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THE AGE OF THE MAGMATIC EVENTS AND EPITHERMAL Au-Ag-BASE METALS MINERALIZATION IN THE CENTRAL ZONE OF THE BANSKÁ ŠTIAVNICA STRATOVOLCANO: K/Ar DATA

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Abstract: The age of sericite from the epithermal Au-Ag-base metal mineralization of the Banská Štiavnica deposit was determined for the first time by the low-blank K/Ar method. Typical magmatic rocks of the central part of the Banská Štiavnica stratovolcano, which are associated with the ore mineralization were dated. The K/Ar ages of the older (II and III) and final (V) magmatic stages (granodiorite porphyry, quartz-diorite porphyry, biotite-amphibole andesite, rhyolite, perlite) lay in the narrow interval of values from 12.7 ± 0.4 to 11.4 ± 1.2 Ma. The age of the hydrothermal sericite according to isochron calculation is equal to 12.1 ± 0.2 Ma. These age values overlap if we take into account the analytical error margins. The proximity in age of all the magmatic events does not allow us to make age correlations of ore mineralization with specific magmatic complexes and formations. The time interval of the rock and Au-Ag-base metal mineralization formation in the central part of the Banská Štiavnica stratovolcano does not exceed 1-2 Ma and is similar to the time intervals for other comparable epithermal structures in the world, for example, Emperor (Tavua Caldera, Fiji), Sleeper (U.S.A) and others.

Key words: Slovakia, Banská Štiavnica-stratovolcano, epithermal mineralization, geochronology, K/Ar age.

Introduction

One of the basic questions in the study of the origin of the vein, epithermal mineralization of the Banská Štiavnica-Hodruša ore field in the last 30 years, was and still is the elucidation its relationship to the magmatic activity during the evolution of the central zone of the Banská Štiavnica stratovolcano. Geochronological study has a key importance for solving this problem. Although, numerous isotope data on the age of the magmatic rocks of the stratovolcano, above all by the K/Ar method and fission track method were already obtained (Bagdasaryan et al. 1968; Konečný et al. 1969; Repčok 1981), the determination of the age of the Au-Ag-base metal and other types of mineralization (e.g. Cu-porphyry, skarn, vein-impregnation and metasomatic) still only has a hypothetical character. It is based on the supposed connection of certain types of mineralization with magmatic rocks, which were subjected to the isotope dating (Burian et al. 1985; Štohl & Kaličiak 1989 etc.). Direct determination of the age of mineralization is still not known to us. The probable cause of this situation is the very infrequent occurrence in the ore mineral associations of such minerals as adular, micaceous minerals, which are appropriate for isotopic age determinations.

This work contributes to some extent to solving this problem. By find an adequate quantity of the admixture of sericite, chlorite and kaolinite in the fillings of the Terézia vein at Banská Štiavnica, and at the same time by use of the high sensitive K/Ar method, the first data on the age of Au-Ag-base metal mineralization were obtained. At the same time new data were obtained, on the dating of some important magmatic rocks of the central zone of the stratovolcano: granodiorite porphyry, quartz-diorite porphyry, biotite-amphibole andesite, rhyolite, perlite, olivine-pyroxene basalt.

Geology and hydrothermal mineralization

The Banská Štiavnica-Hodruša ore district is found in the central part of a polygenetic stratovolcano in the central Slovak neovolcanites. Paleozoic metamorphites, Mesozoic and Paleogene sediments form its pre-Tertiary basement. According to the latest ideas of Štohl et al. (1994), the stratovolcano represents an extensive area of volcanic structure over an area of about 1,000 km^2. The stratovolcano underwent a caldera stage, and finally uplift of the central zone, which today forms the geologically well defined Štiavnica horst (Fig. 1). Andesites (pyroxenic, amphibolic, biotitic) dominate in the composition, with a smaller amount of rhyolite and alkaline basalts from the final magmatic activity. Intrusive formations of varying composition (andesite, diorite, quartz-diorite and granodiorite porphyries, diorites and granodiorites) occur on the surface in the central zone and to a lesser extent in the proximal part. The central zone also includes extrusive formations (biotite-amphibole andesite) which surround the Banská Štiavnica horst like fingers. The multistage

