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Strontium Isotopes in Granitic Rocks of the Western Carpathians

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7 Text-Figures, 2 Tables

Contents

Strontium-Isotope in granitischen Gesteinen der Westkarpaten

Zusammenfassung

Die Granite im Tatrikum-Veporikum (350–280 Mill. Jahre) unterscheiden sich in ihren Strontium-Initial-Werten (Sri). Die erste Gruppe hat Sri-Werte um 0,707, die zweite um 0.7060 oder niedriger. Sie entstammen einem tiefliegenden Herkunftsbereich mit Magmamischungen. Ein Teil des primären Magmas assimilierte während des Aufstieges in die höhere Oberkruste einen wesentlichen Teil der angrenzenden Gesteine. Zwei Typen von Graniten mit unterschiedlichem Anteil von Mantel- und Krustenmaterial kommen im Tatrikum und Veporikum im selben Erosionsniveau vor. Für die Diskrepanzen im Rb- und Sr-Gesamtgesteinsalter und für U-Pb-Alter an Zirkonen werden Mischungsprozesse verantwortlich gemacht.

Die gemerischen Granite intrudierten wahrscheinlich vor 280–290 Mill. Jahren, ihr Rb- und Sr-System ist verjüngt und dürfte im Zeitraum 290–145 Mill. Jahren mehrfach geöffnet worden sein.

Abstract

The granites in the Tatricum and Veporicum (350–280 Ma) differ in values of initial Sr ratio (IRSr). Group 1 has a IRSr mean value around 0.7075, group 2 equal or lower than 0.7060. The granites originated from a deep mixed magma source. A part of the primary magmas, assimilated a substantial part of the wall rocks during their ascent to a higher level of the upper crust. Therefore, two types of granite occur in the Tatricum and Veporicum at the same erosional level with different proportions of mantle and crustal material. Mixing processes are responsible for the discrepancy in Rb-Sr whole rocks and zircon U-Pb data.

The Gemeric granites intruded probably 280–290 Ma ago. They usually represent disturbed Rb-Sr systems often reopened between 290 Ma–145 Ma.

1. Introduction

Granitic rocks in the Western Carpathians (mainly tonalites and granodiorites) occur in three main tectonic units: the Tatricum, the Veporicum and the Gemericum (Text-Fig. 1).

The most striking differences among them are the grade of metamorphism of the basement rocks, the degree of preservation of the textural features of the Variscan structures and the intensity of metamorphism of the Mesozoic cover.

The basement of the Tatricum is represented by highly metamorphosed rocks (gneisses, amphibolites, migmatites) intruded by granite bodies. Significant granite occurrences have been unroofed in ten isolated tectonic horsts called "core mountains" (Text-Fig. 1).

Their sedimentary mainly Mesozoic cover does not show any thermal influence of Alpine metamorphic events.

The Variscan cooling history in the basement rocks is well preserved, as has been documented by muscovite and biotite K-Ar data (BURCHART et al., 1987).

