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PETROLOGY AND GEOCHEMISTRY OF GRANITOID EXOTICS OF THE RAČA UNIT OF THE MAGURA FLYSCH

(5 Figs., 5 Tabs.)

Abstract: The submitted work summarizes the knowledge gained by petrological and geochemical research of granitoid (granite, granodiorite) pebbles and blocks present as so-called exotics in the Rača unit of the Magura Flysch. Special attention has been paid to U, Th and K concentrations in the individual varieties of the rocks studied. The obtained results indicate the genesis of the exotics and make it possible to characterize their source area in more detail.

Резюме: Предлагаемая работа резюмирует данные полученные петрологическим и геохимическим изучением гранитоидных (гранит, гранодиорит) валунов и обломков находящихся в форме так-называемых экзотических элементов в Рачанской единице Магурского флиша. Повышенное внимание уделялось содержаниям U, Th и K в различных типах изучаемых пород. Полученные результаты указывают на генезис экзотических элементов и позволяют более подробно охарактеризовать их регион-источник.

Exotics of granitoid rocks have been studied by me within the partial task of SPZV II-4-4/04 "Complex research of granitoids and mineral-deposit--forming processes on the eastern margin of the Central European Epivariscan platform". The solution of the petrogenesis and provenience of these rocks, including other crystalline exotics, may substantially contribute to explain numerous topical questions regarding material composition, structure and tectonics of the older basement underlying the Carpathian Foredeep and Flysch Belt, and may also provide the data inevitable for the reconstruction of the development of the Bohemian Massif's eastern flank.

Exotics — basic characteristics, origin and forms of occurrence

The term exotics is used in geological literature to designate blocks, pebbles or fragments of rock which is composed of a material from a hypothetical source area. Exotics derived from hypothetical sources buried by the compression of the folded belt mark mainly Alpide flysch of the so-called wildflysch facies (Svoboda et al., 1983).

The term wildflysch originated, according to Marschalko (1969), in the Swiss Alps where it occurs in the form of breccia and conglomerate facies with huge blocks and boulders of exotic rocks genetically associated with the formation of cordilleras or growth of nappes and related to sedimentation--gravitational (slide) and tectonic processes. The most characteristic form of the occurrences of exotics are blocks and boulders whose size attains from

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several metres to hundreds or thousands of metres, their volume locally approaching 200 000 m^3 (Marschalko, 1969). In 1956, Beneo designated these sedimentary klippes as olistoliths.

An example of the occurrence of coarse clastic exotics in the Czechoslovak territory is the front zone of the partial Rača unit of the Magura Flysch. In addition to boulders concentrated in coarse-grained to bouldery layers, it locally comprises also irregular blocks whose size attains up to several m^3. Similar blocks are known in all the tectonic units of the Magura Flysch where they are regarded as olistoliths (Eliáš, 1976) or as tectonic fragments dragged along the thrust plane of the Rača unit and/or some other partial slice (Krystek, 1964).

The exotics consist of crystalline rocks and sediments. In the submitted paper I would like to mention some knowledge which resulted from the present-day centre of interest of my work, i.e. petrological and chemical study of exotic crystalline material with special attention to granitoid rocks.

I carried out the research works at the localities Střílky-Stupava, Zástřizly, Roštín, Salaš, Jankovice, Kvasice, Bílavsko, Rajnochovice, Podolí and Brňov (Fig. 1). At these sites, crystalline is represented by igneous (40 %) as well as metamorphic (18 %) rocks (see Tab. 1). The igneous rocks include granitoids

