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# THE AGE OF MALÉ KARPATY MTS. GRANITOID ROCKS DETERMINED BY Rb-Sr ISOCHRONE METHOD

*(Tabs. 4, Figs. 2)*

Abstract: In the presented article the authors mention the results of nuclear — geochronological datings of Malé Karpaty Mts. granitoids by Rb-Sr isochrone method. By this method the age of Bratislava massif granitoids was established to $347 \pm 4$ mil. y. at $(^{87}Sr/^{86}Sr)_0 = 0.7076 \pm 0.0013$ and the age of Modra massif granitoids to $324 \pm 18$ m. y. at $(^{87}Sr/^{86}Sr)_0 = 0.7075 \pm 0.00032$ $(2\sigma)$. The relative agreement of age of both massifs as well as the agreement of primary ratio $(^{87}Sr/^{86}Sr)_0$ testifies not only to their continuity in age but also genetic. These same relations confirm also genetic continuity of pegmatites and leucocratic granitoids to fundamental types of granitoids building up the Bratislava and Modra massifs.

Резюме: Авторы в предложенной статье приводят результаты ядерногеохронологических датирований гранитоидов Малых Карпат при помощи Rb—Sr изохронного метода. Посредством этого метода был установлен возраст гранитоидов братиславского массива на $347 \pm 4$ милл. лет при $(^{87}Sr/^{86}Sr)_0 = 0{,}7076 \pm 0{,}0013$ и возраст гранитоидов модранского массива на $324 \pm 18$ милл. лет при $(^{87}Sr/^{86}Sr)_0 = 0{,}7075 \pm 0{,}00032$ $(2\sigma)$. Относительное возрастное согласие обоих массивов, как и первичного соотношения $(^{87}Sr/^{86}Sr)_0$ свидетельствует не только об их возрастной соотносительности, но вероятно и об их общем источнике. Те самые отношения подтверждают и генетическую зависимость пегматитов и лейкократовых гранитоидов к основным типам гранитоидов строящих братиславский и модранский массивы.

Successfully continuing cooperation betwen the Geological Institute of the Slovak Academy of Sciences in Bratislava and the Institute of Geological Sciences of the Academy of Sciences — of the Armenian Soviet Socialist Republic in Jerevan was oriented to new determination of isotope contents of Rb and Sr and their ratios in the last time. These works make possible new dating and revaluation of older results, concerning mainly the Malé Karpaty Mts. crystalline rocks. New sampling for these determinations was realized under presence of coworkers from the USSR. In the first part of the stage of investigation data on Rb and Sr isotope contents and their ratios were obtained for granitoids of the Bratislava and Modra massifs, making possible to date these rocks by Rb-Sr isochrone. The data obtained are mentioned in Tabs. 1,2 and 3. Graphical evaluation and results of calculation of the age are

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Table 1

Rb-Sr isotope values for the total rock samples of granitoids of the Bratislava massif (Malé Karpaty Mts.)

| Number of sample | Rock. locality | Rb: mkg/g | Sr: mkg/g | $^{87}Rb/^{86}Sr$ atom. ratio | $^{87}Sr/^{86}Sr$* atom. ratio | $^{87}Sr/^{86}Sr$** atom. ratio |
|---|---|---|---|---|---|---|
| 1.G—40 | Granite, I. type. Way Karlová Ves —Devín; quarry at the chapel. Bratislava | 166.840 | 108.602 | 4.4442 | — | 0.7315 |
| 2.G—38 | Two-mica quartz granodiorite; Železná studnička, granite quarry; Bratislava | 92.618 | 301.005 | 0.8901 | 0.7125 | 0.7135 |
| 3.15—DB77 (14 c) | Fine-grained biotitic granodiorite; Way Karlová Ves—Devín; 50 m from the ramp in the Mokrý Jarok valley, Bratislava | 74.689 | 412.889 | 0.5286 | 0.7103 | — |
| 4.Ž—2 (15 c) | Two-mica granite. Way Karlová Ves—Devín. Starý lom (Old quarry) behind the shooting-range; Bratislava | 125.209 | 217.016 | 1.6691 | 0.7140 | — |
| 5.Ž—1 | Medium-grained biotitic granite; the right side of the Karlová Ves —Devín; way, Great quarry below Breh | 138.795 | 227.771 | 1.7628 | 0.7171 | — |
| 6.8—DB77 | Granite; Mlynská dolina, starý lom (Old quarry) 80 m behind the cross-road near the Botanical garden, Bratislava | 145.287 | 229.355 | 1.8325 | 0.7151 | — |
| 7.7—DB77 | Aplite from two-mica granites; W of the castle, quarry above the swimming-pool | 263.053 | 20.425 | 37.2559 | 0.892 | — |
| 8.22 c | Aplite in leucocratic granites; excavation pit for construction of water-reservoir, Slávičie údolie—valley, Machnáč—Bratislava | 304.702 | 12.846 | 68.6181 | 1.0452 | 1.0858 |