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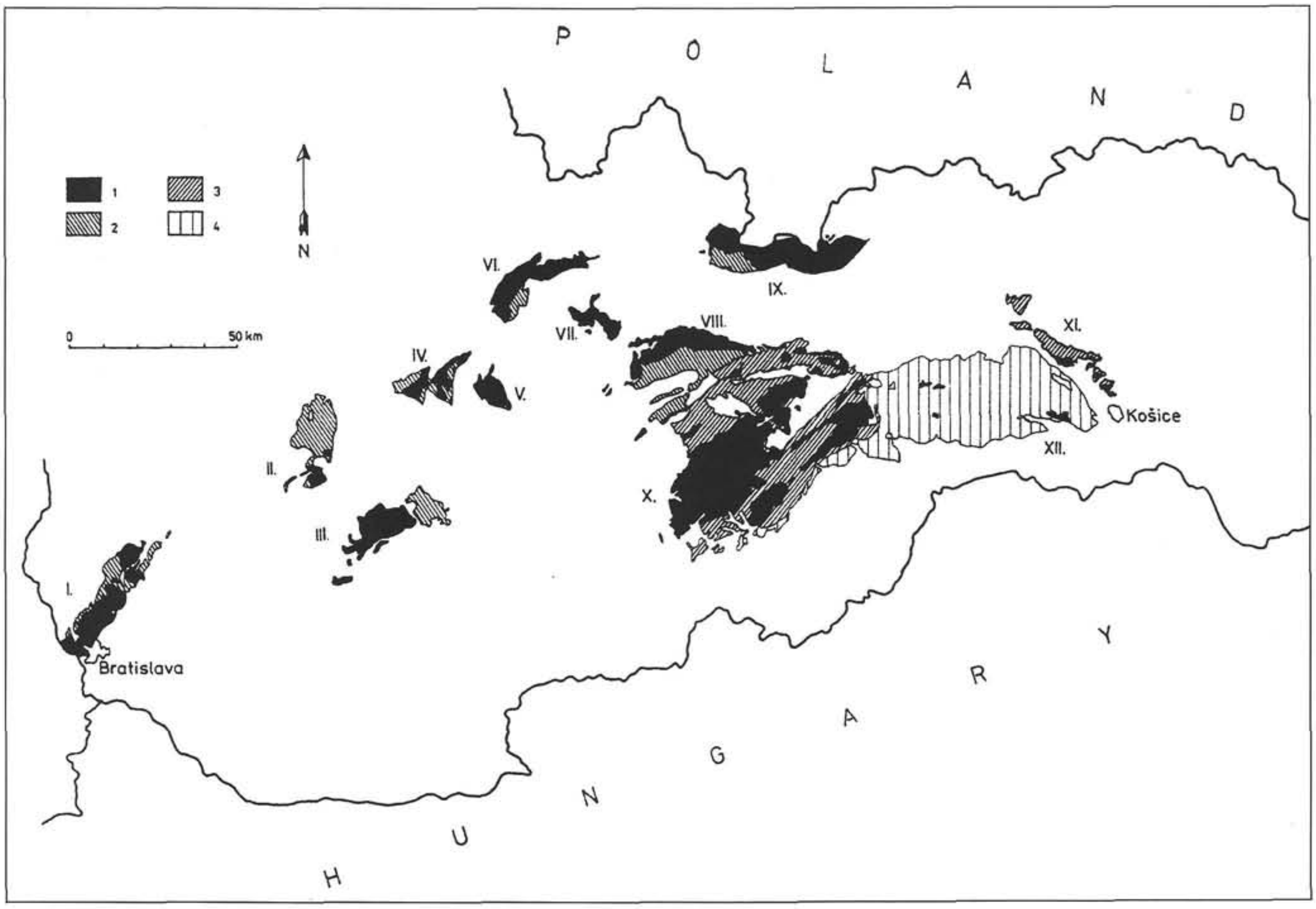


Text-Fig. 1.
The occurence of basement rocks (granites and low and high grade metamorphic rocks) in the Western Carpathians.
Taken and simplified according to MAHEL' (1968).
1 = granites, 2 = metamorphic rocks of the Tatric unit, 3 = metamorphic rocks of the Veporic unit, 4 = Gemeric unit.
I = Malé Karpaty Mts.; II = Považské Inovec; III = Tríbeč Mts.; IV = Strážovské vrchy Mts.; V = iar Mts.; VI = Vel'k Fatra Mts.; VII = Mala Fatra Mts.; VIII = Nízke Tatry Mts.; IX = Tatry Mts.; X = Veporic unit; XI = Branisko and Cierna hora Mts.; XII = Gemericum, Spišsko-gemerské, Rudohorie.

Granites in the Veporicum form the largest plutonic body in the Western Carpathians. Here, the sedimentary Mesozoic cover underwent some metamorphism during the Alpine orogeny. As a result of this significant thermal event, K-Ar values of biotite from the Veporic basement lie almost exclusively on a K-Ar isochron of 94+/-18 Ma (BURCHART et al., 1987).

Both Tatric and Veporic granites represent an absolutely dominating volume of Variscan acid plutonism in this area.

In the Gemericum, only a few small isolated granitic bodies occur in the low grade metamorphic basement rocks. They differ from the Tatric and Veporic granites by a more acid and leucocratic character, a large amount of volatile elements (i.e. boron) and intensive autometamorphism. In contrast to the formerly mentioned granites of pre-Permian age the Gemeric granites were considered for a long time to be Upper Cretaceous.

According to field observations the age of granitic magmatism in the Tatric and Veporic units was traditionally placed between the Sudetic (325 Ma) and Saalian (250 Ma) phases. Nevertheless Rb-Sr whole rock data lie in the interval of 393–280 Ma.

The significance of these results has become questionable since U-Pb zircon data from other identical granite samples have become available. They are lower in age (BIBIKOVÁ et al., 1988, 199; BROSKA et al., 1990) and the most frequent difference is about 40 Ma (Tab. 1).

Table 1.
Zircon U-Pb, Rb-Sr whole rock ages from Tatricum a Veporicum granitic rocks.

