GEOLOGICA CARPATHICA, 42, 2, BRATISLAVA, APRIL 1991,

77–83

PETROGENESIS AND AGE DETERMINATION OF THE HODRUŠA GRANODIORITE (HODRUŠA HÁMRE, ŠTIAVNICKÉ VRCHY MTS., CZECHO-SLOVAKIA)

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(Manuscript received May 7, 1990; accepted in revised form September 7, 1990)

Abstract: The paper describes the results of radiometric dating of the Hodruša granodiorite by various methods (K/Ar, Rb/Sr and U/Pb). Zircons within the granodiorite exhibit ages that are greater than those obtained for the host rock, suggesting that they formed prior to the solidification of the granodiorite. On the basis of the radiogenic Pb^{207}/Pb^{206} atomic ratio, it is possible to estimate that the zircons of the Hodruša granodiorite were formed between Carboniferous and Permian ages. During the period between 21 and 24 m.y. the zircons lost much of their radiogenic lead as a result of partial melting of the surrounding host rock. Radiometric measurements of Rb/Sr isotopes also indicate a Neogene age for the granodiorite. It appears that assimilation of magmatite which is closely related to the monzodiorite-gabbro country rock, or which occurs as xenoliths within the granodiorite body, played very important role.

Key words: zircon morphometry, granodiorite of Neogene age (K/Ar, Rb/Sr, U/Pb), Štiavnické Vrchy Mts., Czecho-Slovakia.

Introduction

The Štiavnické vrchy Mts. comprise volcanics which are considered to be the products of Tertiary tectomagmatic activity within the West Carpathian and Panonian Massif (Fusán et al., 1987). In the area occupied by the Banská Štiavnica, Hodruša, Vyhne and Sklené Teplice settlements, within the larger region consisting of the young volcanic rock we find a surface elevation of pre-Neogene basement (Fig. 1). The core of this elevation comprises the Hodruša granodiorite which is roughly circular in shape, measuring 10 × 8 km. Around its periphery it is possible to find bodies of monzodioritic rock which have variable compositions (quartz diorite, diorite, gabbrodiorite, gabbro). The granodiorite itself consists of oval-shaped xenoliths that are dioritic in composition. The granodiorite body as well as the bodies of the dioritic rock are cross-cut by numerous younger aplitic vein-dykes and by quartz diorite veins. This intrusive complex is usually referred to as the Hodruša intrusive complex (Rozložník and Šalát, 1979) and is the host to the Banská Štiavnica ore district which is famous for its precious metals and polymetallic ores, its position and its petrology. Consequently, the Hodruša intrusive complex has stimulated great geological interest over the past years. Rozložník carried out an investigation of its position (Rozložník in Fusán et al., 1987), whereas Šalát (1954), Rozložník (1979), Lexa (1968) and Šulgan (1987), amongst others studied the petrology of the Hodruša granodiorite and of other parts of the Hodruša complex were investigated by Rozložník, Jakabská and Timčák (1982), Rajnoha (1987) and Jakabská (1990). Other authors concentrated on the metallogenesis of the orebody: Rozložník and Zábranský (1971), Burian et al. (1985).

Two contradictory theories exist regarding the geological location of the Hodruša granodiorite and of the dioritic rocks. The first theory, proposed by Rozložník and Šalát (1979), attest to the geochemical differences between the various intrusions to suggest that they post-date the volcanic complex itself, similar to the Romanian banatites. The second theory (Konečný, 1970; Burian et al., 1985) uses the K/Ar age determination (20–10 m. y.) of the granodiorite in order to postulate that the granodiorite is genetically and temporaly related to the surficial Neogene volcanics.

