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BOHUSLAV CAMBEL* — JÁN KRÁĽ*

ISOTOPIC GEOCHRONOLOGY OF THE WESTERN CARPATHIAN CRYSTALLINE COMPLEX: THE PRESENT STATE

(*7 Figs., 1 Tab.*)

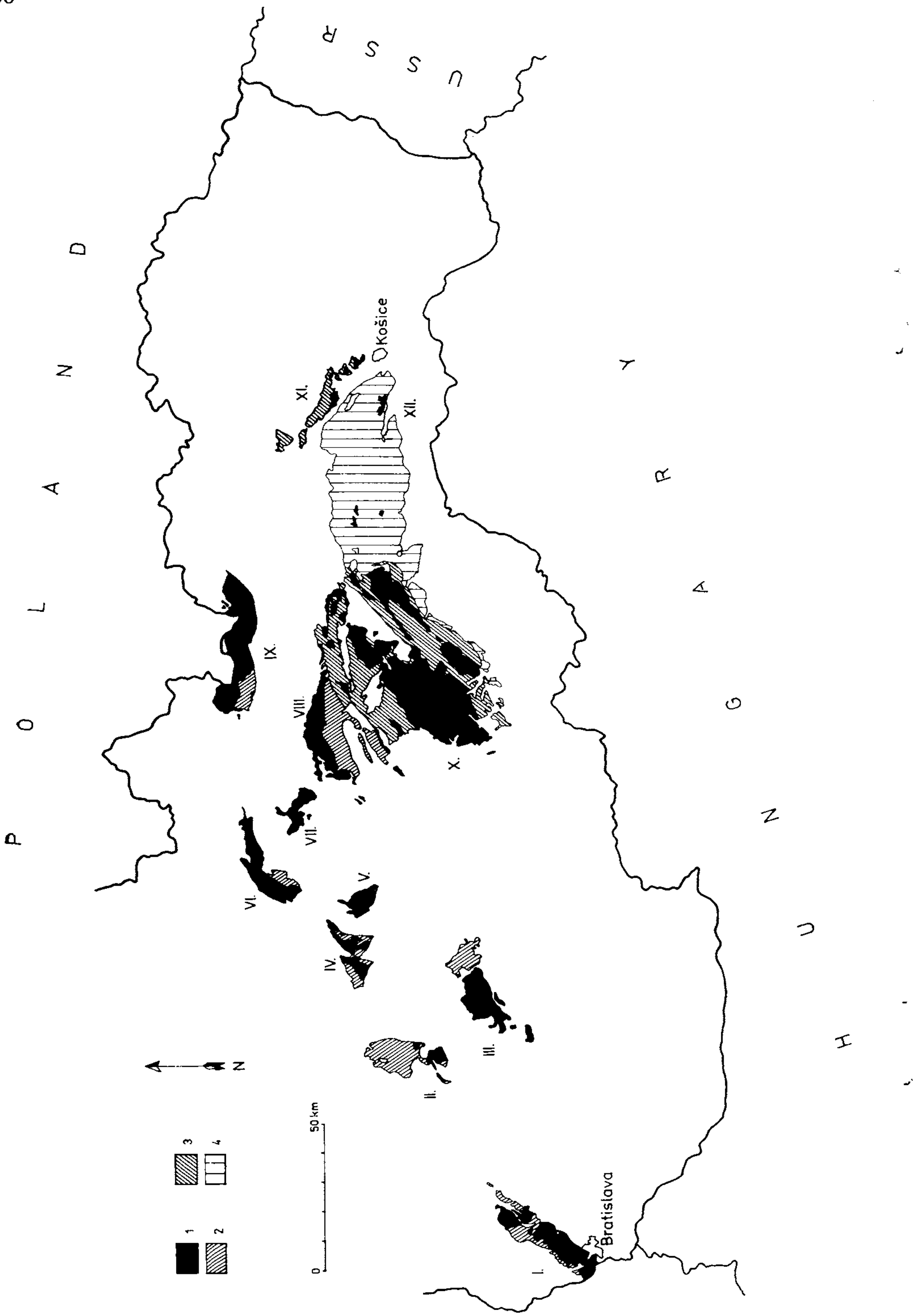
Abstract: Main events in the Western Carpathian crystalline complex documented by U-Th-Pb, Rb-Sr, K-Ar and FT methods are as follows:
Regional metamorphism of sedimentary rocks from the Tatric unit documented by isotopic homogenization of $^{87}Sr/^{86}Sr$ ratio took place 400 m.y. ago (Silurian—Devonian boundary). Subsequent metamorphism of these rocks is associated with intrusions of granitoid bodies. Age of rhyolite volcanism of Gelnica sequence in the Gemericum is identical with age of the first stage of regional metamorphism. Granitoid plutonism covers a large time interval ranging from 390 to 280 m.y., approximately. Presence of late Alpine granites has not been proved yet.
Cooling of rocks from the crystalline complex to the temperature of ca. 270 °C was attained in the Tatric rocks ca. 300 m.y. ago and in the Veporic (Gemeric) rocks ca. 90—120 m.y. ago. The latest post-orogenic uplift differs in the Tatricum (most often Miocene) and the Veporicum (Upper Cretaceous).

Резюме: Главными событиями в кристаллическом комплексе Западных Карпат, обоснованными U-Th-Pb, Rb-Sr, K-Ar и FT методами являются:
Региональный метаморфизм осадочных пород татрицкой единицы, подтвержденный изотопной гомогенизацией отношения $^{87}Sr/^{86}Sr$, проходил 400 млн. лет тому назад (силурско-девонская граница). Последующий метаморфизм этих пород связан с интрузиями гранитоидных тел. Возраст риолитового вулканизма гелницкой серии гемерикума совпадает с возрастом первой степени регионального метаморфизма. Гранитоидный плутонизм занимает широкий диапазон времени с 390 по 280 млн. лет. Наличие поздних альпийских гранитов до сих пор не было подтверждено. Охлаждение пород кристаллического комплекса на температуру около 270 °C было достигнуто в татрицких породах приблиэительно 300 млн. лет тому назад и в вепорицких (гемерицких) породах приблизительно 90—120 млн. лет тому назад. Самое позднее посторогеническое поднятие отличается в татрикуме (наиболее часто миоцен) и в вепорикуме (верхний мел).

Introduction

The Western Carpathian crystalline complex is built on its present surface of granitoid and metamorphic rocks. It is divided into three tectonic units: Gemericum, Veporicum and Tatricum (Fig. 1). Crystalline complex of the Tatricum occurs in isolated tectonic horsts - core mountains where crystalline rocks emerge from the Mesozoic or Cenozoic sediments. The Veporic crystalline complex forms the largest complex of intrusive and metamorphic rocks with

* Acad. B. Cambel, RNDr. J. Kráľ, CSc., Geological Institute of the Centre of Geoscience Research, Slovak Academy of Sciences, Dúbravská cesta 9, 814 73 Bratislava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intensive development of granitoid bodies. In the Gemericum, small isolated granitic massifs lie in low-metamorphosed rocks. There are more characteristic differences between these zones, but the most striking differences are in grade of metamorphism of the rocks (low in the Gemericum, higher in the Tatricum and Veporicum) and in volume of granitoid rocks. Important differences between the units are in degree of preservation of textural signs of the Hercynian structure and in intensity of features of Mesozoic cover metamorphism.

Till the end of the fifties a view of the Palaeozoic age of metamorphic rocks and the Carboniferous age of majority of the granitoid bodies (in the Tatricum and Veporicum) was prevailing. In 1961 Máška — Zoubek ranged the Tatric and Veporic metamorphic rocks with the Precambrian. This view was later taken over and partly modified by J. Kamenický (1967). Presence of controversial views resulted in attempts to obtain exact palynological and isotopic geochronological data. Dominant representation of Palaeozoic spores in the studied metamorphic rocks and many data on isotopic geochronology proves that rocks of the assumed Precambrian belong in fact to the Palaeozoic. Therefore, area of the assumed Precambrian has been quite reduced on the present surface, in contrast to the previous views (J. Kamenický — J. Kamenický, 1983).

Geochronological data are typical of extremely large age dispersion what is documented by histograms of model ages of various rocks and minerals obtained by various methods (Fig. 2). The largest interval is observed in K-Ar data. U-Th-Pb method brings information on the oldest history of the studied rocks. It should be noted that model ages obtained by K-Ar method provided for a long time the only geochronological information on age of rocks from the crystalline complex. Only later these results were confronted with the results of other methods, particularly Rb-Sr.

