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PETROGENESIS OF GRANITOIDS OF THE ČERVENÁ TYPE (CENTRAL BOHEMIAN PLUTONIC COMPLEX)

MILOŠ RENÉ

Institute of Rock Structure and Mechanics, Academy of Sciences of Czech Republic
182 09 Prague 8, V Holešovičkách 41, Czech

ABSTRACT. The Červená type granitoids are a part of a composite magmatic plex of Variscan age emplaced in a ductile shear zone on the boundary of the Bohemicum and the Moldanubian terranes. By their chemical composition, they are closest to the hybrid granites (H–granites). Their origin is associated with the processes of mixing of the differentiated, high–potassium, mantle–derived magmas, assimilation with metavolcanics and metasediments of the upper crust and with subsequent extensive homogenisation of the granitic melt.

KEYWORDS: granite, petrology, geochemistry, Central Bohemian Plutonic Complex

1. INTRODUCTION

Central Bohemian Plutonic Complex (CBPC) is a large composite magmatic body that occupies and
(Holub, Machart
represents
Variscan age on the territory of the Bohemian Massif (Fig. 1). The most widespread rock types are hornblende–biotite granodiorites, complemented by biotite granites, tonalites, melagranites and melasyenites. Gabbros, along with
rocks of predominantly intermediate
orites, la

Granitoids of the
der of CBPC, where they are frequently foliated parallel to the contact with gneisses and migmatites of th
portion of monzogranites and tonalites)
Blatná monzogranites to granodiorites further to north, the Červená type is sometimes regarded as a marginal facies of the Blatná intrusion (Kodym and Suk, 1958; Malecha, Suk and Vachtl, 1960). Bot
of high–potassium to shoshonitic granitoids (HK group — Holub, Machart and Manová, 1997).

Granitoids of the Červená type were established an independent petrographic type by Urban (1930) and their areal extent is thought to be about 185 km^2 (Holub, Machart and Manová, 1997). They were subject of a series of petrogenetic studies.

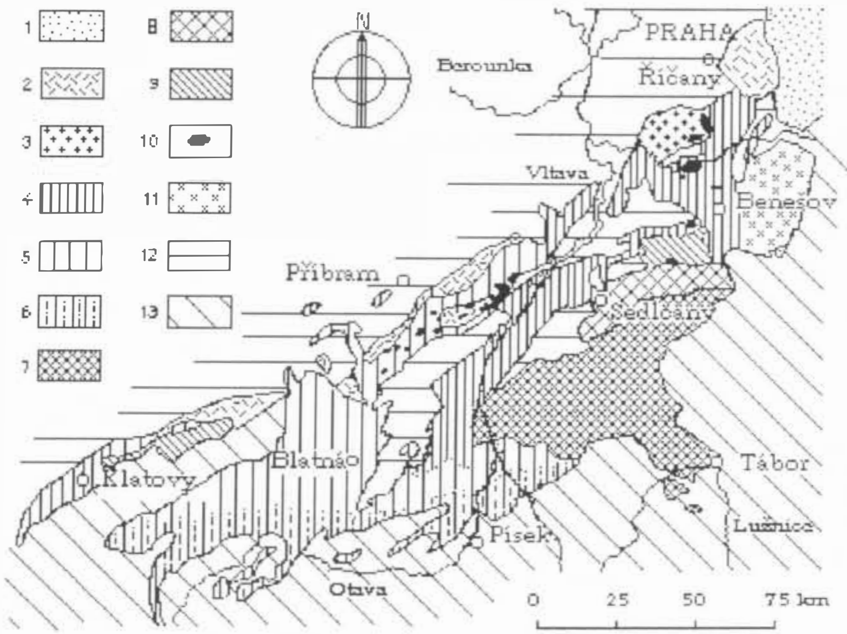

FIG. 1. Geological outline of the Central plex (after Mísař et al., 1983)

1 — Permo-Carboniferous sediments, 2 — Říčany and marginal types, 3 — Požáry type, 4 — Sázava type, 5 — Blatná and Klatovy types, 6 — Červená type, 7 — Tábor and Čertovo břemeno types, 8 — Sedlčany type, 9 — Kozlovice and Maršovice types, 10 — Gabbroic rocks, 11 — Benešov type, 12 — Proterozoic and Lower Paleozoic sediments (Bohemicum), 13 — Moldanubian zone.

Röhlichová (1964) assumed metasomatic origin of this rock type; likewise Palivcová (1965) revised the original magmatic model of Orlov (1937) and Steinocher (1969) according to the classical transfor
the whole CBPC through metamorphic mobilization of
zone. The genetic model of Röhlichová (1964) was later revised and discarded on th
(Nekula, 1986; Melín, 1988).

A new stimulation for
uranium mineralization and subsequent exploration for
and Mečichov, south of Blatná. The exploration for
between 1977 and 1988 and involved drilling of many boreholes
600 m and caving of the Nahošín prospect pit
Kotlovský,
the Blatná and Červená granodiorites (Knotek and Lang, 1985). The geochemical analyses discussed in this paper are also partl
works related

1984). Aim of this study
an independent rock type

2. Geological Setting

Granitoids
and south–eastern
formed by two
Boží apophysis.
zone of pearl gneisses and migmatites
with
contact with the adja
of a rocks of the
to biotite–hornblende
1971; Holub, Machart and Manová, 1997).