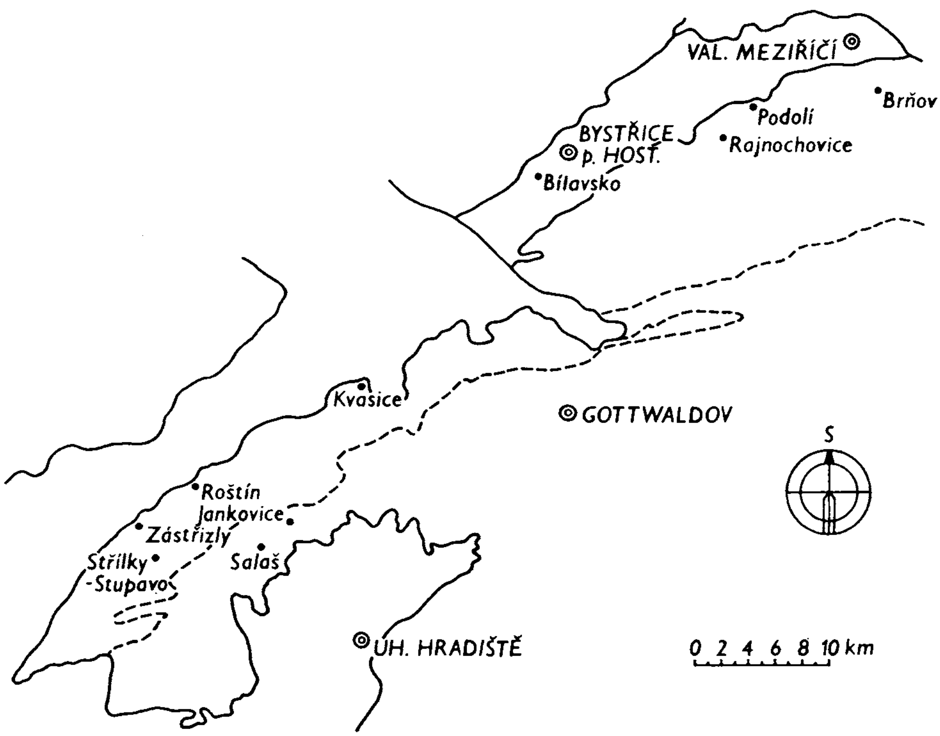

Fig. 1. Schematic map of studied area with localities in which exotics were collected.

and dioritoids (Fig. 2), whereas vein and effusive types are represented by pegmatites, quartz and granite porphyries, rarely also amygdaloid spilites. The metamorphic rocks comprise quartzites, phyllites, gneisses and amphibolites.

Table 1

Quantitative presence of crystalline exotics at studied localities of the Rača unit of the Magura Flysch (after Krystek, 1965)

Locality	Magmatic rocks (%)	Metamorphic rocks (%)
Střílky-Stupava	34.0	18.0
Roštín	22.0	66.0
Salaš	48.0	14.0
Jankovice	36.0	12.0
Kvasice	50.0	2.0
Bílavsko	95.0	—
Rajnochovice	30.0	4.0
Podolí	31.0	18.0
Brňov	15.4	27.3

Petrological characteristics of granitoids

In the sense of Streckeisen's system, granitoids can be classified as diverse varieties of granites (muscovite, biotite-muscovite, exceptionally biotite), granodiorites (muscovite-biotite, amphibole-biotite, biotite) and tonalites (biotite, amphibole-biotite) (Fig. 2).

The granites are predominantly medium-grained (granularity number of Teuscher's classification: 86—98) to fine-grained (181—732) and are of gray--white, pink-gray to gray colour. Their structure is confining, massive; texture mostly hypautomorphic-grained. Some samples were intensively mylonitized. This is reflected mainly in their structure which, in strongly deformed portions, is very similar to parallel structure. In such cases the hypautomorphic-grained structure also grades into cataclastic, mortar-like, locally even tectonoblastic one.

Microscopically, the granites are composed of quartz (30.3 %), K-feldspars (orthoclase, microcline - 32.6 %), Na-rich plagioclase (An_{05-20}) (26.1 %), muscovite (2.6 %), biotite (3.3 %) and accessories (1.6 %). Of secondary minerals, sericite (1.7 %) and chlorite (0.4 %) have been identified. Some samples contain also younger calcite (up to 1 %).

The granodiorites are mostly fine-grained (Teuscher's granularity number: 115—610) with exceptional grading to medium-grained varieties. Their colours are gray-white, light gray, pink-gray to gray. The granodiorites are predominantly clastically deformed. Their structure is confining, massive, in strongly tectonically affected portions similar to parallel structure. The texture of undeformed rocks is hypautomorphic-grained, granitic, whereas mylonitized rocks have mostly cataclastic to mortar-like texture, in places with distinct recrystallization thus gaining the character of tectonoblastic texture.

