Žulová Batholith: a post-orogenic, fractionated ilmenite – allanite I-type granite

Žulovský batolit: postorogenní, frakcionovaný ilmenit-allanitový I-typový granit.

(5 figs, 4 tabs)

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The major-element chemistry as well as mineralogy indicate that Žulová Batholith could be classified as a fractionated I-type granite. The interpretation of gravity data indicates a fair homogeneity of the batholith. The less fractionated amphibole – biotite tonalites and granodiorites form enclaves with remarkable cumulate textures. They are enriched in HFSE and REE as a consequence of crystal accumulation of allanite, apatite, ilmenite and titanite, their feldspar shows a rather simple internal fabric in CL. The more fractionated biotite granites constitute substantial part of the batholith. The enrichment in LILE and depletion in HFSE and REE corresponds to higher content of K-feldspar and lower amount of accessory phases. Feldspars exhibit complex internal fabric in CL, indicating a major role for feldspar fractionation in the evolution of the batholith, as does the pronounced negative Eu anomaly and higher K/Ba ratio. The emplacement of the batholith was probably related to the Westphalian extensional tectonics. The Upper Carboniferous and lower Permian extension seems to have been generally of great importance for magmatic history of the eastern margin of Bohemian Massif, as manifested in the Boskovice Furrow, where the extensional tectonics connected with magmatic activity could be also documented.

Key words: Žulová Batholith, Petrology, Chemistry, Cathodoluminescence, Gravity

1. Introduction and geological setting

Variscan granites are widespread in the Bohemian Massif. Large progress was achieved in the understanding of the evolution and interpretation of the individual batholiths in the last few years (Finger *et al.* 1997, Holub 1997, Breiter *et al.* 1999, Janoušek *et al.* 2000, Kloetzli *et al.* 2001 and many others). But disregarding very intense research activity in the field of granite petrology, some batholiths still remain more or less enigmatic. The Žulová Batholith is an example of a comparatively large body, which lacks even basic petrological data.

Žulová Batholith forms a triangular body approximately 20 km across at the northeastern margin of the Bohemian Massif, close to the Czech-Polish border. Tertiary and Quaternary sediments cover the northern and western parts of the batholith. Eastern contact to the Devonian Velké Vrbno Group is intrusive. The southern contact to the Branná and Staré Město groups is formed by the Marginal Sudetic Fault (Figs 1, 2). But common xenoliths of carbonate rocks, gneisses and amphibolites derived from both groups indicate that the primary nature of the southern contact was intrusive. Some observations (Buday *et al.* 1995) indicate even a recent activity of the Marginal Sudetic Fault.

Based on the structural and petrological analyses of the country rocks, Cháb – Žáček (1994) documented a forcefull diapiric emplacement of the batholith, and its profound thermal influence on the host rocks. Souček (1987) estimated the peak conditions of contact metamorphism at 650–680 °C at 5 kbar, Losos – Hladíková (1988) at 560–730 °C at 3–5 kbar. The outcropping part of the batholith is connected with negative magnetic and gravimetric anomalies, and with slightly positive radiometric (total gamma activity) anomaly. The Ar-Ar geochronological data (Maluski *et al.* 1995) on amphibole (292 ± 3 Ma) and biotite (290 ± 3 Ma) from granites and U-Pb data on monazite from a pegmatite vein (304 Ma) Novák *et al.* (submitted) indicate, that the Žulová Batholith ranks among to the youngest granite intrusions in the Bohemian Massif.

The modern petrological data about Žulová Batholith are infrequent. Musilová (1962) described the main petrographic rock types. Some interpretations were given by Jedlička (1997). In this short report, there was no room for primary data. Therefore the assessment of his conclusions, some of them controversial, is difficult or impossible. Jedlička (1997) interpreted the granites as a typical I-type or magnetite-series batholith. But the granites do not contain magnetite (Hrouda *et al.* 2001, Chlupáčová pers. com). Instead, ilmenite, typical for S-type granites, is very common. The typical large S-type batholiths in the Bohemian Massif like South Bohemian or Karlovy Vary Batholiths are accompanied by pronounced negative gravimetric anomalies. The granitoid complexes with distinct I-type affinity (like Central Bohemian or Nasavrky batholiths) are characterized by a positive anomaly indicating presence of dense rocks at the depth.

We bring some petrological, geochemical and geophysical data that enable us to describe and classify the main rock types. Despite the fact that our data set is limited,