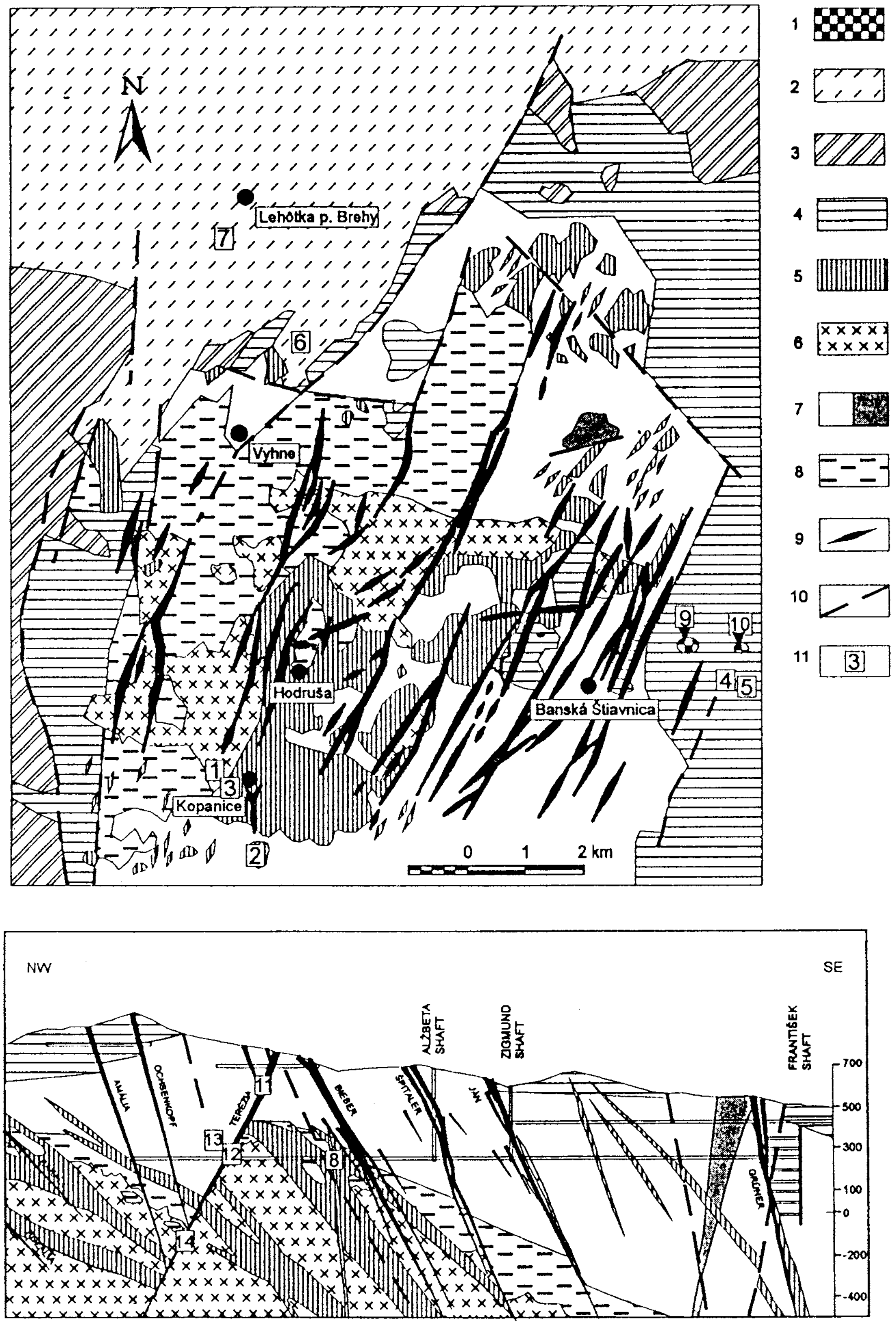

Fig. 1. Geological-structural scheme (a) and profil (b) of the Banská Štiavnica-Hodruša horst (according to Konečný & Lexa 1991). 1 - products of alkaline basalt volcanism; 2 - rhyolites of the Jastrabá Formation (5th stage); 3 - pyroxenic andesites of the 4th stage; 4 - biotite-amphibole andesites of the Studenec Formation (3rd stage); 5 - quartz diorite porphyries of the Banisko intrusive complex (3rd stage); 6 - diorite and granodiorite of the Banská Štiavnica-Hodruša intrusive complex (2nd stage); 7 - andesites and andesite porphyries of lower structure (1st stage); 8 - crystalline complex and sediments of prevolcanic basement undivided; 9 - significant veins; 10 - faults; 11 - location and number of samples.

metallogenesis of Pb, Zn, Cu, Au, Ag and Fe ores of various genetic types (skarn, Cu-porphyry, vein-impregnation, metasomatic, epithermal vein base- and precious metal), was associated in time and space with the development of the Banská Štiavnica stratovolcano complex. The central zone of the stratovolcano was the dominant area for ore mining, with the economically most important Banská Štiavnica-Hodruša ore field.

Analytical methods

The mass-spectrometric analytical complex, specially worked out for the analysis of very small quantities of argon was used for the K/Ar dating. It achieves high sensitivity and reliability in radiogenic ^{40}Ar content determination by complete hermetization of all high vacuum units of the mass-spectrometer and argon extraction system, with the use of a new low-blank furnace (Karpenko & Ivanenko 1993), and by the attainment of a static regime of measurements on the mass-spectrometer MI-1330. The method of isotope dilution with the monoisotope ^{38}Ar was used. The isotopic composition of argon after its extraction and spiking was measured with an automatized data processing system performed with the use of the IBM computer AT 286.