The aim of this paper is to present the nowadays state of isotopic dating, to summarize data on the Western Carpathian crystalline complex obtained by various methods and to confront them with both above-mentioned views. Data published within more than 30 years obtained in various laboratories are presented here. Since 1957 when J. Kantor (Kantor, 1957) published the first K-Ar datum from the Western Carpathian crystalline complex, a great number of isotopic data majority of which (Rb-Sr, K-Ar) come from the Institute of Geological Sciences of the Armenian Academy of Sciences at Erevan has been obtained. U-Th-Pb dating was carried out in laboratories of the Institute of Geochemistry and Physics of Minerals, Ukrainian Academy

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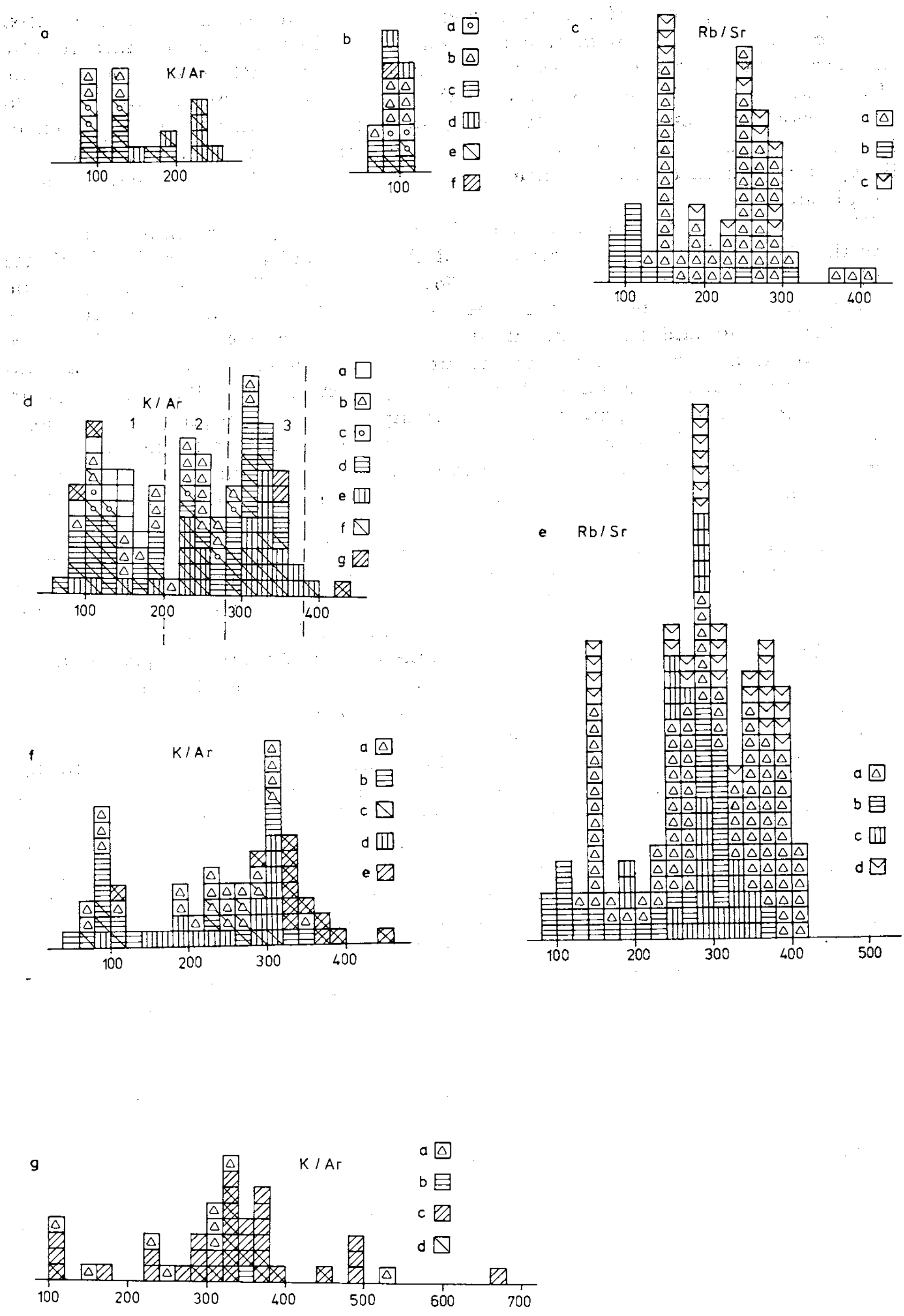
Fig. 1. Schematic sketch of granitoid and metamorphic rocks occurrence in the Western Carpathians.
Explanatory notes: 1 — granitoid rocks, 2 — Tatric metamorphic rocks, 3 — Veporic metamorphic rocks, 4 — Gemeric low-grade metamorphic rocks.

Tatric crystalline complex (I—IX): I — Malé Karpaty Mts., II — Považský Inovec Mts., III — Tribeč Mts., IV — Strážovské vrchy Mts., V — Žiar Mts., VI — Malá Fatra Mts., VII — Veľká Fatra Mts., VIII — Low Tatras, IX — High Tatras.
Veporic crystalline complex (X—XI): X — Veporic pluton, XI — Čierna hora (Branisko) Mts.
Gemeric unit (XII).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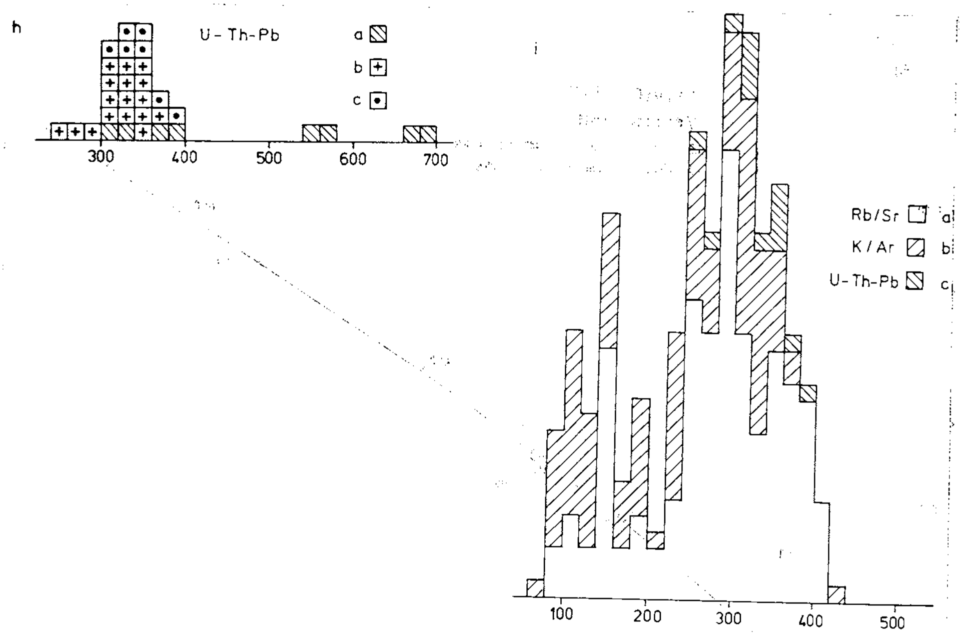

Fig. 2. Dispersion of model ages obtained by various methods from the Western Carpathian crystalline complex.

a — Model ages of the Gemeric granites, K-Ar method: a) K-feldspars, b) whole rocks, c) biotites, d) muscovites, e) data taken over from K a n t o r (1957, 1979); f) amphiboles from Gemeric amphibolitic rocks.
b — Model ages of the Veporic granitoids (mainly biotites). Text common for a and b.
c — Rb-Sr model ages of the Gemeric granitoids: a) whole rocks, b) biotites, c) isochron ages.
d — Model ages of granitoids from the Western Carpathians, K-Ar method: a) distinctly mylonitized rocks, b) rocks without visible signs of secondary alteration, c) K-feldspars, d) biotites, e) muscovites, f) data taken over from K a n t o r, g) amphiboles,
1, 2, 3 — fields of various intensity (from max. to min.) of rocks affected by various post-genetic geological factors.
e — Model ages of granitoid rocks, Rb-Sr method: a) muscovites, b) biotites, c) whole rocks, d) isochron ages.
f — Model ages of metamorphic rocks, K-Ar method: a) whole rocks, b) biotites, c) data taken over from K a n t o r, d) muscovites, e) amphiboles.
g — Model ages of amphibole-containing rocks, K-Ar method: a) whole rocks, b) biotites, c) amphiboles, d) data taken over from K a n t o r.
h — U-Th-Pb dating of zircons and monazites from plutonic and metamorphic rocks ($^{206}Pb/^{238}U$ age): a) sedimentary rocks, b) granitoids, gneissose granites, c) porphyroids and quartzy porphyries.
i — Model ages of granitoid rocks: a) Rb-Sr method, b) K-Ar method, c) U-Th-Pb method ($^{206}Pb/^{238}U$).

of Sciences at Kiev and of the Institute of Geochemistry and Analytical Chemistry, the U.S.S.R. Academy of Sciences at Moscow. Over 500 analyses in total (predominantly K-Ar) were done in laboratory of the Geological Institute of D. Štúr at Bratislava and in the above-mentioned foreign laboratories.