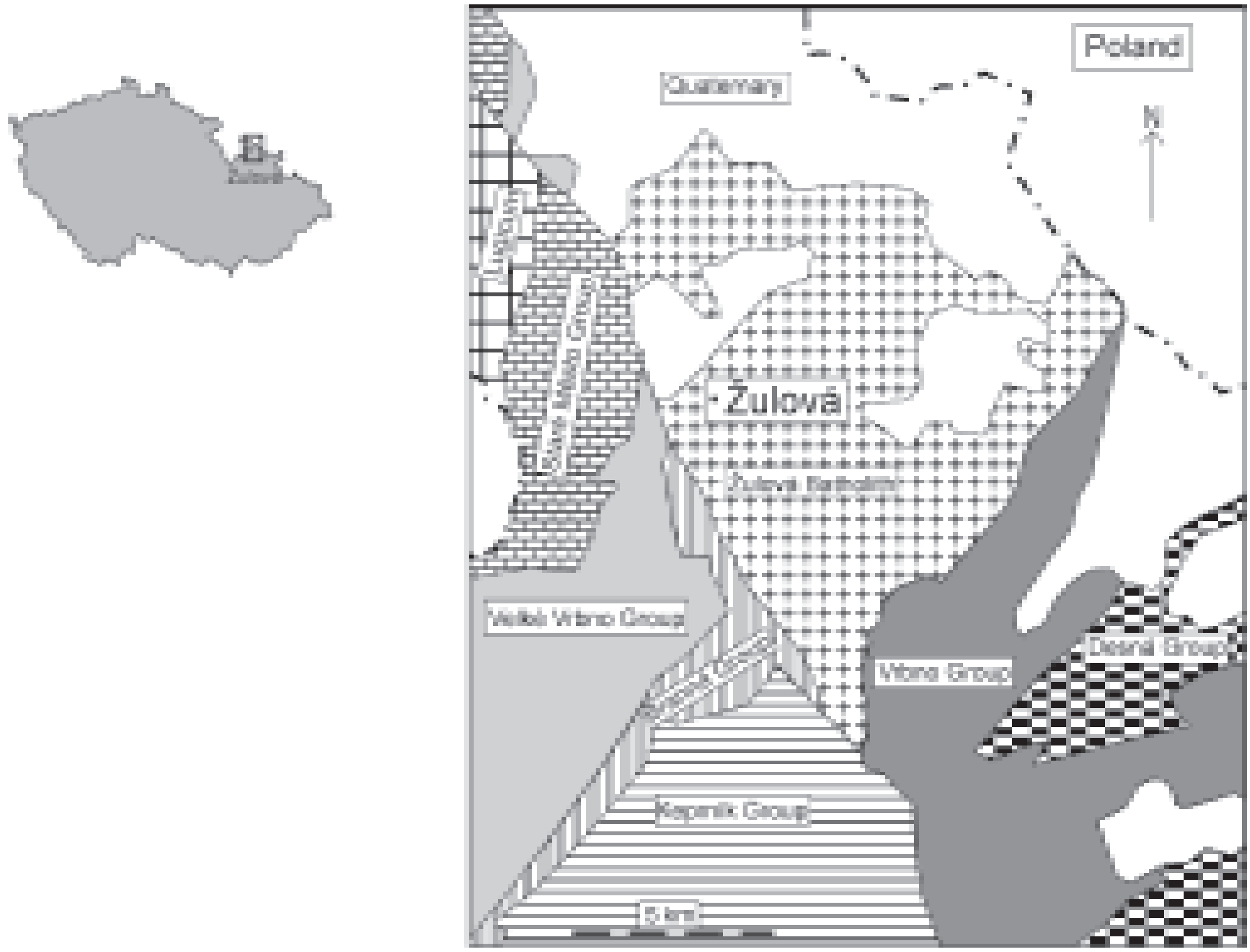


Fig. 1 Simplified geological map of the Žulová batholith

we try to identify main processes that controlled the evolution of the batholith. Electron microprobe analyses of minerals were carried out on the CamScan 4DV instrument with EDX AN 10 000 analysator, in the energy-dispersion mode at the Department of Mineralogy, Petrology and Geochemistry, Masaryk University, Brno. Data were reduced using the ZAF-4 corrections. The samples were analysed using cathodoluminescence equipment with hot cathode HC2-LM, Simon Neuser, Bochum, accelerating voltage 14 kV, beam density 10 $\mu A/mm^2$. Photographic documentation was taken on Fujichrome multispeed positive film and developed at 800 ASA. Whole-rock chemical analyses were performed in the ACME Laboratories, Vancouver, Canada by ICP – ES (major elements) and ICP – MS (trace elements).

2. Gravity

The studied area was covered by detailed gravity measurments in 1985 and 1986. The gravity survey and data processing was performed by Geofyzika Brno (Rychtár – Rybák 1986). The Bouger anomaly map of the Žulová Batholith shows negative gravity anomaly of triangular shape. From ESE the anomaly is delineated by 4 km wide gravity gradient accompanying the Červenohorské sedlo thrust system. The SW margin of this anomaly is marked by many narrower gravity gradients following the Lusatian boundary fault. To isolate the gravity anomaly of the Žulová Batholith we calculated the residual gravity map shown in Fig. 2. High pass Butherworth filter with the central wavelength 20 km was applied. The residual gravity map shows near isometric gravity low among Žulová, Jeseník and Supíkovice with the amplitude 3.6 mgal. In the residual gravity map this anomaly is not closed, but shows pronounced elongation to the SW. This means that the Žulová Batholith (or some other body with negative density contrast) continues beneath the Keprník lower allochton to the SW.

Preliminary estimate of the depth to the center of gravity of the Žulová Batholith range from 3.3 to 5.0 km. The maximum depth increases and is expected 5 km SE of Žulová. The shape of the residual gravity anomaly does not support the idea that the batholith could be composed of several parts of contrasting density. These results are in very good agreement with the gravity modeling performed by Rychtár *et al.* (1991). They modeled the granites of Žulová Batholith as a body of the density 2650 kg/m^3 and thickness 6 km.

