Cryptic trace-element variation as an indicator of reverse zoning in a granitic pluton: the Ríčany granite, Czech Republic

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Abstract: Cryptic variation recognized on the basis of trace-element patterns shows the Ríčany granite in the northeastern part of the Hercynian Central Bohemian Pluton to be a reversely zoned, high-level intrusion. Unlike many other reversely zoned plutons, there are no marked differences in modal composition between the margins and the centre of the intrusion.

The granite is generally peraluminous and geochemically evolved, as demonstrated by its restricted and high SiO2 range and low K/Rb ratio, coupled with a c. two-fold variation in Ba and Sr concentrations. Modelling shows that the geochemical variations can be most readily explained by K-feldspar-dominated fractionation in a magma chamber below the present level of exposure. The reverse zoning is interpreted as the product of emplacement of an essentially single pulse of magma from a deeper level magma chamber in which fractionation has led to a vertical compositional gradient. The least evolved magma was emplaced in the centre of the high-level pluton with the more evolved magma around it.

Recognition of cryptic reverse zoning in granites has major implications for granite petrogenesis in that the magmatic evolution of such bodies has to be established before assessing potential mechanisms of emplacement.

Keywords: Central Bohemian Pluton, emplacement, geochemistry, granites.

Normal zoning, in which the most fractionated part of the magma occupies the innermost part of the igneous body, is a common feature of many granite plutons, whereas reverse zoning is relatively rare. Where it does occur, it is generally demonstrated mainly on the basis of major petrographic differences between the central and marginal parts of an intrusion, with the more acidic rocks forming the latter (Fridrich & Mahood 1984; Bourne & Danis 1987; Gastro et al. 1991; Allen 1992 and references therein). However, in the case of intrusions that show a restricted range in major element composition and petrographic reverse zoning may not be apparent. In this paper we describe the Ríčany granite from the northernmost part of the Hercynian Central Bohemian Pluton, and demonstrate that despite its rather uniform petrography and major element composition, its trace element variations indicate that it is reversely zoned. Such recognition of cryptic reverse zoning in granites has major implications for granite petrogenesis in that the magmatic evolution of the bodies has to be established before assessing potential mechanisms of emplacement as the geochemical variations place important constraints on the earlier development of the magma.

Geological setting and petrography

The Central Bohemian Pluton is a composite mass composed of various plutonic rocks ranging from gabbro and diorite through granodiorite to granite, together with melanocratic K-rich syenites and melagranites (durbachites); it covers about 3200 km² of the Bohemian Massif in the Czech Republic and stretches southwestwards for c. 150 km from near Prague (Fig. 1; Kodym 1966). The individual intrusions of the Central Bohemian Pluton can be grouped into several suites, based on their petrography, relative age, whole-rock and mineral geochemistry, and Sr–Nd isotopic composition (Holub 1992; Janoušek 1994; Janoušek et al. 1995; see Fig. 1). The most evolved of these suites, the Ríčany suite, is represented by the Ríčany granite, which is a roughly circular body of biotite ± muscovite granite that has been intruded along the boundary between low-grade Upper Proterozoic metasediments of the Teplá–Barrandian unit in the west and dominantly high-grade metasediments of the Moldanubian unit in the east (Fig. 1). Its eastern margin is obscured by Upper Carboniferous (Stephanian) and Lower Permian sediments that onlap onto, and contain material derived from, the Ríčany granite. The pluton has been dated by a 40Ar/39Ar biotite age of 336 ± 3.5 Ma (H. Maluski pers. comm. 1995), thus providing another important constraint on the age of its uplift. At depth, and to the east of the Ríčany granite, there is a major negative gravity anomaly indicative of a granite mass about 40 km across (Orel 1975).