The Hodruša granodiorite is very important when considering the genesis of the Neogene volcanism as well as the associated metallogenesis. For this reason, we have attempted to use zircons in order to determine the petrology of the Hodruša granodiorite (Jakabská, 1990) and we have also presented the results of radiometric measurements carried

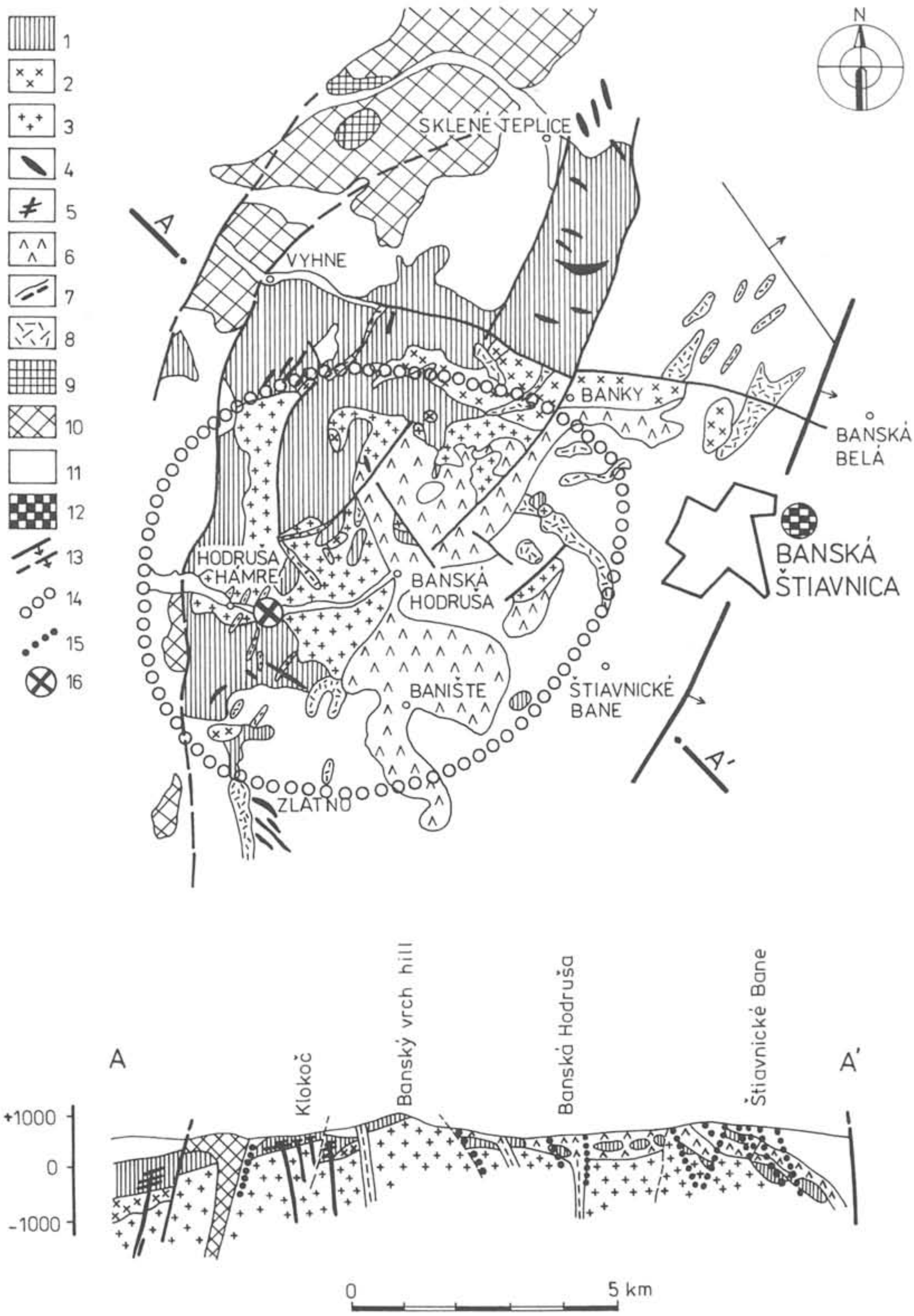

Fig. 1. Geological map of the Banská Štiavnica district. (according Rozložník, 1988).
1 – rocks of pre-Neogene basement; 2 – diorite-gabbrodiorite; 3 – granodiorite; 4 – granodioriteporphyry; 5 – skarns (in geological profile only); 6 – quartz dioriteporphyry (-sills, lacolites); 7 – quartz dioriteporphyry (dykes); 8 – quartz dioriteporphyry (thick dykes). (2–8 Hodruša intrusive complexe – Neogene); 9 – Hliník rhyolites (Sarmatian); 10 – Kremnica rhyolites (Sarmatian); 11 – andesites – undivided (Badenian–Sarmatian); 12 – basanites (Panonian); 13 – faults; 14 – contours of Hodruša intrusive complex on the depth-level 0 m; 15 – ore vein (in geological profile only); 16 – locality "Kukel" – place of granodiorite sample for radiometric investigations.

out, using various methods, on samples of granodiorite obtained from Kukel which is situated in the village of Hodruša Hámre.

Petrographic characteristics of the granodiorite sample

Within the Hodruša granodiorite there is a gradual transition from granodiorite through tonalite to quartzdiorite. The sample which was used for radiometric dating was found to comprise substantial amounts of tonalite substituting for granodiorite.