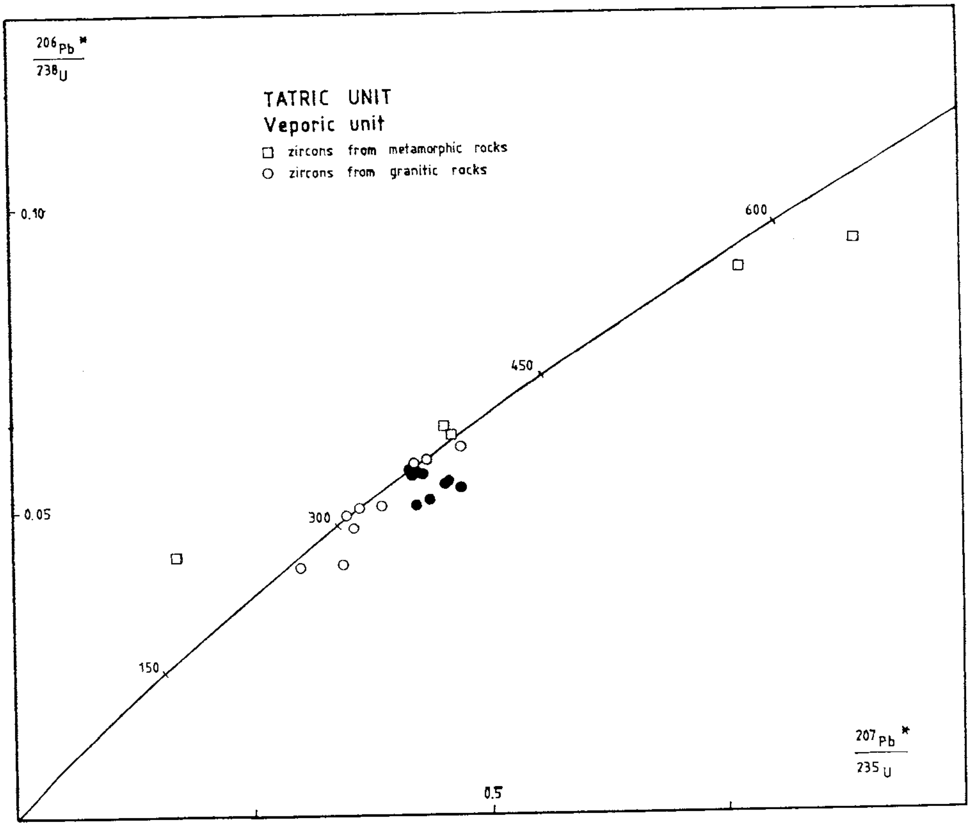

Fig. 3. U-Pb analyses of zircons from the Tatric and Veporic granitoid and metamorphic rocks in concordia diagram. Empty circles —data taken over from Cambel et al. (1977), full circles — from Bibikova et al. (1988), Shcherbak et al. (1988).

Various regions of the crystalline complex were not subjects of the same interest; this resulted in considerable unevenness in geographic distribution of data. Some regions are relatively well-studied, from the other ones isotopic data practically miss.

Evaluation of the obtained isotopic data

U-Th-Pb dating

This dating is placed, as far as its number is concerned, after K-Ar and Rb-Sr datings. The hitherto published analytical data are presented in the papers of Boiko et al. (1974), Cambel et al. (1977), Bibikova et al.

(1988) and Shcherbak et al. (1988). Analyzed minerals, excluding two monazite samples, were zircons. In older papers (1974, 1977) less sensitive method requiring a greater amount of sample was applied, so that one rock sample was represented by only one analytical datum. For these reasons, this dating (mainly in the cases of U-Pb discordant ages) is little informative. It is documented by empty circles in Figs. 3, 4. The samples from the Veporic and Tatric crystalline complexes are plotted in concordia diagram (Fig. 3). Concordant data were obtained from zircons from granodiorite of Sinec type (area X, Fig. 1), synkinematic granite of Králička type (VIII), Muráň gneissose granite (X), from migmatites of the Low Tatras (VIII) and porphyroid from Leňuška valley (X). Analyses of zircons from granite of Hrončok type (X), granodiorite from Tribeč (III), hybrid granodiorite from Dobroč (X) and tonalite of Sihla type from the Veporicum (X) lie very close to concordia. Zircon

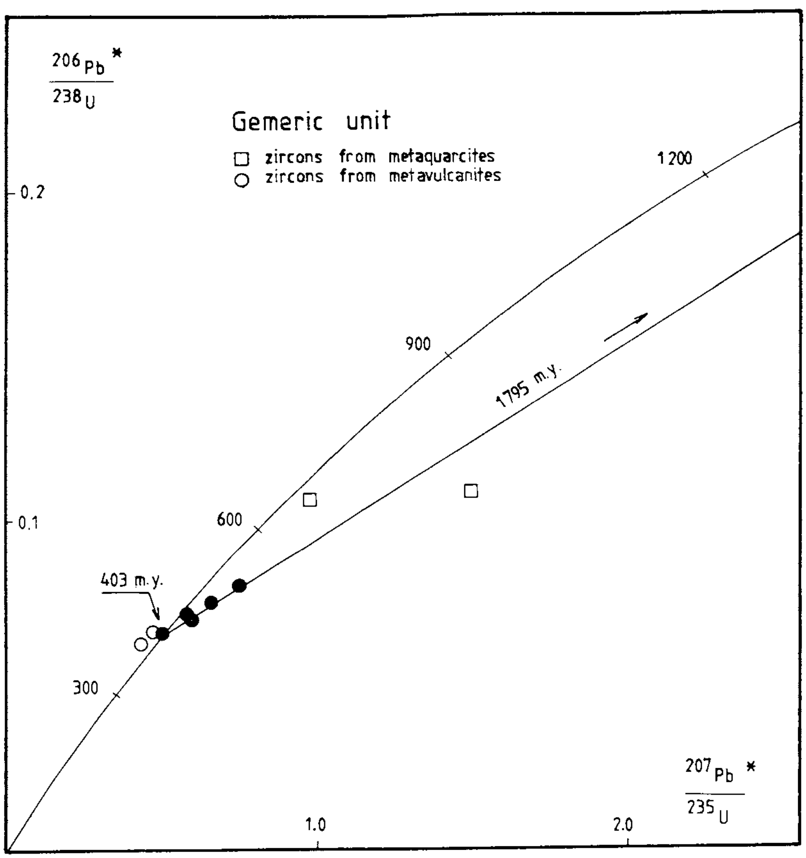

Fig. 4. Concordia plot with U-Pb data on the Gemeric low-grade metamorphic rocks (metavolcanites, metaquartzites). Empty circles — data taken over from Cambel et al. (1977), full circles — from Shcherbak et al. (1988).

samples from metamorphic rocks of the High Tatras (IX) (Račkova dolina valley), from granodiorite of the Low Tatras (Chopok Mt.) and from the Modra massif of the Malé Karpaty Mts. (I) are distinctly discordant.

Zircon samples from the rocks considered to be of the Precambrian age (Muráň gneissose granite, granite of Králička type and migmatites from the Low Tatras) are fully concordant, lying on concordia within an age interval ranging from 300 to 400 m.y., similarly as data obtained from some granitoid rocks. From concordant position of the points it follows that presence of old inherited zircons in these samples can be excluded. Thus, the analyzed samples do not comprise zircons from older metamorphic cycles. We assume that U-Pb concordant ages prove their single origin and simple geological history. Therefore, it cannot be presupposed that parent rocks which are the source of zircons were metamorphosed in some of the Precambrian cycles.