*Remarks:* * direct determinations of isotope ratios $^{87}Sr/^{86}Sr$
** isotope ratios. $^{87}Sr/^{86}Sr$ are calculated from tests under addition of indicator

Table 2

Rb-Sr isotope values for biotites from granitoids of the Bratislava massif (Malé Karpaty Mts.)

| Number of sample | Mineral, location of rock | Rb mkg/g | Sr mkg/g | $^{87}Rb/^{86}Sr$ atom. ratio | $^{87}Rb/^{86}Sr$ atom. ratio | t m. y. |
|---|---|---|---|---|---|---|
| 1. 14 c | Biotite from fine-grained biotitic granodiorite; road Karlová Ves—Devín, 50 m of the ramp in the Mokrý Jarok valley; Bratislava | 458.464 | 16.842 | 78.7472 | 1.0506 | 308 ± 12 |
| 2. 15 c | Biotite from two-mica granite, road Karlová Ves—Devín; Old quarry behind the shooting-range; Bratislava | 555.662 | 18.639 | 86.2415 | 1.0884 | 312 ± 12 |

mentioned in Figs. 1 and 2. In spite of that the results mentioned will still be completed, already now we present their preliminary interpretation of age, which will complete the up to present results published by us (B. Cambel et al., 1979, 1980 and 1981).

*Granitoids of the Bratislava massif*

In the latest works Rb and Sr contents as well as their isotope ratios from 6 samples of total rock of the Bratislava massif granitoids (Tab. 1) and from two biotites of these rocks (Tab. 2) were established. Besides that older analyses of samples of total rocks were verified again and for compiling of isochrone samples G-38 and G-40 were used (Tab. 1). The new obtained results (Tab. 1) are not essentially different from older determinations (B. Cambel et al., 1979, 1980 and 1981), pointing to reliability of older determinations of model age by Rb-Sr method. As Tab. 1 shows the variation coefficients (relative errors) for all geochronometric parameters mentioned in this table are as follows:

$^{87}Sr/^{86}Sr$ — 0.2 %
Rb — 1.9 %
Sr — 1.5 %
$^{87}Rb/^{86}Sr$ — 1.85 %

Mathematic treatment of the obtained values of studied isotopes provides the following equation for regression straight line:

$$y = 0.7076 + 0.004928\ x$$
$$a = (^{87}Sr/^{86}Sr)_o = 0.7076 \pm 0.0013$$
$$y = 0.004928 \pm 0.000055$$

where the errors are established with 95 % probable certainty. The mean

Table 3

Rb-Sr isotope values for the total rock samples of granitoids of the Modra massif (Malé Karpaty Mts.)