The level of ^{40}Ar background in the analytical system (extraction system + mass-spectrometer) varied in the range (6-8) × 10^{-3} ng, or (3-5) × 10^{-9} cm^3 in determination of the radiogenic argon contents ($^{40}Ar_{rad}$, see Tab. 2) from 0.36 to 8.60 ng/g, and the charges of samples 0.2-0.5 g. As a result the proportion of $^{40}Ar_{rad}$ in the total quantity of measured ^{40}Ar did not fall below 30 %, what is sufficiently high for reliable determination of the $^{40}Ar_{rad}$ content and for the K/Ar age calculations. The accuracy of the analyses were checked by periodical measurements of geochronological standard samples, as well as the isotopic composition of atmospheric argon. The content of potassium was determined by the flame-spectrometry method.

The errors of the $^{40}Ar_{rad}$ and the potassium determinations, exhibited in Tab. 2, correspond to 1σ interval whereas K/Ar age value errors are calculated as 2σ based on $^{40}Ar_{rad}$ and potassium determination errors. Both of these errors were individual for each sample. K/Ar isochrons were calculated according to D. York (1966) model.

The following constants were used for calculation of the age:

$\lambda_\beta = 4.962 \times 10^{-10}$ years^{-1}, $\lambda_\varepsilon = 0.581 \times 10^{-10}$ years^{-1},

^{40}K/K = 0.01167 at.%.

Description of the samples dated

As was mentioned above, the main aim of the work was to determine the age position of the epithermal vein Au-Ag-base ore mineralization, forming the most economically important mineralization of the central zone of the Banská Štiavnica stratovolcano. Therefore the authors attempted to obtain new supplementary data on the age of some magmatic rocks, especially those which are thought to have a time and genetic connection with the ore mineralization. Brief information about the studied samples is given in Tab. 1, and their sampling locations are indicated in Fig. 1. The petrological-stratigraphic position of the samples is given in accordance with the scheme of Burian et al. (1985).

According to the above mentioned scheme, the origin of the Fe, Ca-Mg and Cu-skarn mineralization is connected with granodiorites of the Banská Štiavnica-Hodruša intrusive complex (sample No. 1). The major vein Au-Ag-base metal mineralization is associated with granodiorite and diorite porphyry of the Banisko intrusive complex (samples Nos. 2, 3). The origin of the Au-Ag vein mineralization of the Kremnica type is connected with the rhyolite magmatism of the Vth stage (Jastrabá Formation, samples Nos. 6, 7, 8). The biotite-amphibole andesites of the Studenec Formation (samples Nos. 4, 5), the youngest alkaline basaltoids - olivine-pyroxene basalts (samples Nos. 9, 10) were also dated.

Samples with sericite from Au-Ag-base metal ore (Tab. 1, samples Nos. 11-14) which were appropriate for age determination by K/Ar method, were found at various horizons of the Terézia vein. The sericite fractions were separated routinely by sedimentation in distilled water. The grain size of the mineral fractions used for K/Ar dating was estimated by electron microscopy. It lies within the range between 2 and 8 μm for all samples studied. The control by X-ray difraction was performed for determination of sericite polytypic modification as well as for estimation of other mineral contents in the separated fractions.

The results of dating and discussion

The results of the K/Ar dating are given in Tab. 2. In evaluating their analytical reliability it is necessary to say that the content of radiogenic ^{40}Ar is higher than 30 % in all cases. In this way the admixture of non-radiogenic ^{40}Ar in samples, the main factor limiting the accuracy and reliability of K/Ar dating of young formations, is eliminated in these results. Even in samples with a very low content of potassium and $^{40}Ar_{rad}$ (for example in samples Nos. 5b, 5c), this value reaches 62-63 %. The errors, corresponding to ± 2σ are given in Tab. 2 beside the K/Ar age values.

A relatively narrow range of values is characteristic of the dates obtained for the set of samples as a whole and for individual formations. This is little unexpected when we take into account the previously determined K/Ar ages and also the data obtained by the fission track method (Bagdasaryan et al. 1968; Konečný et al. 1969; Štohl 1976; Repčok 1981; Burian et al. 1985 etc.).

An age of 12.6 Ma was determined for the granodiorite porphyry (Tab. 2, sample No. 1) of the second volcano-tectonic stage of the Banská Štiavnica-Hodruša intrusive complex. Close values (11.4 and 12.5 Ma), similar to the preceding value in their margins of error, were determined for the granodiorite porphyry (sample No. 2) and the quartz-diorite porphyry (sample No. 3) of the third volcano-tectonic stage. The value of 11.6 Ma, obtained for biotite-amphibole andesite (sample No. 4) of the Studenec Formation, is compatible with the above results. The origin of these rocks is connected with the third volcano-tectonic stage.