Majority of data on Gelnica sequence comes from metavolcanites lying concordantly in low-metamorphosed rocks (Fig. 4). Discordia with lower intercept of 403 ± 5 m.y. (Shcherbak et al., 1988) was defined from four different zircon fractions separated from metarhyolite from Helcmanovce. This datum is not in contradiction with the proved age of sedimentary rocks where metarhyolites lie (Snopková — Snopko, 1979). It means that lower intercept may be interpreted as age of effusion. Samples contain minimal traces of inherited lead 1795 m.y. old. Ages of zircons separated from low-metamorphosed quartzites (in greenschist facies) represent a mixture of ages of original detritus undoubtedly from the Precambrian or older source. But applied analytical technique does not allow to use these data in more precise geochronological considerations concerning estimation of age of the source.

Rb-Sr dating

Majority of Rb-Sr data represents analyses of whole-rock granitoids from individual Tatric massifs (core mountains), Veporic pluton and individual bodies of the Gemericum. Small number of data was obtained from minerals of these rocks (biotite, muscovite, etc.). Metamorphic rocks and their minerals were analyzed only in two core mountain ranges (Malé Karpaty Mts., the Tatra Mts.). Data available are presented in the papers of Burchart (1968), Bagdasaryan et al. (1982, 1983, 1986), Cambel et al. (1979, 1980, 1988, 1989), Kovách et al. (1979, 1986) and Kráľ et al. (1987).

Metamorphic rocks. Analyses of whole rocks metamorphosed to a various grade (phyllites to gneisses) from Pezinok—Pernek crystalline complex in the Malé Karpaty Mts. (No. I in Fig. 1) prove that isotopic homogenization of original pelitic-psammitic detritus took place 380 ± 20 m.y. ago (Fig. 5A). Identical event practically of the same age is registered also in metamorphic rocks from the Tatra Mts. (Burchart, 1968) (No. IX, Fig. 1). At the same time, mineral isochrons of these rocks register also age of subsequent isotopic homogenization (between mineral phases) caused by thermal effect of granitoid magmas intruding later. Therefore, ages of mineral isochrons of metamorphic rocks are the same as ages of intrusions.

From the Veporic crystalline complex only 4 data obtained from biotites and muscovites from biotite gneiss from the environs of Klenovec and from muscovite schist from the environs of Hačava were published. Isochron fitting these points should have a slope corresponding to 320 ± 10 m.y.

From the Gemeric metamorphic rocks no Rb-Sr results have been published till the present.

G r a n i t o i d r o c k s. Isotopic data on whole rocks and minerals from the Malé Karpaty Mts. (I), the High and Low Tatras (VIII, IX), Strážovské vrchy Mts. (IV), Čierna hora Mts. (XI) were published. From the Veporicum, basic petrographic types (Sihla and Vepor) dominating in the Veporic pluton were dated. From the Gemeric granites, analyses of rocks and minerals, as well as of Rochovce body bored at tectonic contact of the Gemericum and Veporicum were published. The obtained geochronological data are characteristic by large age interval.

Ages of granitoid rocks intrusions determined by whole-rock isochron slope in the Tatric crystalline complex (core mountains) indicate large time interval of Sr isotopes homogenization in the rocks ranging from 300 m.y. (the High Tatras - IX) to 390 m.y. (Strážovské vrchy Mts. - IV). Mineral isochrons constructed from biotite, muscovite, plagioclase, K-feldspar from the High Tatra pluton have concordant age with the whole-rock isochron. On the other hand, mineral isochrons of the Malé Karpaty Mts. have in ca. 40 m.y. lower

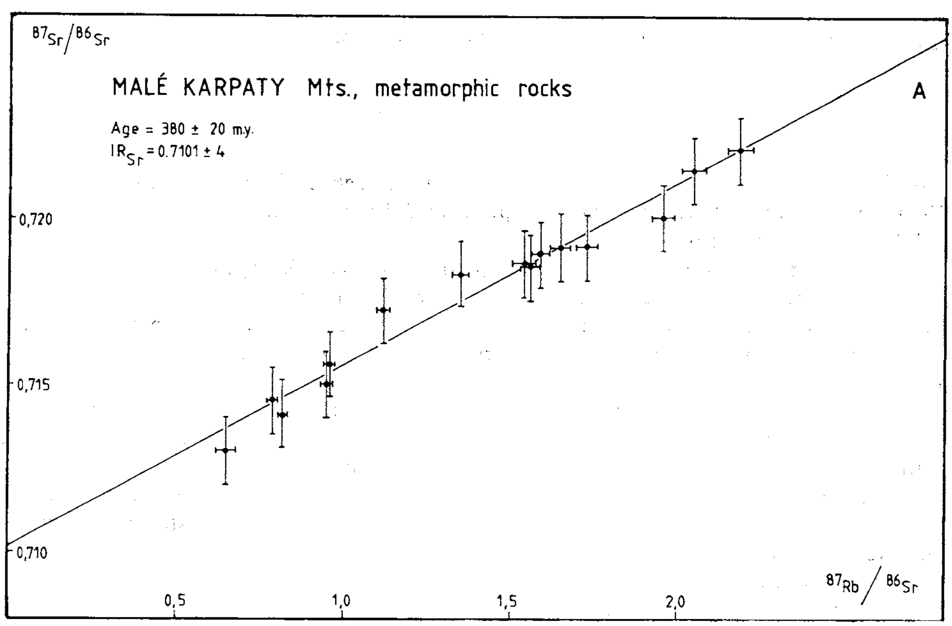

Fig. 5 A. Rb-Sr isochron constructed from rocks of various grade of metamorphism (phyllites — gneisses), Pezinok—Pernek crystalline complex (No. I, Malé Karpaty Mts.). Taken over from B a g d a s a r y a n et al. (1983). Identical age of Sr istopes homogenization is proved also in metamorphic rocks from the High Tatras (No. IX), B u r c h a r t (1968).

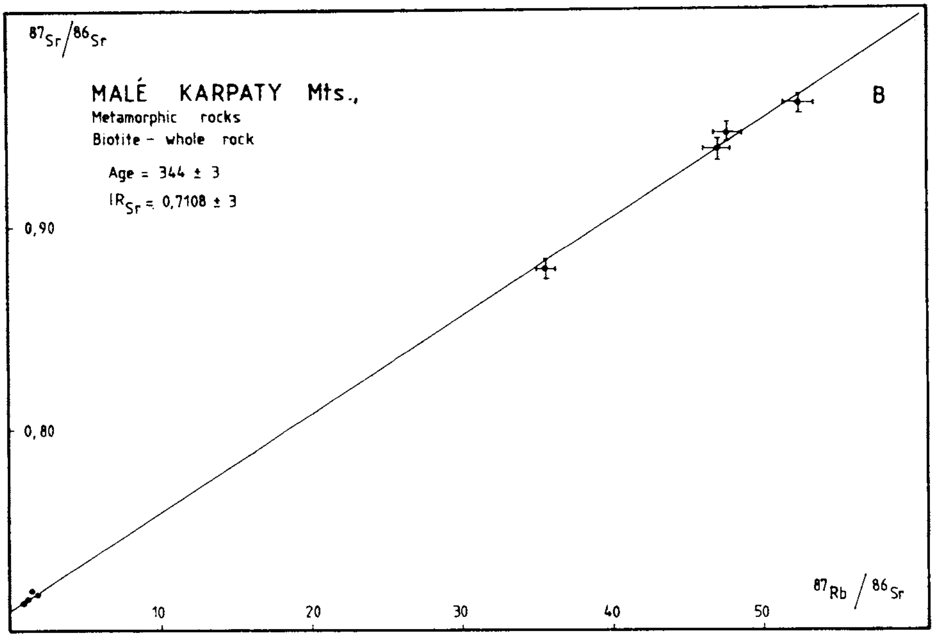

Fig. 5 B. Whole-rock-biotite isochron constructed from some samples of Fig. 5 A.

age than the dated intrusion of the granitoid body. Data obtained from the Western Carpathian crystalline complex and initial ratios $(^{87}Sr/^{86}Sr)_i$ denoted as IR_{Sr} are presented in Tab. 1.

Rb-Sr isochron age of synkinematic granite of Králička type (the Low Tatras) is synchronous with intrusion of the Low Tatra granitoid massif. Striking difference is, in contrast to Ďumbier granodiorite, in IR_{Sr} value which probably proves the close geochemical relation of the former to wall metamorphic rocks.