Macroscopically, the sample exhibits a granular texture (grain size 2–5 mm) and comprises essentially feldspar, which is pink in colour, plagioclase, which is beige, quartz, greenish-black hornblende and biotite. In thin section, the rock is seen to consist of 41.9 % plagioclase (often zonal, centrally located labradorite surrounded by albite and oligoclase), 15 % quenched orthoclase, 21 % quartz, 10.4 % biotite, 9.2 % amphibole and accessory amounts of titanite, pyroxene, zircon, garnet and ore minerals. Biotite and amphibole often display alteration to an assemblage of secondary minerals constituting of chlorite, epidote, zoizite, carbonate and sulphides.

From the chemical composition of this sample (61.01 % SiO_2, 0.52 % TiO_2, 17.75 % Al_2O_3, 3.10 % Fe_2O_3, 3.60 % FeO, 0.09 % MnO, 1.94 % MgO, 5.70 % CaO, 2.31 % Na_2O, 2.62 % K_2O, 0.17 % P_2O_5, 0.96 % H_2O^+, 0.13 % H_2O^-) it can be seen that the rock-type is more dioritic-to-tonalitic in character. The sample contained more FeO, Fe_2O_3, MgO and CaO and less SiO_2 than is commonly found in granodiorites. Higher K_2O and Na_2O contents are not typical of either a granodiorite or a tonalite. The sample is also relatively enriched in trace elements (in ppm: Cr-40, Co-20, V-100, Cu-50, with high amounts of Ba-900, Sr-500, Rb-175, Ce-82, Li-15, Y-20, K/Rb = 149). This suggests that the parent magma may have been of the shoshonite type.

Zircons are comparatively abundant in the granodiorite and are usually associated with the dark components. These zircons exhibit a lenght (width ratio of between 2–3), and are light pink in colour. Larger particles do however have a darker pink colouration. According to Pupin's (1976, 1980) morphology classification (Figs. 2, 3) the zircons can be classified as S_{22}, S_{23} and S_{24} types, with the type S_{23} being the most