The outer part of the Ríčany granite contains K-feldspar phenocrysts (the so-called porphyritic facies; Káťa 1888; Kášpar 1936), whereas in the central part the phenocrysts are scarce (non-porphyrity facies). There is no evidence for the existence of a contact between the two facies (Fig. 1). Although the proportion of phenocrysts varies, the modal composition of the granite is uniform with both facies having c. 35% K-feldspar, 30% plagioclase, 30% quartz and 5% biotite. The K-feldspar phenocrysts are up to 4 cm in length, strongly perthitic and many show pronounced cross-hatched twinning.
They contain numerous inclusions of biotite, quartz and oligoclase, the latter surrounded by thin albite rims. The plagioclase (An15–20) is usually chemically unzoned and occurs as subhedral prismatic crystals on average 1.2–2.0 mm across. Biotite, which forms subhedral flakes on average 0.5–0.75 mm across, is relatively M g-rich, with $F e^2+/F e^{2+}+M g$ ratio of 0.35–0.40. A nhdral quartz grains with a weak undulose extinction are up to 2 mm across. A patite and Fe-Ti oxides are common accessory minerals; zircon is scarce.

The granite contains various types of enclaves, including biotite-rich mafic microgranular enclaves, surmicaceous enclaves and metasedimentary xenoliths (Didier & Barbarin 1991), the latter almost exclusively close to the contact with the Teplá-Barrandian unit. This western contact is intrusive in
character, with a narrow zone of strong thermal metamorphism and disrupted country-rock xenoliths within the granite (Ködmény 1925). It is cut by numerous pegmatite and mafic microgranular enclaves. The central part of the pluton has been intruded by several small bodies of medium-grained two-mica leucogranite (Jevany leucogranite), which is hydrothermally altered and contains fluorite. The southwestern–southern contact of the Ríčany granite is rimmed by a thin leucogranitic rim described in Janoušek (1993 for analytical methods). It is characterized by high K2O and low FeO, MgO, CaO, Na2O/CaO and contains fluorite. The southwestern–southern contact of the Ríčany granite is rimmed by a thin leucogranitic rim described in Janoušek (1993 for analytical methods).

Analytical techniques

Major- and most trace-element analyses were carried out using a Philips PW 1450/20 automatic sequential XRF spectrometer at the University of Glasgow. Ferrous iron was determined by potassium dichromate titration with 0.2% solution of sodium diphenylamine sulphonate as an indicator (Pratt 1894) following a combined H2SO4–HNO3–HF acid attack. The rare earth elements (REE) were analysed using a VG Plasma Quad PQ1 and Cs, Ta and Hf using a VG Plasma Quad PQ2 Turbo Plus ICP-M S at SU RRC, East Kilbride, Scotland. Full analytical details can be found in Janoušek (1994). The Th analyses were carried out with a Cico 8192-channel gamma-spectrometer at the Geophysical Institute of the Czech Academy of Sciences (see Vanvková et al. 1993 for analytical methods).

Rb–Sr and Sm–Nd isotopic data were acquired using techniques described in Janoušek et al. (1995). Rb and Sr were analysed on VG M M 30 and VG 54E thermal ionization mass spectrometers respectively. $^{87}\text{Sr}/^{86}\text{Sr}$ ratios were corrected for mass fractionation using $^{86}\text{Sr}/^{88}\text{Sr} = 0.1194$. The NBS987 standard gave $^{87}\text{Sr}/^{86}\text{Sr} = 0.71023$ (2 s.d.). Nd isotope ratios were determined using a VG Sector 54-30 thermal ionization mass spectrometer in multi-modal dynamic mode. $^{143}\text{Nd}/^{144}\text{Nd}$ ratios are considered to be accurate to better than 0.15%. $^{142}\text{Sm}^{144}\text{Nd}$ values were calculated using the following bulk earth parameters: $^{143}\text{Nd}/^{144}\text{Nd} = 0.511500 \pm 0.000150$, and $^{142}\text{Sm}^{144}\text{Nd} = 0.1966$ (Jacobsen & Wasserburg 1980).