| Number of sample | Rock, locality | Rb; mkg/g | Sr; mkg/g | $^{87}Rb/^{86}Sr$ atom. ratio | $^{87}Sr/^{86}Sr$* atom. ratio | $^{87}Sr/^{86}Sr$** atom. ratio |
|---|---|---|---|---|---|---|
| 1. 9 c | Granodiorite; quarry in the valley Žliabok below elev. p. 467.7; Modra—Harmónia | 59.862 | 636.831 | 0.27193 | 0.7079<br>0.7089 | — |
| 2. 9 c | Biotite from granodiorite; quarry in the valley Žliabok below elev. p. 467.7; Modra—Harmónia | 330.251 | 74.741 | 12.2686 | — | 0.7355*** |
| 3. G—36 | Granodiorite, quarry in the valley Žliabok, Modra—Harmónia | 68.144 | 700.475 | 0.28142 | — | 0.7086 |
| 4. Ž—3 | Granite, road Harmónia—Piesky, valley of Kamenný potok, quarry at the margin of Harmónia | 57.887 | 556.427 | 0.27538 | 0.7098<br>0.7090 | — |
| 5. 18—JV | Granite; south of "Krvavý buk" (Bloody Beech) near elev. p. 435.5; Píla | 65.627 | 580.780 | 0.32689 | 0.7082<br>0.7098 | — |
| 6. 15—JV | Granite; weakly altered by metasomatism, 250 m south of the top of Biela Skala; Píla | 48.970 | 365.402 | 0.38769 | 0.7096<br>0.7095 | — |
| 7. 12 c | Granodiorite; outcrop at the road near the grape-growing school. Modra | 78.930 | 510.029 | 0.44768 | 0.7098<br>0.7092 | — |
| 7. 19—JV | Two-mica granite; 300 m southwest of the gamekeeper's cottage Horná Píla (not far away from the water-reservoir); Píla | 94.065 | 80.246 | 3.39106 | 0.7237<br>0.7225 | — |

*Remarks:* * direct determination of isotope ratios $^{87}Sr/^{86}Sr$
** isotope ratios $^{87}Sr/^{86}Sr$ are calculated from tests under addition of indicator
*** at $(^{87}Sr/^{86}Sr)_0 = 0.706$ value of age of this biotite is 169 m. y.

quadratic deviation of regression line $S \frac{2}{y} = 1.9 \cdot 10^{-6}$ is not distinctly different from the experimentally established deviation ($S \frac{2}{y} = 2 \cdot 10^{-6}$). Therefore the studied group of samples distinctly corresponds to the model of isochrone. The calculated isochrone Rb-Sr age t = 347 ± 4 m.y. (with application of alteration constant $^{87}$Rb equal to $\lambda$ Rb = $1.42 \cdot 10^{-11} r^{-1}$.).

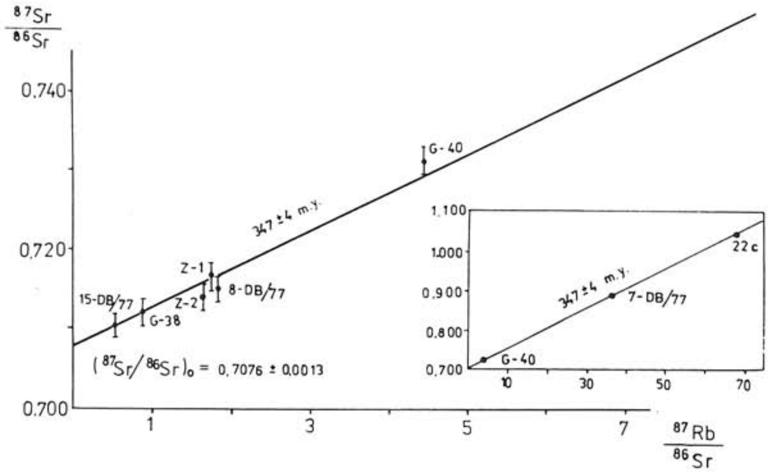


Fig. 1. Rb-Sr isochrone for total rocks samples of granitoids of the Bratislava massif (Malé Karpaty Mts.).

For the biotites investigated from two samples of Bratislava massif granitoids (Tab. 2) somewhat lower (approximately by 10 %) Rb-Sr values of age were established, when compared with the value obtained by isochrone for samples for total rocks. In concrete case for sample 14c the age 308 ± 12 and for sample 15c the age 312 ± 12 mil. y. was determined. These values are in very good agreement with model Rb-Sr values of age for biotites from granitoids of this massif, established already earlier (G-47 291 m.y.; G-32 285 m.y.; G-39 309 m.y.) — see Tab. 4. The relatively little dispersion of Rb-Sr values of age obtained for biotites of the Bratislava massif gives stimulation for their interpretation in this sense that after formation of these granitoids still during the Variscan orogeny they came under the influence of processes connected with general tectonic development of the mountains under study.

