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Rb-Sr isotopic ages of granitoide rocks from the Spišsko-gemerské rudohorie Mts., Western Carpathians, Eastern Slovakia

ADAM KOVÁCH**, EVA SVINGOR**, PAVOL GRECULA*

** Institute of Nuclear Research of the Hung. Acad. Sci., Pf. 51, H-4001 Debrecen, Hungary
* Geologický prieskum, POB. 13, 040 11 Košice, ČSSR

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Рубидий-стронциевый изотопный возраст гранитоидов Спишско-гемерского рудогория, Западные Карпаты, Восточная Словакия

Детальное изучение Rb/Sr изотопного возраста было произведено на образцах пород (валовые пробы) и биотитах отобранных из гранитовых тел тектонической единицы гемерикума. Изохронный возраст был установлен из следующих гранитоидных тел: Гнилец (290 ± 40 млн. лет), Злата Идка (251 ± 16 млн. лет и 223 ± 32 млн. лет), Гумел (270 ± 64 млн. лет и 246 ± 25 млн. лет). Из гранитового тела Бетляр небыл получен результат изохронного возраста, но дистрибуция данных в изохронной диаграмме показывает на палеозойский возраст возникновения гранита, только со сильной вторичной переработкой. Изохронный возраст грубозёрных гранитов местонахождения Подсулёва (142 ± 6 млн. лет) и из грейзенизированных пород Долгой долины (151 ± 14 и 146,6 ± 6 млн. лет) свидетельствует об важном этапе теплотной и тектонической активизации во верхней юре. Рубидий-стронциевый возраст биотитов (приблизительно 100 млн. лет с максимальной величиной 142 ± 4 млн. лет) можно соединить с происхождением альпийских покровов.

В статье сделана попытка сравнивания рубидий-стронциевого и калий-аргонового возрастов гранитов гемерикума.

Rb-Sr isotopic ages of granitoide rocks from the Spišsko-gemerské rudohorie Mts., Western Carpathians, Eastern Slovakia

Detailed Rb-Sr isotopic age studies have been carried out on whole rock and biotite samples from several granitic bodies, as well as on material from altered zones of the Spiš-Gemeric Metalliferous Mountains (Spišsko-gemerské rudohorie Mts., or Gemeric unit).

Total rock isochron ages have been determined for the Hnilec (290 ± 40 Ma); Zlatá Idka (251 ± 16, resp. 223 ± 32 Ma) and Humel (270 ± 64, resp. 246 ± 25 Ma) granites. No isochron could be obtained for the Betliar granite, but the distribution of data in an isochron diagram suggests a Paleozoic origin with a strong secondary overprint of indeterminate age. On the Podsúľová coarse-grained granite an isochron age of 142 ± 6 Ma, on the altered zone of Dlhá dolina isochron ages of 151 ± 14 and 146 ± 6 Ma have been obtained, pointing to an important period of activization during the Late Jurassic.

Biotite Rb-Sr ages cluster around 100 Ma, with a maximal value of 142 ± 4 Ma, brought into connection with Alpine nappe overthrust.
In accordance with K-Ar ages obtained in other laboratories a tentative scheme for the magmatic-metamorphic development of the Gemeric is proposed.

Age relationships of the Gemeric granites have been a matter of debate since their discovery up to recent times. Age assignments by different authors covered the time span from the Late Carboniferous to the Neogene, although more recently a Cretaceous age became generally accepted. The reason of contrasting opinions traces back in part to the intricate Variscan and Alpine structures into which the small granitic bodies of variable petrochemical character became accomodated. The different appraisal of relationships with and within the polyphase mineralization widespread in the mountain contributed in a similar way to the development of controversies among the opinions of different authors. More recently, a new impetus to genetical and age studies has been given by the discovery of high-temperature (Sn—W) ore mineralizations in the mountain, the possible source(s) of which — except the Hnilec and Podsúľová region — could not be ascertained up till now.

The first series of Rb-Sr age determinations published by the present authors (Kovách et al., 1979), as well as new K-Ar data (Kantor and Rybár, 1979) cast doubt on the previously accepted Cretaceous age, and pointed to the Late Paleozoic emplacement of at least some of the Gemeric granites, although maintaining the idea of polyphase development.

In order to obtain a more general picture, the previous studies have been supplemented by Rb-Sr age determinations carried out on total rock and biotite samples from a more extended area, including several granitic bodies and material from altered zones as well. The present paper gives a brief summary of these investigations.

Geological position

Granites in the Gemeric unit expose within Lower Paleozoic formations. All Early Paleozoic sequences are assambled into a single large lithostratigraphic unit, the Volovec Group (Grecula, 1982) including the hitherto lower Gelnica and higher Rakovec Groups in the sense of other authors. According to our data, both units represent synchronous developments originated in remote parts of a single large basin. The Volovec Group (of estimated 2—3 km thickness) is further subdivided (from the base to the top) into the Betliar, Smolník and Hnilec Formations. The probable stratigraphic span is Silurian, or Upper Ordovician, to Lower Carboniferous.

The lithological content of the group is quite variable. Nevertheless, basic features of history are common. The lower subunit (Betliar Formation) is a detritic one composed of a laminated pelite-siltstone sequence with carbonate and lydite layers on the top. A great variety of laminated green phyllite and a peculiar flysch characterize the middle Smolník Formation. The subunit contains only subordinated volcanic constituents (basalt-keratophyre) in its lowermost part. The uppermost Hnilec Formation is, almost exclusively, composed of volcanogenous sequences in which two characteristic developments may be distinguished: a lower bimodal sequence and an upper, either basic (in the north) or acidic to intermediate one (in the centre and south).