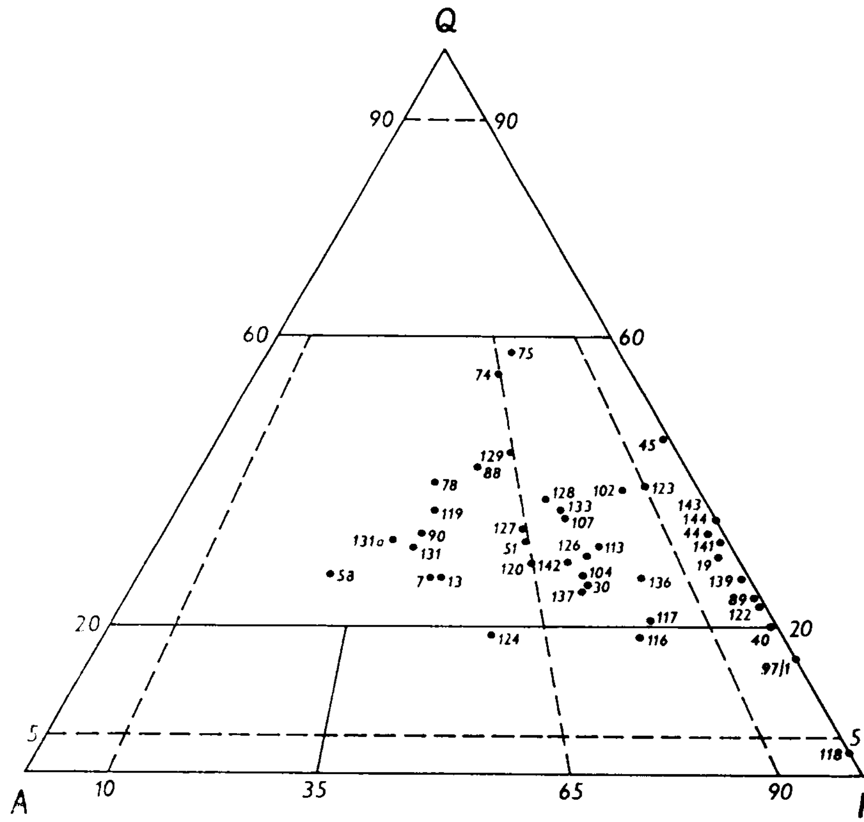

Fig. 2. Classification QAP diagram of igneous rocks present in exotic material of the Rača unit of the Magura Flysch (numerical designation of samples is in Figs. 2—5, for their location see the text).

From mineralogical point of view, the granodiorites consist of quartz (25.8 %), K-feldspars (orthoclase, microcline - 16.0 %), Na-rich plagioclase (An_{11-37}) (44.9 %), muscovite (0.8 %), biotite (5.2 %), common hornblende (1.5 %), accessories (1.3 %) and secondary minerals (sericite - 1.5 %, chlorite - 2.7 %). Like the granites, also the granodiorites contain scarce younger calcite (up to 1 %).

Remarks to possible genesis of the granitoids

Petrological analysis of mineral composition and structural characteristics of the granitoids suggest that they probably represent minerally as well as structurally fairly uniform set which is likely to correspond to a common formational and facial group. The presence of the mineral assemblage biotite + orthoclase + (xenomorphic) quartz may, in accordance with Š í m o v á' s

(1985) views, genetically correspond to intrusive granitoid magmatism which gave rise to early-generation granitoid rocks.

The identified phaneritic textures suggest gradual crystallization of the granites as well as granodiorites under the conditions of roughly equal bathyal level. The proved presence of the relics of mortar-like and tectonoblastic textures may indicate deformation and subsequent crystalloblastesis. Structures of mylonite character confirm the existence of zones of pressure alterations in the source area.

Chemistry of the granitoids

Petrochemical data on the content of oxides of petrogene elements confirm that the investigated set of the exotic granitoids comprises chemically mutually corresponding, close rock types. All the studied exotics have the character of acid igneous rocks ($SiO_2 > 62\,\%$) unequivocally falling into the area of alkali-lime rocks marked by relatively stable total value of the content of alkalies and their mutual ratios (Tab. 4). No supersodic nor superpotassic rock types have been noted.