Tectonic evolut
SE and N–S trending joint
joints
ite tectonics in this part of the magmatic
places form sout
filled by lamprophyre dykes and by other dyke rocks (porphyry, aplite, pegmatite).
The length of the
Occurrences and small uranium ore deposits of metasomatic and vein–type ura
nium mineralization
(Litochleb and Kotlovský, 1988). These joints are in several cases infilled b
veins. The NW–SE trending joint
hydrothermally
mineralization, a

On the
older than the Čertovo břemeno type
than the Sázava type quartz diorites, tonalites
the
granodiorites
For the Blatná intrusion, van Breemen et al. (1982) and Bendl and Vokurka (1989) obtained Rb–Sr WR ages 331 ± 4 Ma and 331 ± 9 Ma respectively. The most recent
zircon evaporation
1997).

Holub, Cocherie and Rossi (1997) proposed large–scale crustal extension in the
Moldanubia
mafic to
with
pearl gneisses and migmatites
CBPC represent
extension, that
dipping foliation

3. PETROGRAPHY

Granitoids of the Červená type are mostly medium-grained to coarse-grained equigranular to slightly porphyritic dark
rock-forming minerals are quartz, feldspars, biotite and hornblende. Content of the dark minerals (biotite and hornblende) is on average 15–45%. The size of individual minerals averages between 0.2 to 10 mm. Potassium feldspars sometimes form porphyritic phenocrysts. Granitoids of the Červená type contains mostly foliated
border
the content of mafic minerals.
erate undulose extinction. The size of its grains is 0.5–3 mm. Potassium feldspar is also anhedral, 10–15 mm across. Plagioclase forms hypidiomorphic to idiomorphic evolved grains with sometimes
Plagioclase shows a wide range in basicity (An_{22-40}), with cores always being more basic than the rims (Knotek and Lang, 1985). The most frequently represented plagioclases are those with An_{30-37} value. Biotite is significantly pleochroic: it is pale yellow-brown parallel to X and dark brown to red brown to Y and Z. For biotite of the Červená type
bole (hornblende to actinolitic hornblende) has subhedral columns, 0.5 to 3 mm in length. Minor proportion of clinopyroxene is also sometimes present. Accessory minerals are represented by zircon, apatite, allanite and sphene, with varying amount of scheelite. Their quantitative proportion was studied by Kodymová and Vejnar (1974). The association of accessory minerals corresponds to that typical of metaluminous granitoids (Bea, 1996).

The modal composition of the Červená type granitoids corresponds, in accordance with
plotting in the monzogranite, quartz monzonite, quartz monzodiorite, quartz diorite and monzonite fields (Fig. 2). Results of 45 modal analyses were taken from Vejnar (1973), Knotek and Lang (1985) and Nekula (1986). In this data set, amphibole was present in 30 and clinopyroxene only in 14 samples.

4. GEOCHEMISTRY

For this study, some 30 published and unpublished major-element analyses were assembled (Vejnar
were completed by 15 newly made ones (analyst J. Bouška, Central laboratory of the Uranium Industry Enterprise) The analy
by X-ray
of water was
was determined by titration after Pratt (Table 1). In the diagram by Maniar and Piccoli (1989) dividing granitoids into metaluminous and peraluminous types, the Červená type granitoids plot at the boundary of both these types (Fig. 3). By their average A/CNK value (alumina saturation index, expressed as a molar ratio
belong to I-type granites

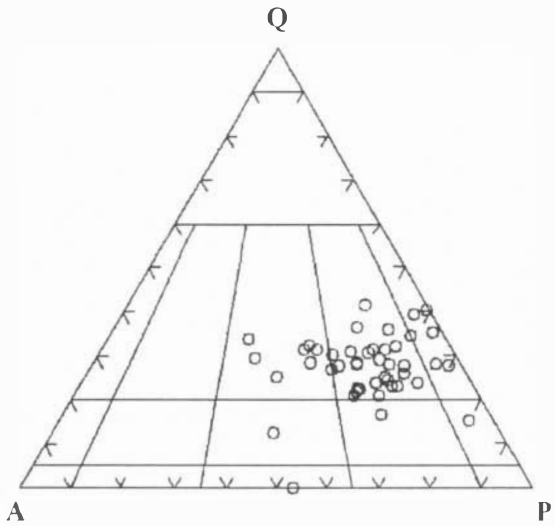

FIG. 2. Modal composition of the Červená type

The average A/CNK value of granitoids of Červená type is lower then the same value

diagram by Batchelor and Bowden (1985) the

at the boundary of pre-plate

(Fig. 4). In K_2O vs. SiO_2 diagram, the Červená type granitoids

of high-potassium calc-alkaline and shoshonitic magmas. High K_2O/Na_2O ratios (arithmetic mean = 1.23) are characteristic.