It is necessary also to point to the very good agreement in earlier determined model values of age for muscovites and isochrone age of Bratislava massif granitoids. (Tab. 4; G-40 = 325 m.y.; G-47 = 350 m.y.; G-45 = 336 m.y.; G-48 = 330 m.y.). This fact could testify that there are essentially primary muscovites falling to the period of formation of granitoids (347 ± 4 m.y.).

Our preceding considerations on the age of granitoids and their minerals were based upon various determinations of model ages and it was taken into account that dispersion of age values was caused by the influence of various processes of the Alpine orogeny, because e.g. by Rb-Sr method biotites with the value of model age already falling to the Alpine orogeny were established (G-40 = 184 m.y.). This assumption was confirmed by values of age obtained by K/Ar method in biotites from granitoids of the studied area, as similar lowered values of age provided also several determinations of age of samples of total rock by K/Ar method (G. P. Bagdasarjan et al., 1977; B. Cambel et al., 1979, 1980, 1981). Variation of model values of age in the same samples was also found on the basis of Rb-Sr method and we ascribed this fact to migration of individual elements with superimposed processes, what may be valid in the first place for individual minerals and to a restricted extent for rocks, which in larger units should represent closed systems. Therefore so far it is not possible to express unambiguously whether the determined lowered values of age determination correspond to Variscan or Alpine processes as also the grade of alteration of minerals can influence re-distribution of elements traced with determination of ages not only by K/Ar but also by Rb/Sr method. Therefore it is difficult to decide whether these superimposed alterations were Alpine or Variscan.

Leucocratic varieties also belong to this isochrone as is seen from Fig. 1.

### *Granitoids of the Modra massif*

The results of determination of rubidium-strontium isotope ratios of six samples of total rock of granitoids of the Modra massif together with isotope values of already earlier analysed sample G-36 are mentioned in Tab. 3. These values were applied for calculation of Rb-Sr of isochrone age. It is necessary to point to the fact that the group of analysed samples is not most suitable because the values of four samples are practically cumulating around one point. Besides that, except 19-JV characteristic of all samples there is a low isotope Rb/Sr ratio and therefore the calculated age for Modra massif granitoids has somewhat greater error of determination when compared with determination of age for Bratislava massif granitoids. In order to reduce the value of relative error of determination of age of Modra massif granitoids by this method, further samples of leucocratic varieties of granitoids with higher potassium content will be taken, when also such types are not characteristic of the Modra massif.

Mathematic-statistic treatment of Rb-Sr isotope values carried out by the method of smallest squares in Tab. 3 gives us the following equation of regression straight line:

$$y = 0.7075 + 0.00460\ x$$

which corresponds to age $t = 324 \pm 18$ m.y. (2) and to primary ratio of strontium isotopes $(^{87}Sr/^{86}Sr)_0 = 0.7075 \pm 0.00013$. The dispersion of points around regression straight line (Fig. 2) is in no case exceeding the extent of experimental errors, pointing to their agreement with requirements of the isochrone model and absence of geochemical dispersion. The established value of isochrone Rb-Sr age as well as of primary Sr isotope ratio $(^{87}Sr/^{86}Sr)_0$ is not essentially different from the values established for Bratislava massif granitoids, indicating their equal age and probably also their common source. The diversity of granitoid varieties (Modra — more basic, Bratislava — more acid) most probably reflects lithofacial differences of the volcanic-sedimentary sequence, which became the source of anatectic processes in formation of granitoid magma.

The newest ages determined by us by Rb-Sr isochrone method for Malé Karpaty Mts. granitoids are in good agreement with values of age established by J. Burchart (1968) by Rb-Sr isochrone method for minerals of the Polish part of the High Tatras granitoid body, providing 300 $\pm$ 15 m.y. with initial isotope Sr ratio $(^{87}Sr/^{86}Sr)_0 = 0.706 \pm 0.003$ and isochrone for samples of total rock, providing the age 290 $\pm$ 10 m.y. and $(^{87}Sr/^{86}Sr)_0 = 0.705 \pm 0.001$.