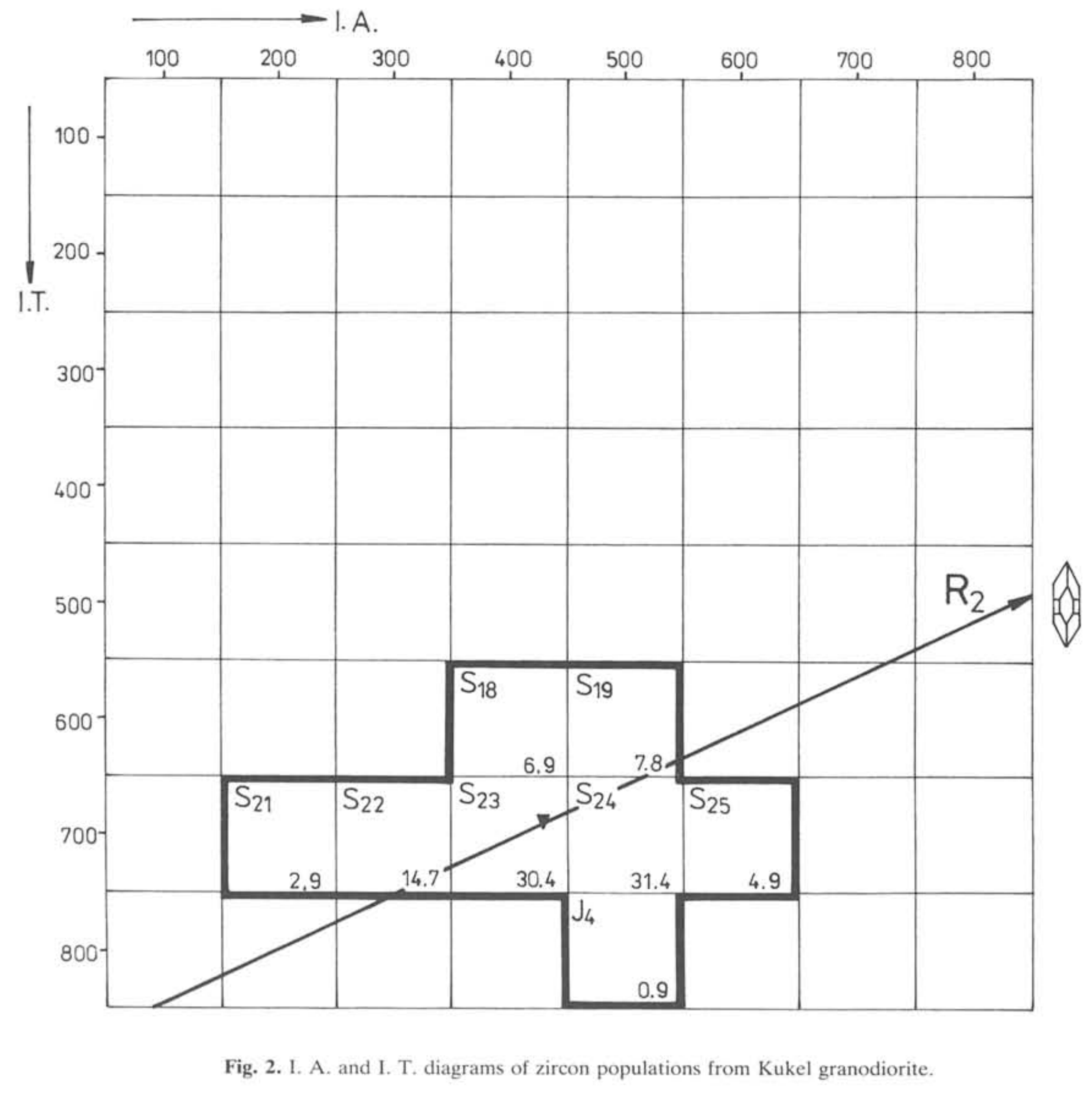

Fig. 2. I. A. and I. T. diagrams of zircon populations from Kukel granodiorite.

abundant (Jakabská, 1990). Types *J* and *D* are very scarce. It must be pointed out that type *D* zircons are typical of dioritic rocks which originate in the mantle. Temperature of crystallization of zircons is high, approximately 850 °C. In general, the morphological properties of zircons in terms of Pupin's classification (1980) (Fig. 3) correspond to a trachyandesite environment, however, this is considerably more basic (alkaline) than is their present host rock, granodiorite. Zircon chemistry (Tab. 1) does not correspond to an alkaline environment of crystallization as the Zr/Hf ratio varries between 45 and 46, whereas in an alkaline rock this ratio is normally double or even higher.