In contrast with the hitherto inferred uniform span of intensities (low- to medium-grade greenschist facies), also rock assemblages metamorphosed under amphibolite facies conditions have been discovered recently (Dianiška — Grecula, 1979; Hovorka et al., 1979; Grecula, 1982) reaching, in places, even to ultrametamorphic degree with characteristics for high temperature-low pressure conditions. The thermal source of this metamorphism may be related to the action of thermal flux confined to the rift domain which, however, took place but after the compression and folding of the basin filling in Lower Carboniferous time. The peak of successive

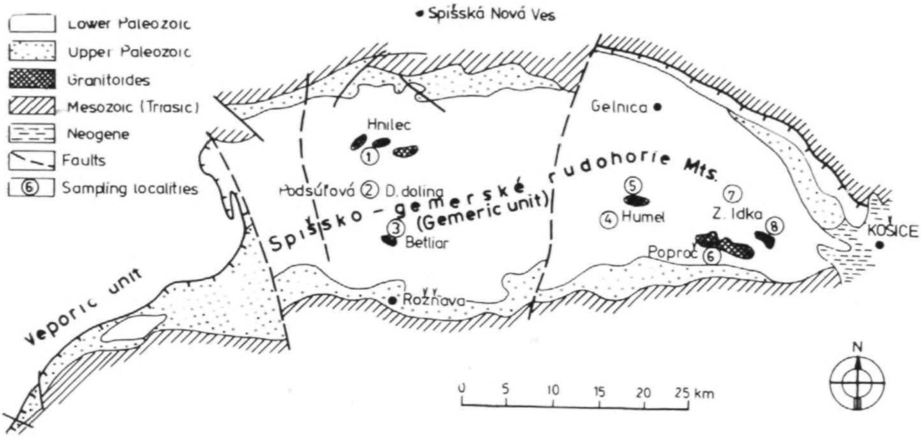

Fig. 1. Simplified geological map of the Spiš-Gemer Metalliferous mountain with sampling localities: 1 — Hnilec — Medvedí potok, 1 km SWW of village; 2 — Podsúľová, drilling PSS-1 in the Krátka dolina valey 9 km N of Gemerská Poloma; outcrop in the Dlhá dolina valley 7 km N of Gemerská Poloma village; 3 — Betliar, stream valley, 4 km northernly of village; 4 — Humel, drilling SG-1, 5 km N of Medzev village; 5 — Humel, outcrops, dolina Humel valley; 6 — Poproč; 7 — Zlatá Idka, drilling ID-1, 3 km NW of village, 8 — Zlatá Idka, outcrop, 5 km SE of village.

metamorphic alterations resulted in migmatitization and granitization processes the product of which remained either in the site of origin or created small intrusive bodies.

After this thermal peak but still during Variscan events, a later strong compression generated the Variscan nappes. The process terminated the previous prograde metamorphism and induced retrogression of older products (foliation of granite, development of blastoporphyric varieties, retrogression of metamorphic assemblages into albite, clinozoisite, new green biotite etc.). A similar retrograde event may, however, also be related with later Alpine (Jurassic to Cretaceous) processes attaining only green-schist grade conditions and preserving still the Variscan products as relics in several places.

The principal tectonic pattern of the Gemeric Unit is its nappe structure. Both Variscan (Upper Permian) and Alpine nappes may be distinguished. Time constraints to Variscan nappe generation are given by the establishment of a new, Upper Permian to Triassic geotectonic cycle of different style, the granite already participating in the nappe structure.

Analytical methods and result

The basic analytical data necessary for dating by the Rb Sr methods (concentrations of ^{87}Rb and ^{86}Sr and the ^{87}Sr/^{86}Sr isotope ratio) have been determined by mass spectrometric methods. In the course of sample preparation an appropriate amount of sample has been pulverized, and following thorough homogenization an amount of 0.2 g — with the addition of pure ^{86}Sr and ^{87}Rb spikes in known amounts for isotopic dilution measurement — has been dissolved in a platinum crucible by hydrofluoric acid, to which a few drops of perchloric acid have been added. Following dissolution the dried residue has been dissolved in 3N hydrochloric acid.

An aliquot part of this sample stock solution was used directly for Rb determination by isotope dilution, another aliquot to prepare pure strontium samples for mass spectrometry, by repeated ion exchange separation on a small (6 mm $\varnothing \times 6$ cm) ion exchange column packed with Dowex-50W×12, 200—400 mesh cation exchange resin. Our experiences