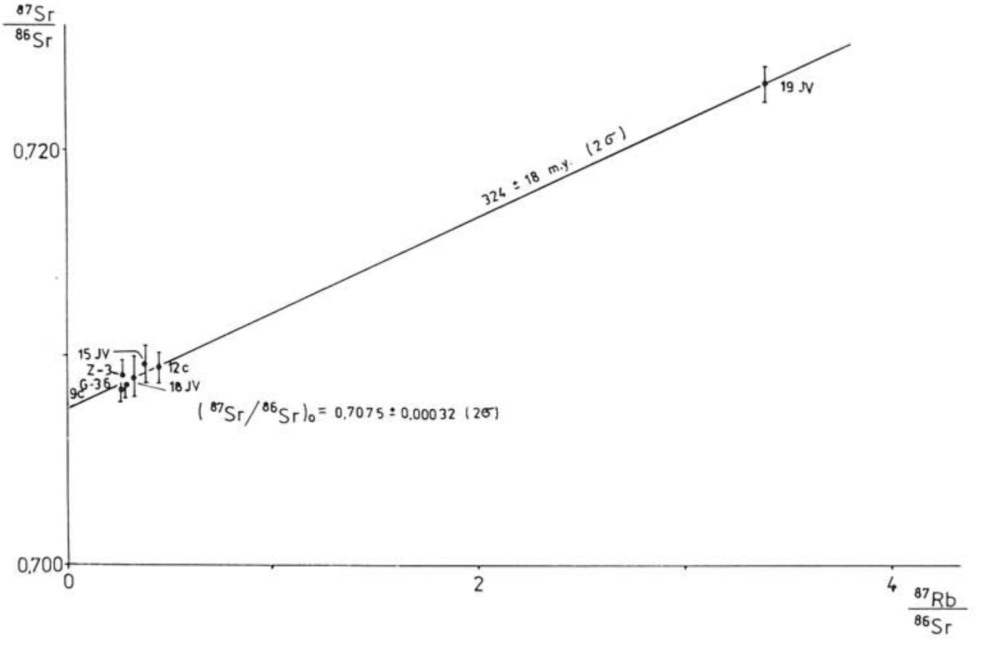


Fig. 2. Rb-Sr isochrone for the total rock samples of granitoids of the Modra massif (Malé Karpaty Mts.).

J. Burchart supposes that these values represent the real range of time, which passed from the intrusion and the clear agreement of these isochrones at relatively low initial Sr ratio indicates that the mentioned granitoid rocks did not undergo relevant development after their intrusion, which would influence total isotope ratios. J. Burchart in his work (l. c.) also states, that pegmatites and aplitoid granites have similar initial ratios of isotopes as granitoids, proving their common magmatic origin according to him. We state the same on the basis of our investigations for granitoids of the Malé Karpaty Mts. The essential difference in our results on the contrary to the results of J. Burchart is that calculation of Rb-Sr isochrone age of Malé Karpaty Mts. granitoids according to samples of total rock is higher (347 $\pm$ 4 m.y. for the Bratislava and 324 $\pm$ 18 m.y. for the Modra massif) and relatively lower are the values of model ages of individual minerals (Tab. 4). So far it is not possible, an unambiguous interpretation of this fact, mainly because it would be necessary to have determined Rb-Sr isochrone age on the basis of individual

Table 4

Rb-Sr isotope value for mica minerals from crystalline Tatride and Veporide rocks of the West Carpathians