The trace element contents were determined by standard X-ray fluorescence spectrometry (analyst J. Janáčková, Unigeo Ostrava, laboratory Brno), the REE contents were determined by ICP-MS (analyst J. Bendl, Analytika Ltd.). Besides that, also analyses from the unpublished studies of Nekula (1986), Melín (1988) and Sončková (1989) were used. The content of U and Th was determined by gamma spectrometry using a multi-channel gamma spectrometer NT-512 in Geofyzika Brno Co. (analyst M. Škovierová).

The Červená type granitoids belong to poorly differentiated granites in the Rb-Ba-Sr discrimination diagram after El Bouseily and El Sokkary (1975). In the discrimination diagram after Pearce et al. (1984) the granitoids of the Červená type lie in the volcanic arc granites field near the boundary with the syn-collision granites and the within-plate granites (Fig. 5). The Rb-Sr diagram shows a very homogeneous composition of the Červená type granitoids without any conspicuous differentiation. A more marked differentiation is visible on the Zr-TiO_2 diagram (Fig. 6). Likewise for other typical metaluminous granites, the P_2O_5, Zr and Ba contents decrease wit

preferential crystallization of apatite, zircon and plagioclases at the outset of cooling of the parental magma The trend of increasing Th and U with increasing

TABLE 1. Representative analyses of the Červená type (wt %)

Sample	Re–780	Re–787	Re–794	Re–796	Re–797	Re–977	Re–990
SiO_2	63.38	66.62	63.26	60.93	64.38	63.25	63.05
TiO_2	0.71	0.51	0.67	0.74	0.48	0.59	0.70
Al_2O_3	16.02	15.53	16.68	16.32	15.57	16.07	16.40
Fe_2O_3	0.80	0.70	0.83	0.96	0.55	0.45	0.57
FeO	3.55	2.76	3.46	4.09	3.34	3.60	4.00
MnO	0.07	0.06.	0.07	0.09	0.06	0.08	0.08
MgO	2.65	2.24	2.65	3.44	2.09	2.73	3.03
CaO	3.25	2.81	3.45	4.13	3.12	3.06	3.35
Na_2O	3.06	3.39	3.25	3.21	3.27	2.75	2.83
K_2O	4.11	4.14	3.89	3.57	4.18	4.48	3.76
H_2O^+	0.86	0.77	0.64	0.78	0.90	1.80	1.00
H_2O^-	0.19	0.20	0.22	0.27	0.26	—	—
P_2O_5	0.26	0.20	0.22	0.31	0.23	0.25	0.25
CO_2	—	—	—	—	—	0.33	0.22
Total	98.91	99.93	99.29	98.84	98.43	99.44	99.24
Rb ppm	101	121	105	88	99	189	143
Ba ppm	1562	1119	1284	1432	1253	1370	1350
Sr ppm	466	306	261	349	312	440	367
Zr ppm	223	164	195	190	160	186	192
U ppm	7.9	7.5	8.3	6.8	11.0	3.8	5.7
Th ppm	14.6	20.8	12.8	7.4	22.2	13.2	11.9

Re–780 — amphibole–biotite granodiorite, Mečichov, borehole Mč–21A, 52.60 – 52.80 m. Re–787 — biotite tonalite, Mečichov, borehole Mč–21A, 196.50 m. Re–794 — amphibole–biotite granodiorite, Mečichov, borehole Mč–106, 292.10 m. Re–796 — amphibole–biotite quartz monzodiorite, Mečichov, borehole Mč–106, 551.0 m. Re–797 — amphibole–biotite granodiorite, Mečichov, borehole Mč–105, 98.20 m. Re–977 — amphibole–biotite granodiorite, Mečichov, borehole Mč–150, 99.0 m. Re–990 — amphibole–biotite granodiorite, Mečichov, borehole Mč–159, 265.60 m.

distinguishes granitoids of the Červená type from
and may be due to the preferential
which probably crystallized in the end of cooling of the granite melt.

For REE patterns of t
La_N/Yb_N ratios and negative Eu anomalies (Fig. 8) (see also Melín, 1988; Holub, Cocherie and Rossi, 1997). For comparison with granitoids of known tectonomagmatic position, plots of trace element abundances normalized to the ocean–ridge granites (Pearce et al., 1984) are shown for the Červená and Blatná granitoids (Fig. 9). Both resemble rocks of perhaps continental–arc affinity or some post–