TAB. 1

Compilation of analytical data obtained on total rock samples

Sample No	^{87}Rb μg/g	Rb μg/g	^{86}Sr μg/g	Sr μg/g	$^{87}Sr/^{86}Sr$ atomic ratio	$^{87}Rb/^{86}Sr$ atomic ratio	$T_{isochr.}$ (Ma)
Podsúľová granite							
SGR-1	111.9	402	1.277	13.74	0.9090 ± 0.0050	86.620	
-2	19.0	68	4.906	50.90	0.7419 ± 0.0022	3.834	142 ± 6
-5	65.0	234	2.745	28.59	0.7809 ± 0.0020	23.403	
-3	48.4	174	1.367	14.29	0.8189 ± 0.0054	35.028	
-4	166.8	599	1.140	12.16	1.0292 ± 0.0051	129.278	
Humel granite (Drilling SG-1)							
SGR-7	91.2	326	3.516	36.72	0.8085 ± 0.0060	25.654	
-8	100.5	361	6.170	64.24	0.7764 ± 0.0049	16.093	
-9	79.2	285	3.060	31.96	0.8100 ± 0.0070	25.582	246 ± 25
-10	80.37	289	5.339	55.55	0.7711 ± 0.0051	14.880	
-11	81.3	292	3.588	37.43	0.7964 ± 0.0044	22.404	
Humel granite (from surface)							
SGR-16	68.3	245	5.432	56.51	0.7689 ± 0.0017	12.436	
-17	70.7	254	4.744	49.40	0.7786 ± 0.0015	14.723	270 ± 64
-18	11.6	42	4.381	45.41	0.7317 ± 0.0008	2.606	
Hnilec granite (from surface)							
SGR-28	117.2	421	4.096	42.86	0.8281 ± 0.0009	28.280	
-29	97.3	350	1.878	19.84	0.9294 ± 0.0008	51.236	
-30	109.8	395	2.849	29.90	0.8602 ± 0.0008	38.107	290 ± 40
-32/A	38.1	137	4.076	42.34	0.7535 ± 0.0008	9.230	
-32/B	32.9	118	3.576	37.13	0.7489 ± 0.0010	9.092	
-31	163.5	588	5.248	55.24	0.8899 ± 0.0008	30.797	
-33	69.4	249	3.932	41.07	0.8094 ± 0.0011	17.452	
Betliar granite (from surface)							
SGR-19	45.5	163	3.651	38.03	0.7820 ± 0.0007	12.311	
-20	67.6	243	5.145	53.52	0.7677 ± 0.0009	12.988	
-21	127.9	467	5.027	52.52	0.8134 ± 0.0011	25.150	272 ± 47
-22	155.1	557	5.005	52.32	0.8175 ± 0.0017	30.633	
-24	374.7	1346	2.905	31.50	1.2067 ± 0.0010	127.502	
-23	112.7	405	4.872	50.64	0.7605 ± 0.0008	22.866	
Zlatá Idka granite (Drilling ID-1)							
SGR-43	78.5	282	4.846	50.46	0.7777 ± 0.0016	16.007	
-44	93.6	336	2.174	22.83	0.8642 ± 0.0017	42.568	
-45	5.43	19.5	3.182	32.98	0.7322 ± 0.0028	1.685	223 ± 32
-46	78.3	281	3.730	38.88	0.7889 ± 0.0028	20.748	
-47	71.48	257	6.429	66.84	0.7681 ± 0.0032	10.975	
Zlatá Idka granite (Drilling ID-2)							
SGR-6	65.4	235	10.723	111.20	0.7348 ± 0.0055	6.032	
-48	69.6	250	4.676	48.61	0.7624 ± 0.0017	14.709	
-50	65.9	237	8.356	86.72	0.7435 ± 0.0011	7.782	
-51	61.2	220	8.079	83.82	0.7418 ± 0.0009	7.488	251 ± 16
-58	66.6	239	2.095	21.91	0.8232 ± 0.0008	31.429	
-59/1	75.8	272	2.485	25.99	0.8243 ± 0.0014	30.160	
-59/2	65.7	236	7.824	81.18	0.7421 ± 0.0017	8.296	
-49	103.3	371	3.413	35.57	0.7866 ± 0.0007	29.927	
-56	69.2	249	7.066	73.35	0.7463 ± 0.0007	9.674	148 ± 20
-57	89.8	323	4.514	46.94	0.7650 ± 0.0017	19.672	

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Dlhá dolina altered zone (from surface)							
SGR-25I	30.5	110	0.997	10.40	0.7956 ± 0.0031	30.230	
-25II	37.4	135	1.249	13.02	0.7872 ± 0.0019	29.631	
-26I	24.6	88	0.494	5.18	0.8416 ± 0.0068	30.230	151 ± 14
-26II	22.3	80	0.654	6.83	0.8056 ± 0.0011	33.633	
-27	191.2	687	1.831	19.39	0.9542 ± 0.0026	103.223	
-60	25.2	90	1.232	12.81	0.7636 ± 0.0036	20.195	
-61	11.4	41	1.099	11.41	0.7417 ± 0.0034	10.218	146 ± 6
-62	33.1	119	0.771	8.05	0.8066 ± 0.0015	42.401	
-63	97.8	351	0.870	9.21	0.9515 ± 0.0018	111.134	

Remark: Isochron ages have been calculated using the ^{87}Rb decay constant $\lambda = 1.42 \,.\, 10^{-11} a^{-1}$

showed, that a double-pass separation yields strontium samples free of contaminants even on columns of small size. The eluate fraction containing Sr has been dried and taken up again in a few drops of 1N nitric acid.

In the mass spectrometric measurements a modified MI-1309 type mass spectrometer equipped with a triple-filament ion source (central filament: Re; side filaments: Ta) has been used. Discriminating effects have been corrected by normalizing the measured isotopic rations to the standard value $^{86}Sr/^{88}Sr = 0.1194$. The accuracy of the measurements has been checked by repeated determinations on the Eimer and Amend standard strontium carbonate sample ($^{87}Sr/^{86}Sr = 0.7080$; adopted value) with an average $^{87}Sr/^{86}Sr = 0.7079 \pm 0.0006$ over an extended period.

Rock samples for the present study have been chosen so as to represent granitic bodies from different parts of the mountain, as well as some altered rocks. Sampling localities are shown in Fig. 1 within the frames of a simplified geological map of the mountain.

To ensure adequate, fresh rock material most of the samples originate from exploratory drillings (SG-1: Humel intrusive, ID-1 and ID-2: drillings exposing different parts of the Zlatá Idka granitic body). From a more extensive collection the actual samples have been chosen so as to represent a petrochemically differentiated rock series for each locality, including samples both of "average" and differentiated character (e. g. besides representative granitic-granodioritic samples also aplites, samples affected by hydrothermal alteration, etc.) too. Each sample underwent petrographical examination, in this respect the careful and thorough work of I. Dianiška is highly appreciated.

The analytical data obtained on whole rock samples are summarized in Table 1, arranged according to the different sampling localities. The result for the Podsúľová granite and for the material of the drilling SG-1 (Humel) already published (Kovách et al., 1979) have been included for the sake of completeness. The compilation of Table I. contains for each sample the concentrations of ^{87}Rb, total Rb, ^{86}Sr, total Sr — all in μg/g units; the (measured) $^{87}Sr/^{86}Sr$ isotopic ratio, as well as the (calculated) $^{87}Rb/^{86}Sr$ ratio, both as atomic (molar) ratios. The last column gives the Rb/Sr total rock isochron age for the individual units.