Tatricum - "core mountains"		
	U-Pb (Ma)	Rb-Sr (Ma)
Malé Karpaty (1)	~ 310*	348 +/- 4
Tribeč (2)	306+/-10	352 +/- 5
Stráž. vrchy (2)	348*,350**	393 +/- 6
Malá Fatra (2)	353 +5/-11***	
Nízke Tatry (1)		362 +/- 21
Kralička		365 +/- 17
Tatry (2)		300 +/- 10
Veporicum - main petrographic types		
Sihla (2)	303 +/- 2 378*	380 +/- 30
Hrončok (Ipeľ.) (2)	255*	286 +/- 20
Kohút zone (1)	350 +/- 5 313	391 +/- 6

(2) = IRSr ratio < = 0.7060;1) = IRSr ratio > 0. 7075.
* = model 206Pb/238U age from discordant data; ** = Pb-Pb single grain data, unpublished; *** = the upper intercept of discordia.
Data without asterisk represent concordant U-Pb datings.

The aim of this paper is to summarize the Rb-Sr data from granites and demonstrate some specific features in Sr evolution of the Western Carpathian's granites. The discussion of the results is based on analytical data published in papers of BAGDASARYAN et al. (1982, 1986), CAMBEL et al. (1979, 1989) and KOVACH et al. (1979, 1986). A complete list of papers dealing with U, Th-Pb, Rb-Sr, K-Ar and FT geochronology can be found in CAMBEL et al. (1990).

2. Rb-Sr Data

According to their modal and chemical composition (KAMENICKY, 1968), the granitic rocks of the Tatric and Veporic units are very similar but they differ significantly from the Gemeric granites. For example, the average Rb/Sr ratio is about of 0.2–0.3 in the former group but almost 5.0 in the latter (Tab. 2). The difference is also manifested in the graph of their initial Sr ratio – IRSr: ($^{87}Sr/^{86}Sr$)i versus Rb/Sr whole rocks age (Text-Fig. 2a,b).

According to the values of initial strontium ratios (IRSr), the Tatric and Veporic granites (Text-Fig. 2a) form two distinct groups, independent from their tectonic assignment:

- granites with IRSr values greater than 0.7075, but not exceeding 0.708 – group 1,
- granites with IRSr values about 0.706 or lower – group 2.

Text-Fig. 2a demonstrates the Rb-Sr age span from 393 Ma to 280 Ma for the Tatric and Veporic granites, practically identical in both groups, with very small variations in IRSr within each group. For comparison, there are only two IRSr data known from the surrounding metamorphic cover; they are significantly higher and thus different from the granitic ratios – 0.7101 in 380 Ma old metamorphic rocks from the Male Karpaty Mts. (Text-Fig. 1) and 0.7157 for 360 Ma

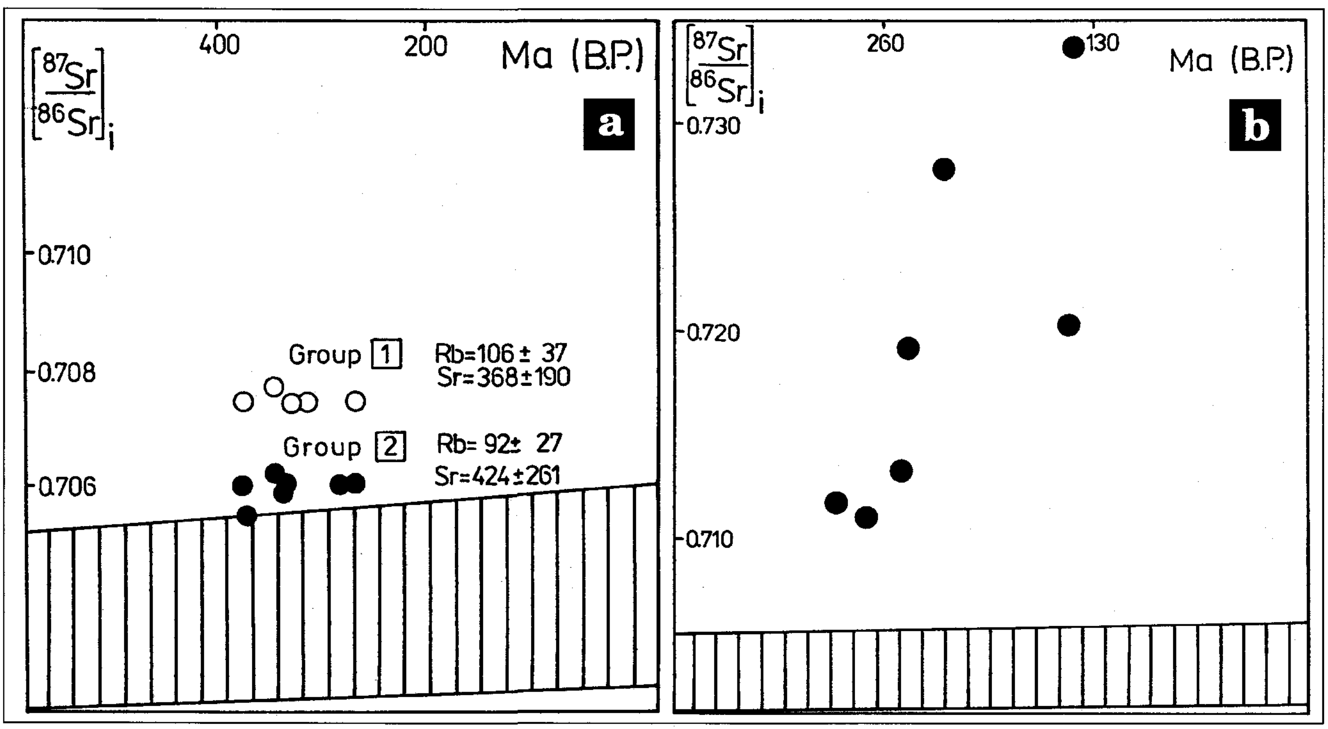
Table 2.
Rb and Sr concentration (ppm) in granitic rocks of the Western Carpathians.
Average values are calculated on the base of tectonic assignment of the granites. N = number of samples analyzed; Rb, Sr = average concentrations of the elements in whole rocks samples; SD - standard deviation of the concentrations.