Whole-rock geochemical character

Representative geochemical data for the Ríčany granite are given in Tables 1 and 2. Compared with other igneous suites within the Central Bohemian Pluton, the Ríčany granite is characterized by high K2O and low FeO, MgO, CaO, Na2O/K2O and F/4O2/F2O3 (Holub 1992; Janoušek 1994; Janoušek et al. 1995). The granite is generally peraluminous as shown by its high A/CNK (0.90–1.39; Table 1). It has a high and restricted SiO2 range (c. 69–72%), compatible with the very limited...
variation in modal composition, and low $K/R_b$ (99–154). On a normative Q–Ab–Or plot (Fig. 2) the rocks, especially those from the marginal part, plot close to the cotectic line $P-E^*_5$, not very far from the low-pressure granite minimum. Although $SiO_2$ shows limited variation, certain trace elements, especially Ba and Sr, show significant ranges in concentration. Such characteristics are typically found in fractionated granites (Chappell & White 1992).

The relatively low, but variable, REE content ($\Sigma$REE 82 to 153 ppm) of the granite (Table 2; Fig. 3) is possibly related to the relative scarcity of accessory phases which are the main contributors to the whole-rock REE budget (Fourcade & Allegre 1981; Gromet & Silver 1983; Sawk 1988). The granite has a variable and negative Eu anomaly ($Eu/Eu^*$ = 0.8–0.9); amongst the granitoid types within the Central Bohemian Pluton it shows both the strongest LREE enrichment ($Ce_N/Yb_N = 20$; see Janoušek 1994) and the lowest total content of HREE. Initial $^{87}Sr/^{86}Sr$ ratios show a limited range from 0.71024–0.71077 (Table 3). Similarly $^{143}Nd$ values are very uniform from $-6.8$ to $-7.7$, although a mafic microgranular enclave has a value of $-8.9$.

On the basis of the high $K_2O$ and $SiO_2$ contents, the Říčany suite is transitional in character between high-K calc-alkaline and shoshonitic (Janoušek et al. 1995) with the Říčany granite having some affinities to the subalkaline group of Barbarin (1990 and references therein). Such subalkaline granitoids typically develop in an environment transitional between late orogenic compressional and extensional regimes (Barbarin 1990) and this is compatible with additional evidence pointing to the Říčany granite being one of the youngest intrusions in the Central Bohemian Pluton (Holub 1992).

**Evidence for reverse zoning**

The Říčany intrusion exhibits a progressive increase in both Ba and Sr, coupled, to a lesser extent, by a decrease in $R_b$ from the marginal porphyritic facies towards the innermost non-porphyritic facies (Fig. 4). If the pluton evolved by fractional crystallization from the walls inwards, the Ba–Sr data imply that the fractionating assemblage would have to be dominated by amphibole to produce such a trend, but this mineral is absent both in the granite and its enclaves. The trend could also be produced by the accumulation of $K$-feldspar ± plagioclase and biotite in the central part of the intrusion. However, as mentioned above, the modal mineralogy of the pluton is constant throughout, and the central parts do not exhibit cumulate textures. Such observations argue against the geochemical variation being produced by $K$-feldspar accumulation in the centre of the intrusion. An alternative explanation is that the pluton is reversely zoned with the more evolved compositions occurring towards the margins: this is now examined on the basis of the geochemical data.
Because SiO₂ shows little variation in the Říčany intrusion, Harker plots offer little scope for genetic considerations. Instead, Sr has been used as a fractionation index because plots involving Sr on the abscissa are characterized by a relatively low scatter and significant variation (Fig. 5). To take into account the presence of the reverse zoning and to illustrate how the contents of various elements change with fractionation, the Sr axis is reversed on Fig. 5. Despite its limited range, the SiO₂ values at the centre of the intrusion are lower than those toward the margin (Fig. 5a). There are also trends of slightly decreasing K₂O, Na₂O and CaO with fractionation, whereas Fe₂O₃ is constant (Fig. 5a). Th and Zr both decrease with increasing degrees of fractionation (Fig. 5b).