To facilitate easy comparison, the isotope analytical data summarized in Table 1 are also displayed in conventional isotope evolution diagrams in Figs. 2—8. The figures show all the analytical data points, even those which for any reason have

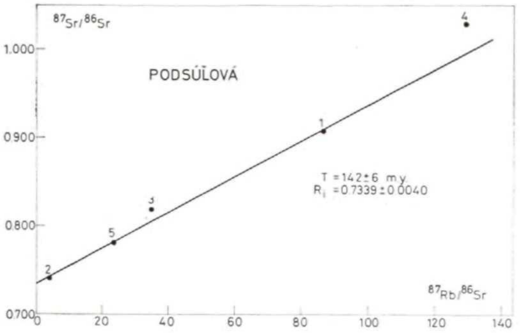

Fig. 2. Isochron diagram of analytical whole-rock data for the Podsúľová coarse-grained granite

been omitted in the isochron age calculations. Each figure gives the calculated isochron age (if an isochron exists) and the corresponding initial $^{87}Sr/^{86}Sr$ ratio, both with error values corresponding to the 95 % probability confidence interval.

The data for the Podsúľová granite (Fig. 2) and for the material of the drilling SG-1 (Fig. 3) have been dealt with in our earlier paper (Kovách et al., 1979). We should like to stress again, that the samples SGR-3 and 4 represent the coarse-grained granite with remains of primary rocks, thus the isochron age given was calculated on the base of the remaining samples representing granite with coarse-grained megacryst of potassium feldspar and quartz. The Podsúľová granite is intensively tectonized.

The three samples of the Humel granite taken from the surface (SGR-16, 17, 18) yield an isochron age of 270 ± 64 Ma, differing (although within the error limits) from the 246 ± 14 Ma age obtained for the SG-1 drill core suite (samples from the drilling SG-1 represent a deeper part of Humel granite body). The petrographical check of the samples in question pointed to the possibility of acid metapyroclastics derivation of the surface suite (samples were taken from the uppermost part of the granite body without thermal contact), so the age difference might reflect genetic heterogeneities within the Humel granite body. For this reason, the surface samples have been treated separately (see Fig. 4).

Results obtained from the Hnilec granite (Medvedí potok locality) are shown in Fig. 5. Although all the examinated samples shown a granoblastic fabric with various degree of high-temperature alteration (greisenization); the samples SGR-31 and 33 fall off the linear array defined by the remaining samples. It seems highly probable, that these two samples — in contrast to the others of endogenous derivation — represent samples of the

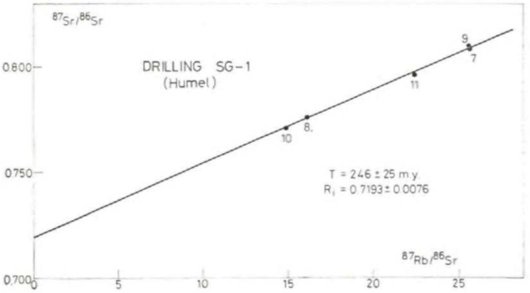

Fig. 3. Isochron diagram of analytical whole rock data for the drilling SG-1 (Humel region)

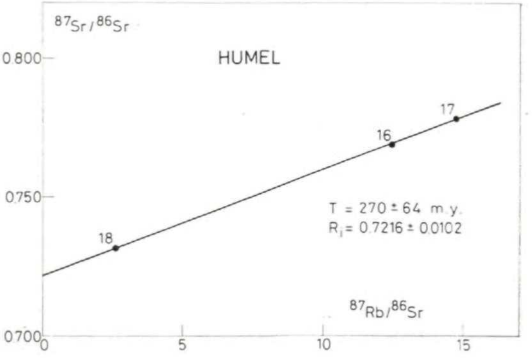

Fig. 4. Isochron diagram of analytical whole rock data for surface samples from the Humel granitic body

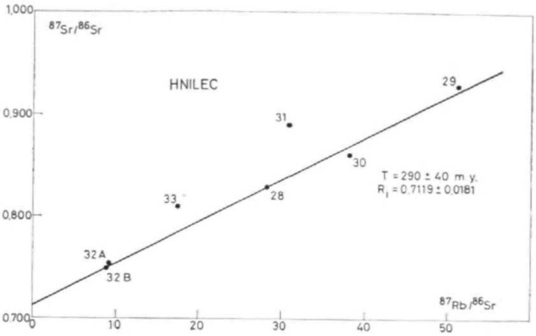

Fig. 5. Isochron diagram of analytical whole rock data for granites from the Hnilec granite

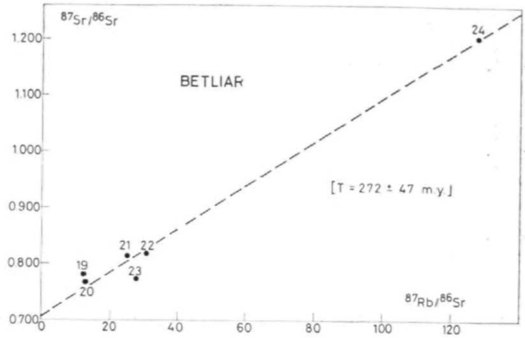

Fig. 6. Isochron diagram of analytical whole rock data for the Betliar granite

exocontact zone of the granite, and contain inherited radiogenic strontium which escaped isotopic homogenization during melt emplacement. The two mentioned samples have been omitted in the isochron calculation.