Table 2

Chemical analyses of exotic granites of the Rača unit of the Magura Flysch

Sample No.	7	119	131	90	51	41	58
SiO_2	72.88	77.24	71.99	73.65	73.55	68.51	72.23
TiO_2	0.28	0.11	0.14	0.20	0.16	0.43	0.41
Al_2O_3	11.47	12.07	13.16	13.63	14.52	15.04	13.16
Fe_2O_3	0.24	0.40	0.26	0.29	0.18	1.24	0.51
FeO	0.51	0.62	0.39	0.69	1.00	1.98	0.83
MnO	0.05	traces	0.04	0.01	0.01	0.04	0.02
CaO	3.34	0.35	2.58	1.30	1.10	0.76	1.07
MgO	0.03	0.05	0.02	0.08	0.18	1.31	0.12
K_2O	5.27	4.95	5.85	4.94	4.98	5.08	8.58
Na_2O	3.04	3.47	3.17	3.76	3.81	3.49	2.29
Li_2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total S	0.00	0.00	0.00	0.00	traces	traces	traces
CO_2	2.41	traces	1.89	0.69	traces	0.68	0.00
P_2O_5	0.00	0.00	0.00	0.03	0.00	0.27	0.14
H_2O^-	0.10	0.18	0.09	0.10	0.14	0.22	0.16
H_2O^+	0.39	0.49	0.36	0.53	0.59	1.12	0.42
Total	100.01	99.93	99.94	99.90	100.22	100.17	99.94

Analysed by Faimon — Kadlec, Faculty of Natural Sciences, J. E. Purkyně University, Brno; for numerical designation of samples and their location see the text.

A characteristic genetic sign of the development of the investigated igneous rocks is their potassium content only slightly exceeding that of sodium or contents of these two elements are equal (Tab. 4). This fact can be, in accordance with Šímová (1985), explained by the absence, or only slight manifestations of secondary processes in the source area.

Table 3

Chemical analyses of exotic granodiorites of the Rača unit of the Magura Flysch

Sample No.	102	107	33	113	123	30	137	136	104	142
SiO_2	72.86	75.29	74.93	72.77	71.69	66.41	68.16	67.84	66.39	70.86
TiO_2	0.21	0.26	0.14	0.10	0.24	0.41	0.59	0.49	0.20	0.42
Al_2O_3	14.73	13.00	13.39	13.60	14.49	14.97	14.19	14.54	15.27	14.46
Fe_2O_3	0.69	0.45	1.13	0.49	0.37	2.61	2.21	2.08	4.39	0.91
FeO	0.66	0.64	0.76	0.96	1.62	1.56	1.35	1.40	1.30	0.80
MnO	0.03	traces	0.02	0.01	0.02	0.08	0.05	0.06	0.02	0.03
CaO	1.21	0.57	0.16	1.79	3.61	3.94	3.79	4.56	2.61	2.02
MgO	0.12	0.06	0.11	0.17	0.22	0.61	0.28	0.32	0.50	0.12
K_2O	4.22	4.98	3.56	3.67	2.88	3.44	3.54	3.68	3.65	4.59
Na_2O	4.30	3.85	5.17	4.52	3.19	4.00	4.01	3.75	3.10	4.57
Li_2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total S	0.00	0.00	traces	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO_2	traces	traces	0.10	0.53	0.54	0.30	traces	traces	traces	0.15
P_2O_5	0.02	0.05	traces	0.14	0.07	0.16	0.22	0.16	0.14	0.16
H_2O^-	0.13	0.13	0.26	0.09	0.17	0.18	0.43	0.27	0.44	0.18
H_2O^+	0.78	0.60	0.44	1.07	0.74	1.21	1.16	0.87	1.93	0.59
Total	99.96	99.88	100.17	99.91	99.85	99.88	99.98	100.02	99.94	99.86

Analysed by Faimon — Kadlec, Faculty of Natural Sciences, J. E. Purkyně University, Brno; for numerical designation of the samples and their location see the text.