| Number of sample | Mineral. locality | Rb; mkg/g | Sr; mkg/g | $^{87}Rb/^{86}Sr^*$ atom. ratio | $^{87}Sr/^{86}Sr$ atom. ratio | t m. y. $(^{87}Sr/^{86}Sr)_0 = 0.706$ |
|---|---|---|---|---|---|---|
| 1. G—40 (51/63) | Biotite from two-mica granite; Malé Karpaty Mts., Bratislava; road Karlová Ves—Devín, guarry near the chapel | 897.246(1) | 29.432(2) | 88.2192 | 0.9364(2) | 184 |
| 2. G—47 (27/63) | Biotite from two-mica granite; Malé Karpaty Mts. — Borinka, valley Prepadlé, the western side of the elev. p. 511.4 | 456.971(1) | 39.128(1) | 33.7856 | 0.8455(1) | 291 |
| 3. G—32 (57/54) | Biotite from two-mica granodiorite, Malé Karpaty Mts., Bratislava, Železná Studnička, granite quarry | 705.626(1) | 25.466(1) | 80.1554 | 1.0305(1) | 285 |
| 4. G—45 (56/63) | Biotite (with admixture of muscovite) from two-mica granodiorite, Malé Karpaty Mts. Záhorská Bystrica, hill Cymbal | 626.162(2) | 22.026(2) | 82.2416 | 0.9642(2) | 221 |
| 5. G—39 (47/63) | Biotite from granite containing pyrite, Malé Karpaty Mts., road Karlová Ves—Devín; Great quarry below Breh | 801.80(2) | 12.088(2) | 191.8770 | 1.5481(2) | 309 |
| 6. G—35 (23/63) | Biotite from Modra granodiorite, Malé Karpaty Mts., Modra—Harmónia, quarry in the Žliabok valley below elev. p. 467.7 | 352.460(1) | 24.150(1) | 42.2202 | 0.9241(1) | 364 |
| 9. G—40 | Muscovite from two-mica granite; Malé Karpaty Mts., Bratislava, road Karlová Ves—Devín, quarry near the chapel | 401.716(1) | 19.130(1) | 60.7485 | 0.9865(1) | 325 |

Continuation of Tab. 4

| | | | | | | |
|---|---|---|---|---|---|---|
| 10. G—47 (27/63) | Muscovite from two-mica granite, Malé Karpaty Mts., Borinka, valley Prepadlé, western side of the elev. p. 511.4 | 375.250(2) | 66.357(1) | 16.3592 | 0.7873(1) | 350 |
| 11. G—45 (56/63) | Muscovite from two-mica granodiorite Malé Karpaty Mts., Záhorská Bystrica, hill Cymbal | 279.072(1) | 49.334(1) | 16.3642 | 0.7842(1) | 336 |
| 12. G—48 (26/63) | Muscovite from leucocratic fine-grained facies of granite, Malé Karpaty Mts., Marianka | 1395.722(2) | 4.3350(2) | 931.402 | 5.0672(2) | 330 |
| 13. G—46 (28/63) | Muscovite from veiny granite hydroautometamorphic, Malé Karpaty Mts., Borinka, gamekeeper's cottage Horvátka | 399.400(1) | 16.772(2) | 68.8862 | 0.9843(2) | 284 |

*Remarks:* * values of model age are calculated with using of desintegration constant $^{87}Rb$ and value $\lambda = 1.42 \cdot 10^{-11} r^{-1}$. In the parentheses is given the number of determinations

minerals. When we use for interpretation the isochrone age established for total rocks and model ages of minerals, then it would be possible deduce that the lower ages of minerals could indicate superimposed metamorphic processes on consolidated rock in the Variscan orogeny (around 300 m.y.), which caused the changes of Rb and Sr isotope ratios. This statement would be more unambiguous, when there were no apparent tectonometamorphic influences of the Alpine orogeny, which also could have caused the change of isotope ratios in a considerably younger period.

It is evident from the above mentioned that for solving of this question such investigations must be carried out, which make comparison of the isochrone age of minerals with the isochrone age of total rocks of the massif possible.

## *Conclusion*

By Rb-Sr isochrone method the age of Bratislava massif granitoids was determined to 347 ± 4 m.y. at $(^{87}Sr/^{86}Sr)_o = 0.7076 \pm 0.0013$ and the age of Modra massif granitoids to 324 ± 18 m.y. at $(^{87}Sr/^{86}Sr)_o = 0.7075 \pm 0.00032$ $(2\sigma)$. The relative agreement of ages of both massifs as well as of primary isotope ratio $(^{87}Sr/^{86}Sr)_o$ testifies not only to their continuity in age but also genetic. These same relations also confirm genetic relation of pegmatites and leucocratic granitoids to fudnamental types of granitoids building up the Bratislava and Modra massifs (two-mica and biotite granites and granodiorites). Ratio of isotopes $^{87}Sr/^{86}Sr$ clearly proves the crust origin of the Malé Karpaty Mts. granitoids.

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