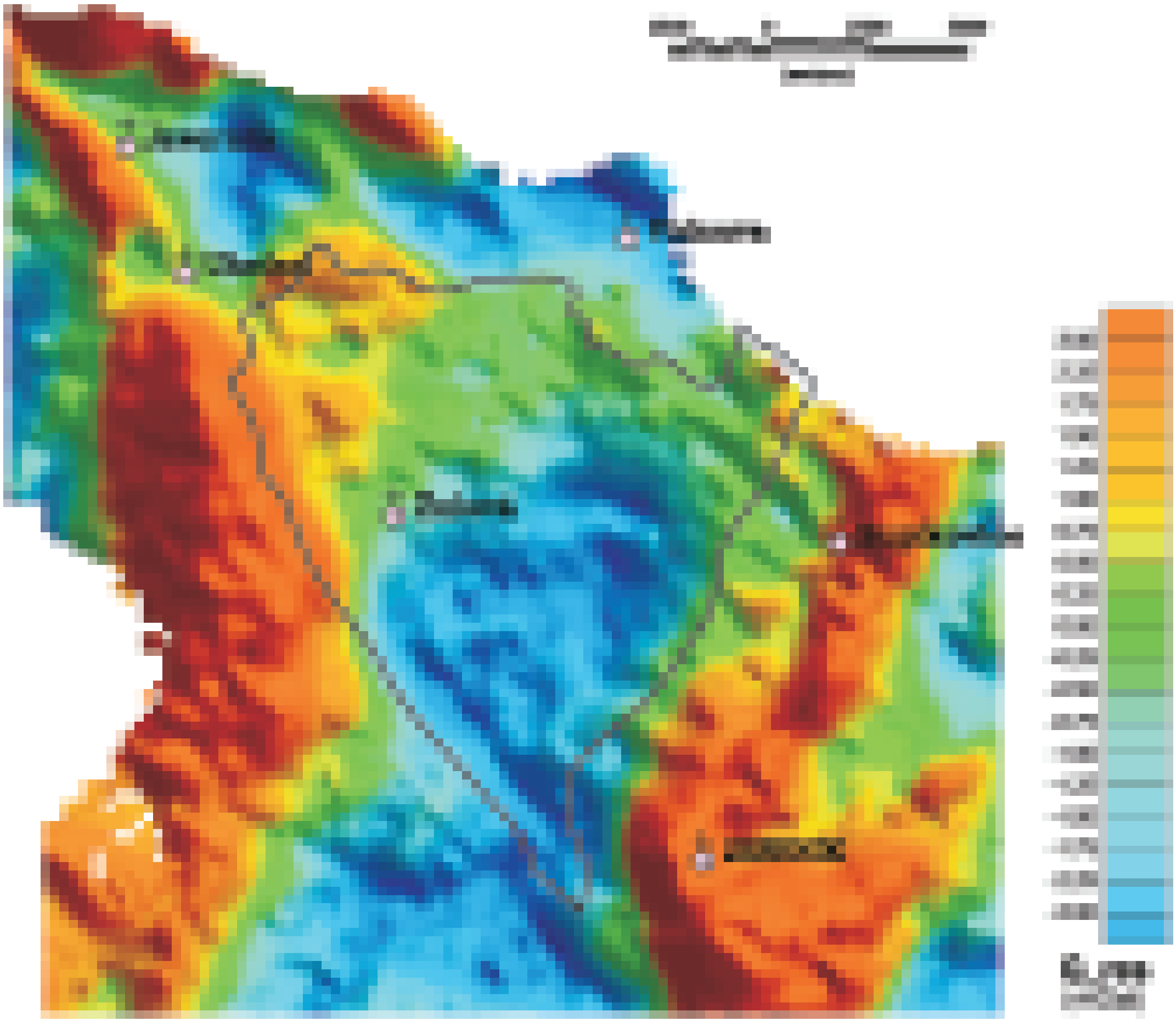


Fig. 2 Colour shaded-relief residual gravity map with an outline of Žulová Batholith. Illuminated from the north, contour interval 0.5 mgal

3. Petrology

Two main lithologies were distinguished within the pluton – mafic enclaves and granites.

3.1 Mafic enclaves

Mafic rocks form small bodies up to 200 m long enclosed in granites mainly in the southern part of the batholith (Musilová 1962, Jedlička 1997). The mafic enclaves are heterogeneous, they range from tonalites to melagranodiorites. More mafic rock types (eg. diorites or monzodiorites) are voluminously less important, forming only small layers in the prevailing tonalites. Our samples come from the quarry at Kaní Hora (Hutberg).

3.1.1 Tonalites

Tonalites form irregular bodies, up to tens of meters long. The contacts with host granite are mainly transitional, sharp ones are rare. The tonalites are melanocratic (M 40–50) medium-grained rocks consisting of subhedral to euhedral plagioclase and amphibole, subhedral to anhedral K-feldspar, biotite and quartz. Ilmenite with titanite rim is the most common accessory phase. Apatite forms needles, up to 2 mm long, around vol. 1 % (Fig. 3c). Zircon, xenotime and allanite are other common accessories. Homogeneous biotite (xMg=MgO/FeO+MgO = 0.31, Tab. 3) locally replaces amphibole at the rim and along the cleavage.

Plagioclase is simply continuously zoned under CL (Fig. 3b). The central part of the grain exhibits bright blue CL (An 58, Tab. 2) which continuously decreases towards the rim (An 48). The most outer part of the grain has a dull blue CL (An 21). Some domains of the grain were affected by alteration that changed primary blue CL to brown. Similar zoning is typical for K-feldspar. The central bright blue zone is slightly richer in Ba (0.6 % BaO) than the darker zone at the rim (0.4 wt %, Tab. 2, Fig. 3a). Amphibole corresponds to ferrohornblende (Leake *et al.* 1997, Tab. 4).