On the basis of the Ba–Sr plot (Fig. 4), the observed geochemical variations of decreasing Ba and Sr towards the margin of the intrusion can be explained by c. 20% K-feldspar-dominated crystal–liquid fractionation. Although this plot is also consistent with a major role for biotite, the Rb–Sr diagram (Fig. 4) does not favour such a model. Instead it does support K-feldspar-dominated fractionation, with the greater scatter of the data being due to a more limited role for biotite. Moreover, this hypothesis is also consistent with the trend observed on the Q–Ab–Or ternary diagram (Fig. 2). The low normative An content (CIPW norm; Ab+Ab+Q+Or = 100) of the granitoids from the central part of the intrusion (An ~ 5.6–7 wt%) implies that these samples plot below, but close to, the plagioclase+alkali feldspar+L+V cotectic surface (i.e. into the K-feldspar domain of the Q–Ab–Or–An tetrahedron). This mineral together with Ab-rich plagioclase would be the main crystallizing phases until the cotectic line P–E’ is reached (Winkler et al. 1975).

Trends of rapidly decreasing Sr and Ba with increasing Rb and little change in SiO₂, Al₂O₃, Na₂O and K₂O in the course of fractionation have been documented, for example, in the granites of the Lachlan Fold Belt in eastern Australia, and are considered to be characteristic of evolved granites crystallizing K-feldspar-dominated assemblages (Chappell & White 1992). The decrease of Zr and Th with decreasing Sr (Fig. 5b) indicates fractionation of zircon and possibly minor amounts of monazite, respectively.

An alternative would be a hypothesis accounting for the inward geochemical trends observed in the Říčany granite by increasing degrees of partial melting. Such a hypothesis would be also consistent with the Q–Ab–Or ternary diagram (Fig. 2). The low normative An content (CIPW norm; Ab+Ab+Q+Or = 100) of the granitoids from the central part of the intrusion (An ~ 5.6–7 wt%) implies that these samples plot below, but close to, the plagioclase+alkali feldspar+L+V cotectic surface (i.e. into the K-feldspar domain of the Q–Ab–Or–An tetrahedron). This mineral together with Ab-rich plagioclase would be the main crystallizing phases until the cotectic line P–E’ is reached (Winkler et al. 1975).

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Table 3. Sr–Nd isotopic data for the Říčany granite

<table>
<thead>
<tr>
<th>Sample</th>
<th>Rb (ppm)</th>
<th>Sr (ppm)</th>
<th>⁸⁷Rb/⁸⁶Sr</th>
<th>²⁸⁷Sr/⁸⁶Sr</th>
<th>²⁸⁷Sr/⁸⁶Sr</th>
<th>Sm (ppm)</th>
<th>Nd (ppm)</th>
<th>¹⁴⁷Sm/¹⁴⁴Nd</th>
<th>¹⁴⁳Nd/¹⁴⁴Nd</th>
<th>D_Rb</th>
<th>D_Sr</th>
<th>D_Nd</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ri-1</td>
<td>310.7</td>
<td>374.1</td>
<td>2.4058</td>
<td>0.72154</td>
<td>0.71024</td>
<td>4.06</td>
<td>24.1</td>
<td>0.1020</td>
<td>0.512053</td>
<td>6</td>
<td>0.511833</td>
<td>-7.4</td>
</tr>
<tr>
<td>Ri-2</td>
<td>326.9</td>
<td>360.2</td>
<td>2.6299</td>
<td>0.72267</td>
<td>0.71031</td>
<td>4.98</td>
<td>29.0</td>
<td>0.1005</td>
<td>0.512035</td>
<td>6</td>
<td>0.511818</td>
<td>-7.7</td>
</tr>
<tr>
<td>Ri-4</td>
<td>319.2</td>
<td>377.7</td>
<td>2.4483</td>
<td>0.72216</td>
<td>0.71066</td>
<td>4.59</td>
<td>27.9</td>
<td>0.0995</td>
<td>0.512062</td>
<td>11</td>
<td>0.511847</td>
<td>-7.1</td>
</tr>
<tr>
<td>Ri-5</td>
<td>310.4</td>
<td>399.5</td>
<td>2.2510</td>
<td>0.72134</td>
<td>0.71077</td>
<td>3.83</td>
<td>23.6</td>
<td>0.0980</td>
<td>0.512074</td>
<td>14</td>
<td>0.511862</td>
<td>-6.8</td>
</tr>
<tr>
<td>Ri-6</td>
<td>317.3</td>
<td>386.6</td>
<td>2.3776</td>
<td>0.72186</td>
<td>0.71069</td>
<td>4.56</td>
<td>28.1</td>
<td>0.0980</td>
<td>0.512068</td>
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</tr>
<tr>
<td>Ri-10</td>
<td>322.9</td>
<td>322.4</td>
<td>2.9034</td>
<td>0.72431</td>
<td>0.71067</td>
<td>4.40</td>
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</tr>
<tr>
<td>RIE-1</td>
<td>330.4</td>
<td>297.9</td>
<td>3.2142</td>
<td>0.72571</td>
<td>0.71062</td>
<td>12.59</td>
<td>71.0</td>
<td>0.1071</td>
<td>0.511909</td>
<td>6</td>
<td>0.511758</td>
<td>-8.9</td>
</tr>
</tbody>
</table>