Two distinct types of granitoid rocks are dominant in the Veporic crystalline complex. Rb-Sr dating documents also their age diversity. From the published data on more basic type (granodiorites), a common isochron for granitoid rocks from Kohút zone (Fig. 6) can be plotted. Slope of the isochron corresponds to the age of 391 $\pm$ 6 m.y., IR_{Sr} = 0.7076 $\pm$ 2. Tonalite samples, typical representatives of Sihla type, cannot be placed to this isochron, since, though synchronous in age, they have markedly lower IR_{Sr} value (0.7054 $\pm$ 2).

Leucocratic varieties occurring in the Veporic pluton are younger; slope of the isochron constructed from these rocks from various localities (including granite of Hrončok type) corresponds to the age of 286 $\pm$ 20 m.y., IR_{Sr} = =0.7060 $\pm$ 3. Ascertained differences typical of petrographically diverse granitoid types refer to biphase granitoid magmatism within a time interval greater than 70 m.y.

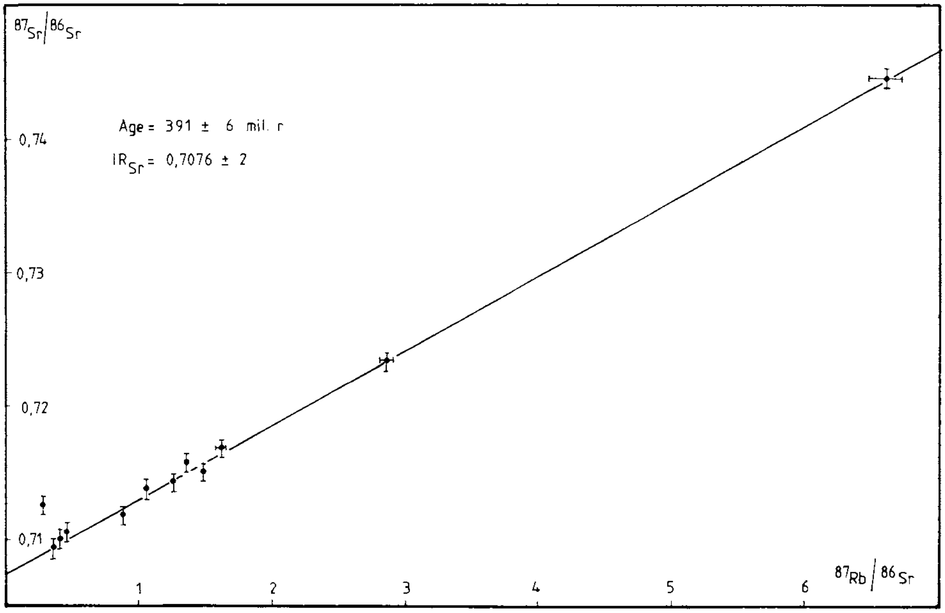

Fig. 6. Whole-rock isochron constructed from granitoid rocks of the Kohút zone (X); according to C a m b e l et al.'s data (1988).

The quoted papers of K o v á c h et al. (1979, 1986) bring interesting information on the Gemericum which completes its characteristic differences with granitoid rocks from the core mountains and the Veporic crystalline complex.

First characteristic feature is that a great deal of data does not fit calculated isochrons. Only a half of eight published isochrons has MSWD lower than 2 (Podsúľová, Humel, Zlatá Idka), values of the rest (Zlatá Idka — borehole ID-2, Hnilec — surface, Betliar, Dlhá dolina valley) are even extreme, e.g. 195 for the Betliar body. Thus, at least a half of data forms pseudochrons. Though new dating from Hnilec (C a m b e l et al., 1989) gives values of age concordant with K o v á c h et al.'s (1986), it differs in IR_{Sr} values. These are evident proofs of isotopic inhomogeneity of the Gemeric bodies as a whole. This fact causes that geochronological and geochemical interpretation of data is quite problematic.

Second characteristic feature of the Gemeric granites is a great dispersion of IR_{Sr} values. In isochrons they vary from 0.720 ± 10 to 0.734 ± 3, in pseudochrons from 0.707 ± 10 to 0.722 ± 5. Errors of this parameter (± 1 SD) refer to its markedly worse applicability to geochemical interpretations.

But it seems that in spite of the mentioned complications, the following statements result from the published data:

1. The Gemeric granitoid rocks are of older age than the Cretaceous (Permian), isochron ages vary from 280 to 144 m.y., pseudochron ages from 346 to 159 m.y. Great dispersion of "chronological" data is not caused by long

Table 1

Rb-Sr ages obtained from the Western Carpathian granitoid and metamorphic rocks (in m. y.).

	Granitoid rocks	Metamorphic rocks
TATRIC UNIT (I.—IX.)		
I. Malé Karpaty		
Bratislava massif	WR: 347 ± 4 (0.7076 ± 13)	WR: 380 ± 20 (0.7101 ± 4)
Modra massif	WR: 324 ± 18 (0.7075 ± 13)	WR—Bi: 344 ± 3 (0.7108 ± 3)
II. Považský Inovec	No data available	No data available
III. Tríbeč	No data available	No data available
IV. Strážovské vrchy	WR: 393 ± 6 (0.7060 ± 2)	No data available
V. Žiar	No data available	No data available
VI. Malá Fatra	No data available	No data available
VII. Veľká Fatra	No data available	No data available
VIII. Low Tatras	WR: 362 ± 21 (0.7079 ± 2) main body	No data available
	Králička type WR: 365 ± 17 (0.7157 ± 17)	
IX. High Tatras	WR: 300 ± 10 (0.706 ± 1)	WR: 420 WR—Bi, Mu: 300 ± 12
VEPORIC UNIT (X.—XI.)		
X. Veporic pluton	WR:	
granodiorite (Kohút zone)	391 ± 6 (0.7076 ± 2)	No data available
tonalite (Sihla type)	387 ± 27 (0.7054 ± 3)	
granites (Vepor type)	284 ± 22 (0.7060 ± 3)	
XI. Čierna hora	WR—Bi: 297 ± 35	No data available
GEMERIC UNIT (XII.)		
Hnilec	WR: 290 ± 40 (0.7119 ± 181)	No data available
Betliar	WR: 272 ± 40 (0.7112 ± 200)	
Humel	WR: 246 — 270 (0.7193 — 0.7216) WR—Bi: 92 — 138	
Zlatá Idka	WR: 223 — 251 (0.7133 — 0.7279) WR—Bi: 100—141	
Dlhá dolina valley	WR: 146 — 151 (0.7204 — 0.7330)	
Podsúľová	WR: 145 ± 6 (0.7339 ± 40)	
Rochovce	WR—Bi: 101 ± 5 (0.7093 ± 9)	

Initial ratio $(^{87}Sr/^{86}Sr)_i$ (IR_{Sr} in the text) is given in parentheses. Data are taken over from Bagdasaryan et al. (1982, 1983, 1986), Burchart (1968), Cambel et al. (1979, 1988, 1989), Kovách et al. (1979, 1986) and Kráľ et al. (1987). WR — whole-rock isochron; WR—Bi, Mu — internal, whole-rock-biotite-muscovite isochron.

duration of granitoid plutonism, but it is rather a manifestation of total opening of Rb-Sr system in these rocks. Kovách et al. (1986) suppose that chronological data are not even related to homogenization during intrusions, but to the moment when the bodies penetrated with fluids became drier. This would mean that the obtained data on age have not any relation to original ages of intrusions.

2. The source of granitic magmas of the Gemeric granites is evidently isotopically different when compared with the Tatric or Veporic granitoids. High initial ratios IR_{Sr} prove old, crustal source with high Rb/ Sr ratio.

From the Gemeric granites, analyses of whole rocks and 7 biotite samples were carried out. Age of two-point isochrons obtained in such way varies from 90 to 142 m.y., most often within an interval ranging from 100 to 112 m.y. Their discordance to whole-rock isochrons proves closure of Rb-Sr chronometer only later, similarly as in case of the Malé Karpaty Mts. The ages may be connected with change of temperature conditions what is associated with overthrusting of nappes assumed by Kovách et al. (1986).