The melatonalites are heterogeneous. The inhomogeneity is caused mainly by irregular distribution of mafic minerals and variation in grain size. We found fre-

Table 1 Whole rock chemical analyses

	1	2	3	4	5
SiO_2	66.2	57.3	74.0	74.5	74.4
TiO_2	1.1	1.7	0.3	0.3	0.3
Al_2O_3	14.7	15.1	12.9	12.3	13.0
Fe_2O_3	5.5	9.0	2.3	2.2	2.3
MnO	0.1	0.2	0.0	0.0	0.1
MgO	1.2	3.4	5.7	0.5	0.4
CaO	3.8	5.7	1.5	1.2	1.9
Na_2O	3.6	3.2	3.1	2.9	3.3
K_2O	2.7	2.1	4.6	5.3	3.7
P_2O_5	0.2	0.7	0.1	0.1	0.1
LOI	0.6	0.7	0.6	0.6	0.4
Total	99.7	99.7	99.9	99.8	99.9
Sc	14.0	16.0	5.0	5.0	4.0
V	89.0	106.0	24.0	16.0	25.0
Co	10.3	23.8	3.5	2.8	3.7
Ni	30.0	73.0	35.0	212.0	nd
Ga	21.4	22.2	18.6	18.9	19.0
Rb	105.8	58.5	154.9	183.3	116.8
Sr	273.4	393.2	159.0	137.4	210.9
Y	45.1	46.9	29.0	31.5	27.6
Zr	349.3	420.2	199.7	237.1	198.1
Nb	25.0	42.3	17.2	20.5	14.8
Cs	2.4	1.4	1.7	3.4	2.4
Ba	755.0	673.0	751.0	720.0	568.0
Hf	9.2	10.3	6.3	6.9	6.6
Ta	2.2	3.0	1.8	2.1	2.6
Tl	0.4	0.2	0.5	0.7	0.4
Th	22.3	7.2	18.6	18.6	13.4
U	3.7	3.1	2.8	2.3	2.6
La	107.0	58.7	45.9	54.2	35.5
Ce	194.7	126.5	92.1	110.4	73.5
Pr	21.4	16.7	10.5	12.9	8.5
Nd	70.9	66.2	36.3	43.3	31.2
Sm	12.0	12.3	7.4	7.7	6.3
Eu	1.8	3.0	0.8	0.8	1.0
Gd	9.3	9.8	5.6	5.7	4.7
Tb	1.4	1.5	0.9	0.9	0.7
Dy	8.2	8.8	5.0	5.3	4.7
Ho	1.8	1.8	1.0	1.2	0.9
Er	5.0	5.3	3.1	3.4	3.0
Tm	0.7	0.6	0.4	0.5	0.4
Yb	4.2	4.4	3.1	3.2	3.4
Lu	0.6	0.7	0.5	0.4	0.5

1, 2 – mafic enclave; 3, 4, 5 – granite

quent domains, strongly enriched in mafic minerals (up to 75 %). The mafic nests and 0.5 m thick layers of dioritic composition become gradually more felsic and are finally surrounded by coarse-grained layers, poor in mafic minerals (M – 20 %). Nests are rich in ilmenite and secondary titanite, amphibole, biotite and apatite; plagioclase was found as the only felsic mineral in the mafic facies. The felsic facies (dominated by plagioclase) is coarser-grained relative to common medium-grained tonalite. Apart from mafic minerals (ilmenite, amphibole, biotite, apatite), quartz and K-feldspar are present. We interpret this structure as mafic cumulate originated as a consequence of gravity settling of mafic minerals.

3.1.2 Granodiorites

The granodiorite enclaves are lighter (M ~ 20) and finer grained compared to diorites. The mineral composition is identical to tonalites, but the proportions of the minerals are different. Granodiorites are richer in K-feldspar and poorer in amphibole, biotite, ilmenite, and titanite. Biotite is rarely replaced by chlorite, the An-rich zones in plagioclase are altered to prehnite. Apatite (in small short prismatic crystals or grains, ~ 0.3 mm long) contents are significantly lower then in tonalites (Fig. 3f). Subhedral, zoned and metamict allanite grains, up to 1.5 mm across are more abundant than in tonalites and granites.

3.2 Granites

Granites form dominant part of the batholith. They were formerly divided into the fine- and coarse-grained types (Krystek – Harazim 1956), main and marginal types (Musilová (1962) or alkali feldspar granites and syeno- to monzogranites (Jedlička 1997). We did not systematically map the whole batholith, but observed that variation in the mineral composition and structure is relative-

Table 2 Representative electron microprobe (EMP) analyses of feldspars

	1	2	3	4	5	6	7	8	9
SiO_2	63.8	62.4	62.0	55.5	53.0	63.5	63.7	63.2	63.4
Al_2O_3	22.3	22.9	23.2	27.6	29.2	18.3	18.3	18.4	18.4
CaO	3.2	4.7	4.5	9.9	11.9	0.0	0.0	0.0	0.0
Na_2O	10.0	9.4	9.5	6.3	5.1	0.6	0.6	1.1	0.7
K_2O	0.0	0.2	0.0	0.0	0.0	17.1	16.4	16.0	16.5
BaO	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.6	0.4
FeO	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0
Total	99.3	99.6	99.2	99.6	99.2	99.4	99.5	99.3	99.5
	Number of atoms based on O = 8								
Si	2.8	2.8	2.8	2.5	2.4	3.0	3.0	3.0	3.0
Al	1.2	1.2	1.2	1.5	1.6	1.0	1.0	1.0	1.0
Ca	0.1	0.2	0.2	0.5	0.6	0.0	0.0	0.0	0.0
Na	0.9	0.8	0.8	0.6	0.4	0.1	0.1	0.1	0.1
K	0.0	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.0
Σ *apfu*	5.0	5.0	5.0	5.0	5.0	5.1	5.0	5.1	5.0

Plagioclase: granite:1 – rim, 2 – core; tonalite: 3 – rim, 4 – intermediate zone, 5 – core
K-feldspar: granite: 6 – rim, 7 – core; tonalite: 8 – core, 9 – rim

ly low and the previously defined types seem to be closely related to each other. The differences between the types could be explained as a product of a different degree of fractionation, crystal accumulation, different conditions of cooling or assimilation of single parental magma. Granite consists of quartz, K-feldspar, plagioclase, biotite, accessory allanite, apatite, zircon and rare monazite.