Data on the mono-mineral fractions separated from another andesite of the same kind (Tab. 2, Nos. 5a, 5b, 5c), showed clearly discordant K/Ar age values. The ages obtained from low potassium minerals - amphibole and plagioclase, have substantially higher values (14.8 and 15.8 Ma) than the age of biotite (12.7 Ma). The biotite is mineralogically fresh unchanged, characterized by a high, almost theoretical potassium content.

Such discordant K/Ar age values of minerals in the same rock allow us to assume the presence of radiogenic ^{40}Ar excess. This effect is not important for biotite, or for the rock as a whole, but its influence is substantial for the low potassium minerals with

Table 1: Location and brief characteristic of the samples colected for the K/Ar dating from the central zone of the Banská Štiavnica stratovolcano.

No.	Sample	Sample location and characteristic
1	Št-61/89	Granodiorite porphyry of the Štiavnica-Hodruša intrusive complex (II volcano-tectonic stage). Mineral composition (%): pl - 60, hb - 5, bt - 10, Kfs - 10, q - 15. Rock weakly chloritized, non-transparent plagioclase. Vlčia Hora (Kopanice), 20 m N of the TV-tower (rock outcrop on the ridge).
2	Št-57/89	Granodiorite porphyry of the Banisko intrusive complex (III volcano-tectonic stage). Mineral composition (%): pl - 70, hb - 5, bt - 3-5, Kfs - 10, q - 7-10. Insignificant signs of pyritization. Šementlov, elluvium on the slope E of the end of the Kalná Valley, 190 m in the direction 120° from the elevation point 687.
3	Št-60/89	Quartz-diorite porphyry of the Banisko intrusive complex (III volcano-tectonic stage). Mineral composition (%): pl - 60, hb - 20, px - 10, q - 3-5, mg - 5. The dark minerals are weakly pyritized. Kopanice, eastern edge of the village (rock outcrop in a road cutting).
4	Št-65/89	Biotite-amphibole andesite of the Studenec Formation (III volcano-tectonic stage). The content of the porphyry phenocrysts is 50 % on the average. Mineral composition of phenocrysts (%): pl - 60, hb - 20, bt - 10, mg - 10. The phenocrysts are unchanged, the matrix partly is composed of isotropic glass and partly (50 %) is nontransparent. Barlangie (Kysihýbel) quarry, 50 m NW of the asphalt road, 300 m in the direction 230° from the elevation point 608.
5	Št-83/91	Biotite-amphibole andesite (the locality and geological position as are in the case of the sample Št-65/89). The content of phenocrysts is 40 % on the average. Mineral composition of phenocrysts (%): pl - 62, hb - 18, bt - 18, opx - 2, q, mg - single grains. The phenocrysts are unchanged, the matrix is composed predominately of isotropic glass and in small proportion the matrix is micro-spherolitic.
6	V-7/91c	Rhyolite of the Jastrabá Formation (V volcano-tectonic stage). The content of phenocrysts is close to 35 %. Their mineral composition (%): q - 50, Kfs - 35, bt - 15. K-feldspar is predominately unchanged, however it contains plagioclase inclusion which are weakly substituted for sericite. Biotite is highly substituted for chlorite. The matrix is felsitic, unchanged. Vyhne, "Kamenné more".
7	L-8/91	Perlite of the Jastrabá Formation (V volcano-tectonic stage). The rock consits of volcanic glass (90 %) and of small size phenocrysts (10 %). The last represent euhedral crystals of plagioclase and biotite, which are fresh without signs of transformations. The matrix glass is homogenous and isotropic. Lehôtka pod Brehmi quarry.
8	Kl-1/91	"Rhyolitic vein" Klotilda of the Jastrabá Formation (V volcano-tectonic stage). The rock porphyritic texture is determined by phenocrysts of K-feldspar (15 %) sited in fine-graned matrix. The secondary rock alteration is traced by presence of pyrite (0.5-1 %). Banská Štiavnica, Nová šachta, 12th horizon.
9	Št-85/91B	Olivine-pyroxene basalt of the final volcano-tectonic stage. The rock consists of fine-grained matrix (55 %) and phenocrysts (45 %). Mineral composition of phenocrysts (%): ol - 22, cpx - 67, pl - 11. Quite visible amounts (1-2 %) of fine-grained biotite and K-feldspar occur along cracks and edges of phenocrysts. The rock is fresh, unaltered. Banská Štiavnica, Kalvária.
10	Št-84/91	Olivine-pyroxene basalt of the final volcano-tectonic stage. The rock texture and the ratio of matrix to phenocrysts as are in the case of Kl-1/91. Mineral composition of phenocrysts (%): ol - 7, cpx - 28, pl - 65. Olivine is partly cracked and altered. Another components of the rock are fresh. Kysihýbel, quarry near Banský Studenec railway station.
11	Te-I-10a	Sericite from Au-Ag-base metal ore, 4th mineralization period. Sericite associated with galena and sphalerite take part in fillings of hollows in porous quartz. It is represented by polytype 1M. Sericite content in the concentrate prepared is about 95 %. Banská Štiavnica, Nová šachta, Terézia vein, 1st horizon, 5 m north of Mb. 8.
12	Te-IX-9b	Sericite from Au-Ag-base metal ore, 4th mineralization period. Sericite forms edge zones around chalcopyrite-galena-sphalerite aggregates. It is represented by polytype 1M. The concentrate prepared contains about 90 % of sericite, the admixture is defined as quartz and kaolinite. Banská Štiavnica, Nová šachta, Terézia-vein, 9th horizon Mi-T-5a block.
13	Te-IX-10	Sericite from Au-Ag-base metal ore, 4th mineralization period. Sericite associated with quartz occurs in ore breccia cement. It consists of polytype 1M with minor admixture of polytype 2M1. The concentrate prepared contains 20-25 % of sericite, the remainder is quartz. Banská Štiavnica, Nová šachta, Terézia vein, 9th horizon, southern part of the Mi-T-25c block, KT-161 chimney.
14	Hbo-V-1	Sericite from Au-Ag-base metal ore, 4th mineralization period. Sericite enter into the composition of sphalerite-galena-carbonate veinlet, is represented by polytype 1M. Sericite content in the concentrate prepared is 60-70 %, the remainder is chlorite. Banská Štiavnica, Nová šachta, Terézia-vein, 5th deep horizon.