	N	Rb	± SD	Sr	± SD	Rb/Sr
Tatricum	63	96	30	401	227	0.24
Veporicum	26	103	34	403	262	0.25
Gemericum	55	296	214	60	91	4.91

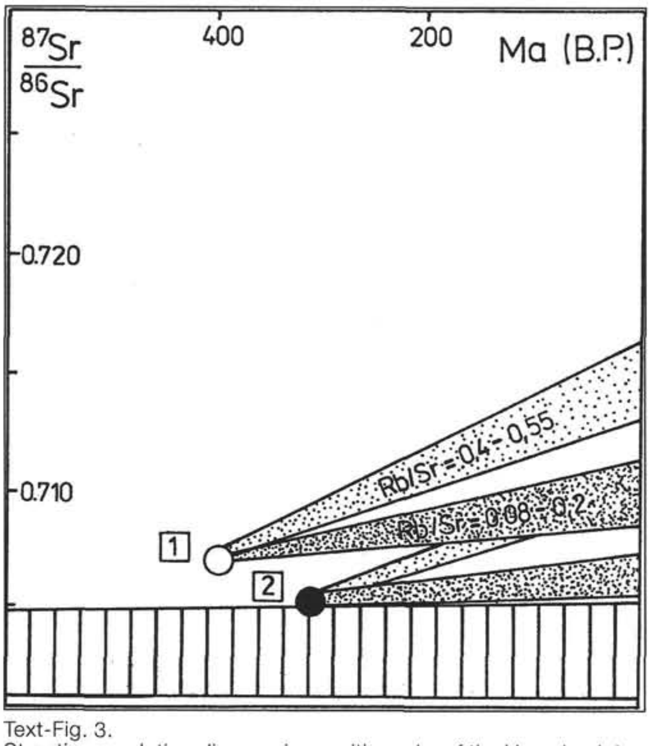
old anatectic granite (Kralicka type) synchroneous with the intrusion of the Nízke Tatry Mts. granite body (Text-Fig. 1, Tab. 1). It is important to note that U-Pb data patterns of zircon are often discordant indicating the presence of recycled material in rocks of both groups (CAMBEL et al., 1990; KRÁL', 1992).

The recalculation of Rb and Sr average concentration from samples that form Rb-Sr isochrones with different IRSr ratio shows a shift of their average values if compared with the data from Tab. 2, in which the granites were grouped according to their tectonic units (Text-Fig. 2a). Group 1 has slightly higher Rb and lower Sr contents than group 2.

Recently, several petrological criteria have been suggested to differentiate between the Western Carpathian granites. The accessory mineral assemblages allanite-magnetite and monazite-ilmenite respectively are preferred to be the best criteria to distinguish the two petrological families in these granites (BROSKA & GREGOR, 1992). According to detailed petrological studies (HOVORKA & PETRÍK, 1992), their magmas differed in both oxidizing and hydrous states, temperatures and depth of formation. However, the relation of these petrologically and isotopically defined groups is unclear.