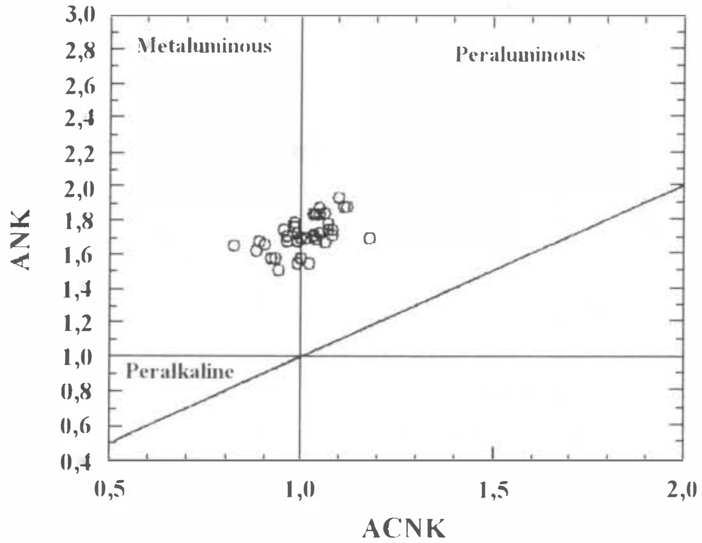

FIG. 3. Diagram of the Shand index for the Červená type after Maniar and Piccoli (1989)

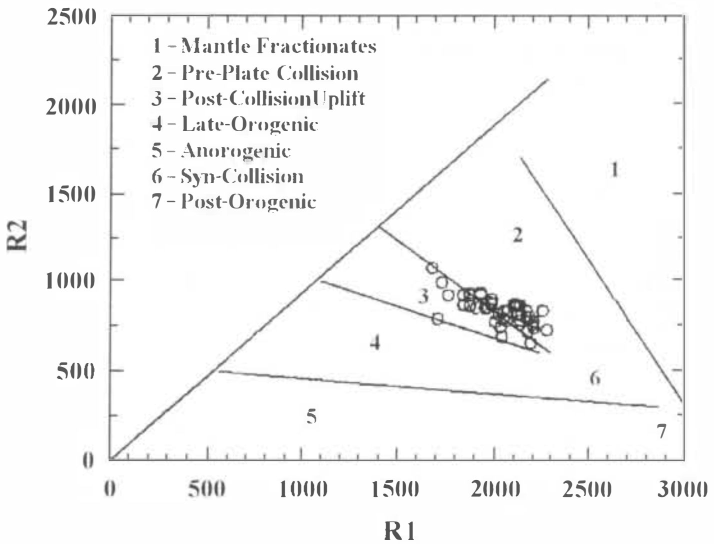

FIG. 4. Multicationic discrimination diagram after Batchelor and Bowden (1985) for the Červená type

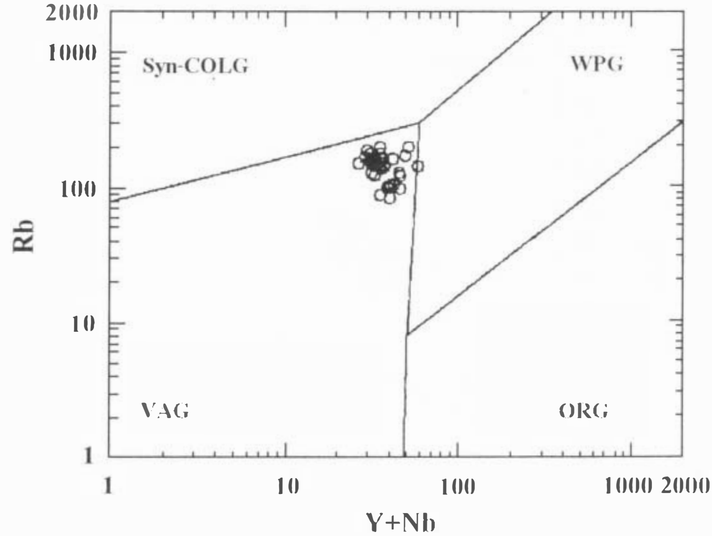

FIG. 5. The Rb versus Nb + Y discrimination diagram after Pearce et al. (1984) for the Červená type
VAG — volcanic-arc granites, Syn-COLG — syn-collision granites, WPG — within-plate granites, ORG — ocean-ridge granites