a low content of their own radiogenic argon. The age data obtained can be corrected by data processing from above three minerals of the andesite, using an isochron diagram with the coordinates $^{40}K/^{36}Ar$ - $^{40}Ar/^{36}Ar$ (Fig. 2). This calculation yields an age value of 12.4 ± 0.2 Ma, at an initial value $^{40}Ar/^{36}Ar$ = 397 ± 50 Ma. This figure is more than 1.3 time higher than the usual atmospheric value of the ratio of $^{40}Ar/^{36}Ar$. The excess of the radiogenic ^{40}Ar in the andesite studied is most likely to be captured by the rock-forming minerals from magma during the crystallization process. The age value of biotite-amphibole andesite from the Barlangie quarry, obtained from the K/Ar isochron, seems to be trust worthy.

Among the dated samples from the Jastrabá Rhyolite Formation (fifth volcano-tectonic stage), the most reliable K/Ar age value was obtained from fresh well preserved biotite from perlite in the quarry at Lehôtka pod Brehmi (sample No. 7b): 12.7 Ma. The value of 11.4 Ma for the same sample, obtained from glass with clear signs of hydratation (sample No. 7a) is somewhat lower, as for biotite. This is probably connected with an insignificant loss of argon from the glass during hydratation.

Table 2: K/Ar isotope data from some rocks and minerals of the Banská Štiavnica stratovolcano.

No.	Sample	Rock	Material	K (%)	^{40}Ar$_{rad}$^{1} (ng/g)	^{40}Ar$_{rad}$^{1} (%)	Age ±2σ (Ma)	Isochron age calculated ±2σ (Ma)
1	Št-61/89	granodiorite porphyry	WR	3.30±0.04	2.90±0.07	47	12.6±0.8	
2	Št-57/89	granodiorite porphyry	WR	1.81±0.03	1.43±0.07	32	11.4±1.2	
3	Št-60/89	quartz-diorite porphyry	WR	1.83±0.03	1.59±0.03	53	12.5±0.6	
4	Št-65/89	biotite-amphibole andesite	WR	2.12±0.04	1.71±0.09	31	11.6±1.2	
5a	Št-83/91	"	biotite	7.23±0.04	6.38±0.08	88	12.7±0.4	12.4±0.2
5b	Št-83/91	"	amphibole	0.58±0.02	0.597±0.009	63	14.8±1.2	from samples
5c	Št-83/91	"	plagioclase	0.33±0.02	0.365±0.006	62	15.8±2.0	5a, 5b, 5c (see Fig. 2)
6	V-7/91c	rhyolite	K-feldspar	9.42±0.04	7.61±0.09	93	11.6±0.3	
7a	L-8/91	perlite	glass	4.33±0.04	3.42±0.05	71	11.4±0.4	
7b	L-8/91	"	biotite	7.01±0.04	6.18±0.08	79	12.7±0.4	
8	Kl-1/91	rhyolite	K-feldspar	11.00±0.04	8.69±0.11	83	11.4±0.3	
9	Št-85/91B	olivine-pyroxene basalt	WR	1.04±0.03	0.414±0.008	37	5.7±0.4	
10	Št-84/91	olivine-pyroxene basalt	WR	1.25±0.03	0.679±0.01	63	7.8±0.4	
11	Te-I-10a	Au-Ag-base metal ore	sericite	6.62±0.04	5.67±0.07	79	12.3±0.4	12.1±0.2
12	Te-IX-9b	"	sericite	5.98±0.04	5.05±0.08	67	12.1±0.2	from samples
13	Te-IX-10	"	sericite	1.43±0.03	1.31±0.02	57	13.2±0.8	11–14
14	Hbo-V-1	"	sericite	4.44±0.04	4.12±0.07	51	13.3±0.6	(see Fig. 3)