The granodiorites contain zircons corresponding to a more alkaline and more basic trachyandesitic magma. The dioritic rocks of the Hodruša intrusive complex contain zircons that correspond to an alkaline, basaltic magma originating in the mantle (Jakabská, 1990). As has already been pointed out, it is interesting to note that the diorites or diorites and granodiorites contain zircons of the same type *D*.

Granodioritic and the dioritic rocks are the only members of the Hodruša intrusive complex that exhibit a common origin which is manifested in the alkaline trend of their respective magmas. This conclusion can also be derived, not only from the morphology of the zircons contained therein, but also from the geochemical characteristic (Rozložník and Šalát, 1979).

Results of radiometric investigation

The age of the granodiorite from Hodruša-Hámre (Kukel) was determined by K/Ar, FT, Rb/Sr and U/Pb methods.

K/Ar method

It was used in the Laboratory of the Geological Faculty of the University of I. Frank in Lvov (Merlich, 1966, personal communication) provides an age of 16.9 ± 3.0 m.y. for the granodiorite from "Kukel". The age of granodiorites from other localities within the area of Banská Štiavnica-Hodruša, as determined by K/Ar method were found to be between 19.5 and 10.5 m.y. old (Konečný et al., 1983). This variation

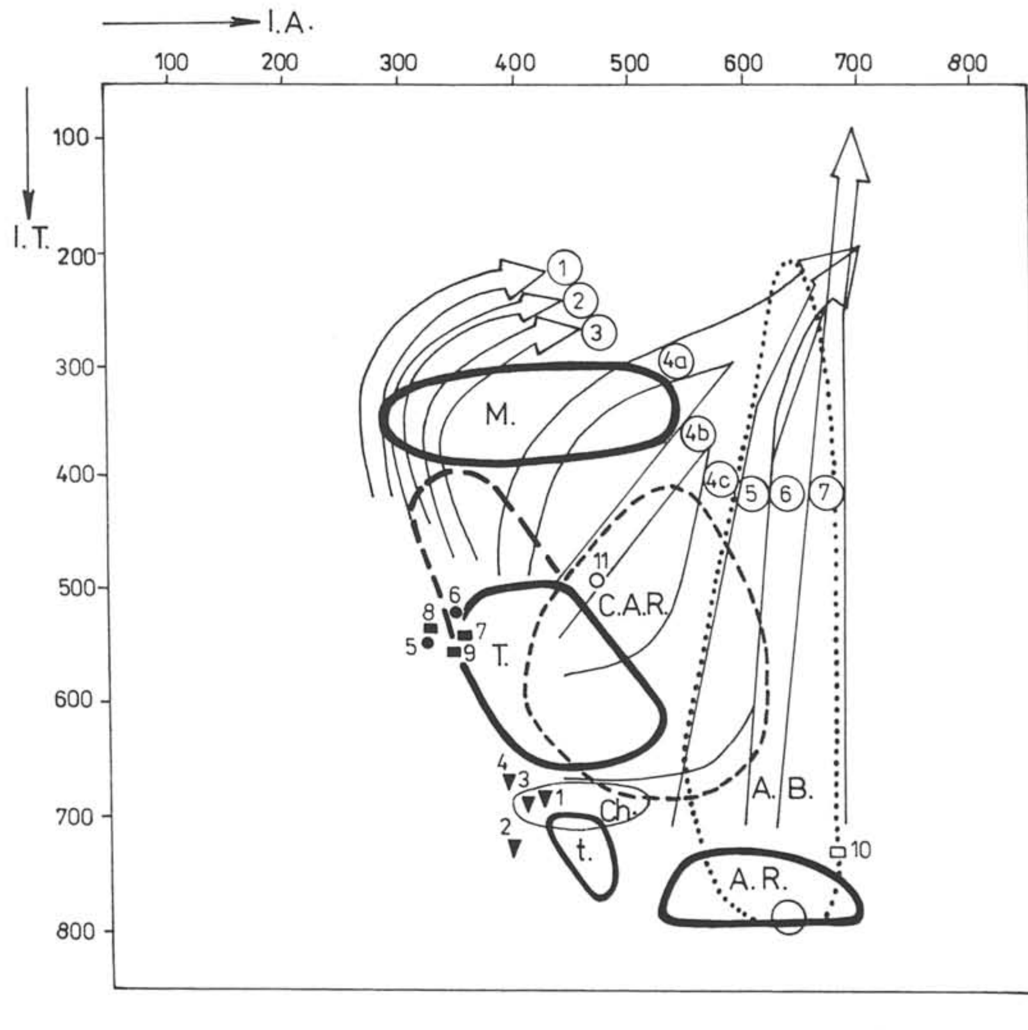

Fig. 3. Evolution trends of some non granitic groups of endogenous rocks (Pupin, 1980).
A. B. – alkaline basalts with gem quality zircons; A. R. – alkaline series rhyolites from anorogenic complexes; C. A. R. – calcalkaline series rhyolites orogenic complexes, M. – migmatites; t – trachyandesites; T. – tonalites. Sample numbers: 1–4 – granodiorite; 5–6 – quartz dioriteporphyry; 7–9 – granodioriteporphyry; 10 – diorite; 11 – graniteporphyry.