Both feldspars are complexly oscillatory zoned in CL. Fig. 3e shows a CL photograph of a plagioclase grain. The well-preserved zoning is visible in the lower left corner. The green yellow zones are richer in anorthite (An 23), the blue zones are more albitic in composition (An 15, Tab. 2). Thin, primary An-rich zones, situated in the central part of crystal are replaced by prehnite with bright yellow or brown CL. More complex fabric was found in the K-feldspar (Tab. 2, Fig. 3d). The central part of the grain exhibits chaotic, probably secondary disturbed zoning. The core is surrounded by a few concentric zones, which exhibit their own individual zoning with a bright blue CL at the base of the zone and somewhat darker blue CL at the top. Elevated concentration of Ba (up to 0.4 wt % BaO, Tab. 2) is typical for the zones with bright CL, whereas the dark zones are almost Ba free. We interpret the observed zoning of both feldspars as a product of fractional crystallization. Biotite has lower xMg (0.17) and is TiO_2 poor (Tab. 3) compared to that from tonalites.

4. Chemistry

The SiO_2 contents display broad variation from 57 to 74 wt % (Tab. 1). The rocks are metaluminous, following a calc-alkaline trend in the AFM diagram (Fig. 4). SiO_2 correlates negatively with TiO_2 (1.7–0.3 wt %), Al_2O_3 (15.1–12.3 wt %), Fe_2O_3 tot (9.0–2.2 wt %), MgO (5.7–0.4 wt %), CaO (5.7–1.2 wt %), P_2O_5 (0.7–0.1 wt %), and xMg. Correlation with K_2O and Na_2O is not equivocal. Positive correlation between K/Ba ratio and SiO_2 was observed, whereas Sr/Rb ratio vs SiO_2 plot displays negative correlation (Fig. 4). The mafic enclaves are enriched in HFSE, REE and Fe and Mg relative to granites. Higher concentration of HFSE and REE elements in the mafic enclaves corresponds well with the observed high contents of zircon, apatite, ilmenite, titanite, xenotime and allanite (Schitter – Finger 1997, Dahlquist 2001). Similarly, following data indicate the highest concentration of the element in mafic enclaves and lowest concentration in granite. Zr (420–198 ppm), Nb (42–15 ppm), Y (47–28 ppm), Hf (10.3–6.3 ppm), Σ REE (439–174, Table 1).

Normalized REE and trace-element patterns are given in Fig. 5. The tonalites have flat REE patterns with very weak Eu anomalies. They exibit highest concentration of HREE. This is in a good agreement with established highest concentration of zircon, titanite and xenotime (Bea 1996, Schitter – Finger 1997). Granodiorites exhibit more pronounced negative Eu anomalies. They are strongly enriched in LREE, which corresponds well with the highest concentration of allanite (Bea 1996). Granites are generally depleted in both LREE and HREE and display well-developed negative Eu anomaly.

The spider plots (Fig. 5) document very similar patterns for REE and HFSE. However, on the left hand side in the area of LILE and radioactive elements less clear order was found. The granites are generally enriched in Cs, Rb and K. But the concentration of K and, to a lesser extent, Rb and Cs, might be influenced by locally developed chloritization of biotite. The concentrations of U and Th were probably affected during the metamictization of allanite and zircon.

5. Discussion and conclusions

The negative correlation between SiO_2 and xMg, and Sr/Rb ratio, but positive correlation SiO_2 – K/Ba (Fig. 4), as well as increase in the magnitude of negative Eu anom-

Table 3 Representative EMP analyses of biotite from granite

	1	2	3	4
SiO_2	35.1	34.8	35.4	36.3
TiO_2	3.3	3.8	4.6	4.4
Al_2O_3	15.2	14.7	14.4	14.6
FeO	26.7	27.1	21.2	21.3
MgO	5.8	5.6	9.5	9.8
K_2O	10.3	9.9	9.5	9.7
Total	96.8	96.4	95.1	96.6
Number of atoms based on O = 22				
Si	5.5	5.5	5.5	5.5
Ti	0.4	0.5	0.5	0.5
Al	2.8	2.7	2.6	2.6
Fe^{2+}	3.5	3.6	2.8	2.7
Mg	1.3	1.3	2.2	2.2
K	2.1	2.0	1.9	1.9
Σ *apfu*	15.7	15.7	15.6	15.7

granite: 1 – rim, 2 – core;
tonalite: 3 – rim, 4 – core

Table 4 Representative EMP analyses of amphiboles

	1	2
SiO_2	47.4	48.0
Al_2O_3	6.1	5.5
FeO	17.9	17.6
MnO	0.4	0.4
MgO	10.9	11.3
CaO	11.8	11.9
TiO_2	0.9	0.9
K_2O	0.5	0.6
Na_2O	<0.3	<0.3
Cl	<0.5	<0.5
Total	96.0	96.2
Number of atoms based on O = 23		
Si	7.2	7.3
Al	1.1	1.0
Fe	2.3	2.2
Mn	0.1	0.1
Mg	2.5	2.5
Ca	1.9	1.9
Ti	0.1	0.1
K	0.1	0.1
Σ apfu	15.2	15.2