No reliable whole rock isochron age could be determined for the Betliar samples, obtained from near the type locality and representing various types of the Betliar granite. The data points show a wide scatter in the diagram of Fig. 6, obviously due to secondary effects. Sample SGR-20 represents the typical, porphyritic type of the granitic body, together with the biotite-rich variety of sample SGR-24. All other samples show the effect of different secondary processes (albitization, tourmalinization, etc.) with incomplete isotopic homogenization. The age value given in the figure (272 $\pm$ 47 Ma) was calculated for sample SGR-24, taking the average of all remaining samples as a reference. Although no significant weight is given to the actual figure, it clearly points to the Paleozoic origin of the Betliar base granite, with secondary alterations essentially destroying any previous isochron relation. The highly radiogenic character of sample SGR-24, however, makes the age value above a reliable estimate, being insensitive to the actual choice of the initial $^{87}Sr/^{86}Sr$ ratio.

The drillings ID-1 and ID-2 disclosed different parts of the Zlatá Idka granitic body. For the material from the drilling ID-1 showing signs of deuteric alteration (formation of sericite and clinozoisite at the expense of plagioclase, traces of tourmaline in some of the samples, etc.) an "errorchron" could be obtained only, the deviation of the points for the samples SGR-46 and 47 from the interpolating straight line exceeding their analytical uncertainties. Assuming a direct link between this fact and the presence of postmagmatic alterations, the model age assigned to the interpolating "errorchron" should be regarded as a minimum age.

Fig. 8 displays the results obtained on drill core samples taken at different depths from the drilling ID-2. The samples SGR-59/1 and 58 are of aplitic character, while most of the other samples represent "average" calcalkaline granites of the Zlatá Idka body, with the sample SGR-59/2 from the immediate neighbourhood of the aplitic sample SGR-59/1.

The "average" and aplitic samples together define an isochron with a model age

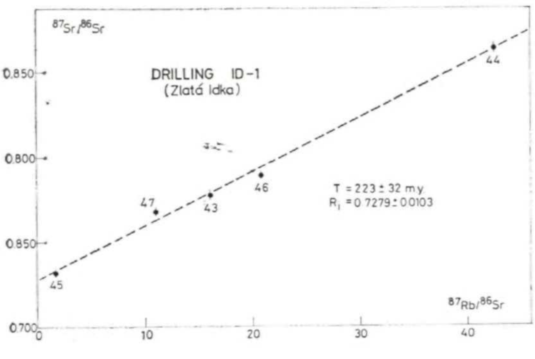

Fig. 7. Isochron diagram of analytical whole rock data for the drilling ID-1 (Zlatá Idka granitic body)

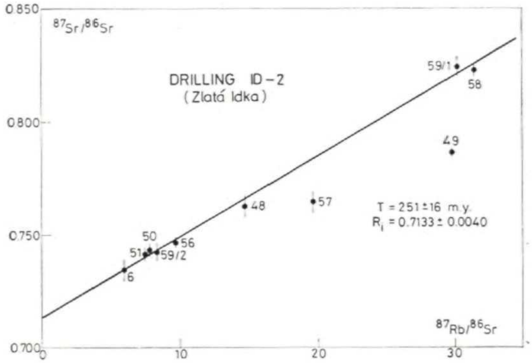

Fig. 8. Isochron diagram of analytical whole rock data for the drilling ID-2 (Zlatá Idka granite body)

of 251 ± 16 Ma, whereas the samples SGR-49 and 57, representing the gerisenized granite fall off the isochron, and suggest a much younger model age. If treated separately, these samples (SGR-49, 57) yield a two—point isochron age of about 150 Ma, and the straight line connecting the sample points would cross the "primary" isochron in the field of "average" samples.

It seems thus highly probable, that the deviating behaviour of these samples reflects the influence of a local alteration process on to the Rb/Sr isotopic system and point to the formation of the metasomatic type of granite separated in time from the processes of granite emplacement.

Similar young model ages have been obtained in the altered zone of Dlhá dolina, near Gemerská Poloma. All the samples show the effect of high-temperature alteration, the primary mineral fabric being totally destroyed. The variation in the Rb-Sr ratio strictly follows the muscovite content of the samples, thus the two parallel isochrons obtained in the course of repeated sampling within the area can be regarded as mineral isochrons, the only Rb-enriched mineral in the suite being muscovite formed during the alteration process. The existence of parallel isochrons might reflect original heterogeneity in the protolith material or it reflects the intensive tectonic reworking and destruction of rocks (samples were taken from outcrops which are situated as an isolated block within the fault and overthrust zone). The model ages of the two suites (see Fig. 9) agree well within the error bounds of the isochron ages.

The whole rock studies dealt with in this section have been supplemented by analyses carried out on biotites, the analytical data being compiled in Table 2.

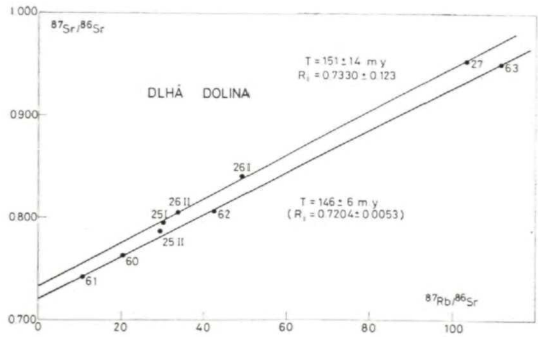

Fig. 9. Isochron diagram of analytical whole rock data for the Dlhá dolina altered zone (near Gemerská Poloma)