*Isotopic ratios with subscript ‘330’ are age-corrected to 330 Ma.

Fig. 4. Large ion lithophile-based fractional crystallization modelling for the Říčany suite: labelled vectors correspond to 10% fractionation (i.e. F = 0.9) of the rock-forming minerals (bi, biotite; hb, hornblende; plg, plagioclase; Kf, K-feldspar). The trends through the data points show the effects of up to 30% fractionation of K-feldspar. Trace element partition coefficients used in the modelling are from Hanson (1978).
Assuming all the chemical variation observed in the Říčany granite is solely due to batch partial melting of a homogeneous source and using, as upper constraints, unrealistically high bulk distribution coefficients for Ba and Sr in the residue ($D_{Ba} = 6.36$; pure biotite, and $D_{Sr} = 4.4$; pure plagioclase; Hanson 1978) we can calculate the minimum degrees of partial melting required in order to reproduce the Ba and Sr concentrations of 470 and 1015 ppm, and 209 and 378 ppm, respectively, for the margins and the centre of the intrusion. If the lower values in the margins represent the result of minuscule degrees of partial melting of the source ($F \rightarrow 0$) then the higher values indicate that the centre was formed by 64% and 58% melting for Ba and Sr, respectively. In reality, the bulk distribution coefficients would be significantly lower than the modelled values, due to the presence in the residue of minerals with lower $D_{Ba}$ and $D_{Sr}$ (such as quartz) as well as the fact that the $D_{Ba}$ for plagioclase is much lower than 1 (Hanson 1978). Moreover, the modelling assumes a negligible degree of partial melting for granitoids from the margin of the intrusion ($F \rightarrow 0$); this is clearly an unrealistic end-member scenario, and the degree of melting would have had to have been significantly higher to produce melts capable of separating from the residue and intruding into higher crustal levels. From this it is apparent that the minimum degree of partial melting calculated above (c. 60%) must be strongly underestimated. However, even such degrees of partial melting are unrealistically high, as the melt would probably begin to escape at a lower degree of melting, following the breakdown of the framework of residual minerals after reaching the so-called critical melt fraction (Miller et al. 1988); such values would be even lower if melt generation were to have been accompanied by deformation in the source (Wickham 1987).

It is theoretically possible that the geochemical variation could be caused by an initial melt crystallizing to form the outer parts of the Říčany granite, with the central part representing a remelt of the residue after the first melt has been extracted (i.e. the pluton is multi-pulsed). However, the absence of evidence of internal contacts within the intrusion suggests that the pluton crystallized as a single pulse. Moreover, such a model, each pulse would crystallize from its walls inwards; given the observed geochemical trends in the pluton, this implies that each pulse would itself have to be reversely zoned with all the attendant problems it entails. Consequently, such a melting model is unlikely to reflect the petrogenetic processes by which this pluton formed.