Table 4

Some correlation coefficients, indices and norms of exotic granitoids of the Rača unit of the Magura Flysch

Sample No.	$Fe_2O_3 + FeO$	$\frac{Fe_2O_3}{FeO}$	$\frac{Fe_2O_3}{Fe_2O_3 + FeO}$	-fe-	-mg-	-ti-	alk	-k	-na-	-al-	$\frac{alk}{Al_2O_3}$	SI
7	0.75	0.5	0.32	96.2	3.9	37.3	8.31	0.6	0.4	0.42	0.7	<1
119	1.02	0.7	0.39	95.3	4.7	10.8	8.42	0.6	0.4	0.41	0.7	1
131	0.65	0.7	0.40	97.0	3.0	21.5	9.02	0.7	0.4	0.41	0.7	<1
90	0.98	0.4	0.30	92.5	7.6	20.4	8.70	0.6	0.6	0.61	0.6	1
51	1.18	0.2	0.15	86.8	13.2	13.6	8.79	0.6	0.4	0.38	0.6	2
41	3.22	0.6	0.39	71.1	28.9	13.4	8.57	0.6	0.4	0.36	0.6	10
58	1.34	0.6	0.38	91.8	8.2	30.6	10.87	0.8	0.5	0.45	0.8	1
102	1.35	1.1	0.51	91.8	8.2	15.6	8.52	0.5	0.5	0.37	0.6	1
107	1.09	0.7	0.41	94.8	5.2	23.9	8.83	0.6	0.4	0.41	0.7	<1
33	1.89	1.5	0.60	94.5	5.5	7.4	8.73	0.4	0.6	0.40	0.7	1
113	1.45	0.5	0.34	89.5	10.5	6.9	8.19	0.5	0.6	0.38	0.6	2
123	1.99	0.2	0.19	90.1	10.0	12.1	6.07	0.5	0.5	0.30	0.4	3
30	4.17	1.7	0.63	87.2	12.8	9.8	7.44	0.5	0.5	0.33	0.5	5
137	3.56	1.6	0.62	92.7	7.3	16.6	7.55	0.5	0.5	0.35	0.5	3
136	3.48	1.5	0.60	91.6	8.4	14.1	7.43	0.5	0.5	0.34	0.5	3
104	5.69	3.4	0.77	91.9	8.1	3.5	6.75	0.5	0.5	0.31	0.4	4
142	1.71	1.1	0.53	93.4	6.6	24.3	9.16	0.5	0.5	0.39	0.6	1

$$\text{-fe-} = \frac{Fe_2O_3}{Fe_2O_3 + FeO + MgO} \cdot 100; \quad \text{-mg-} = \frac{MgO}{MgO + Fe_2O_3 + FeO} \cdot 100; \quad \text{-ti-} = \frac{TiO_2}{Fe_2O_3 + FeO}; \quad alk = Na_2O + K_2O;$$

$$\text{-k-} = \frac{K_2O}{K_2O + Na_2O}; \quad \text{-na-} = \frac{Na_2O}{Na_2O + K_2O}; \quad \text{-al-} = \frac{K_2O + Na_2O}{K_2O + Na_2O + Al_2O_3}; \quad SI = \frac{MgO}{MgO + FeO + Fe_2O_3 + Na_2O + K_2O} \cdot 100;$$

For numerical designation of the samples and their location see the text.

In addition to the mineral composition of the studied granitoids, the uniform character of the magma from which they were formed, is also reflected by $K_2O + Na_2O/Al_2O_3$ ratio and correlation between this ratio and SiO_2.

Agpaite coefficient -al- amounting to 0.0, which expresses absolute predominance of Al_2O_3 over $K_2O + Na_2O$, has not been found in the studied rock set. This coefficient mostly varies within a fairly narrow range 0.36—0.45 for the granites and 0.31—0.41 for the granodiorites (Tab. 4), which in both cases exceeds the tabular value of 0.20 representing the lower boundary of granitoid to dioritoid acidites.

According to some authors (e.g. Marakushev, 1965; Kostyuk, 1970; Perchuk, 1970) the oxides Al_2O_3 and MgO are reliable indicators of the depth of the development of magmatism. Their mutually corresponding contents in individual samples support the assumption that the analysed material is genetically associated with a magmatic body within which it was formed in the same, or at least mutually corresponding, depth levels.

Within the studied set, a similar course of magmatic melt differentiation can be observed also by the comparison of the coefficients -fe-, -mg-, and -ti- and by their mutual correlation.

The oxidation grade of iron corresponds to its oxidation grade given in literature for rocks of effusive and intrusive complexes.