tonalite 1 – core, 2 – rim

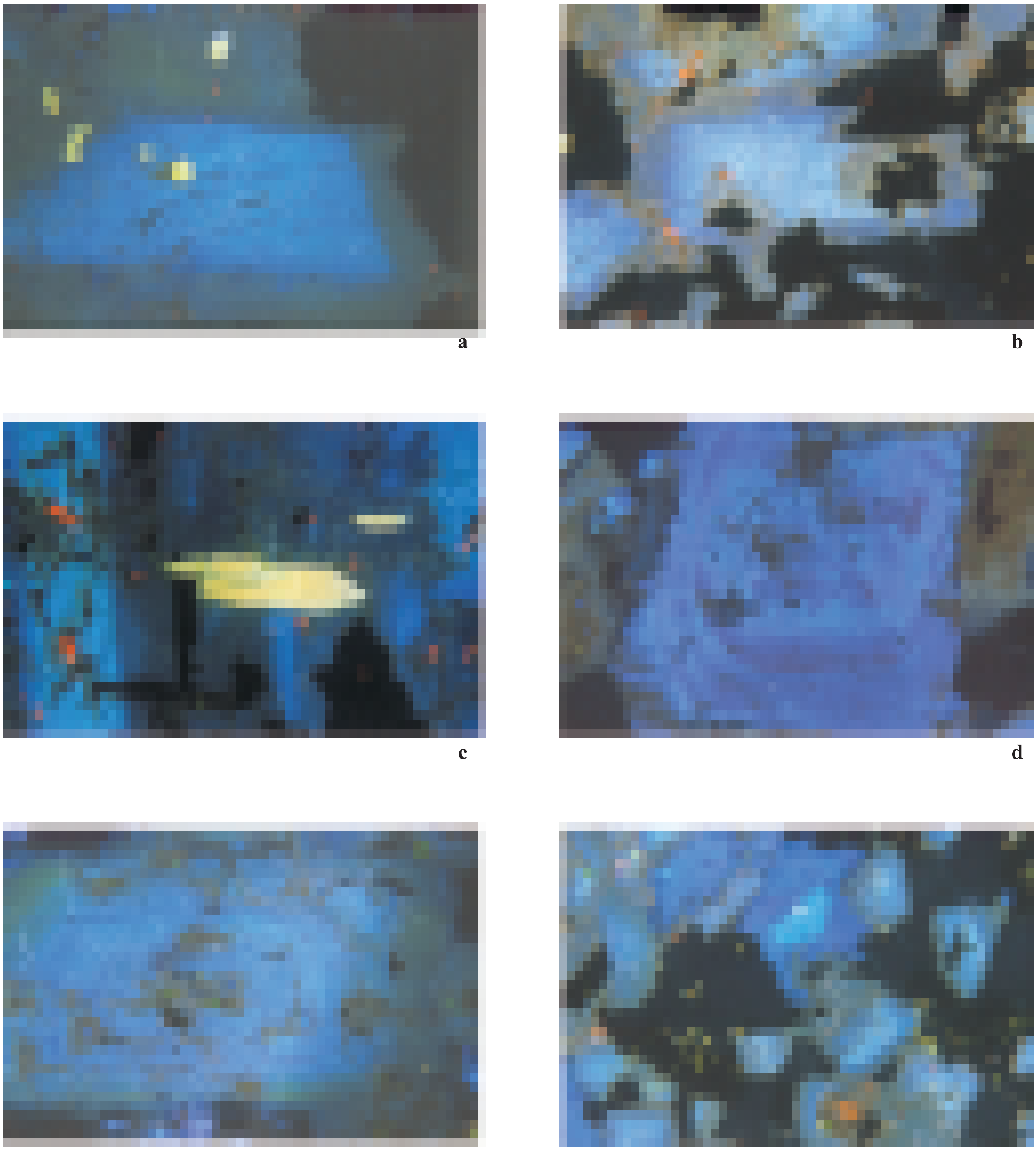


Fig. 3 a–c: tonalites; d–e: granites

a – slightly zoned K-feldspar. The bright blue central part is enriched in BaO (0.64 wt %), whereas the green-blue margin is BaO poor (0.39 wt %). The yellow inclusions are apatites.

b – continuously zoned plagioclase. The central part with bright blue CL correspond to labradorite (An 58), the intermediate zone (An 48) exhibits dull blue CL. Oligoclase (An 21) with brown-blue CL was detected at the rim of the grain. The small orange grains are secondary carbonates

c – large zoned apatite with yellow-grey core and bright blue rim typical of tonalites.

d – oscillatory zoned K-feldspar. The zones with light blue CL are enriched in BaO (0.43 wt %), whereas the zones with dull blue CL are almost Ba free. The areas in K-feldspar, which show week CL or are non-luminescent, were affected by secondary haematitization.

e – oscillatory zoned plagioclase. The primary zoning is visible at the bottom-right corner of the photograph. The zones with brighter blue CL are generally enriched in anorthite component (up to An 23) compared to the darker one. The yellow-green margin corresponds to albite. The brown and yellow flakes within the grain are prehnites. Note, that tha alteration affects preferentially the An rich zones.

f – small apatites (yellow CL) enclosed in biotite (non-luminescent). Light blue plagioclases prevail over the dark blue K-feldspars.