Text-Fig. 2.
The position of the Western Carpathians granitic rocks in a plot of initial $^{87}Sr/^{86}Sr$ versus age.
a) Granites from the Tatricum and Veporicum.
○ = group 1 with IRSr ratios higher then 0.7075; ● = group 2 with IRSr ratios equal or lower then 0.7060.
b) Gemeric granites.
The area with vertical hatching represents basalt field.



Text-Fig. 3.
Strontium evolution diagram in granitic rocks of the Veporic pluton (schematized).
The strontium evolution lines belonging to both IRSr groups 1 and 2 plot characteristic well defined fields because of similar distribution pattern of Rb/Sr ratio in both group.
The area with vertical hatching represents basalt field.

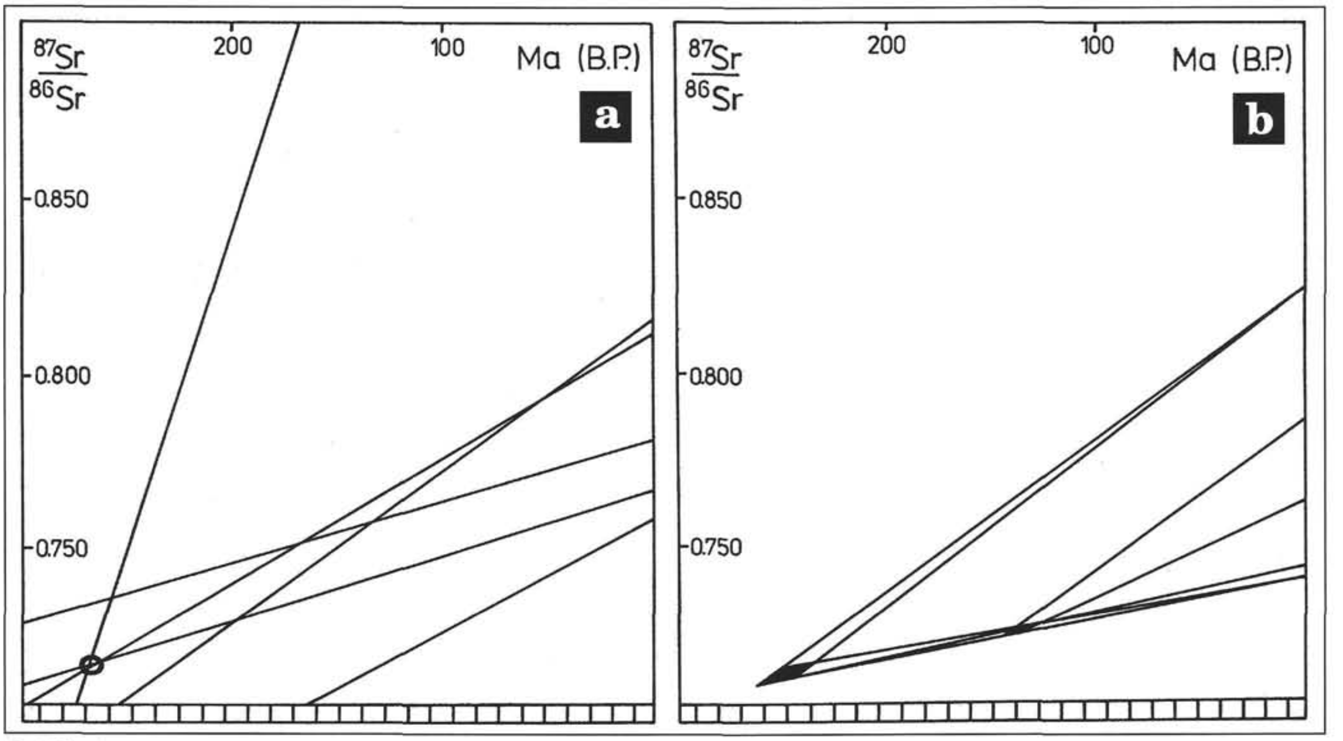
The remarkable features in Rb/Sr ratios are exemplified in Text-Fig. 3 using granite samples of the Veporic pluton. The granites belong to both IRSr groups 1 and 2. Two distinct sets of Rb/Sr ratios in both groups have almost identical values; they cluster between 0.1–0.2 (heavy dots) and 0.4–0.55 (light dots). The possible interpretation of this pattern will be discussed later.

In case of an undisturbed Sr evolution when the Rb-Sr system is initially isotopically homogenized and during its geological history remaines isotopically closed – all Sr evolution lines of komagmatic granites (from one isotopic source) with different Rb-Sr ratios must plot on a well defined intersect in a graph of IRSr versus age. Its coordinates in the graph represent the Rb-Sr age and the IRSr. As expected, the majority of Sr lines fit this model but some of the samples indicate unconformity. The reason for this can probably be due to post-crystallization changes, or in same cases, to isotopically different sources. Typical examples of strontium evolution trends in the Tatric and Veporic granites were recently published by KRÁL' (1992).