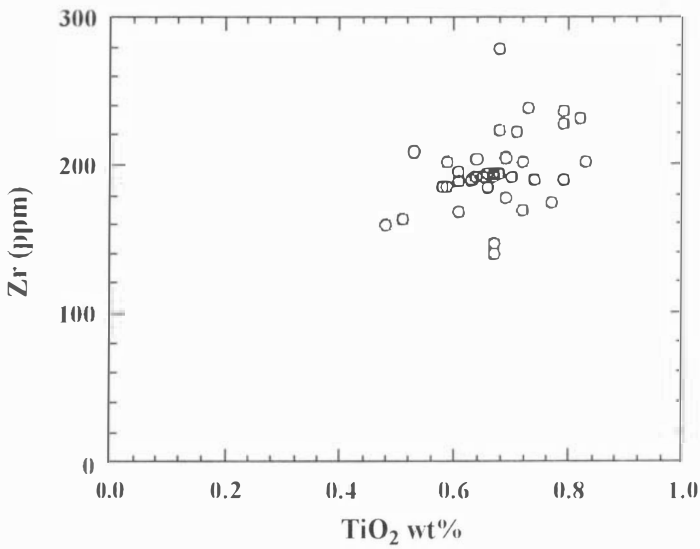

FIG. 6. Variation diagram of Zr and TiO_2 for the Červená type

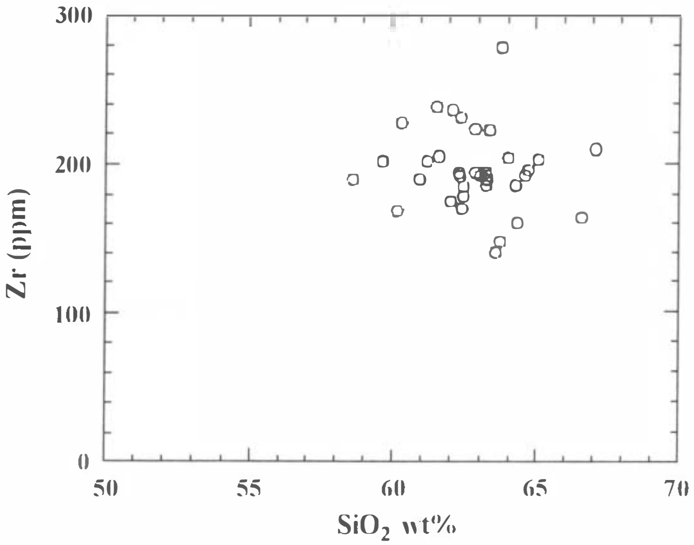

FIG. 7. Variation diagram of Zr and SiO_2 for the Červená type

collision granitoids.

5. DISCUSSION

The Červená type granitoids geochemically resemble monzogranite to granodiorite of the Blatná type. These granitoids are by their alumina saturation index assigned to the I–type granites or better to I/S transitional granites in term of Liew, Finger and Höck (1989). The above mentioned authors used this term form some granitoids from the Moldanubian batholith. Mixed I/S types from the Moldanubian batholith (excepting the mafic K–rich rocks of the Rastenberg pluton) are, however, characterized by absence or scarcity of typical microgranular enclaves which are frequent in granitoids of the Červená type. Geochemical evolution of I–type granites is interpreted on the basis restite–unmixing model, on the magma–mixing model and on basis models of fractional crystallization, partial melting, assimilation and fractional crystallization (AFC) (Brown, 1981; Didier, Duthou and Lameyre, 1982; Brown et al., 1984; Finger et al., 1997; Clemens and Petford, 1999). Červená granodiorite with initial $^{87}Sr/^{86}Sr$ ratio 0.7092 and ε Nd -5.3 (Janoušek, Rogers and Bowes, 1995) was interpreted as having resulted from either mixing between different magmas of the suite with distinct isotopic signatures, or crustal contamination of a more basic magma. According to the granitoid classifications, it is plausible to denominate the Červená type granitoids as hybrid H–granites in the sensed of the Castro et al. (1991) classification. These authors subdivide the H–granites into further sub–groups. Their subdivision assigns the Červená type granitoids to the subgroup of H_{ss}–granites, i.e. typical hybrid granites in the sense of the classification proposed by Castro et al. (1991). The appurtenance to the metaluminous

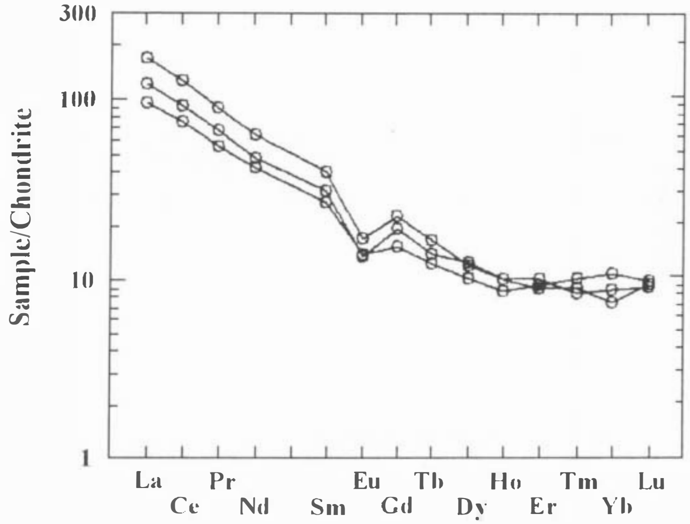

FIG. 8. Chondrite–normalized REE pattern for samples of the Červená type. Normalizing values are from Taylor and Mc Lennan (1985)