TAB. 2

Compilation of analytical data obtained on biotites

Sample No	Locality	^{87}Rb µg/g	Rb µg/g	^{86}Sr µg/g	Sr µg/g	$^{87}Sr/^{86}Sr$ atomic ratio	$^{87}Rb/^{86}Sr$ atomic ratio	
SGR-12	SGR-V-10	97.2 (24.4)	349 (87)	5.389 (95.46)	56.08 (987.9)	0.7722 ± 0.0032 (0.7111 ± 0.0039)	17.802 (0.252)	245 ± 20
SGR-14	SGR-V-10	87.7 (20.7)	315 (74)	4.529 (94.82)	47.24 (981.1)	0.7965 ± 0.0015 (0.7131 ± 0.0026)	19.133 (0.216)	310 ± 21
SGR-6	ID-2	243.6 (65.4)	875 (235)	1.563 (10.723)	16.39 (111.2)	1.0327 ± 0.0044 (0.7348 ± 0.0055)	154.043 (6.032)	142 ± 4
SGR-16	Humel	290.1 (68.3)	1042 (245)	4.116 (5.432)	43.29 (56.51)	0.8813 ± 0.0008 (0.7689 ± 0.0017)	69.664 (12.436)	138 ± 9
SGR-17	Humel	225.1 (70.7)	809 (254)	4.181 (4.744)	43.75 (49.40)	0.8288 ± 0.0030 (0.7786 ± 0.0015)	53.220 (14.723)	92 ± 18
SGR-38	Rochovce	171.9 (68.0)	618 (244)	5.704 (96.00)	59.21 (992.9)	0.7475 ± 0.0014 (0.7094 ± 0.0003)	29.794 (0.700)	92 ± 11
SGR-39	Rochovce	169.6 (55.3)	609 (199)	7.761 (56.97)	80.53 (589.5)	0.7427 ± 0.0012 (0.7137 ± 0.0006)	21.602 (0.959)	99 ± 14
SGR-42	Rochovce	193.8 (45.2)	696 (162)	4.514 (45.18)	46.97 (467.4)	0.7710 ± 0.0010 (0.7118 ± 0.0006)	42.429 (0.989)	101 ± 8
SGR-43	ID-1	313.3 (78.5)	1126 (282)	1.618 (4.846)	17.28 (50.46)	1.0482 ± 0.0017 (0.7777 ± 0.0016)	191.408 (16.007)	109 ± 3
SGR-47	ID-1	260.1 (71.4)	935 (257)	1.795 (6.429)	19.06 (66.84)	0.9783 ± 0.0023 (0.7681 ± 0.0032)	143.237 (10.975)	112 ± 4
SGR-48	ID-2	183.7 (69.6)	660 (250)	1.622 (4.676)	17.10 (48.61)	0.9056 ± 0.0029 (0.7624 ± 0.0017)	111.953 (14.709)	104 ± 7
SGR-51	ID-2	227.0 (61.2)	816 (220)	2.172 (8.079)	22.84 (83.82)	0.8779 ± 0.0014 (0.7418 ± 0.009)	103.311 (7.488)	100 ± 4

Remark: All biotite model ages were calculated with the ^{87}Rb decay constant $\lambda = 1.42 \,.\, . 10^{-11} a^{-1}$ and referred to the recpective whole rock samples, analytical data of which are given in parantheses following the biotite analytical data

Besides the basic data obtained by measurement, Table 2 contains in the last column the model ages of the individual biotite samples, calculated with reference to the respective whole rock samples from which the biotite concentrates have been obtained. Table 2 contains the results of some biotite analyses, which refer to samples not included in Table 1 (granodiorite of the drilling SGR-V-10 from near Košice — Čierna hora Mts. and Rochovce drill core material). The reason of neglecting these whole rock data is that they proved to be inadequate for whole rock isochron studies.

The age data outlined in the present section forms the base of the following interpretation, taking into consideration the tectonic position of the Gemeric granites.

Tectonic position of the Gemeric granites

The samples used throughout this study have been collected from different granitic bodies of the Spiš-Gemer Metalliferous Mountains. These bodies may represent apical parts, resp. apophyses of a single deep-seated intrusion (Plančár et al., 1977), or may be treated as independent bodies of various size and forming parts of the overthrusted nappe elements of the mountain (Grecula, 1975, 1982). According to this interpretation based on the complex geological-geophysical study of the eastern part of the mountain (Grecula and Kucharski, 1981, Grecula, 1982) the granitic bodies are distributed among several subordinate nappe units. The southern belt of granitoide rocks (Jedľovec nappe) represented by the Poproč granites sinks to the west (in the direction of Smolník, Štós and Úhorná) below the metamorphic series of the Early Paleozoic. The northern belt — Humel nappe (Humel, Zlatá Idka, Tinesova dolina) extends in the direction of Smolnícka Huta as far as to the Rožňava valley and Betliar range. The Holica, Prakovce, Stará Voda, Dlhá dolina, Podsúľová belt (Prakovce nappe) occupies the central part of the mountain. The northernmost belt (Kojšov nappe) along the line Gelnica, Mníšek nad Hnilcom, Švedlár, Delava and Hnilec is not so well disclosed in its eastern part, although a well known exposure of granites with accompanying tin mineralization reaches the surface in the Hnilec area. In the exposure of Medvedí potok (Baran et al., 1970) the granitic body has a SW—NE strike, in oblique direction to the lithological and tectonic orientation of the envelope. This fact could actually treated as speaking in favour of the idea of the granitic intrusion post-dating the main overthrust event. The idea of post-overthrust development of the Gemeride granites has been put forward by several geologists. Our detailed studies (Grecula, 1982) did not support this interpretation, being also in contradiction with both the Rb-Sr age data of the present paper and the K-Ar muscovite age data of Kantor and Rybár (1979). Recent results prove, that a clear distinction should be made between the formation of a primary folded-thrusted structure under amphibolite grade conditions with accompanying hydrothermal mineralization; and the main phase of overall nappe overthrust with the internal tectonic reworking of the individual nappe units in which different types of mineralization could be preserved or rejuvenated. The granites of the nappe units have been segmented into smaller, rootless bodies, which changed their position in space to a considerable extent during the main overthrust phase. According to this viewpoint, the present arrangement of granitic bodies within the individual nappe units does not correspond to a primary situation and the individual granites might represent quite different genetical or spatial varieties and types irrespective to their present position both vertically and horizontally.