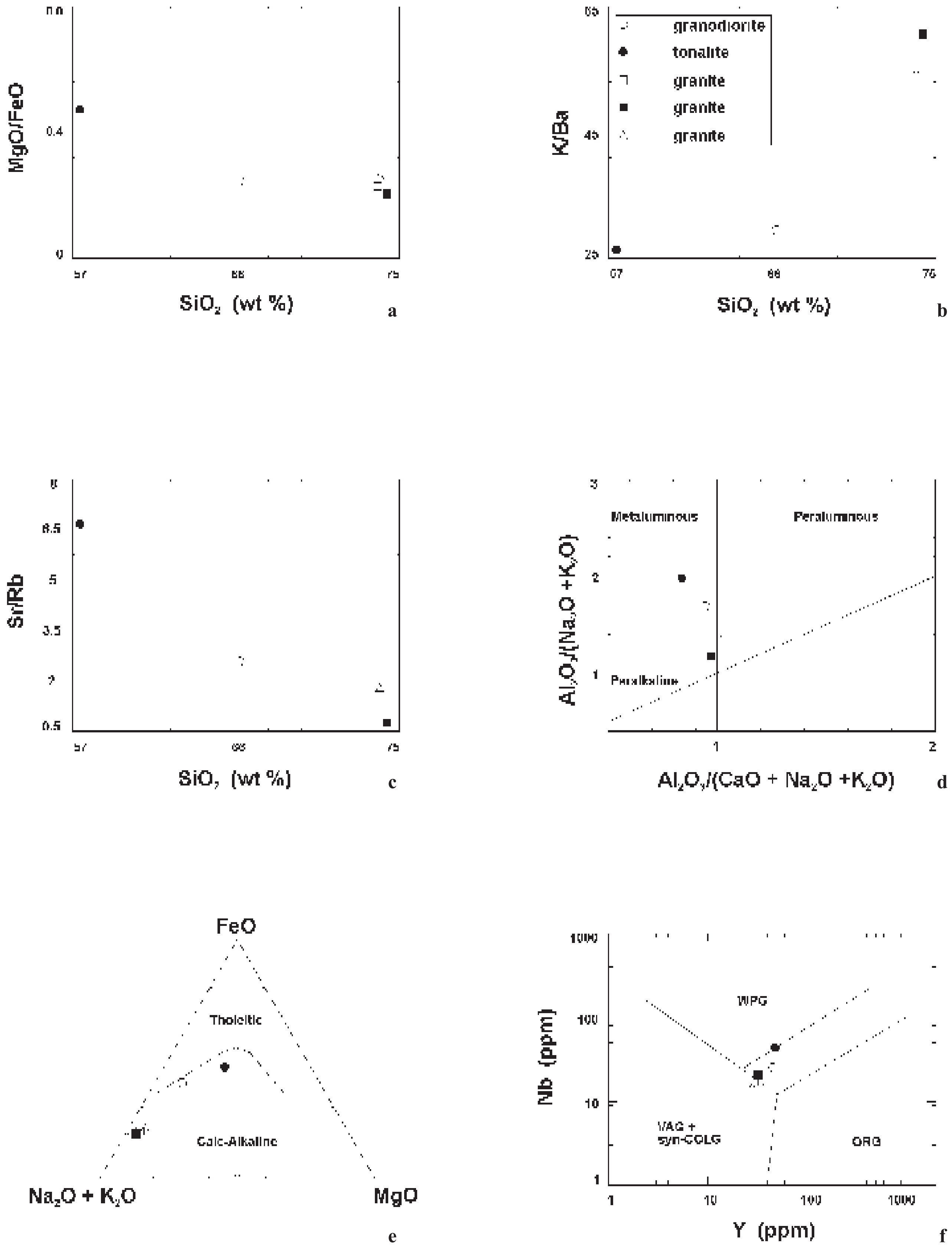


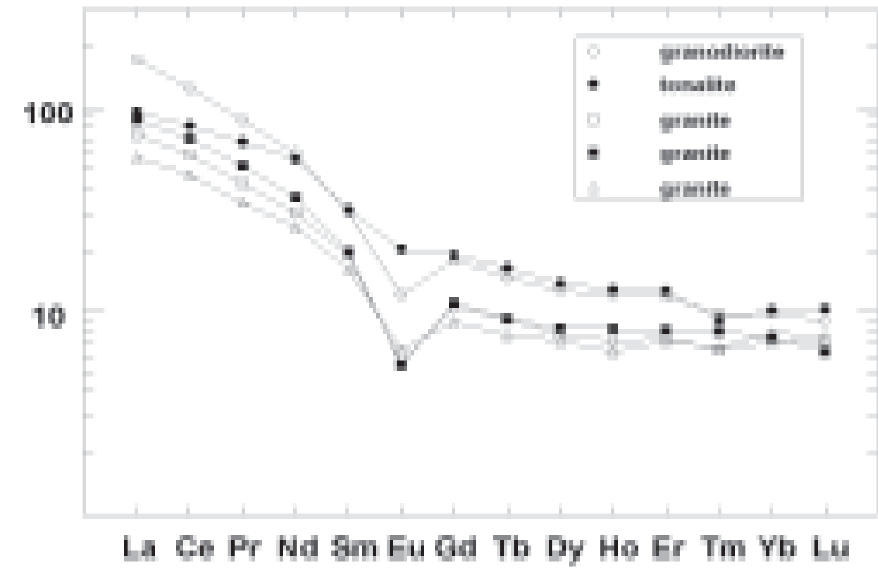
Fig. 4 a – MgO/FeO vs. SiO_2 diagram, b – K/Ba vs. SiO_2 diagram, c – Sr/Rb vs SiO_2 diagram, d – A/CNK diagram, e – AFM diagram, f – Nb-Y diagram according to Pearce *et al.* (1984). For symbols see Fig. 4b.

aly with SiO_2 indicate a substantial role of fractionation processes in the evolution of Žulová Batholith. The whole-rock geochemical data are supported by the compositional evolution of individual minerals: Biotites from granites have much lower xMg, compared to those from tonalites. K-feldspar from tonalites is richer in Ba, and contemporaneously K-feldspars from granites exhibit much more complex internal structure, documenting a role of fractionation (Shore – Fowler 1996). Plagioclase from granites has a similar complex structure and is more albitic in composition than plagioclase from tonalites.