In the tectonic zone separating the Gemericum from Veporicum, granitic body was bored near Rochovce (Klinec et al., 1980). According to this paper, Rochovce granite is considered as Alpine, but its genesis is questionable. Construction of the whole-rock isochron from the published data is not possible due to extremely small dispersion of Rb/Sr ratios in individual analyzed samples. Slope of mineral isochron (constructed from whole rocks and biotites from this body) corresponds to the age of 101 $\pm$ 5 m.y. with IR_{Sr} = = 0.709. This datum is identical with ages of mineral isochrons of the Gemeric granites. This value cannot be compared with data on the Veporic granitoids, because of their lack. Statistical analysis of whole-rock data of Kovách et al. (1986) and recent data of Cambel et al. (1989) proves that Rochovce granite can be placed on the whole-rock isochron constructed from analyses of some samples from Hnilec, rather than on e.g. isochron of leucocratic Veporic granites which are very close in age.

K-Ar dating

K-Ar data represent, for the time being, the most numerous set of isotopic data from the Western Carpathian crystalline complex. Model K-Ar data from the Tatricum, Veporicum and Gemericum form an extremely dispersed "cloud" of values corresponding to an age interval from the Palaeogene to Precambrian in geological scale of time. This state required reinterpretation of data (Burchart et al., 1987) based on evaluation of agreement of the published data with Harper's model (1970). This model enables to disclose and define K-Ar geochronometer deviation from its model functionality, even when using the simplest type of isochrons (^{40}Ar vs. ^{40}K). Such analysis enabled to make verification of data and to select those which can be applied to geochronological interpretations. Dating of whole rocks is omitted in evaluation of K-Ar data importance. Spectrum of their apparent and pseudochron ages has no relation to any age-defined geological event and, consequently, data of such type cannot be denoted as "ages".

It should be noted that K-Ar model dating of some geological objects in the Western Carpathians gives valuable information only on the certain regions.

K-Ar model ages are sometimes close to true ages (in comparison with Rb-Sr data). It is valid for some core mountain ranges, whereas dating of the other regions does not determine age of primary rocks origin even approximately. Detailed evaluation of model ages importance of individual samples is dealt with in the papers of Kantor (1957—1981), Bagdasaryan et al. (1977) and Cambel et al. (1979, 1980). Summary evaluation of model ages is represented in Fig. 2 a—i.

Metamorphic rocks. Data on amphiboles from amphibolites, as well as on muscovites and biotites from metamorphic rocks have been published so far (Bagdasaryan et al., 1977; Cambel et al., 1979; Kantor 1959 a—d, 1960, 1980; Kantor—Rybár, 1979; Kantor et al., 1981; etc.)

Amphiboles belong to the minerals whose model ages have the greatest dispersion. As isochron analysis of original data has proved, the most probable source of model ages dispersion is excess or loss of ^{40}Ar; this was also quantitatively estimated (Burchart et al., 1987).

From the Tatric crystalline complex, most of K-Ar data on amphiboles is from the Malé Karpaty Mts. Model ages vary from 362 to 112 m.y. K-Ar isochron constructed from these samples has a negative intercept indicating loss of ^{40}Ar. Slope of the isochron corresponds to the age of 394 $\pm$ 24 m.y. and it is practically identical with age of Sr isotopes homogenization in metamorphic rocks. Therefore, we assume that age of main metamorphism in the Malé Karpaty Mts. is determined by these data. From the other core mountains, only individual data not enabling to make isochron control are known, and, consequently, they cannot be adequatly interpreted.

Amphiboles from the Veporic crystalline complex are heterogeneous, coming from various rocks. In addition to amphiboles from amphibolites, also amphiboles from ultrabasic bodies were analyzed. These data do not give interpretable ages, because of shortage of analyses and a great dispersion of model ages even from one body (Vagnár). Only 5 samples can form linear dependence. Slope of this isochron would correspond to the age of 330 m.y. which is identical with age of Rb-Sr mineral muscovite-biotite isochron of the Veporic metamorphic rocks.

From the viewpoint of geological structure of the region, isochron of the Gemeric amphibolites gives seemingly controversial data. Analyzed amphiboles are from the region with high-temperature metamorphism features (according to Hovorka—Spišiak, 1981, 500—600 °C determined in the pair garnet — amphibole from Rudňany). Excess of argon in these samples caught during recrystallization of amphiboles caused that model ages were practically devalued for interpretation. Isochron age equals to 264 $\pm$ 18 m.y. (Burchart et al., 1987). Occurrence of pebbles of the similar rocks from unmetamorphosed Carboniferous sequence appears paradoxically in such situation. Undoubtedly, the problem of high-temperature metamorphism age determination in the Gemericum requires more detailed study.

Amphiboles from the Malé Karpaty crystalline complex date an age of metamorphic event, while ages of biotites and muscovites from the Malé Karpaty Mts., the other core mountains and Veporicum belong to another category of ages, these are cooling ages. Regionally observed trend is that muscovite ages are always higher than biotite ones, not reaching, however, age of whole-rock Rb-Sr isochrons. This phenomenon can be characterized as a result of rock

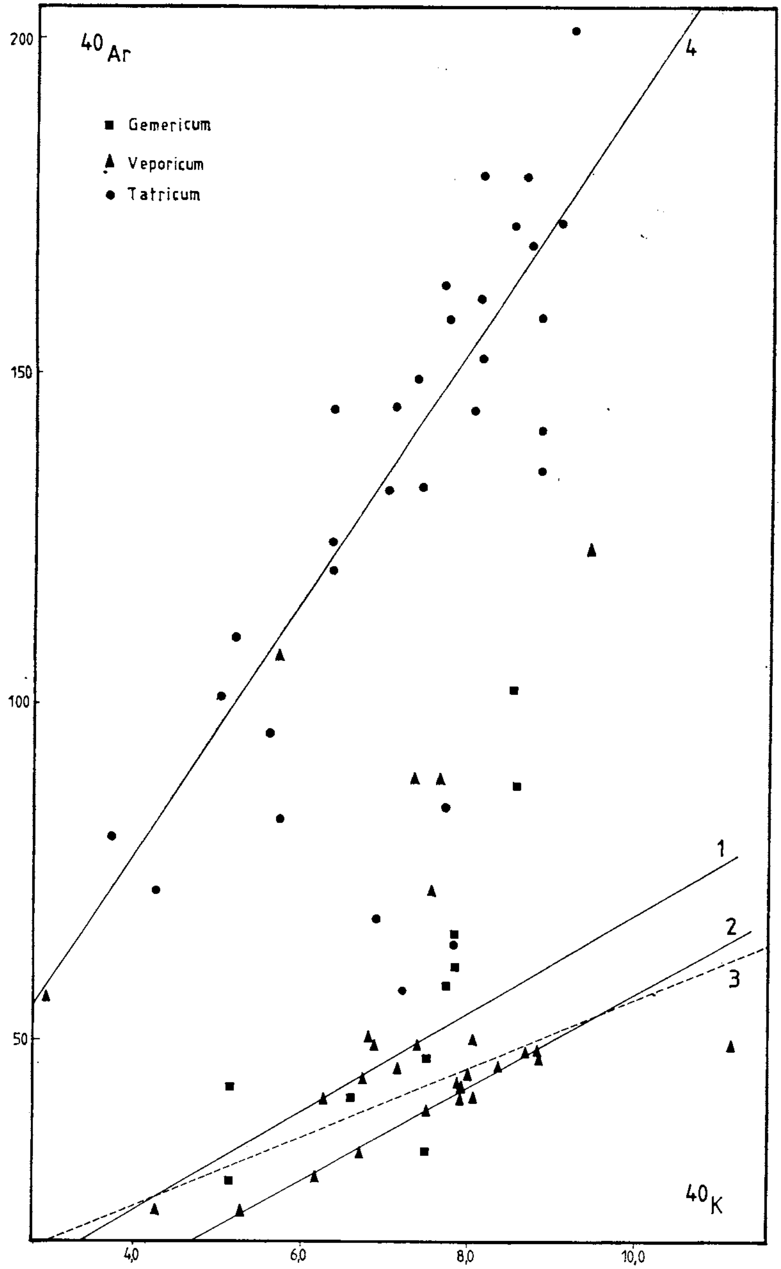

Fig. 7. Plot of ^{40}Ar vs. ^{40}K contents dependence in biotites from the Tatric, Veporic and Gemeric granitoid rocks. Samples from the Tatric crystalline complex form fundamentally different dependence (line 4) in comparison with the samples from the Veporic crystalline complex (lines 1—3).

cooling rate depending on time when minerals passed through isotherms corresponding to their different blocking temperatures.