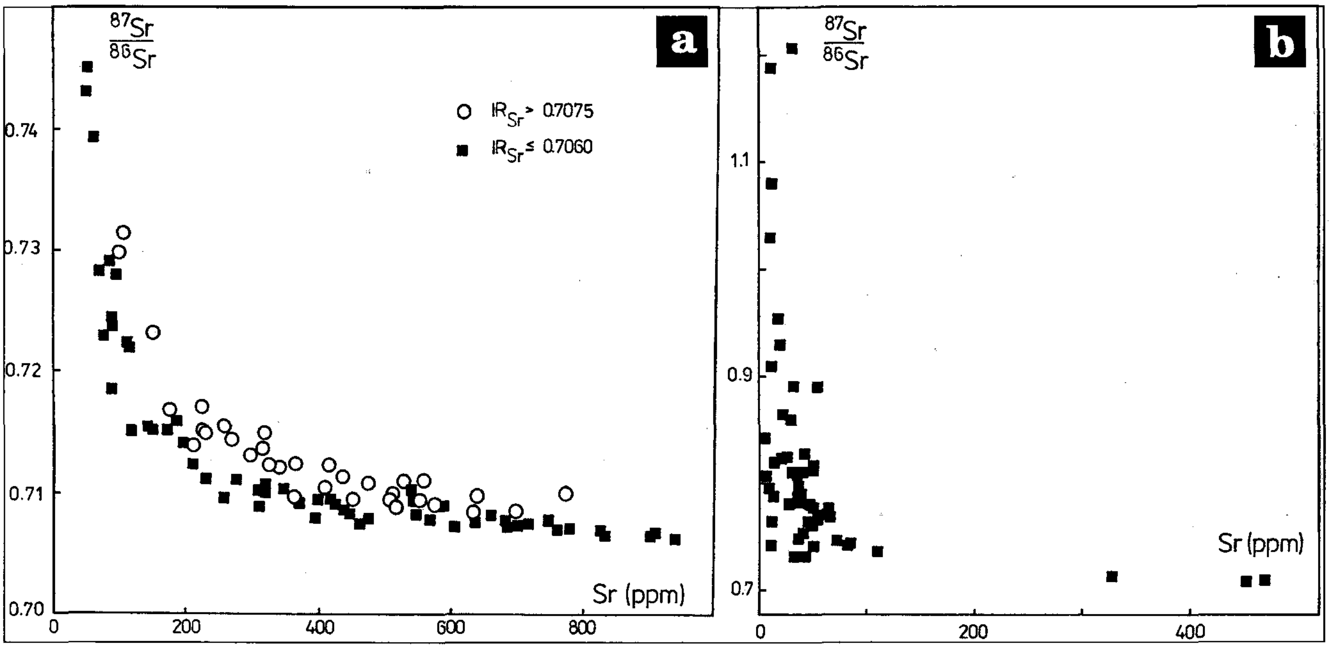
The samples from the Gemeric granites offer a quite different picture (Text-Fig. 2b). A wider range of IRSr ratios (0.707–0.732) and ages (145–290 Ma) are typical. There is a tendency towards a positive correlation of IRSr and age. However, the majority of the published isochrons (KOVACH et al., 1986) are errorchrons, with high values of MSWD, due to the great scatter of points across the isochrons. As a result, Sr evolution lines do not fit the model presumption in many cases (Text-Fig. 4).

3. Discussion

The initial Sr ratio in magmatic rocks represents not only the starting point for post-crystallization evolution, but also at the same time the end point of the pre-crystallization history of the Sr evolution in the precursor rocks. Therefore, two principal questions arise:



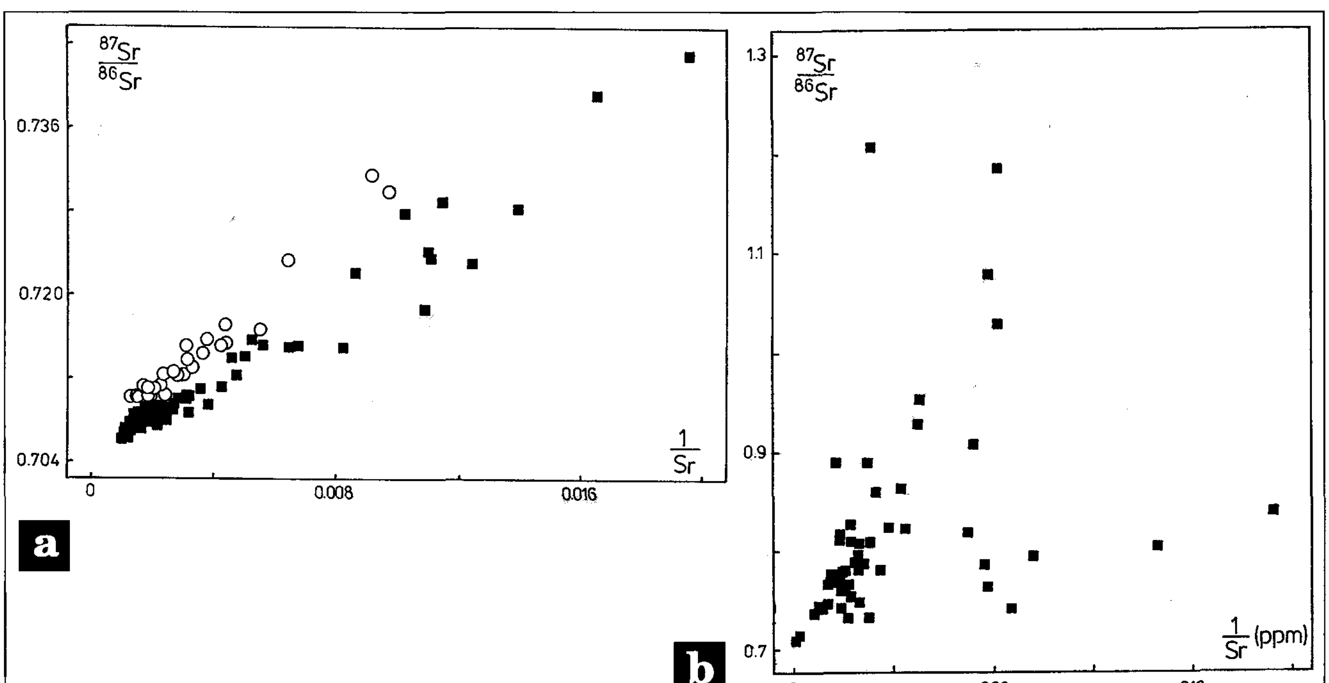
Text-Fig. 4.
Two examples of strontium evolution diagram for two Gemeric granite bodies.
a) Sr evolution lines demonstrate isotopically fully disturbed system.
The lines do not plot the intersect expected in case of the "age" is indicated by a circle.
b) The part of Rb-Sr system closed since 250 Ma B.P. was reopened at 145 Ma BP.
The area with vertical hatching represents basalt field.



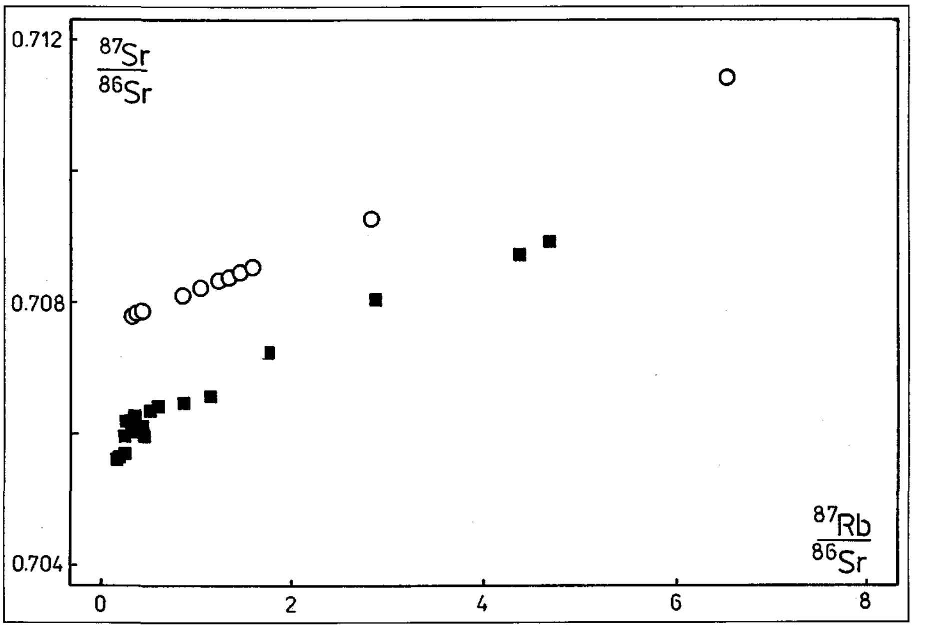
Text-Fig. 5.
Dependence of measured $^{87}Sr/^{86}Sr$ ratios vs. Sr concentration [ppm], in the Tatric and Veporic granites (a) and in the Gemeric granites (b).