The assumed tectonic position of the Gemeric granites sketched above explains in an appropriate way the considerable and often irregular changes in the geochemical, petrological and metallogenetical characteristics of the granites both along the main E—W arcuate strike and in the transverse N—S direction. The emplacement of granites might be contemporaneous, although the original space of 100 km order attributed to the area of Early Paleozoic sedimentation encompassing also the Gemeric granites allows for considerable petrological differences, as well as for variations in the time of melt generation and in consolidation/emplacement age for the S-type granites in different segments of the crust affected. The emplacement of granite bodies in the Late Permian was accompanied with their tectonic destruction, very often on a regional scale. The primary features of granites were destroyed during the Alpine overthrust events.

Interpretation of the results

The Rb-Sr geochronological data obtained on whole rock samples when compared with the present position of the granitic bodies in the different tectonic units of the mountain, point to the spatial displacement in the time of melt consolidation, resp. termination of development under hydrous, high-temperature conditions. The Hnilec granites in the northern granitic belt yield the highest isochron age of 290 ± 40 Ma. (Farther to the north, the Veporic granodiorites in the Čierna hora region show even older biotite ages up to 320 ± 20 Ma.) The more southern nappe units of the Gemericum encompass granites with continuously decreasing whole rock ages with the limiting value of 223 ± 32 Ma in the southernmost belt at Zlatá Idka. The time span of about 80 Ma thus obtained seems to be quite realistic over an extended (now considerably shortened) region and is comparable with results obtained under similar conditions in other areas (e. g. Tauson, 1978; Dallmeyer et al., 1982).

The isochron age of the Hnilec granite corresponds to the Late Carboniferous, the error limits extending into the Early Permian. The greisenized character of the granite (see the preceding section of the paper) however, makes it highly probable, that the primary emplacement of this body occurred somewhat earlier, i. e. definitely during the Late Carboniferous. Being the oldest age obtained up till now, it might be inferred that the magmatic development of the Gemeric granites started with this event, tentatively assigned to the Sudetic orogenic phase. The development of the granitic complex (s. s.) continued during the whole Permian up to the Permian/Triassic boundary as shown by the gradually changing total rock isochron ages (see Table 3).

It is tempting to bring into connection the observed time span with plate tectonic processes involving the collision of smaller continental blocks presumably having commenced at the Early/Late Paleozoic boundary in the development area of the Kojšov unit, which was connected with northernly situated areas with the ophiolitic complex in the Rakovec unit; (the Kojšov unit is northernmost nappe unit with the oldest granitoide rocks), and which processes expanded with a time delay into the more southerly region (Mníšek, Prakovce, Humel, Jedľovec and Medzev units) where granites with Permian model ages are to be found. The development of granitic melts in the subduction zone assumes the gradual melting of sediments, the thermodynamic conditions of the amphibolite facies and partial melting being reached first in the northern areas and only later in the more southern ones. The gradual shortening of the original sedimentary area might have resulted in the gradual sinking of the sedimentary column, the (partial) melting and consequently the emplacement of the granitic bodies thus being extended over a considerable time span. This possible interpretation is in accordance with the spatial distribution of the whole rock isochron ages, and might explain the differences in the ages of the individual granitic-granodioritic bodies of the mountain at least in a formal way.

The tentative interpretation sketched above, however, relies on the not necessarily realistic assumption, that the individual whole rock isochron ages give realistic estimates of the emplacement age(s) of the respective melts, emplacement following regularly the phases of melt production and segregation. The petrographical data of the samples (see the discussion of the results in the preceding section of the paper) strongly emphasise the effect of postmagmatic-deuteric alteration processes distinguishable from those connected with later hydrothermal, tectonic and tectono-magmatic effects affecting the individual bodies locally but not as a whole. Instead of interpreting the total rock isochron ages as the time of emplacement (favourizing temperature out of the thermodynamical parameters) it is possible to take the isochron ages as the time when the hydrous state of the respective granite body changed to a relatively dry one, i. e. to interpret the isochron age as the seizure of intensive, penetrative fluid circulation throughout the granitic mass causing large-scale isotopic equilibration. This possible interpretation emphasises the importance of the fluid phase in "starting the clock", instead of temperature-controlled (solid state) diffusion as in the classical interpretation schemes (see also e. g. Deutsch and Steiger, 1985).

Additional support to this interpretation is given by the conspicuous correlation of the isochron ages with the corresponding initial $^{87}Sr/^{86}Sr$ rations the younger model ages being associated with increased initial ratios (see Table 3).

TAB. 3

Compilation of Rb-Sr whole rock isochron data

Locality	Initial $^{87}Sr/^{86}Sr$ ratio	whole rock isochron age (Ma)
Hnilec	0.7119 ± 0.0181	290 ± 40
Betliar	0.7112 ± 0.0200	272 ± 47
Drilling SG-1	0.7193 ± 0.0076	246 ± 25
Drilling ID-2	0.7133 ± 0.0040	251 ± 16
Drilling ID-1	0.7279 ± 0.0103	223 ± 32
Dlhá dolina	0.7330 ± 0.0123	151 ± 14
	0.7204 ± 0.0053	146 ± 6
Podsúľová	0.7339 ± 0.0040	142 ± 6

The correlation between isochron model age and initial Sr isotopic ratio suggests a two-stage magmatic development, allowing an ample time span between melt generation resp. intrusion and the closure of the (local) Rb-Sr whole rock isotopic system. This concept favours the near-contemporaneous formation (and possibly also the deep-level intrusion) of the granitoide melts. The observed differences in the isochron ages should be attributed to the spatial non-uniformity in the behaviour of the post-intrusion alteration system allowing also differences in the timing of final emergence to shallow crustal levels of the different parts from the primary intrusion. Thus, according our view the polyphase character of the Gemeride granites can be brought into connection with a prolonged and in space segmented development of melts produced in the course of a single primary melt-forming process.