^{1},- radiogen ^{40}Ar, WR - whole rock samples

Almost equal age values (within the range of analytical error): 11.6 Ma from rhyolites of the Kamenné More near Vyhne (sample No. 6) and 11.4 Ma from the rhyolite of the Klotilda dyke in Banská Štiavnica (sample No. 8), were obtained for the fraction of K-feldspars from two other samples of the Jastrabá Rhyolite Formation.

The K/Ar data from the alkaline basaltoids (samples Nos. 9, 10) comprise 5.7 Ma (Kalvária in Banská Štiavnica) and 7.8 Ma (Kysihýbel), which agrees with the older published age values (Kantor & Wiegerová in Repčok 1981; Balogh et al. 1981). The origin of these rocks is substantially distant in time from the formation of the Banská Štiavnica stratovolcano, and represents an independent stage of magmatism.

On the basis of the K/Ar age values from typical rocks of the magmatic activity of the central zone of the Banská Štiavnica stratovolcano, we came to the conclusion that various magmatic formations were formed during a very short time interval. This interval, on the basis of the obtained marginal K/Ar age values, is formally determined at 11.4 to 12.7 Ma. Some of these K/Ar dates, obtained from K-feldspar and whole rock samples, may be slightly "younger" as a results of the frequently observed losses of argon in K-feldspars, and in accordance with the poorer tolerance of their K/Ar isotope system in comparison with micas (biotite). Therefore the probable age interval of the origin of the magmatic complexes of the second to fifth volcano-tectonic stages is even narrower, at 12 to 13 Ma. In every case the studied period of the magmatic activity, corresponds in age to the Early to Middle Sarmatian.

Let us take up the findings for isotopic dating of Banská Štiavnica epithermal mineralization which seem to be the most important in the present paper. The dated sericite is part of the hydrothermal mineral associations which represent the 4th (major) period of Au-Ag-base metal ore formation. As can be seen from Tab. 1 the samples studied represent 3 vertical levels (upper, middle and lower) of the ore mineralization in the central part of the Terézia vein system, the length of which exceeds 7 km. The sericite has common to all four samples structural polytype 1M, whereas the admixture of other minerals (quartz, kaolinite and chlorite) is variable. Considering that these minerals practically don't contain potassium it is believed that the dopants have not the influence on balance and behaviour of radiogenic ^{40}Ar.

The dispersion of the individual age values (12.1, 12.3, 13.2 and 13.3 Ma), which have been obtained for sericite samples (Tab. 2) somewhat exceeds the variation level which is determined by the analytical errors. The isochron calculation of K/Ar data for sericite was done on the assumption that the additional dispersion (as in the case of above discussed andesite sample Št-83/91) is due to initial capture of the argon having ^{40}Ar/^{36}Ar anomalous value. The data obtained, 12.1±0.2 Ma is a likely age of epithermal mineralization (Fig. 3). This data will most probably be time-averaged value while the duration of ore-forming processes within Banská Štiavnica deposit is liable to reach 1-1.5 Ma. Firstly, it is not inconceivable that the dispersion of the K/Ar age values obtained for individual sericite samples reflects in part the lenght of the mineralization processes of the Terézia vein. Secondly, the total duration of the ore-forming process within the Banská Štiavnica deposit as a whole must have been longer than the mineralization period within one ore body, even a very significant one.

When we take into account the real variability of the obtained K/Ar dates and the margins of analytical errors, we see that the age intervals of the display of Au-Ag-base metal epithermal mineralization and the magmatic activity in the central zone of the Banská Štiavnica stratovolcano overlap. This does not allow us to clarify a more detailed age correlation between the origin of the