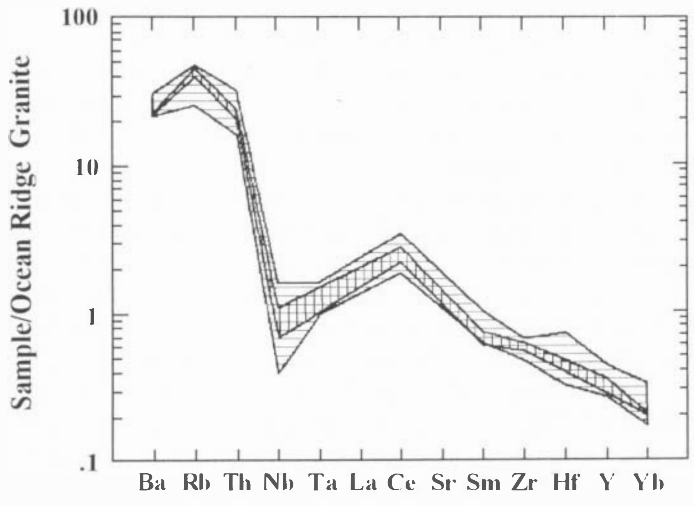

FIG. 9. Spidergram of selected elements normalized to average ocean–ridge granite (ORG) after Pearce et al. (1984) for the Blatná and the Červená types. Horizontal lines — the Červená type, vertical lines — the Blatná type.

granites in the sense of Shandd's classification is also based on the heavy mineral association. According to Bea (1996), the allanite, sphene and apatite association is characteristic of metaluminous granites.

The high–potassium magmatism is known from active plate margins, post–collisional and within–plate environments. Models for origin of high–potassium metaluminous granitoids include after Clemens and Petford (1999) assimilation of crustal rocks by basaltic magmas, partial melting of enriched mantle, reactive assimilation of wall rock by normal K–magmas, magma mixing and melting of interlayered pelitic and amphibolitic source rocks. Clemens and Petford (1999) on the basis their experiments suppose, that high potassium granitoids can be derived by single stage melting of typical old arc crust. In western and mid–European Variscan chain occur the high potassium granitoids sometimes in the form of smaller bodies. They were described from Massif Central (some bodies from Limousin tonalite belt, Didier and Lameyre, 1971; Shaw et al., 1993), Vosges (Ballons Massif, Pagel and Leterrier, 1980), Odenwald (Liew and Hofmann, 1988; Henes-Klaiber, 1992) After Stafejev, (1989) and Rossi and Cocherie (1995) this high–potassium magmatism took place within relatively short period within pull–apart structures along a crustal mega–shearzone. This structural feature formed after Rossi and Codierie (1995) the southern margin of the Variscan orogen and affected the Gondwana paleo–continent after the crustal–collision processes. For all above mentioned granitoid massifs is typical high K_2O/Na_2O ratio, LREE–enriched patterns, and higher contents of incompatible and HFSE elements.

In the CBPC high potassium granitoids form a zone in its southern part. The high potassium granitoid group is represented by the Kozárovice, Blatná, Klatovy, Marginal and some other less important granitoid types. The geochemical affinity between Červená and Blatná types can be seen on the distribution of the incompatible elements (Fig. 9), or on the diagrams Th and Zr vs. SiO_2 (Fig. 10, 11) and on diagram Rb vs. Zr (Fig. 12). From distribution of incompatible elements and from isotopic research (Janoušek, Rogers and Bowes, 1995) we can assume that both rock types (the Blatná and Červená types) are products of fractionation of mantle–derived magmas followed by assimilation those magmas with relatively heated metamorphic rocks of the Moldanubian zone Fractionation both above mentioned rock types we can see for example on the distribution of Rb, Zr and Th. Higher contents of Rb and Th over their content in the ocean ridge granites (Fig. 9) show with higher probability presence of following assimilation of mantle derived magma through metamorphic rocks of the Moldanubian zone. The intrusion was connected with a rapid uplift and decompression of surrounding metamorphic rocks and gave rise to an extensive zone where could locally participate either process of magma mixing and assimilation of metamorphic rocks. On other side geochemical evolution of granitoids of the Blatná and the Červená type is not directly controlled by distance to border CBPC with metamorphic rocks of the Moldanubian zone (see also Machart, 1991).

In the past Röhlichová (1964) argued that granitoids of the Červená type originated through metasomatic granitization of gneisses of the Moldanubian zone. Palivcová (1965) and Palivcová, Waldhausrová and Ledvinková (1989) elaborated

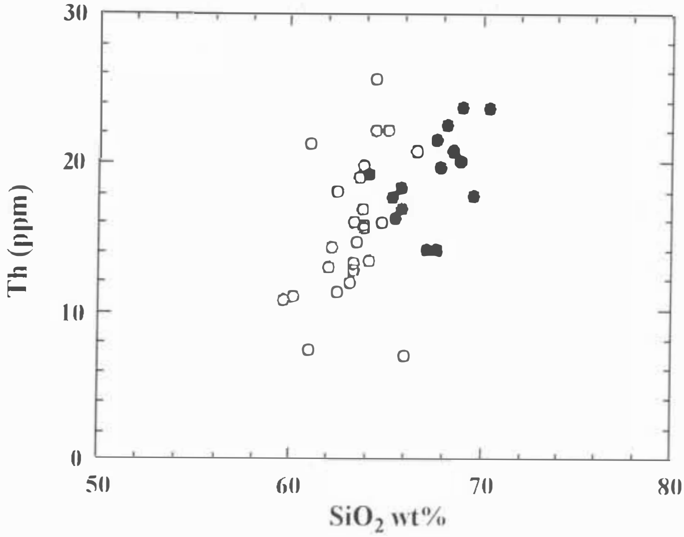

FIG. 10. Variation diagram of Th and SiO_2 for the Blatná and the Červená types. Empty circles — the Červená type, full circles — Blatná type.

hypothesis of isochemical granitization for origin of the whole CBPC from various older protoliths. After this theory granitoids of the high–potassium suite originated from volcanoclastic rocks of the Jílové zone and Moldanubian zone. Theory of a metasomatic granitization ignores some important geological observations like the intrusive contacts and enclaves of the mantle–derived rocks in the granitoids of the Červená Červená type and homogeneity of great volumes of monzogranites to granodiorites of the Blatná type.