One of petrochemical criteria which allow quantitative evaluation of differentiation grade within the studied collection is the crystallization index SI. Its fairly low values (Tab. 4) suggest that our exotic granitoids belong into the dacite group (Kuno, 1968) corresponding to highly differentiated rock types.

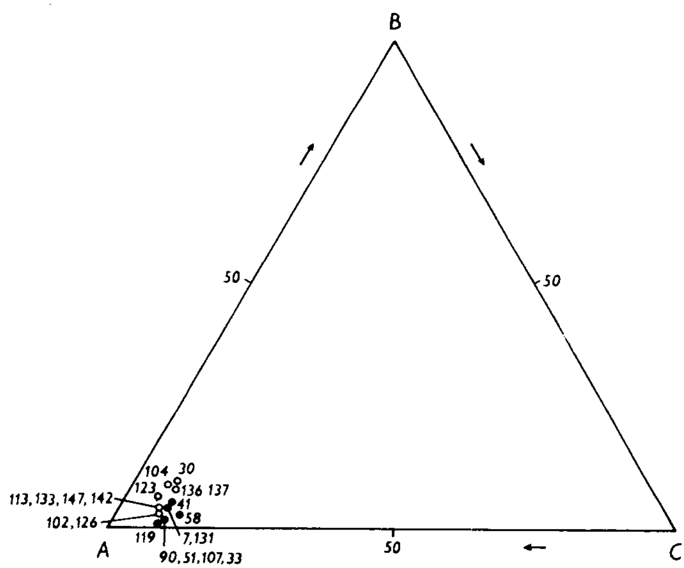

Fig. 3. Correlation ABC diagram ($A = SiO_2 + Al_2O_3$, $B = CaO + MgO + Fe_2O_3 + FeO$, $C = Na_2O + K_2O$) of studied exotic granitoids of the Rača unit of the Magura Flysch (● = granites, ○ = granodiorites).

If we take into consideration views of some authors (e.g. B o w e n, 1928, 1947; Y o d e r — T i l l e y, 1962; G r e e n, 1968), according to which magnesium and calcium play the decisive role in the initial stage of rock development, whereas the share of alkalies and iron increases in later differentiation products, more femic elements marking deeper development in contrast to subsurface - sialic one, we may distinguish granitoids of one facial type within the triangular diagram (Fig. 3) which are genetically bound to a mutually analogical bathyal level of hypabyssal type.

The uniform provenience of the analysed exotic granitoids may be suggested also by their position in the AFM diagram (Fig. 4).

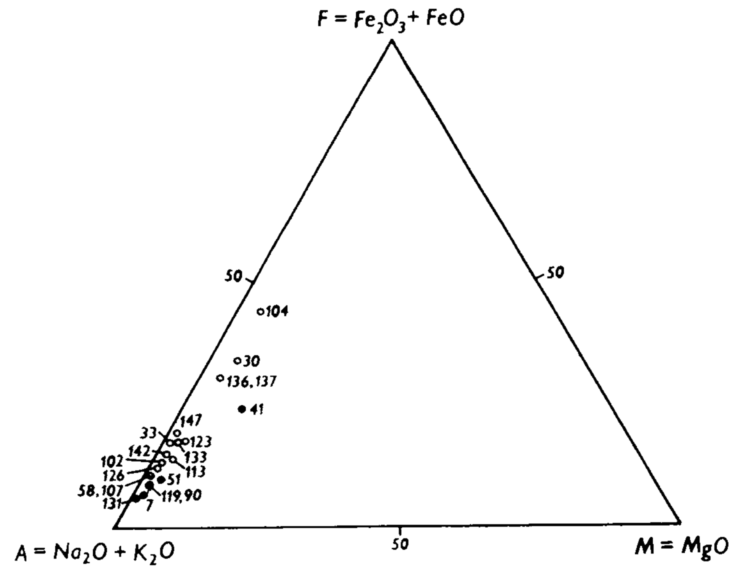

Fig. 4. Correlation diagram $Na_2O + K_2O$ — $Fe_2O_3 + FeO$ — MgO of exotic granites and granodiorites of the Rača unit of the Magura Flysch (explanations see in Fig. 3).