Important constraints on the behaviour of accessory zircon in the course of crustal anatexis are provided by the zircon saturation model of Watson & Harrison (1983). The calculation for the Říčany granite gave a saturation temperature of $824 \pm 10^\circ C$ (1σ) (Janoušek 1994), indicating that the granite was probably saturated in zircon for most (if not all) of its history. For crustal anatexis, Watson & Harrison (1984) have distinguished two cases, with the Zr concentration of the source higher and lower, respectively, than the required saturation level. In the first instance, the melt is saturated in Zr throughout the melting event and its Zr content is buffered at a constant level, independent of the degree of partial melting. In the second instance, the melt is saturated in Zr only for a limited time span until the Zr in the source is exhausted, and, consequently, the melt extracted becomes gradually more and more Zr depleted. However, in the Říčany granite the observed sharp increase in Zr from the margin to the centre of the intrusion cannot be satisfactorily explained by the partial melting model.

From the various lines of evidence it is very unlikely that the geochemical variation in the Říčany body was caused by partial melting. Rather they imply a major role for fractional crystallization. The geochemical data are consistent with the
Ríčany pluton being reversely zoned with fractionation being dominated by K-feldspar. It must be stressed that the reverse zoning in this pluton is not apparent petrographically, but is only revealed in geochemical variation, especially the trace elements.

If this crystal-liquid fractionation had taken place in situ, a normally zoned pluton would have been produced. Accordingly the fractionation must have occurred in a deeper magma chamber, the existence of which is compatible with the presence of the major negative gravity anomaly beneath and to the east of the Ríčany granite.

Generation of the reverse zoning

Possible explanations of the reverse zoning are formation by: (1) mixing (including assimilation and, or, periodic influx of fresh, little-fractionated magma into the centre of the intrusion); (2) emplacement of the granite in several separate batches possibly associated with cauldron subsidence; or (3) emplacement of an essentially single pulse of magma from a deeper level magma chamber with a vertical compositional gradient.

Explanation of reverse zoning on the basis of the less evolved facies in the central parts of the intrusion having been produced by mixing between an originally more evolved melt with basic magma (Allen 1992) would be viable only if the geochemical compositions of the mafic microgranular enclaves plotted on the extensions of the trends defined by the granite on Fig. 5, but this is not the case. Although the occurrence of mafic microgranular enclaves in the centre of the Ríčany intrusion could be consistent with the magma-mixing hypothesis, their uniform distribution throughout the intrusion does not suggest more extensive mingling and mixing in the central part.

The minimal field evidence for wall-rock contamination, a process suggested by Gastil et al. (1991 and the references therein) for generation of other reversely zoned plutons, indicates that this process could not have been a constraining factor. While the increase in A/CNK and B content towards the margins of the Ríčany body (Némec 1978) is consistent with contamination by the country rocks (mainly Upper Proterozoic shales of the Teplice–Barrandian unit), such variation could be explained solely by increasing degrees of fractionation of the melt. Wall-rock assimilation appears to be rather exceptional in upper-crustal conditions, as the operation of this process would be likely to rapidly freeze the contact zones of the majority of granitic plutons (Pitcher 1993). Moreover, the shales have lower SiO$_2$ and Rb as well as higher A1$_2$O$_3$, Fe$_2$O$_3$, MgO and Na$_2$O than the Ríčany granite (Table 1). Therefore, their assimilation could not account either for the trend of outwards increasing SiO$_2$ and Rb coupled with decreasing Al$_2$O$_3$ and Na$_2$O, or for the nearly constant Fe$_2$O$_3$ and MgO throughout the intrusion. Furthermore, the $^{87}$Sr/$^{86}$Sr$_{330}$ isotopic ratios of the granite itself are remarkably uniform and very different from those of the shales ($^{87}$Sr/$^{86}$Sr$_{330}$=0.7073–0.7080; Fig. 6; Janoušek et al. 1995).

While the development of reversely zoned plutons by emplacement of successive batches of magma during cauldron subsidence may be applicable elsewhere (Pitcher 1993), there is no evidence to support it in the case of the Ríčany intrusion. The boundary between the central and marginal parts of the Ríčany intrusion is gradational, and no evidence has been found for the existence of the ring faults. Likewise the nature of the boundary negates a model in which acid magma breaks the already crystallized roof of a vertically graded magma chamber and taps the underlying more mafic magma, that forms the core of a higher level pluton (Lacorne Complex, Québec; Bourne & Danis 1987).