But the observed cumulate structures affecting the mafic minerals and some accessory minerals eg. apatite, biotite, titanite, zircone, allanite and xenotime indicate that processes of crystal accumulation played an important role in the earliest stages of the evolution. Therefore we interpret the mafic enclaves as cumulates (Didier – Barbarin 1991, Best – Christiansen 2001), or orthocumulates (Shelley 1997), which were trapped and disrupted by granitic melt. The accumulation of accessory minerals controlled the distribution of REE and HFS elements. Cumulates are strongly enriched on REE, Y, Zr, Nb, Ti and P, and granites are depleted in these elements. The genetic interpretations of tectonic diagrams like the Y/Nb plot (Pearce *et al.* 1984, Fig. 4) seem to be misleading because Y and Nb were preferably concentrated in the cumulates and later granites are therefore strongly depleted in these elements.

The major-element chemistry and mineralogy indicate strong I-type affinity of the batholith (Chappele – White 1992) dominated by accumulation and fractional crystalization. The high amount of allanite and low abundance of monazite are typical for I-type granites as well (Broska – Uher 1991, 2001). The high content of ilmenite and decrease of xMg in biotite with increasing total silica content are typical attributes of an ilmenite series batholith (Ishihara 1981). The presence of ilmenite instead of magnetite, which is normally more common in I-type granites, could be explained by intrusion of the I-type magma in graphite- and carbonate-bearing rocks (Branná or Velké Vrbno groups) serving as a reducing agent (Ishihara 1981).

The composition of parental magma was probably granodioritic, because it must have allowed formation of mafic tonalite cumulates together with fractionated granites. Since the ratio between cumulate and fractionated products could not have been established in the field due to a possible influence of erosion, the precise composition of parental magma remains uncertain. However, because the both cumulates and fractionates are metaluminous, the parental melt was very likely metaluminous as well. Consequently, the protolith could be seen in the



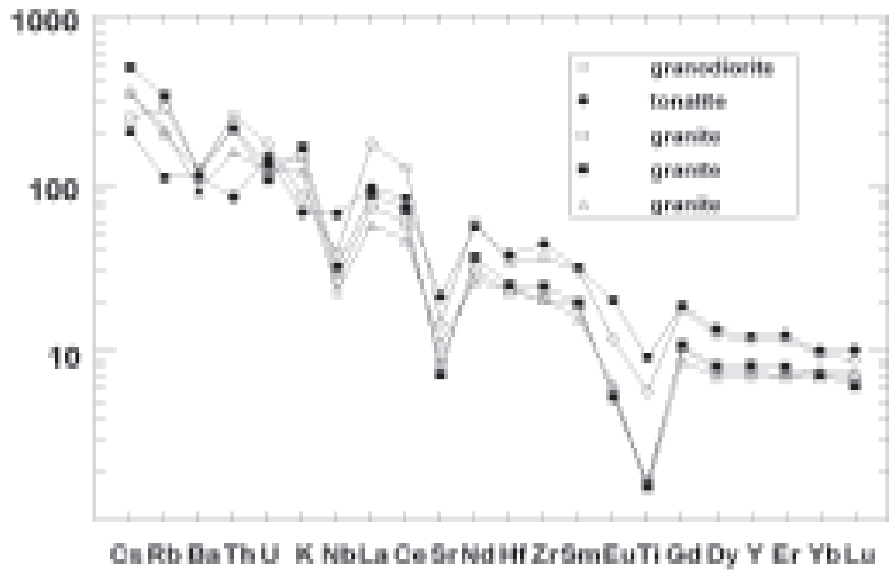


Fig. 5 Trace-element plots normalized to PRIM (Wood *et al.* 1979)

even strongly metaluminous rocks such as amphibolites or chemically related rocks (Johannes – Holtz 1996). The comparetively high contents of RE and HFS elements in the granites indicate that their relatively refractory carrier-phases (O'Hara *et al.* 2001) eg. zircon and apatite were involved in the melting. Therefore it was probably a high-degree melting.

The emplacement of the batholith was likely related to the Westphalian extensional tectonic event (Maluski *et al.* 1995) which affected the northeastern margin of the Bohemian Massif. The late Carboniferous and early Permian extensional tectonics seems to be generally of great importance for magmatic history of the eastern margin of Bohemian Massif. Further manifestation of the extensional tectonics, followed by magmatic activity, could be documented in the Boskovice Furrow, where relatively primitive low-K, high-Na basaltic trachyandesites, intruded lower Permian sediments (Leichmann 1996) and volcanoclastic material from effusive rocks forms a substantial proportion of the basin fill (Jelínek 2001).

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Žulovský batolit: postorogenní, frakcionovaný ilmenit-allanitový I-typový granit.

Geochemická a mineralogická data naznačují, že žulovský batolit představuje frakcionovaný I typový granit. Interpretace gravimetrických dat indikuje relativní homogenitu batolitu. Málo frakcionované amfibolicko-biotitické tonality a granodiority tvoří enklávy v granitech. Charakteristické jsou pro ně kumulátové struktury. Tyto horniny jsou v důsledku akumulace allanitu, apatitu, ilmenitu a titanitu silně obohaceny o HFSE a REE. CL analýza ukazuje relativně jednoduché vnitřní stavby plagioklasu a K-živce. Více frakcionované biotitické granity tvoří rozhodující část batolitu. Vyšší koncentrace LILE jsou doprovázené nižšími obsahy HFSE a REE v důsledku zvýšeného obsahu K-živce a nižší koncentrace akcesorických minerálů. Oba živce vykazují při CL studiu relativně složité vnitřní stavby, naznačující významnou roli frakcionace živců ve vývoji batolitu, v souladu s dobře vyvinutou negativní Eu anomálií a vysokými K/Ba poměry. Intruze tělesa je vázána na vestfálskou extenzní tektoniku. Svrchně karbonská a permská extenze hrála pravděpodobně důležitou roli v magmatické historii východního okraje ČM. Její další projevy doprovázené magmatickou aktivitou je možno nalézt jižněji v oblasti boskovické brázdy.