Whichever interpretation might be correct, the whole rock Rb-Sr isochron age data obtained in the course of the present study confines the primary development of the granites to the time period covering the Late Carboniferous and the entire Permian and closing near the Permian-Triassic boundary.

The next and definitely distinct period of tectonothermal activization — already stated on the Podsúľová granite in the earlier studies of the authors (Kovách et al., 1979) — seems to affect the different subordinate nappe units of the mountain in a quite uniform way. The timing of this event at about 140—150 Ma (Latest Jurassic) can be brought into connection with the onset of Alpine development, the phenomena observed in the Spiš-Gemer Metalliferous Mountains being necessarily of compressional character regarded as counterparts of tensional (ophiolitic) development in other parts of the Early Alpine orogene. This activization period is reflected in the Spiš-Gemer Metalliferous Mountains mainly by local effects: in preformed tectonic zones intensive retrograde and destructive activity caused local mylonitisation (Dlhá dolina) and rejuvenation of the protolith of granitic composition (Podsúľová). Besides the whole rock data, the latter statement is also supported by the SGR-6 biotite age of 142 ± 4 Ma obtained on a sample from the same drilling.

The importance of this second period of thermal activization is also shown as the upper limit of biotite K-Ar ages determined by Kantor and Rybár (1979), and in a tentative way, may be made responsible at least in parts for the lowering of muscovite K-Ar ages (Kantor and Rybár, 1979) determined in the Hnilec region with respect to the Rb-Sr whole rock isochron age determined for the same locality.

The third period of activization is clearly marked by the clustered biotite Rb-Sr ages around 100 Ma, being in excellent agreement with biotite K-Ar ages of Kantor and Rybár and other authors. This datum being in agreement with age values obtained over extended regions in the Austroalpine system, should be clearly interpreted as the time of Alpine nappe overthrust giving rise to the present shape and tectonic style of the mountain (Thöni, 1981).

Summary conclusions

Summarizing the main conclusions of the preceding discussion, the following scheme for the magmatic-metamorphic development of the Gemeric granites is proposed:

1. Variscan metamorphic events acting on to the sedimentary sequences of the mountain (not dealt with in the present paper);

2. Formation of granitic melts during the Late Carboniferous, orogenic-metamorphic events, with the emplacement of the first Gemeric granites accompanied also by ore mineralization;

3. Prolonged evolution of the granitic masses under hydrous conditions throughout the Permian with the seizure of deuteric alterations (postmagmatic alteration, cataclastic deformation, mylonitization and retrograde metamorphism) at different times in different parts of the granitic substrate during this period;

4. Reactivation of the area with local rejuvenation and hydrothermal activity in tectonically preformed zones during the Latest Jurassic;

5. Tectonic activity and low-grade meta-

morphism below 300 °C at the Early/Late Cretaceous boundary in connection with Alpine nappe overthrust;

6. Closing of the magmatic-metamorphic evolution during the Latest Cretaceous as shown by the minimum of K-Ar ages.

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Rb-Sr izotopické veky granitoidov Spišsko-gemerského rudohoria

Podrobné štúdium Rb-Sr izotopického veku sa realizovalo na celohorninových vzorkách a biotitoch odobraných z granitových telies gemerika.

Izochrónny vek sa stanovil z granitov týchto lokalít: Hnilec (290 ± 40 mil. r.), Zlatá Idka (251 ± 16 mil. r.), Zlatá Idka — Poproč (223 ± 32 mil. r.), Humel (270 ± 64 a 246 ± 25 mil. r.). Z granitového telesa Betliar sme nezískali izochrónny vek, ale distribúcia údajov v izochrónnom diagrame ukazuje na paleozoický vek vzniku granitu, ale so silným sekundárnym prepracovaním. Izochrónny vek hrubozrnných granitov z lokality Podsúľová (142 ± 6 mil. r.) a z greizenizovaných hornín v Dlhej doline (151 ± 14 a 146 ± 6 mil. r.) poukazuje na dôležité obdobie teplotnej a tektonickej aktivizácie vo vrchnej jure.

Rb-Sr vek biotitov (okolo 100 mil. r. s max. hodnotou 142 ± 4 mil. r.) možno spájať s tvorbou alpínskych príkrovov.

Získané izochrónne veky spolu s inými geologickými údajmi umožňujú pokúsiť sa o rekonštrukciu magmaticko-metamorfného vývoja gemerika: 1 — Variské metamorfné etapy sedimentárnych hornín sa pomocou nových geochronologických údajov nedajú presne stanoviť. 2 — Formovanie granitickej taveniny bolo počas vrchnokarbónskych orogénno-metamorfných udalostí s následným prvým rozmiestnením telies granitu, ako aj s vývojom rudnej mineralizácie. 3 — Počas permu vývoj granitovej taveniny pokračoval v oblastiach s vyšším stupňom metamorfózy pri dostatku vody. Lokálne boli aj intrúzie granitu, najmä v strednom a vrchnom perme, ako aj ďalšie zrudňovacie fázy. V tomto období sa v rozličných častiach paleozoických horninových sekvencií a v granite odohrali aj významné deuterické alterácie (napr. postmagmatické premeny, kataklastické deformácie, mylonitizácia, retrográdna metamorfóza). 4 — Vo vrchnej jure v tektonicky aktívnych zónach predpokladáme lokálnu rejuvenizáciu a hydrotermálnu aktivitu. 5 — Tektonickú aktivitu a nízky stupeň metamorfózy (pod 300 °C) v spojitosti s orogénno-metamorfnými udalosťami na hranici spodnej a vrchnej kriedy odvodzujeme najmä pomocou vekov získaných z biotitov granitu. 6 — Ukončenie magmaticko-metamorfného vývoja vo vrchnej kriede indikujú K-Ar veky.