Table 1. Average electron microprobe analysis data for the investigated zircon.

Oxides	Al_2O_3	ZrO_2	HfO_2	La_2O_3	MgO	Ce_2O_3	Y_2O_3	FeO	SiO_2	CaO	ThO_2	Σ
Spec. No_1	0.0003⁺	65.953	1.261	0.002	0.016	0.112	0.072	0.010	34.453	0.004	0.005	101.896

Elements	Zr	Hf	Y	Ce	La	Th	Zr/Hf	ZrO_2/HfO_2	I. A.	I. T.
Spec. No 1	48.825	1.079	0.028	0.048	0.0008⁺	0.004	45.25	51.97	429.40	686.27

⁺ Data below the detection limit of the microprobe. Note: The limits of reliable detection is the second place after the decimal point. According to the Data Comission for geological materials of the Geological Institute of the Slovak Academy of Sciences, analyses with data sum between 95 and 105 % can be taken into consideration provided they are not improportionate with the exact analyses. The analyses were done at the Laboratory for Electron Microanalysis of the D. Štúr Geological Institute Bratislava. Analyses have been curried out an JEOL SUPER PROBE 733.

NAA data on the investigated zircon

Elements (ppm)	Se	Fe %	Co	Zn	Zr %	La	Ce	Nd	Sm	Eu	Tb	Tm	Yb	Lu	Hf	Th	U	Ta
Spec. No 1	55	0.21	1.2	65	43.7	30.0	120	<350	30.0	0.84	4.3	<30.0	220	45.4	9500	210	270	2.1

Analyzed at the Training reactor of the Technical University Budapest, Hungary.
The conditions of analysis were the same as or given an Abdel Wahab H. S. (1977).

may be due to the repeated heating of the granodiorite body and to the intrusion of younger porphyry and aplite dykes.

Fission track method

Repčok (1981) determined a similar age of 17.2 ± 1.5 m.y. by FT method using granodiorite amphiboles taken from the same locality. Biotite from the same area was found to be considerably younger and Repčok (1981) suggested that this might be due to that the K/Ar method used for dating might have been affected by a variable amount of a component of a rock sample used for age determination.