Data on model ages of muscovites from the Tatric crystalline complex range from 379 to 217 m.y. Analyzed muscovite samples do not form any isochron dependences in the isochron graphs. Ages of biotites vary from 325 to 284 m.y. having a distinct tendency of forming ^{40}Ar vs. ^{40}K linear dependence in the graph, whereby slope of isochron corresponds to the age of 302 m.y. (Fig. 7, line 4). Consequently, the age datum is distant from an age of metamorphic and plutonic processes as dated by Rb-Sr method. On the basis of a certain analogy with the Alpine crystalline complex (Wagner et al., 1977), this datum is considered as time which has passed since transition of the Tatric rocks through the isotherm of ca. 270 °C (Burchart et al., 1987). Dispersion of values around the isochron is noticeable. It means that crystalline rocks outcropping to the present surface need not represent the same level of erosive section. The fact that biotite samples from metamorphic and granitoid rocks from the Malé Karpaty Mts. lie on this isochron together, regardless their previous history, supports an idea of their cooling ages.

Micas from the Veporic crystalline complex cooled in different time. Model ages of muscovites vary within a large interval: 90—317 m.y., similarly as biotites, the only difference being that major part of biotite samples (28 analyses) is concentrated around two parallel isochrons giving the ages of ca. 126 m.y. (Fig. 7, lines 1—2). Since radiogenic argon has been produced in these samples since the Palaeozoic, it is evident that major part of argon was lost in them. Undoubtedly, isochron ages of biotites from the Tatricum and Veporicum prove substantially different thermal history associated probably with different tectonic development, e.g. outstaying of the Veporic rocks at greater depth, in zone of higher temperatures. This is a fundamental difference in comparison with the samples from the core mountains.

FT dating

Features of FT geochronometer impede to date ages of plutonic and metamorphic processes, particularly in such polymetamorphic region, as the Western Carpathians are. But in tectonically mobile regions with rapid vertical movements, information on age of uplifts (Wagner — Reimer, 1972), above the temperature limit given by retention of spontaneous tracks in used mineral can be obtained.

FT ages of apatite from the Tatric and Veporic granitoid and metamorphic rocks (Burchart, 1972; Kráľ, 1977) vary within an interval from 10 ± 2 to 89 ± 10 m.y. At the same time, most of data from the core mountains does not exceed the Miocene boundary. Data from the Veporic crystalline complex (53 ± 7 to 89 ± 10 m.y.) are sharply contrasted with the above data. Documented differences support the fact that the youngest tectonic history of the Tatric crystalline complex differs considerably from that of the Veporic crystalline complex. Cooling below the limit of ca. 100 °C is registered in the Veporicum at the end of the Cretaceous, in the core mountains, on the other hand, in the Miocene. From this viewpoint, the Low Tatras represent a transitional member what is supported by well-known palaeogeographic and palaeontologic proofs (Marschalko—Váňová, 1963; Köhler, 1975).

It is important that FT data on the Western Carpathian crystalline complex, in spite of their low number, record the processes which are beyond sensibility limit of the other geochronological methods. Preliminary scheme of FT ages distribution proves crystalline blocks ages lowering from the south to the north, to external parts of the Carpathian arc. This is evidently associated with the tectonic processes present at the contact of the Carpathians, the Bohemian massif and Polish epi-Hercynian platform.

Discussion

Set of geochronological data on rocks from the Central Western Carpathian crystalline complex obtained by various methods brings information changing the stereotype of views of chronology of metamorphism and granitoid plutonism processes in this region deduced from purely geological and tectonic considerations.

Generalizing the present knowledge of isotopic geochronology, the fact following from these data cannot be underestimated: though the studied crystalline complex does not cover a large territory and many parts are very close, as far as geological structure and rock content are concerned (particularly the Tatric and Veporic crystalline complexes), direct geochronological parallelism is not possible only on the basis of the mentioned analogies. Therefore, more general chronological schemes can be made only in the regions where there are enough geochronological or other stratigraphic data. It is questionable to what extent are they valid for the whole area of the crystalline complex which is not yet equally and, regarding complexity of its structure, sufficiently studied.

From distribution and dispersion of chronological data it follows that isotopic data can be divided into two categories:

1. The first category of data gives information which directly indicates age of the metamorphic and plutonic processes, e.g. part of U-Pb data (concordant ages of zircons). Rb-Sr data of whole rocks — granitoid and metamorphic, also provide information of such type. If there are no indications of isotopic inhomogeneity (as in some of the Tatric and Veporic rocks), these data can be regarded as ages of the processes. The only exception is represented by the Gemeric granites whose analytical data prove their considerable isotopic inhomogeneity.

K-Ar data obtained from amphiboles from amphibolites are placed to this category too. This statement is certainly valid for data on the Malé Karpaty Mts. and probably for isochron data on amphiboles from the Gemericum and Veporicum.

2. The second, largest group of isotopic data is represented by data which are no longer directly related to the age of the metamorphic and plutonic processes. These are K-Ar cooling ages or ages of subsequent isotopic homogenization between individual mineral phases which can be obtained by Rb-Sr mineral isochron. As it follows from documented analyses, the cooling ages include K-Ar data obtained from biotites, muscovites or feldspars and FT data. These ages

indicate time when the samples passed through the isotherms corresponding to the blocking temperatures. Besides this, excess or loss of ^{40}Ar is usual in alalyzed samples, as mentioned above. This fact causes incorrect function of K-Ar geochronometer and it totally devaluates importance of several model ages. Only a part of K-Ar ages determined in muscovites is closest to the true ages. For these reasons, interpretation of individual K-Ar data must be avoided, if isochron control is not possible (B u r c h a r t et al., 1987).

If the hitherto published ages are evaluated from this point of view, then it is evident that a group of data which dates ages of the plutonic and metamorphic processes is smaller than that which indicates only the postgenetic processes, especially cooling. Therefore, there is not a sufficient number of data discounting or supporting presence of the Precambrian rocks in the Western Carpathian crystalline complex. Only few samples from the rocks of the assumed Precambrian (according to the view of L. K a m e n i c k ý — J. K a m e n i c k ý, 1983) were analyzed: U-Pb dating of zircons from Muráň gneissose granite, from migmatites of the Low Tatras, including anatectic granite of Králička type and from gneisses of Račkova dolina valley. From these rocks, only granite of Králička type was simultaneously dated by Rb-Sr method. In addition to gneisses from Račkova dolina valley whose zircons display markedly different degree of discordance, the other data are practically concordant, lying within an age interval of 300—400 m.y. Particularly their concordant position suggests an idea that analyzed population is chronologically homogeneous. There are no traces after old lead what proves the fact that these rocks were formed by the processes of the Palaeozoic age. Provided that two data on zircons from Račkova dolina valley (from very close localities) reflect different retention of radiogenic lead on thermal effect (they are originally identical in age and fit one discordia), the obtained lower intercept indicates an age of metamorphism of about 400 m.y. It is a common datum provided by lower intercepts of U-Pb dating of zircons from high-grade metamorphic rocks from central Europe (G e b a u e r — G r ü n e n f e l d e r, 1977).

Clearly proved thermal event of regional importance is metamorphism taking place 400—380 m.y. ago which caused the first homogenization of Sr isotopes in the sedimentary rocks. Age of this metamorphism and its presence are documented by Rb-Sr analyses of whole metamorphic rocks from the Malé Karpaty and Tatra Mts., by K-Ar isochron of amphibolites from the Malé Karpaty Mts. and probably also by assumed lower intercept of two-point discordia of the samples of zircons from Račkova dolina valley in the Western Tatras. From the other regions no analytical material from which we can come out at our considerations has been published so far.

Age of metamorphism being determined at the Silurian—Devonian boundary is beyond chronological schemes accepted till the present. Orogene of this age has not yet been documented by characteristics of orogenic nature (uplift, erosion, discordance) in the Western Carpathians, but it is presupposed in Lepontine area, the Swiss Central Alps (K ö p p e l et al., 1981). Substantial part of these Lower Palaeozoic sedimentary rocks may be formed by Precambrian or even Middle Proterozoic components building a part of continental crust in Hercynian Europe. U-Pb data on zircon detritus (K o b e r — L i p p o l t, 1985; G e b a u e r, 1986; K r ö n e r et al., 1988) and apparent ages of crustal residence indicated by Nd model ages (Liew — Hofmann, 1988) support this fact.

Progressive metamorphic processes took place in the Tatric crystalline complex or in its part, but the Gemericum represented a region with intensive volcanic activity in this period. Analyses of zircons from metarhyolites, metamorphic volcanic rocks (Gelnica sequence) whose effusion ages are dated at 400 m.y. are in favour of this fact.