The application of the correlation diagram MgO - FeO + 0.9 Fe_2O_3 - Al_2O_3, which allows modelling of geostructural situations, to exotic granitoids of the Rača unit of the Magura Flysch indicates the uniform geotectonic position of these granitoids which might correspond to igneous rocks of intrablock structures (Fig. 5).

The knowledge obtained so far on the chemistry of granitoid exotics, quantitative presence of petrogene elements, submitted correlation coefficients, indices and norms indicate their uniform geostructural assignation. Although the results of this study and the fact that the granitoids are comagmatic could suggest that the exotics came from a single source, it will be necessary to take into consideration also the view of N ě m c o v á-H l o b i l o v á (1964) according to which the geochemical identity of the analysed material may, besides the common origin, indicate also its development in districts of a similar material composition formed under relatively equal conditions.

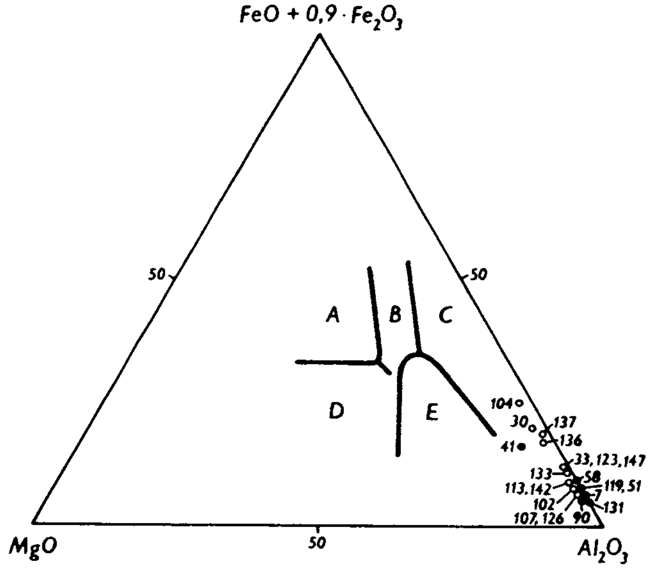

Fig. 5. Correlation MFA diagram of petrogene elements of studied exotic granitoids of the Rača unit of the Magura Flysch in relation to tectonics (Chayes—Velde, 1965) (explanations see in Fig. 3).
Rocks: A — of ocean islands, B — continental, C — of intrablock structures, D — of ocean floor and ocean ridges, E — of orogenic structures.

Results of study of natural radioactivity

To clear up some questions regarding the genesis of the studied granitoids as well as indications of possible younger geological processes which affected the rocks of the source area, the natural radioactivity of the analysed material has been gammaspectrometrically determined, i.e. thorium, uranium and potassium concentrations have been measured (Tab. 5).

As far as the distribution of the above-mentioned elements is concerned, the investigated rocks represent a fairly uniform set characterized, in comparison with Clark values for granitoids given in literature, by anomalous data, mainly by markedly lower U, Th contents and their higher mutual ratio.

High anomalous uranium contents in granitoids are most probably caused by autometamorphic processes in these granites accompanied ba their alteration (albitization, greisenization) and/or manifestations of high-temperature epigenetic alterations (Ustinov, 1962; Tréger, 1972; Kátlovský, 1981), and therefore the results of the gammaspectrometric analyses rule out such processes in the source area of the exotic granitoids of the Rača unit. Also unlikely seems, from the same viewpoint, the origin of the studied exotics from endocontact parts of a granitoid body, which are marked by high concentrations of radioactive elements.

As regards the time of its formation, the investigated exotic material can be assigned to early granitoid intrusions of high differentiation grade marked

Table 5

Natural radioactivity values of studied granitoids from exotic material of the Rača unit of the Magura Flysch

Sample No.	Rock type	Th (ppm)	U (ppm)	K (%)	Th/U
131	muscovite granite	7.2	0.5	3.0	14.4
146	muscovite granite	4.9	0.5	3.0	9.4
129	biotite-muscovite granite	4.2	0.6	3.0	6.4
145	biotite-muscovite granodiorite	4.6	0.7	3.0	6.8
147	biotite-muscovite granodiorite	4.1	0.7	3.2	5.5
133	muscovite-biotite granodiorite	8.4	1.2	2.0	7.0
136	hornbl.-biot. granodiorite	22.3	2.7	2.8	8.2
138	biotite granodiorite	8.0	1.7	1.7	4.7
142	biotite granodiorite	35.6	1.9	3.7	18.7
—	Vinogradov (1962)	18.0	3.5	3.3	5.2

For numerical designation of the samples and their location see the text. Analysed by Research, Slovak Academy of Sciences, Bratislava.

by predominantly lower radioactivity rather than to their younger equivalents. This knowledge supports also some other partial conclusions resulting from the study of the material composition and chemistry of the exotics.

