации расплава, чем ко времени альпийского омоложения.

History of geochronologic study of the Vepor Pluton

There are several isotopic datings available for the Vepor Pluton – a part of which are the Sihla tonalites – obtained by various methods on all of its varieties: Sihla, Vepor and Ipel granitoid types (Krist, 1981), as well as for the Hrončok granites.

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K-Ar dating on biotites from the Vepor Pluton gives a wide range of ages – from 110 to 240 m.y. (Bagdasaryan et al., 1977; Cambel et al., 1979). Biotites and potassium feldspars from the Hrončok granites gave the age 96–214 m.y. (Kantor, 1959; Bagdasaryan et al., 1977; Cambel et al., 1979). Thus, K-Ar datings do not give any age earlier than Triassic.

There are some U-Pb datings on zircons from the rocks of the Vepor Pluton. They all proved to be discordant and according to the ratio $^{206}\text{Pb}/^{238}\text{U}$ the ages are as follows: Sihla type - 380 m.y., Vepor type - 320 m.y., Hrončok type - 260 m.y. (Semenenko – Cambel et al., 1977; Cambel – Shcherbak et al., 1977). Regarding the discordant character of these values as well as the applied macromethod the use of which has already been abandoned, it is necessary to view these results with caution.

Granitoids of the Vepor Pluton have also been dated by the Rb-Sr isochrone method. The following isochrones have been obtained: Sihla tonalites - 387 ± 27 m.y., Vepor and Ipeľ type granites - 284 ± 22 m.y. (Bagdasaryan et al., 1986). These data allow to make a conclusion on the heterogeneity of the Vepor Pluton formation: the intrusion of the Sihla tonalites took place in the Lower Devonian and Vepor and Ipeľ granites intruded at the boundary of the Upper Carboniferous and Permian.

Controversial character of these data indicates that there is so far no clear age scheme for the formation of the Vepor granitoids. However, it is indisputable that after their crystallization the rocks of the Vepor Pluton were to a lesser extent affected by a post-Variscan rejuvenation event related to the Alpine cycle.

In relation to these problems we attempted an isotopic study with the aim of determining the age of the Sihla tonalites – supposedly the earlier phase of the Vepor Pluton.

Description of samples

Two samples have been collected for the isotopic studies, from relatively fresh as well as from blastomylonitized tonalite varieties, 20 kg in weight.

Sample SI-1 (from the central part of the massif), is tonalite with preserved magmatic texture. The sample was taken from a rock outcrop near the main road, on the pass between the villages Čierny Balog and Sihla, approx. 100 m from the memorial (Fig. 1).

The tonalite has hypidiomorphic-granular texture and unclear porphyric structure due to plagioclase phenocrysts. Primary paragenesis: $\text{Bt}_{\text{Ti}} + \text{Pl} + \text{Qtz}$, accessories $\text{All} + \text{Sph}$.^{*} Large sphene crystals are sometimes resorbed by magmatic plagioclase indicating thus magmatic origin of at least a part of sphenes. Tonalite was affected by intensive secondary alterations predominantly of autometasomatic character, the newly formed paragenesis being $\text{Bt}_{<\text{Ti}} + \text{Ms} + \text{Chl} + \text{Ep} + \text{Ser} + \text{Ab} + \text{Ab} + \text{Leuc}$. Primary-magmatic, apparently Ti-rich biotites (Bt_{Ti}), practically preserving their flaky form, are totally substituted by secondary lower-Ti biotite (1.7–1.8 % TiO_2) (Bt_1) with abundant small leucoxene inclusions. Biotite and plagioclase are also substituted by large-flaked muscovite. Plagioclases are replaced by albites (2–5% An) with ingrowths of sericite and epidote. Large epidote grains can be found as well, sometimes intergrown with chlorite.

Sample HR-2 (from the north-eastern end of the massif), is blastomylonitized tonalite with secondary schistosity, but preserved massive structure. The sample was collected on a rock

^{*} Mineral symbols: Ab – albite, All – allanite, An – anorthite, Bt – biotite, Chl – chlorite, Ep – epidote, Leuc – leucoxene, Ms – muscovite, Pl – plagioclase, Qtz – quartz, Sph – sphene.