On the other side some authors, who supposed a magmatic origin granitoids of the Červená type (Kodym and Suk, 1958; Malecha, Suk and Vachtl, 1960), regarded granitoids of the Červená type as a marginal facies of the Blatná type. On a diagrams of distribution the incompatible elements (Rb, Zr, Th) (Fig. 10, 11, 12) we can see that both granitoid types build independent groups in common suite of the high potassium granitoids. Incompatible element patterns of the Červená and Blatná types suggest the independent fractionation of both rock types.

6. CONCLUSION

Granitoids of the Červená type represent an independent rock type in the suite of the high potassium granitoids occurring within the CBPC. By their age they belong to the group of Early Carboniferous Variscan magmatites of the Bohemian Massif. Based on their mineral and chemical composition they can best be assigned to the group of hybrid granites in the sense of Castro et al. (1991). They are characterized by aluminium saturation index as transitional I/S granites. The most plausible

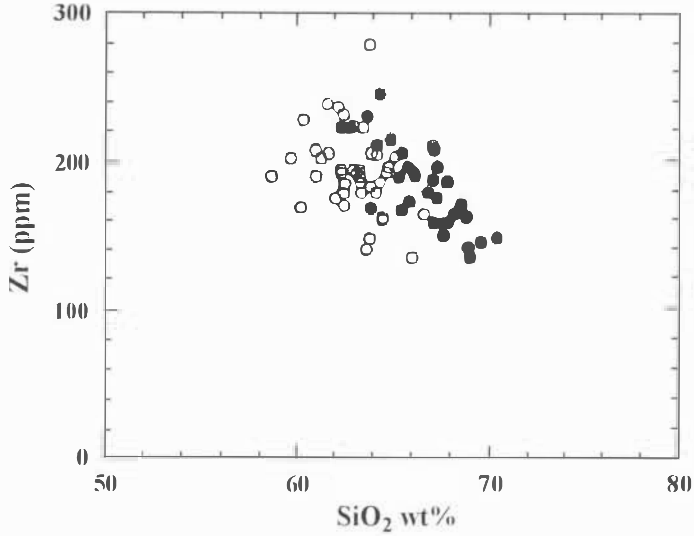

FIG. 11. Variation diagram of Zr and SiO_2 for the Blatná and the Červená types. Symbols as in Fig. 10.

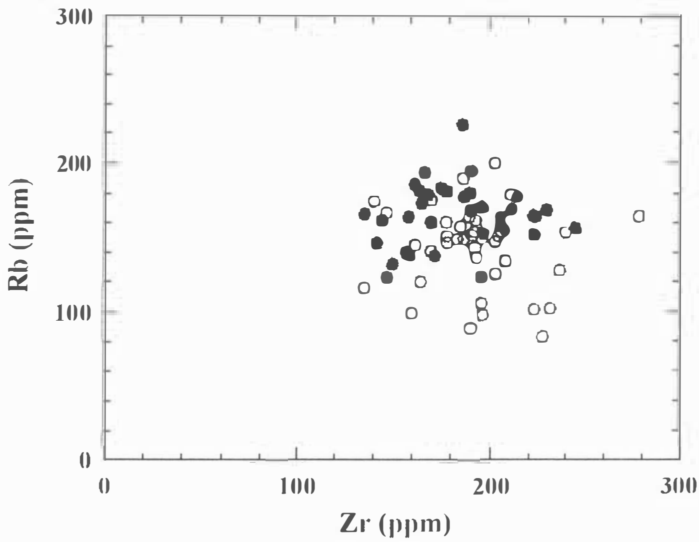

FIG. 12. Variation diagram of Rb and Zr for the Blatná and the Červená types. Symbols as in Fig. 10.

model for their origin is mixing of mantle derived high–potassium magmas with some upper crust magmas and assimilation with metavolcanics and metasediments of the upper crust. Based on the distribution of the individual components, first of all distribution of incompatible elements theories about metamorphic mobilization and in situ granitization must be regarded as less possible.