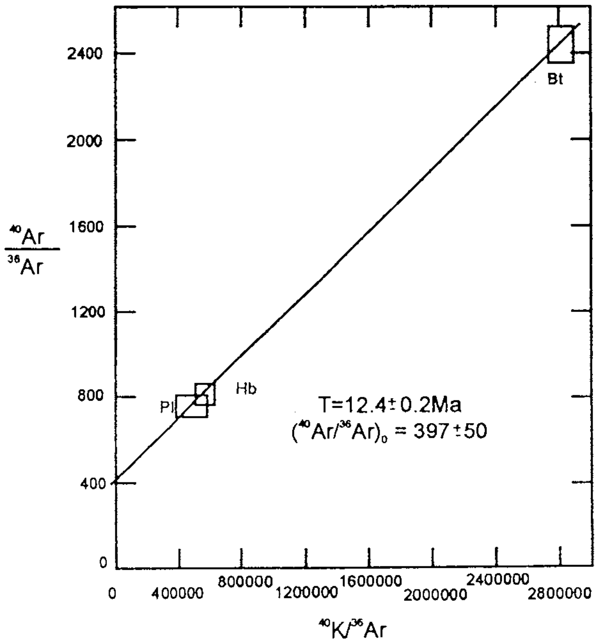

Fig. 2. K/Ar isochron diagram with data points of mineral fractions (biotite - **Bt**, amphibole - **Hb**, plagioclase - **Pl**) from the biotite-amphibole andesite Št-83/91. Central zone of the Banská Štiavnica stratovolcano. The box sizes correspond to 2σ-error limits.

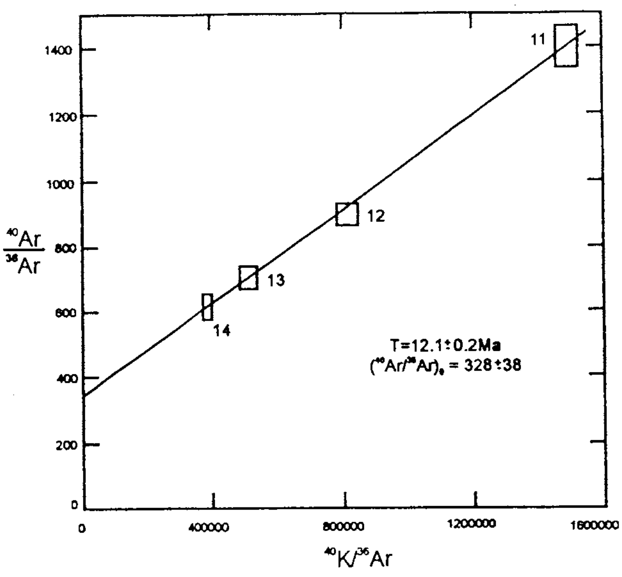

Fig. 3. K/Ar isochron diagram with data points of 4 sericite samples from the Au-Ag-base metal epithermal ores of the Banská Štiavnica deposit, Terézia-vein. The box sizes correspond to 2σ-error limits.

epithermal ore mineralization and any specific impulse of the magmatic activity during the development of the stratovolcano.

It is known that there are problems with precise isotopic dating of Neogene magmatic and hydrothermal complexes. Nevertheless, in recent years some works have appeared giving results which allow us to assess the age and the length of spatially associated magmatic and ore-forming processes during the activity of individual magmatogene-hydrothermal systems. Thus, according to the data of Setterfield et al. (1992), the magmatic and associated hydrothermal activity in the Tavua Caldera on Fiji, during which the large epithermal Emperor Au-telluride ore body originated, lasted from 4.7 to 3.7 Ma, that is 1 Ma. A somewhat longer interval (from 16.5 to 14.1 Ma) has been fixed for the origin of the rhyolite dome and the associated origin of the rich Au-adular-quartz-epithermal ore body Sleeper (U.S.A.), with amounts of gold greater than 100 tons (Conrad et al. 1993). Similar geochronological characteristics were also found for other epithermal precious metal ore bodies (Silberman et al. 1972; Ashley & Silberman 1976). Therefore the duration of ore-forming processes, its estimation based on the isotopic studies of Tertiary complexes can be given as a range of values from 0.5 to 1.5 Ma (Silberman 1985).

It can be seen from this, that the geochronological characteristics determined by us for the area of the central zone of the Banská Štiavnica stratovolcano are also typical for similar ore bodies elsewhere in the world.

We are trying to explain some difference between the newly obtained geochronological data from the central zone of the Banská Štiavnica stratovolcano, and older published data. The know geochronological schemes for the origin of the Banská Štiavnica stratovolcano (Štohl 1976; Burian et al. 1985) are based on data from K/Ar dating, obtained mainly by G.P. Bagdasaryan (Bagdasaryan et al. 1968; Konečný et al. 1969) and data obtained by Repčok (1981) by the fission track method. In the last general work (Burian et al. 1985) the evolutionary scheme of the magmatic complexes contains the following age boundaries: rocks of the initial (I) stage of development of the stratovolcano - 16.2 Ma, granodiorites of the Štiavnica-Hodruša intrusive complex (II stage) - 17.0 ± 0.5 and 17.2 ± 1.5 Ma, andesites of the Studenec Formation (III stage) - from 15.0 ± 1.2 to 16.4 ± 1.4 Ma. Štohl (1976) and Repčok (1981) give very close values for the age of these, and also other complexes of rocks of older stages of magmatism. Data for the age of rocks of the rhyolite formation (V stage), given by the above mentioned authors, vary from 10.8 to 12.4 Ma. It follows from this that the dating of the rocks of the rhyolite formation, given in the present work, and older published data are in agreement. But, at the same time, the data obtained by us for the older stages of magmatism, and the evaluation of the length of development of the stratovolcano following from them, are significantly different from the older published data. In our view this may have various causes.