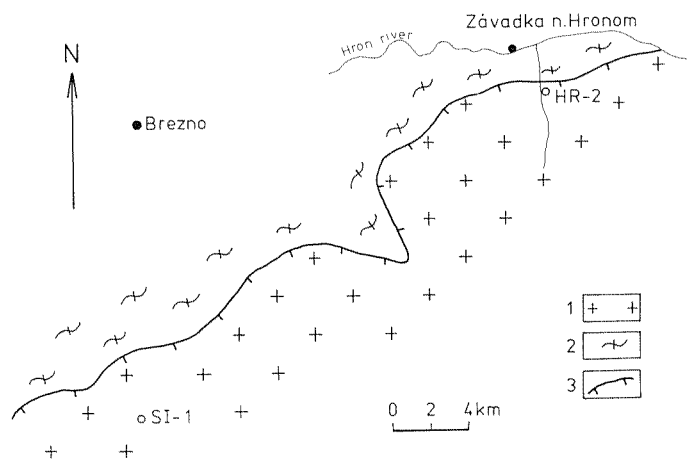


Fig. 1. Geological situation map of sampling.

Legend: 1 – granitoids of Vepor Pluton; 2 – metamorphic rocks of Hron complex; 3 – overthrust plane.

Table 1
Chemical composition (wt. %) of tonalite samples

	SI-1	HR-2
SiO ₂	64.72	62.15
TiO ₂	0.92	0.96
Al ₂ O ₃	15.70	16.45
Fe ₂ O ₃	2.09	1.68
FeO	2.08	1.54
MnO	0.069	0.066
MgO	2.02	2.29
CaO	3.24	3.86
Na ₂ O	4.13	4.34
K ₂ O	2.61	2.39
H ₂ O ⁻	0.10	0.08
H ₂ O ⁺	1.66	3.43
BaO	0.17	0.24
SrO	0.09	0.12
P ₂ O ₅	0.36	0.40
CO ₂	0.12	0.20
Li ₂ O	0.0059	0.0056
Rb ₂ O	0.0060	0.0052
Cs ₂ O	0.00015	0.00014
	100.09	100.20

Analysts: O. G. Unanova, G. E. Kalenchuk. The analyses have been carried out in the Central chemical laboratory of IGEM. Acad. Sci. of the USSR.

Note: The analyses show that the compositions of the rocks are very similar and they can be classified with the group of tonalite (SI-1) — quartz diorite (HR-2).

outcrop on the right side of the Hronec river valley, south of the village Závadka nad Hronom, 300 m from a quarry, on the line of the Pohorelá fault (Fig. 1).

Hypidiomorphic-granular texture of the tonalite is transformed into secondary schistosity due to segregations of secondary biotite, sericite and chlorite. Primary paragenesis: $Bt_{Ti} + Pl + Qtz$, accessories – Sph with apatite admixture. Primary-magmatic biotites (Bt_1) are like in the sample SI-1 pseudomorphically substituted by low-titanium biotite Bt (1.6–1.8% TiO_2) with leucoxene inclusions. Plagioclase is albitized (< 9% An) with inclusions of Ep and Ser. The schistose aggregate contains small flakes of secondary light-coloured biotite (Bt_2), sericite, chlorite and epidote.

Thus, in both samples, with preserved (SI-1) or disturbed (HR-2) magmatic texture, magmatic biotites do not preserve their primary composition and they are substituted by medium-or low-temperature minerals.

Chemical composition of both samples is listed in Tab. 1.

Morphology of zircons and results of their U-Pb dating

Accessory zircons in the samples SI-1 and HR-2 proved to be identical. They are represented by idiomorphic prismatic grains with an elongation of 3–4, light-pink in colour. The freshest zircons were in the sample HR-2, they are transparent, without inclusions. Zircons in the sample SI-1 contain numerous pyrite inclusions, many grains are semitransparent. In the large fraction of zircon (> + 100 μ) some grains have a dark center.

The application of Pupin's (1980) morphometric classification produced very similar typograms, the gravity centers for zircons SI-1 having the parameters $\overline{L.T.} = 443$, $\overline{L.A.} = 308$, and for zircons HR-2 $\overline{L.T.} = 444$, $\overline{L.A.} = 293$. This is a proof of their typologic identity. The largest number of zircons in both samples belongs to the types S_{12} , less frequently S_{11} and S_7 . Thus, the predominant mass of zircons was separated at relatively high temperatures, and with the evolution of melts at decreasing temperature their quantitative content rapidly decreased. The identity of the evolution of zircons determined on the basis of typograms indicates also common evolution of tonalites represented by both samples (Fig. 2).

Isotopic compositions of zircons from tonalites as well as the results of their age determination are presented in Tab. 2.

The contents of uranium in the zircons are relatively low - 500–600 ppm. Zircons from the sample SI-1 contain a relatively high admixture of common lead, apparently due to sulphide inclusions. Calculations show that this lead has anomalous composition.