In a similar manner, the origin of reverse zoning in the Grizzly Peak cauldron, Colorado, has been explained by re-arrangement of a vertically graded magma chamber at depth during magma emplacement to higher crustal levels (Fig. 7; Fridrich & M. Ahood 1984). In this model, however, the reverse zoning is produced during a single evacuation of a deeper level magma chamber, rather than being a product of successive pulses of magma. In this scenario, progressively less-evolved magma from successively deeper levels in a stratified magma chamber would have risen into core of the intrusion, displacing more evolved magma towards the margins. The preservation of the emplacement pattern would be facilitated by rapid solidification or volatile loss (Fridrich & M. Ahood 1984); there is evidence for such loss in the marginal parts of the Ríčany intrusion (Némec 1978). Taken together, the model of Fridrich & M. Ahood (1984) appears to explain satisfactorily the origin of the reverse zoning in the Ríčany intrusion.

Origin of the Ríčany magma

The genesis of the parental magma to the Ríčany granite through closed-system fractional crystallization of any of the
other igneous suites of the Central Bohemian Pluton can be discounted on the basis of their differing Sr–Nd isotopic signatures; the analysed samples from the Říčany granite have relatively high \(^{187}\text{Sr}/^{166}\text{Sr}\) and low \(^{143}\text{Nd}/^{144}\text{Nd}\) values compared to the majority of other intrusions within the Central Bohemian Pluton (Fig. 6; Janoušek et al. 1995). Additionally, geochemical and Sr–Nd isotopic data indicate that the Říčany suite could not have been produced through contamination of magmas belonging to the K-rich Červoto břeženo suite (or similar to the associated minettes) by metasediments of the Teplá–Barrandian unit. Furthermore, this evidence also indicates that the Říčany suite is unlikely to represent a highly contaminated version of the Blatná suite (Janoušek et al. 1995).

The low HREE contents of the Říčany granite may provide evidence of garnet being retained in the residue during crustal melting although some of the HREE depletion could be attributed to zircon fractionation in the deep reservoir prior to the high-level intrusion (cf. The rapid decrease of Zr with fractionation; Fig. 5b). The generally peraluminous nature of the granite may be consistent with an origin through melting of a metasedimentary protolith, although such a composition could also be generated by partial melting of metapelitic igneous rocks or by fractional crystallization of metapelitic minerals from a metapelitic melt (Miller 1985). The Sr–Nd isotopic signature of the granite is similar to that of the metasediments of the Moldanubian unit (Fig. 6). In addition, the whole-rock geochemical characteristics of the Říčany granite fulfill all but one of the criteria set out by Miller (1985) for pelite-derived magmas (i.e. Na\(_2\)O<3.5–4%, CaO<2%, granite fulfills all but one of the criteria set out by Miller (1985) for pelite-derived magmas (i.e. Na\(_2\)O<3.5–4%, CaO<2%, corundum (C; CIPW norm), which rarely exceeds 1000 ppm, Rb/Ba>0.25). The only exception is the normative 

Conclusions

(1) The Říčany granite represents a generally peraluminous, geochemically evolved, high-level, reversely zoned granitoid pluton in which the zoning is manifested by variations in the whole-rock geochemical composition (particularly trace elements) rather than in gross petrography. A such zone is cryptic in nature.

(2) Its parental magma probably originated by anatexis of largely metasedimentary material, and developed through K-feldspar fractionation in a crustal reservoir below the present level of exposure. This granite is fractionated as shown by its restricted SiO\(_2\) range and low K/Rb ratios, coupled with c. two-fold variation in certain trace elements.

(3) The origin of the reverse zoning is explained by high-level emplacement as a single batch of magma from a deeper level, vertically graded magma chamber.

(4) On a wider scale, this study highlights that whole-rock major- and particularly trace-element zoning patterns have to be taken into account if the mode of emplacement and pre-crystallization history of an individual granitoid intrusion are to be determined, as the presence of zoning may not be shown by either petrographic features or major-element compositions, especially in differentiated plutons such as the Říčany granite.

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