The higher Th/U ratio may indicate that the source area of the exotic granites and granodiorites was not subject to pneumatolitic-hydrothermal autometamorphic processes, in the course of which the granitoids would be enriched in uranium (without Th).

Exceptional increase in natural radioactivity can most probably be explained by a quantitative growth of diadochic U and Th in some mafic and accessory minerals (e.g. biotite, zircon, titanite) which are principal hosts to these two radioactive elements in igneous rocks.

Acknowledgement: I thank to Academician B. Cambel for allowing me to conduct gammaspectrometric analyses at the Geological Institute of the Centre of Geoscience Research, Slovak Academy of Sciences at Bratislava. I am obliged to RNDr. V. Kátlovský, CSc. for carrying the analyses carefully out.

LOCATION OF SAMPLES OF STUDIED EXOTICS AND THEIR NUMERICAL DESIGNATION

7, 131, 131a — Zástřizly — abandoned open-pit quarry in fields, about 700 m NE of the village, ***muscovite granite.***
107 — Zástřizly, ***biotite-muscovite granodiorite.***
9, 11, 102 — Střílky-Stupava — abandoned shelf quarry, right of the road Brno/Uherské Hradiště, about 800 m from the turning to Stupava, ***biotite-muscovite granodiorite.***
104 — Střilky-Stupava, *biotite granodiorite.*
13, 14 — Kvasice — abandoned shelf quarry, about 1.5 km NW of the village (foothill of the elevation point Chlum), on the left side of the road Kvasice-Střížovice, ***muscovite-biotite granite.***

30, 120, 137 — Bílavsko — abandoned shelf quarry on the eastern margin of the village, on the foothill of the elevation point Chlum (418 m above sea level), *hornblende-biotite granodiorite.*
116 — Bílavsko, *quartzmonzodiorite.*
117, 136 — Bílavsko, *biotite-hornblende granodiorite.*
118 — Bílavsko, *biotite-hornblende diorite.*
119 — Bílavsko, *muscovite granite.*
33 — Rajnochovice — rock outcrop in front of the village, right of the road from Podhradní Lhota, *muscovite-biotite granodiorite.*
40, 44, 45 — Rajnochovice — abandoned shelf quarry "Hrad" (castle) in the upper part of the village, right of the road from Podhradní Lhota, *biotite tonalite.*
41 — Rajnochovice, *biotite-muscovite granite.*
51 — Rajnochovice, *muscovite-biotite granite.*
58 — Podolí — abandoned shelf quarry, left of the road Loučka-Podolí, quite near to the village, *biotite granite.*
123 — Podolí, *muscovite-biotite granodiorite.*
124 — Podolí, *quartzmonzonite.*
141 — Podolí, *biotite tonalite.*
142 — Podolí, *biotite granodiorite.*
74, 78, 88, 90 — Salaš — abandoned shelf quarry in the village (behind the local library), left of the road from Velehrad, *biotite-muscovite granite.*
75, 146 — Salaš, *muscovite granite.*
89 — Salaš, *biotite tonalite.*
126, 127, 145, 147 — Salaš, *biotite-muscovite granodiorite.*
128 — Salaš, *muscovite-biotite granodiorite.*
97 — Jankovice — abandoned shelf quarry in front of the village (on the left side of the road), about 1 km behind the turning Jankovice-Košíky, *quartzdiorite.*
113, 133 — Roštín — abandoned shelf quarry on the margin of a forest SSE of the village, about 800 m from a recreation resort, *muscovite-biotite granodiorite.*
143, 144 — Brňov — abandoned shelf quarry about 3 km SSE of Valašské Meziříčí, left of the road Valašské Meziříčí (Křivé)-Brňov, about 500 m from the village, *biotite tonalite.*

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