According to isotope ratios we obtained from the morphologically "ideal" zircon of the sample HR-2 absolutely concordant age values - 303 ± 2 m.y. Similar to these values are ages obtained on the basis of the isotope ratio $^{206}Pb/^{238}U$ and for various zircon fractions from the sample SI-1 (305, 295, 315 m.y.). The highest value of age - 315 m.y. - has been obtained from the largest zircon fraction (+ 100 μ) where an admixture of older radiogenic lead component has been determined.

Thus, the age of zircons in tonalites of the samples SI-1 and HR-2 is 303 ± 2 m.y. The magmatic form of the zircons, the absence of any regeneration rims in them is an evidence that the obtained age corresponds to the time of magmatic crystallization of the tonalites. Secondary processes in the tonalites did not have any effect on magmatic zircons.

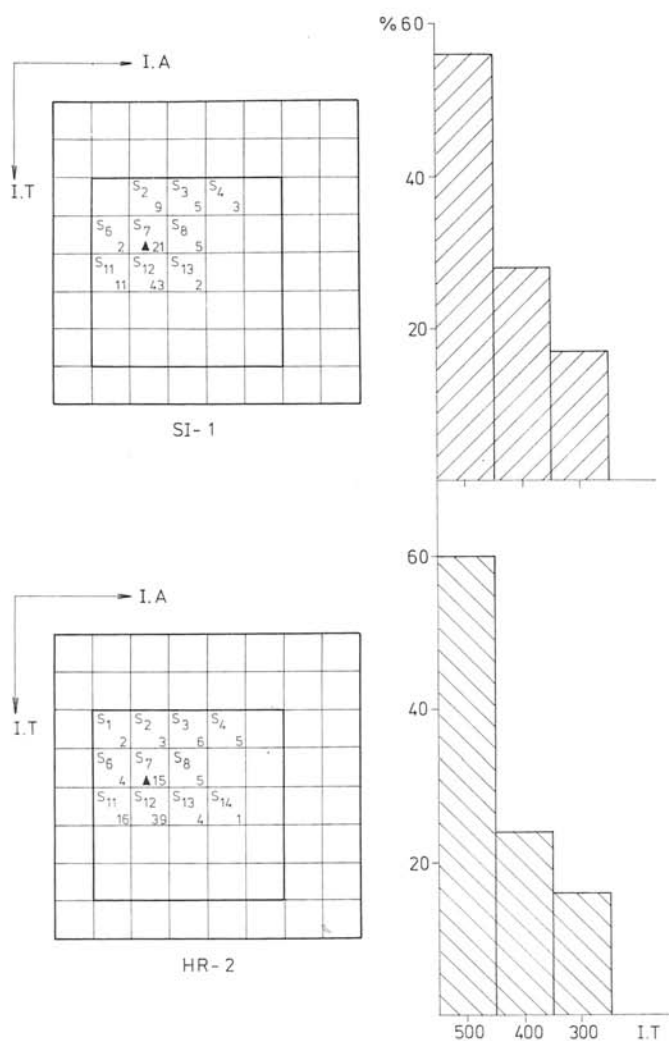


Fig. 2 A — Distribution of zircons in tonalites of the samples SI-1 and HR-2. The typograms are representing the contents of zircons in %, triangles denote the mean values of zircon types and subtypes.

Table 2
Isotope age of accessory zircons from Sihla tonalites

Sample No. Fraction	Contents (ppm)		Isotope composition of lead				Age acc. to $^{206}\text{Pb}/^{238}\text{Pb}$ (m.y.)	Isotope relations (rad.)		
	Pb	U	^{204}Pb	^{206}Pb	^{207}Pb	^{208}Pb		$^{207}\text{Pb}/^{235}\text{U}$	$^{207}\text{Pb}/^{206}\text{Pb}$	$^{208}\text{Pb}/^{206}\text{Pb}$
HR-2 +63	27	526	0.047	80.282	4.908	14.763	303	0.3473	0.0524	0.1636
-125+100	29	504	0.108	78.467	5.927	15.497	315	0.3840	0.0554	0.1500
SI-1 -100+70	29	562	0.077	80.789	5.020	14.114	305	0.3198	0.0481	0.1417
-70	28	484	0.211	73.979	6.737	19.072	295	0.3183	0.0494	0.1638

The authors have used the following values of the decay constant:

$\lambda^{238}\text{U} = 1.55125 \times 10^{-11} \text{ years}^{-1}$; $\lambda^{235}\text{U} = 9.8485 \times 10^{-10} \text{ years}^{-1}$; $^{238}\text{U}/^{235}\text{U} = 137.88$ (Steiger—Jäger, 1977).
Correction to common lead in samples HR-2 and SI-1 to 300 m.y.: $^{206}\text{Pb}/^{230}\text{Pb} = 18.316$; $^{207}\text{Pb}/^{204}\text{Pb} = 15.644$; $^{208}\text{Pb}/^{204}\text{Pb} = 38.280$.