- What phenomenon is responsible for the well documented discrepancy between the Rb-Sr and U-Pb ages, especially the older ages of Rb-Sr whole rocks isochrons (the "ageing" – to get apparently older age) observed in the granites of the Western Carpathians?
- What is the reason for two distinct granite groups with two different IRSr ratios? Are there two different isotopic sources or can this fact be explained in another way?

All granite samples from the Tatricum and the Veporicum plot on a hyperbolic curve in $^{87}Sr/^{86}Sr$ versus Sr concentration diagram (Text-Fig. 5). A linear correlation, two lines with different slopes originate when inverting the Sr concentration (Text-Fig. 6). Such relations indicate mixing processes (FAURE, 1972). Recalculation of the measured $^{87}Sr/^{86}Sr$ values from group 1 and 2 to U-Pb zircon ages leads to two nearly parallel lines in the classical isochron plot (Text-Fig. 7) with the lower being the mixing line. Its slope at the time of zircon formation adds to the isochrons thus causing their "ageing". Besides, it would be very hard to imagine a situation in which two isotopically different sources produced identical parameters of mixing. Therefore, the suggestion is that the lower mixing line represents the primary source from



Text-Fig. 6.
Transformation of relationships from Text-Fig. 5 a,b, by plotting of the reciprocals of the Sr concentration.
a) Tatric and Veporic granites.
Samples of group 1 and 2 plot two linear arrays with different slopes.
b) Gemeric granites.



Text-Fig. 7.
Plot of reduced $^{87}Sr/^{86}Sr$ vs $^{87}Rb/^{86}Sr$.
The reduction of $^{87}Sr/^{86}Sr$ ratios is confined to concordant (nearly concordant) U-Pb zircon ages.

which the granites of group 2 can be directly derived. As shown by CLEMENS & VIELZEUF (1987), the mixture of clay minerals from the continental crust and submarine weathered basalts is a highly fertile potential source of magmas. Based on isotope data, such a source is preferred for many European Variscan granites (PIN and DUTHOU, 1990).

In some cases, this primary magma, during its ascent, assimilated crustal rocks, richer in Rb and poorer in Sr. The process of complete assimilation shifted the IRSr value to a higher level with the preservation of its slope forming a second mixing line (Text-Fig. 7). This scenario easily explains all substantial characteristic features of both granite groups, for example the differences in IRSr, the change of Rb and Sr content, the preservation of typical Rb/Sr ratio distribution patterns (see Text-Fig. 3) and discordant U-Pb age patterns often observed in granitic zircons.

The Rb/Sr data from small bodies of the Gemeric granite have given interesting, but contradictory results. The correlation between ages and IRSr values (Text-Fig. 2b) may suggest the subsequent, time controlled emplacement of the granitic bodies from one isotopic source. This idea is not quite realistic; in some biotites and muscovites from the "youngest" bodies K-Ar ages over 200 Ma have been preserved. This is the reason why KOVACH et al., (1986) interpreted the Rb-Sr isochron ages as the time of intensive penetrative fluid circulation throughout the granitic massifs causing large-scale isotopic reequilibration. This process lasted in different bodies over a time interval of 100 Ma. Therefore, the Gemeric granites may be considered to be co-magmatic and their emplacement age is probably equal to oldest Rb-Sr data (ca. 290–280 Ma B.P.), known from this tectonic unit.

4. Conclusions

There are significant geochemical data supporting the regional duality of Carboniferous to Permian granitoid types in the central Variscan fold belt (FINGER & STEYRER, 1990). The analysis of Sr isotope data from the Western Carpathian area leads to three principal conclusions:

1. The granitic bodies in the Tatricum and Veporicum originated from one deep mixed magma source. A part of the primary magmas, during their ascent assimilated a substantial part of the wall rocks from higher levels of the upper crust which shifted the original IRSr ratio to a higher value. Therefore, in the Western Carpathian territory at the same erosional level, two types of granite occur with definitely different proportions of mantle and crustal material.
2. Mixing processes are responsible for the discrepancy in Rb-Sr and U-Pb data. Therefore, the onset of granitic plutonism in the Western Carpathians can be placed between 350– 280 Ma, which is in good agreement with many granitic bodies in central and western Europe.
3. The comparison of IRSr ratio in granites and the surrounding metamorphic rocks proves that these rocks of the basement, with initial IRSr ratio of 0.7101–0.7157, could not be the source of anatectic granitic magmas that subsequently formed the Variscan granitic bodies in the Western Carpathians basement as was previously assumed.

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