Discordance of U-Pb ages obtained from analyzed metarhyolites is remarkable. But it is questionable to what extent the upper intercept of discordia (1800 m.y.) indicates age of the source rocks; in any case it fits in the picture discussed above. Low-grade metamorphism of these rocks in the greenschist facies had to be younger than age of the lower intercept, but its age is, for the time being, unknown. K-Ar isochron age of amphiboles from high-temperature facies appears to be partly paradoxical in this context. Isochron age dated at 265 ± 18 m.y. is contradictory to the present view of age of this metamorphism.

Period of regional metamorphism is followed by the period of granitoid rocks intrusions. Rb-Sr data on the Tatric, Veporic and Gemeric whole rocks register differences in ages of about 100 m.y. between individual bodies or various petrographic types. Range of determined age interval is surprisingly large. Ages, in fact, lie within an age interval of the Palaeozoic intrusions of granitoid rocks forming e.g. the French Massif Central (Duthou et al., 1984), the Armorican Massif (Bernard-Griffiths et al., 1985) and in the other regions of Hercynian Europe (Schwarzwald complex, Hofmann, 1979). Ages of some granitoid rocks intrusions from the Gotthard massif are practically identical with leucocratic granitoid rocks from the Veporic pluton (Oberli et al., 1981).

The oldest ages of granitoid rocks dated at about 390 m.y. (basic types in the Veporic pluton, granitoids from core of Suchý Mts. - Strážovské vrchy Mts.) are higher than the oldest ages of the Hercynian granitoids (360 m.y.) and close to the ages identical with homogenization of Sr isotopes in the crystalline schists documented in the Tatricum. Ages of granitoid rocks from the Tatric crystalline complex are not related to a certain petrographic type, but to individual massifs as a whole. This is supported by placing of granodiorites and their leucocratic varieties (autometamorphic types) from the High Tatras, Low Tatras and Malé Karpaty Mts. on chronologically same isochrons. On the other hand, rocks from the Veporic pluton built of basic Sihla type and leucocratic Vepor type differ in petrography and age. Isotopic data demonstrate polyphase character of granitoid plutonism in the Veporic pluton, as well as in the whole region of the Western Carpathians.

Geochemical development of the Gemeric granites represents an interesting problem. On one hand, clear proofs of their isotopic heterogeneity have been obtained what points out complications in interpretation of Rb-Sr data, on the other hand, IR_{Sr} values are much higher in comparison with the Tatric and Veporic granitoids, though those of some bodies are close to these values (Hnilec, Rochovce). There are no doubts that source of the Gemeric granites must have had much higher Rb/Sr ratio than the source of the Tatric and Veporic granitoids. Rb-Sr and K-Ar isotopic data do not support an idea of polyphase origin of the Gemeric granites (K a n t o r — R y b á r, 1979), but they document their complicated postgenetic geochemical development.

Studying ages of granite genesis in the Tatricum and Veporicum, the fact that trend to higher Rb-Sr and lower U-Pb ages determined in zircons is observed in that part of the samples from which Rb-Sr and U-Pb analyses have been carried out. It is a paradoxical finding: in some samples this difference makes even 40 m.y. Smaller differences are recorded in some samples from Sihla tonalite and Modra massif in the Malé Karpaty Mts. This problem is unusual, therefore it must be found out what causes this age diversity. In original papers dealing with this problem, an idea of contamination of some samples (particularly of those with high Rb/Sr ratio) by strontium from the surrounding rocks with high $^{87}Sr/^{86}Sr$ ratio is preferred. We assume that this problem may be more complicated. One of the reasons which might cause this age discordance can be mixing of masses differing in isotopic characteristics. The Tatric and Veporic granitoid rocks lie closely above the basalt field what proves a partial contamination by older crustal material having apparently different $^{87}Sr/^{86}Sr$ ratio. In case of imperfect mixing, these differences might be caused by slope of mixing line, and, consequently, by corresponding apparent „aging" (F a u r e, 1977). Hyperbolical dependence of $^{87}Sr/^{86}Sr$ ratios of the whole rocks on the total Sr content proved in the studied set of rocks is in favour of this idea. Discordant U-Pb ages of some granitoid rocks refer to presence of older, assimilated material. Presence of inherited lead supporting this idea is markedly manifested in the sample of Modra tonalite (Malé Karpaty Mts.) and in the sample of granodiorite (ZK-3) from the Low Tatra body. The latter has anomalous position in Rb-Sr isochron graph (see B a g d a s a r y a n et al., 1983). If this idea was fully proved geochemically, it would become evident that ages of Rb-Sr whole isochrons might be distorted and "older" than the true ages. From the viewpoint of degree of possible contamination, tonalites of Sihla type from the Veporicum can be considered as least contaminated. Complete data on chronology of the granitoid and metamorphic processes and initial ratios $^{87}Sr/^{86}Sr$ (IR_{Sr}) are given in Tab. 1.

The second stage of metamorphism registered by geochronological methods was represented by metamorphism of rocks caused by intrusions of granitoid bodies. There is irrefutable evidence (from the Malé Karpaty Mts. and the High Tatras) that homogenization of Sr isotopes in minerals of wall metamorphic rocks took place in the same time as intrusions of these bodies (Fig. 5B). Since this process is connected with considerable effect of temperature, important information on thermal conditions and their changes in granitoid bodies and wall rocks can be obtained from these data.

It has been shown above that K-Ar data on micas belong to data giving information on the course of cooling processes following the intrusive or metamorphic events. It is documented by frequent chronological sequence of the studied rocks. Relation of individual ages is as follows:
Rb-Sr (WR) >, K-Ar (Mu) >, K-Ar (Bi).

This age pattern is caused by differences in the blocking temperatures of individual minerals, extent of differences is connected with cooling rate. This model can be applied to the core mountains (B u r c h a r t et al., 1987) and partly to reconstruction of thermal history of the Gemeric granites. From this it follows that samples from the Veporic crystalline complex have quite different thermal history when compared with samples from the Tatric crystalline complex: samples from the Tatricum passed through the isotherm of ca. 270 °C approximately 300 m.y. ago, samples from the Veporicum approx. 90—120 m.y. ago. Owing to the Palaeozoic age of granite formation, it is evident that their posttectonic development must have been totally different. The Tatric crystalline complex, in comparison with the Veporic crystalline complex, might have represented, for example, a more stable part of the Earth's crust.

Tectonic development of the crystalline complex was completed by the youngest vertical movements, as documented by FT data obtained from apatites. These data register differences manifested by diverse ages of uplifts of the Tatric (Miocene) and Veporic (Upper Cretaceous) crystalline complexes.

Conclusion

Relatively great number of geochronological data from the Western Carpathian crystalline complex represents a concrete basis for solution of the problems clarification of which becomes more urgent. It seems that at present there is enough exact knowledge to refute traditional views, but still not enough to form a new complex model.

Results obtained by methods of isotopic geochronology prove dominant character of the plutonic and metamorphic processes of the Palaeozoic age in this region. Studying the obtained data it comes out that there are still not enough data to solve the problem of occurrence of older Precambrian rocks in this region. But the existing data have not proved these views.

Overall view of the obtained data shows that isotopic age of metamorphism dated at the Silurian—Devonian boundary and documented large age dispersion of the processes of granite genesis are remarkable. Hitherto traditionally dated at the Upper Carboniferous (J. Kamenický, 1967), age of these processes in the Tatric and Veporic crystalline complexes ranges from 390 to 286 m.y. Older ages of metamorphic processes (isotopic homogenization ca. 400 m.y. ago), large age dispersion of intrusive rocks may be perhaps surprising for the Carpathian geologists, but these data put the Western Carpathian crystalline complex nearer to Hercynian Europe making it less exceptional.

Division of the data into two groups having different relation to age of the metamorphic and plutonic processes explains why a detailed picture of their chronology cannot be, for the present, compiled. A lot of obtained isotopic data registers only processes which have no more direct relation to the true ages. Isotopic data from many regions of the crystalline complex, from various rock types or tectonic units and from lithologically defined sequences are totally missing (e.g. age of metamorphic rocks from the Veporicum, Gemericum, etc.). In spite of this, we assume that presented set of data may serve as an appeal for concentrated solution of the problems concerning age of granitoid and metamorphic rocks which are still topical for comprehension of the Western Carpathian crystalline complex chronostratigraphy.

Translated by O. Mišániová

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