Rb/Sr method

Ages for the granodiorites and diorites were also determined by Rb/Sr dating at the Institute of Nuclear Research of the Hungarian Academy of Sciences at Debrecen. A bulk rock sample from "Kukel", as well as biotite separated from this rock type were subjected to radiogene element analysis and yielded the following results:

Rock:
Rb: 171 ppm
Sr: 477 ppm
^{86}Sr: 46.1 ppm
^{87}Rb: 47.7 ppm

$^{87}Sr/^{86}Sr$: 0.7102 ± 0.0005
$^{87}Rb/^{86}Sr$: 1.023

Biotite:
Rb: 281 ppm
^{87}Sr: 8.998 ppm
^{87}Rb: 78.2 ppm

$^{87}Sr/^{86}Sr$: 0.7123 ± 0.007
$^{87}Rb/^{86}Sr$: 8.589

The age of the mineral determined from the radiogenic elements is:

$$T = \frac{1}{1.42 . 10^{-11}} \ ln \left(1 + \frac{0.7123 - 0.7102}{8.588 - 1.023} \right) = 19.6 \pm \pm 8 . 10^6 \ years$$

Method $^{207}Pb/^{235}U$ and $^{206}Pb/^{238}U$

Measurements carried out on zircons separated from the granodiorite collected (sampled at "Kukel") and analysed at the Centre de Recherches Petrographiques et Geochimiques in Nancy gave the following results:

Zircons with a particles size greather than 75 μm:
$^{207}Pb/^{235}U$ = 0.0240989 = 24.2 m.y.
$^{206}Pb/^{238}U$ = 0.0032613 = 21.0 m.y.

Pb ppm = 1.063
U ppm = 309

Unclassified zircons:
$^{207}Pb/^{235}U$ = 0.020876 = 21.0 m.y.
$^{206}Pb/^{238}U$ = 0.0029093 = 18.7 m.y.

Pb ppm = 1.121
U ppm = 309

Difficulty was experienced in carrying out Pb/U age determinations mainly due to the extremely low content of lead in the samples. The data given above correspond well with the intensive metamorphism of the rock, due to overheating or even melting, during which time the zircons lost a substantial amount of their radiogenic lead. Other evidence of this metamorphism and of the fact that zircons are much older than the age determined from the date of solidification of the host rock, is found in the variations between ages from different samples.

First sample $^{207}Pb/^{206}Pb$ = 0.053592 = 367 m.y.
Second sample $^{207}Pb/^{206}Pb$ = 0.052044 = 299 m.y.

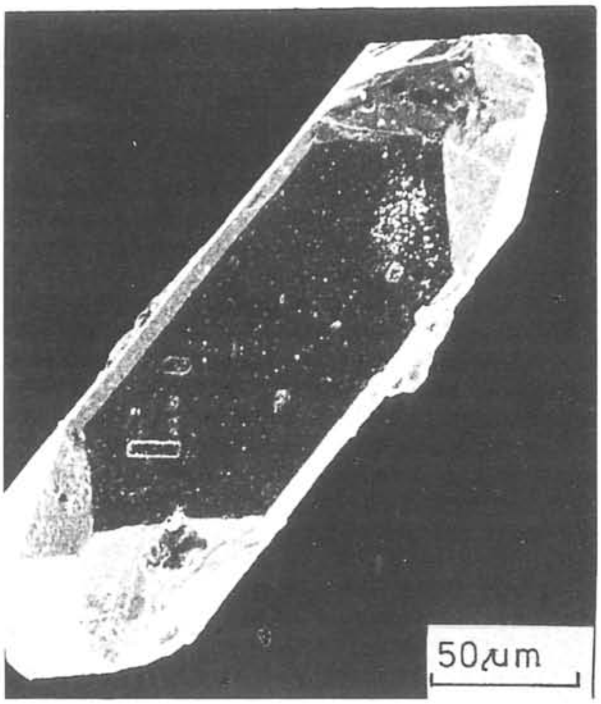

Fig. 4. Morphological type of zircon: S_{22} from Kukel granodiorite, magn. 300×.