Data on isotopic Rb-Sr and K-Ar dating of biotites

For Rb-Sr and K-Ar age determination of micas from the tonalites, relatively large flakes of biotite were separated from the fraction >0.16 mm. Petrographic and microprobe data have shown that this fraction contains primary-magmatic biotites preserving the contours and size of grains, but totally recrystallized and substituted by lower-titanium medium-temperature biotite with inclusions of leucoxene grains. Individual small, newly-formed secondary biotites with a size of less than 0.1 mm were not included in this fraction.

The results of K-Ar analysis are presented in Tab. 3.

Table 3

Date on K-Ar dating of biotites (Bt₁)

Sample No.	Contents			Age m.y. ± 1.6 σ
	K % ± σ	Radiogenic Ar		
		ng/g ± σ	Ar ⁴⁰ rad. %	
			Ar ⁴⁰ com.	
SI-1	7.79±0.07	137±2.5	78; 86	236±8
HR-2	7.67±0.07	156±2.5	86; 87	272±8

Note: the calculation of age has been done with the constants recommended by the International Subcommission for Geochronology, i.e.

$\lambda_K = 0.581 \times 10^{-10} \text{ year}^{-1}$; $\lambda_\beta = 4.962 \times 10^{-10} \text{ year}^{-1}$; $^{40}\text{K} = 0.01167 \text{ (at. \%)}$.

The results of Rb-Sr analysis of biotites are presented in Tab. 4.

The model age has been calculated with the ratio of $^{87}\text{Sr}/^{86}\text{Sr} = 0.707 \pm 2$, which corresponds to the value of strontium ratio for tonalites of the Sihla type in the Vepor Pluton (Bagdasaryan et al., 1986).

Table 4

Date on Rb-Sr analysis of biotite systems (Bt₁)

Sample No.	Contents		$^{87}\text{Rb}/^{86}\text{Sr}(\text{at.})$ $\pm 2 \sigma$	$^{87}\text{Sr}/^{86}\text{Sr}(\text{at.})$ $\pm 2 \sigma$	Age m.y. $\pm 2 \sigma$
	$^{87}\text{Rb}(\text{ppm})$	$^{86}\text{Sr}(\text{ppm})$			
SI-1	104	1.23	83.6 \pm 10	0.8116 \pm 2	88 \pm 4
HR-2	88	1.94	44.8 \pm 5	0.7694 \pm 7	98 \pm 7

Interpretation of the results

The absolutely concordant age values of magmatic zircons in the sample HR-2 and similar age values of zircons from the sample SI-1 prove that the time of their crystallization and thus also the time of crystallization of the Sihla tonalites themselves was 303 ± 2 m.y., which corresponds to the Upper Carboniferous. Secondary processes affected neither primary age, nor magmatic habit of the zircons. Quite to the contrary, the most ideal form was preserved by zircons from more blastomylonitized and altered tonalites of the sample HR-2.

Paradoxical and highly important for our interpretations proved to be the relations of Rb-Sr and K-Ar ages of micas. It was discovered that K-Ar age of secondary biotites (~240–270 m.y.) is older than their model Rb-Sr age (88–98 m.y.). How can this be explained from the isotope and petrological point of view?

First, it is indisputable that Rb-Sr system of biotites retained the real effects of the Alpine event with an age of approx. 93 ± 10 m.y. This value corresponds to the general Alpine geochronologic maximum determined by Burchart – Cambel – Král (1987) on the basis of statistical analysis of K-Ar datings for Veporicum of the Western Carpathians.

Second, the preservation of radiogenic Ar (fixing the K-Ar age at ~240–270 m.y.) in these secondary biotites can be explained only in the case if the Alpine effects were predominantly not thermal but hydrothermal (fluid), and they took place at temperatures considerably lower than 300 °C. Especially in this case, due to low temperatures, Ar does not escape entirely but only partly, and at the same time with different intensity in different parts of the tonalite massif, depending on the temperature and duration of the Alpine effects in each section. Hydrothermal character of the Alpine effects could explain the presence of anomalous lead in inclusions of sulphides in zircons.

From this viewpoint K-Ar ages of biotites can be interpreted in two ways.