The first cause of this discrepancy is methodological in character. It is related to the fact that the most of K/Ar data of rocks from Central and Eastern Slovakia previously (more than 25 years ago) published (Bagdasaryan et al. 1968; Konečný et al. 1969) were obtained with the so-called volumetric method of radiogenic argon determination. This method possessed a big and disregarded analytical error, especially in the case of young Kz-Mz rocks study, and has long been replaced by the more precise and sensitive isotope dilution technique. The above-mentioned previous K/Ar datings now represent the historical interest and, as we reason, they may not be discussed in the context of the modern precise results.

Another possible cause of the age values contradiction observed has a geological meaning. The "cooling" ages problem (see, for example, Dodson 1979; Jäger 1979) is topical undoubtedly in geochronological studies of the Banská Štiavnica stratovolcano as is conditioned by a probable thermal impact of the younger magmatic complexes on the older ones. In the strict sense, the K/Ar age values obtained represent "cooling" ages. That is they signify the points in time at which the cooling rocks (or minerals) had reached the "closure" temperature at which the rocks (minerals) dated start to retain their radiogenic ^{40}Ar. In interpretation of the K/Ar age data obtained for the Banská Štiavnica stratovolcano we took into account high enough "closure" temperatures of biotite and potassium feldspars (respectively 310-250 °C and 350-280 °C, Dodson 1979) as well as the supercrust character of the rocks suggesting their increased cooling rates. One cannot exclude the processes of the K/Ar age rejuvenation in the Banská Štiavnica stratovolcano rocks. For example, the older rocks within some local areas might be episodically reheated during the generation of the younger rhyolite formation.

If widespread K/Ar rejuvenation of the rocks in the Banská Štiavnica stratovolcano occurred, it clearly would not be possible to determine ages older than 12-13 Ma with the FT-method. This is because the temperature for annealing of fission tracks from uranium in crystalline lattice of minerals (apatite - 100-110 °C, amphibole - 150 °C, phlogopite - 130 °C, see Faure 1986) is substantially lower than the temperature for the radiogenic ^{40}Ar loss from the dated minerals. However, a large body od FT-age values have been obtained over a range of 13-17 Ma (Repčok 1981), which significantly exceeds the age of the younger rhyolite formation. One more possibility should be recognized: the rocks attributed to definite older stages of magmatism within the Banská Štiavnica stratovolcano are probably heterogenous and of different age. As this took place, the differences in the obtained age data (i.e. K/Ar versus FT) may also be the result of unrepresentative sampling.

From the foregoing discussion it is seen that the K/Ar data on the later rhyolite formation may be considered as reliable in a sense of correspondence with the real age of rocks. This age practically coinsides with the age of epithermal ore mineralization. As for the initial magmatic formations of the Banská Štiavnica stratovolcano, their further more detailed geochronological study should be done with regard to the key importance of the Banská Štiavnica stratovolcano complex and its metallogenesis. In any case this further study must be called on to attract more detailed sampling for K/Ar dating as well as to employ other methods in parallel. True, such methods are limited in number owing to the young age of the Banská Štiavnica stratovolcano. The Rb-Sr method could be put to use in some favourable cases, such as biotites with a high Rb/Sr ratio. In this connection the ^{39}Ar-^{40}Ar method usage is clearly the most promising, insofar as this technique can provide the information relating to the behaviour of the K/Ar system in the rocks and minerals dated.

Conclusions

1 - The collection of rocks dated represent the greater part of magmatic events (II-V stages) which formed the central part of the Banská Štiavnica stratovolcano. The K/Ar datings of the magmatic events fit in the narrow range of values 12.7 to 11.4 Ma. The probable interval of manifestation of these magmatic stages when taken into account the most reliable data may be determined as 13-12 Ma age.

2 - The time proximity of the later V magmatic stage (the rhyolite formation) and the epithermal Au-Ag-base metal mineralization (12.1 ± 0.2 Ma) is evident enough. Thus the time interval of the rock and metal mineralization formation in the central part of the Banská Štiavnica stratovolcano with consideration of the analytical uncertanties does not exceed 1-2 Ma. It is similar to the time intervals for some known comparable epithermal systems in the world.

3 - The K/Ar "rejuvenation" of the older rocks in the local areas of the Banská Štiavnica stratovolcano is not excluded. A thermal impact by younger magmatic events in principle may be responsible for such phenomena. To test this hypothesis and refine the age of initial magmatic events of Banská Štiavnica stratovolcano a new set of petrological and isotopic studies should be carried out.

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