From these ages it is inferred that zircon growth occurred between the end of the Carboniferous and the beginning of the Permian. The $^{207}Pb/^{206}Pb$ age (299 m. y.) can be considered as the maximum age of zircon formation. Nevertheles it is known that the loss of the intermediate products of 238 U family is greater than that of the 235 U, therefore the $^{207}Pb/^{206}Pb$ age is often higher than the true age of the mineral. Consequently, it is suggested that the formation of zircons occurred between the end of Carboniferous and the beginning of Permian. The zircons lost a considerable amount of their radiogenic lead at the end of Oligocene, or at the beginning of Miocene. The content of the radiogenic Pb/U in zircons presumably changed between 21–24 m.y. This conclusion can be drawn because it seems that the ratio of the radiogenic $^{207}Pb/^{235}U$ is a more reliable indicator than the $^{206}Pb/^{238}U$ ratio. The variations in radiogenic element contents are considered to be associated with the changes in hafnium content in the zircons (which does not correspond to the amount that would be estimated from their morphology).

Discussion on the petrogenesis of the Hodruša granodiorite

The results obtained from the isotope analysis suggest that the formation of the Hodruša granodiorite took place during Late Oligocene–Early Miocene times, when older Permian–Carboniferous rocks were remelted. From the morphological analysis of zircons it is suggested that the magmatite of mantle origin (alkaline-intermediate or even basic in chemical nature) was subjected initially to partial melting which was followed by assimilation.

The possibility that the Hodruša granodiorite is the product of assimilation is not at all surprising. Prior to this research being carried out, opinions existed, based on chemical and mineralogical properties, which suggested that the rock itself was an anomalous magmatite (Rozložník et al., 1966; Rozložník and Šalát, 1979). It was noted that the rock contained xenolithe restites and accessories, having very unusual shapes, in which large amounts of ferroaugite and titanite were found. Another anomaly was the extremely high CaO, FeO, MgO and Fe_2O_3 contents which are very atypical in granodiorites. Uncommon zonal structures in plagioclase suggest that the rock underwent a two-stage crystallization process which was terminated by fast cooling (Lexa, 1969). The anatexic-hybrid origin of the Hodruša granodiorite complex explains the somewhat exotic character of zircons which originate from a mantle derived magma of alkaline or even basic character. On the basis of this origin, one can account for some microchemistry characteristics of the granodiorite, namely, high Cr, Co, V, Cu, Ba, Rb, Ce contents. High $^{87}Sr/^{86}Sr$ ratios presented in the text above also attest to the occurrence of assimilation processes.

It is very likely that the Hodruša granodiorite was created by remelting of younger Palaeozoic magmatite which is chemically closely related to the dioritic host rock which is now seen as xenoliths within the granodiorite. Dioritic rocks contain zircons corresponding to an alkaline basalt mantle magma. Zircons of a similar origin and having a similar chemical composition to that of the rock situated along the monzonite trend, are taken to be confirmation of the relationship between the Hodruša granodiorite and the dioritic rock. The dioritic rock also exhibits signs of having undergone a rather complex evolution. The residual dioritic rock which can be found in the granodiorite are rather atypical due to the occurrence of orthopyroxene inclusions in clinopyroxene. The pyroxenes exhibit uralitization and the amphiboles have undergone biotization. The composition of the Hodruša granodiorite also appears to have been influenced by the assimilation of granitoid rocks.

The radiometric dating of the Hodruša granodiorite not only reveals interesting petrological characteristics but is also interesting from the methodological point of view. It seems that zircons are very useful in the determination of the origin of the magma of the host rock, but only in the case where the radiogenic lead and uranium are certainly similar. In the first case 21–24 m. y. age was determinated by U/Pb method from zircon. The second Late Paleozoic age correspond to the dioritic rocks, forming also xenolithes in Hodruša granodiorites.

Acknowledgements: The authors express their gratitude to RNDr. J. Határ and RNDr. J. Krištín of the Laboratory of the Electron Microscopy of the Geology Institute of D. Štúr, Bratislava for their assistance. The contribution of the staff of the Training Reactor at the Technical University Budapest, Hungary is acknowledged. We also thank Gillian Drennan for her assistance with English editing.

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