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PETROGENEZE GRANITOIDŮ ČERVENSKÉHO TYPU (STŘEDOČESKÝ PLUTONICKÝ KOMPLEX)

Miloš RENÉ

Granitoidy červenského typu jsou součástí složitého magmatického komplexu variského stáří, který vyplňuje duktilní střižnou zónu na rozhraní bohemika a moldanubika. Granitoidy výše uvedeného typu se vyskytují na jižním a jihovýchodním okraji středočeského plutonického komplexu (CBPC), který svým složením představuje jedno z nejvíce diferenciovaných magmatických těles variského stáří na území Českého masivu. Na styku s rulami a migmatity moldanubika jsou granitoidy červenského typu často usměrněné paralelně s průběhem rozhraní obou jednotek. Vzhledem k tomu, že někdy plynule přecházejí do granitoidů typu Blatná, jsou granitoidy typu Červená některými autory považované za okrajovou facii výše zmíněného typu. Granitoidy typu Červená vytvářejí obvykle 2–10 km široký pruh, který vyplňuje dvě apofýzy na jihozápadním okraji CBPC, apofýzu kolineckou a matkobožskou, které se spojují ve výraznou chanovickou apofýzu. Na styku s granitoidy typu Červená je v moldanubiku vyvinuta zóna perlových rul a migmatitů. V některých místech obsahují granitoidy typu Červená bazické pecky tvořené biotiticko–amfibolickými diority, monzonity a vzácně melasyenity.

Strukturní vývoj jižní části středočeského plutonického komplexu je ovlivněný rovněž mladší disjunktivní tektonikou V–Z, SZ–JV a S–J směru. Struktury V–Z směru jsou zdůrazněny výplní žilných hornin (lamprofyry, porfyry, aplity a pegmatity). Výskyty a drobná ložiska uranové mineralizace vyplňují S–J struktury, které jsou někdy vyplněny rovněž čistě křemennou mineralizací.

Z terénních pozorování vyplývá, že granitoidy typu Červená a Blatná jsou starší než melagranity a melasyenity typu Čertovo břemeno. Přechody mezi typy Červená a Blatná jsou často pozvolné, byly však zjištěny i ostré kontakty obou typu.

Granitoidy typu Červená jsou zastoupené obvykle středně až hrubě zrnitými, někdy nevýrazně porfyrickými granodiority až tonality, přičemž některé planimetrické analýzy ukazují rovněž na přítomnost monzogranitů, křemenných monzonitů, křemenných monzodioritů, křemenných dioritů a monzonitů. Tmavé minerály jsou zastoupené biotitem, amfibolem (obecný amfibol, aktinolitický amfibol), vzácně klinopyroxenem. Bazicita plagioklasu se pohybuje v širokém rozmezí (An_{22-40}) s největším množstvím hodnot v rozmezí An_{30-37}. Akcesorické minerály jsou zastoupené zirkonem, allanitem, titanitem a někdy rovněž scheelitem.

Průměrná hodnota poměru A/CNK 1.01 je řadí k metaaluminním granitům, které lze v souladu s klasifikací Chappella a Whiteho (1974) přiřadit k I-granitům. V diagramu Batchelora a Bowdena (1985) padají granitoidy typu Červená na rozhraní kolizních granitů a postkolizních granitů. Díky vyšším obsahům draslíku lze tyto granitoidy přiřadit k draslíkem bohatým vápenato-alkalickým nebo shoshonitovým horninám. Z hlediska distribuce Rb, Ba a Sr patří granitoidy typu Červená k slabě diferenciovaným granitům. V diskriminačním diagramu podle Pearceho et al. (1984) náležejí granitoidy typu Červená ke granitům vulkanických oblouků. Výraznější diferenciace tohoto typu granitoidů se projevuje v distribuci Zr a TiO_2. Podobně jako u typických metaaluminních granitů je pro granitoidy typu Červená typická záporná korelace mezi obsahy SiO_2 a obsahy P_2O_5, Zr a Ba. Pozitivní korelace mezi obsahem U, Th a SiO_2 naznačuje přednostní vazbu U a Th na allanit, který zřejmě krystaloval v závěru chladnutí granitové taveniny.

Distribuce REE vykazuje vyšší hodnotu poměru La_N/Yb_N a negativní europiovou anomálii. Svým chemickým složením jsou granitoidy typu Červená blízké monzogranitům až granodioritům typu Blatná. Na základě hodnoty poměru A/CNK je lze přiřadit k I-granitům nebo lépe k I/S přechodným granitům. S ohledem na klasifikaci granitoidů navrženou Castrem et al. (1991) lze granitoidy typu Červená přiřadit k hybridním H-granitům, resp. k subtypu H_{ss}, které představují typické hybridní granity. Na druhé straně distribuce inkompatibilních prvků (Rb, Zr, Th) naznačuje, že granitoidy typu Červená představují samostatný horninový typ a nelze je považovat za okrajovou facii monzogranitů až granodioritů typu Blatná. Z hlediska modelů vzniku granitoidů lze pro typ Červená považovat za nepřijatelnější model vzniku mísením původně plášťových, draslíkem bohatých magmat se svrchně korovými granity doprovázené asimilací svrchně korových metavulkanitů a metasedimentů. Někdy uvažované teorie o vzniku těchto granitoidů prostřednictvím metamorfní mobilizace a granitizace in situ lze považovat za méně pravděpodobné.