1. It is a result of a single very low-temperature event of the Alpine process with an age of ~93–94 m.y., and then the values 236 and 272 m.y. do not have any real geological meaning, they reflect only the grade of partial loss of radiogenic Ar in each sample. In this case the loss of argon and thermal rejuvenation of the central part of the Sihla Massif (where rocks preserve their unaffected texture – sample SI-1) would be more intensive than in blastomylonitized tonalites near the Pohorelá fault.

In this variant K-Ar ages of micas from tonalites can be of any value between 303 and 94 m.y. This viewpoint is evidenced by the considerable variability of K-Ar datings of micas from the Vepor Pluton, giving an interval (see above and our data) of 110 to 272 m.y.

2. The Alpine cycle affected only slightly the loss of Ar from micas and the ages 236 and 272 m.y. reflect either concrete Permian thermal events, or they fix the age of cooling of various parts of the massif to 300 °C, i.e. the final stage of postmagmatic processes. No evidence has been found to support this theory. The second alternative is not very probable also in view of the fact that the time of crystallization of the pluton would have been 31 to 67 m.y. This contradicts data from other regions indicating that the time of solidification of mesoabyssal granitoid massifs usually does not exceed 5–10 m.y.

What types of mineral changes in tonalites can be connected with the Alpine cycle? Taking into account its assumed hydrothermal, low-temperature character, this stage could include the appearance of fine-flaked sericite in the tonalites, possibly also a part of chlorite, and sericitization of plagioclases. A concentrated result of the Alpine effect can be considered also the formation of carbonate, quartz-carbonate, quartz-calcite-pumpellyite-chlorite veinlets, frequently observed in tonalites along fissures and slickensides. Carbon-dioxide solutions, as we know, dissolve very well not only Ca, but also Sr and Pb. Ca and Sr being geochemically closely related, the latter could be transported by fluids, and exchange reactions of Sr between fluids and micas could have led to rejuvenation of biotites. This is true also for Pb: its supply led to the appearance of anomalous lead in sulphide inclusions in zircons.

The possible mineral changes in tonalites in the Alpine cycle were however generally low-temperature ones, or the K-Ar rejuvenation of biotites would have reached 94 m.y. Slight loss of Ar from autometasomatically recrystallized biotites indicates that secondary biotites, relatively large muscovites, a greater part of chlorites, epidotes, albite-clinozoisite-sericite pseudomorphs after plagioclases were formed in the stage of tonalite solidification. These substitutions are typical of acidic postmagmatic stage in granitoids, affecting not only

blastomylonitized rocks, but also rocks preserving their magmatic structure. Mineral changes in the tonalites shall be discussed in a special paper.

Thus, the obtained data lead us to the conclusion that the intrusion of Sihla type tonalites, and possibly of the whole Vepor Pluton, did not take place in the stage of peak Variscan granite formation in Western Carpathians (~350 m.y.), but in the Late Variscan stage, together with the beginning of the formation of the Upper Carboniferous–Permian mantle of the crystalline complex. Because of this, Sihla tonalites should, from the formational viewpoint, correspond to post-metamorphic orogenic granitoids – in relation to the Variscan regional metamorphism.

It is clear that Sihla tonalites are synchronal in the time of their intrusion with the Tríbeč tonalites. This is evidenced by U-Pb age determination on zircons from the Tríbeč tonalites giving similar values of 306 ± 10 m.y. (Broska – Bibikova et al., 1990). It is indicated also by the similarity of accessories, chemistry, of the type of post-magmatic processes and tectogenetic processes in the Sihla and Tríbeč tonalites (Petrík – Broska, 1989; Putiš, 1981, 1987, 1989; Putiš in Krist et al., in press, and data in the presented paper).

Conclusion

According to the data obtained by the authors, geological history of the Sihla tonalites can be presented in the following way:

1. Intrusion and crystallization of the massif, as well as of the Tríbeč tonalites, took place in the Upper Carboniferous, 303 ± 2 m.y. ago.

3. Intensive autometasomatism in the stage of solidification of the massif caused the recrystallization of the tonalites and the formation of medium- and low-temperature associations in them, including low-titanium biotite, muscovite, epidote, chlorite, albite. These minerals were formed in the period between 303 and 240 m.y. ago, indicated by K-Ar dating of secondary biotites.

3. In the conditions of Alpine tectonic cycle the Sihla tonalites were affected by low-temperature (< 300 °C) hydrothermal processes with assumed migration of radiogenic Sr and Pb, causing the rejuvenation of Rb-Sr age of biotites and enrichment of sulphide inclusions in zircons by anomalous lead. At the same time biotites lost a very small portion of radiogenic argon, retaining K-Ar datings close to the time of conclusion of post-magmatic processes in the tonalites.

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