Trabajos de Geología, Universidad de Oviedo, 30 : 289-295 (2010)

Oviedo (Spain) 1-3 July 2008 International Meeting of Young Researchers in Structural Geology and Tectonics
ORSGET

Magnetic fabric of the Říčany granite, Bohemian Massif

J. TRUBAČ[1, 2, 4*], J. ŽÁK[1, 2] AND V. JANOUŠEK[2, 3]

[1]*Institute of Geology and Paleontology, Faculty of Science, Charles University, Albertov 6, Prague, 128 43, Czech Republic.*

[2]*Czech Geological Survey, Klárov 3, Prague, 118 21, Czech Republic.*

[3]*Institute of Petrology and Structural Geology, Faculty of Science, Charles University, Albertov 6, Prague, 128 43, Czech Republic.*

[4]*Institute of Geochemistry, Mineralogy and Mineral Resources, Faculty of Science, Charles University, Albertov 6, Prague, 128 43, Czech Republic.*

**e-mail: jakub.trubac@gmail.com*

Abstract: The Říčany pluton represents an elliptical shallow-level intrusion made up of outer, more fractionated, strongly porphyritic granite and inner, less evolved, weakly porphyritic granite. Mesoscopic foliation defines an onion-skin pattern and corresponds well to the magnetic (AMS) foliations. Magnetic lineation plunges shallowly (0-20°) and is subparallel to the contact in the outer part of the pluton, whereas in the pluton center lineation dips steeply (60-70°) with variable trends. We interpret the fabrics in the pluton as being a result of helical flow, whereby faster subvertical flow in the low-viscosity pluton center generated subhorizontal flow in the outer, higher-viscosity (phenocryst-rich) margin.

Keywords: anisotropy of magnetic susceptibility (AMS), Bohemian Massif, granite, magma flow, pluton.

Unravelling the geometrical patterns and the likely physical causes of magma flow in granitic magma chambers is one of the central aspects of understanding magma chamber dynamics. In many (or most?) cases, however, direct field evidence for chamber-wide flow or convection is completely erased from the rock record. Magmatic fabrics in plutons (i.e. foliations and lineations formed during the presence of a melt; Paterson *et al.*, 1989) commonly fail to provide unambiguous evidence for chamber-wide magma flow or convection. Instead, the preserved pluton fabrics are acquired late in magma chamber history along migrating crystallization fronts and are also easily reset by regional tectonic deformation, making inferences on large-scale convection or flow patterns difficult or rather problematic (e.g. Paterson *et al.*, 1998).

In the present paper, we investigate an example of a post-tectonic pluton (the Říčany pluton, Bohemian Massif; figure 1) where the magmatic fabrics have not been overprinted by regional deformation and thus likely preserve a record of internal processes and magma flow. Below we present integrated structural, microstructural, and anisotropy of magnetic susceptibility (AMS) data, which revealed an unusual pattern of magmatic fabrics in the pluton. Subsequently, we discuss the significance of the observed fabrics and AMS and interpret these data to record a helical flow,

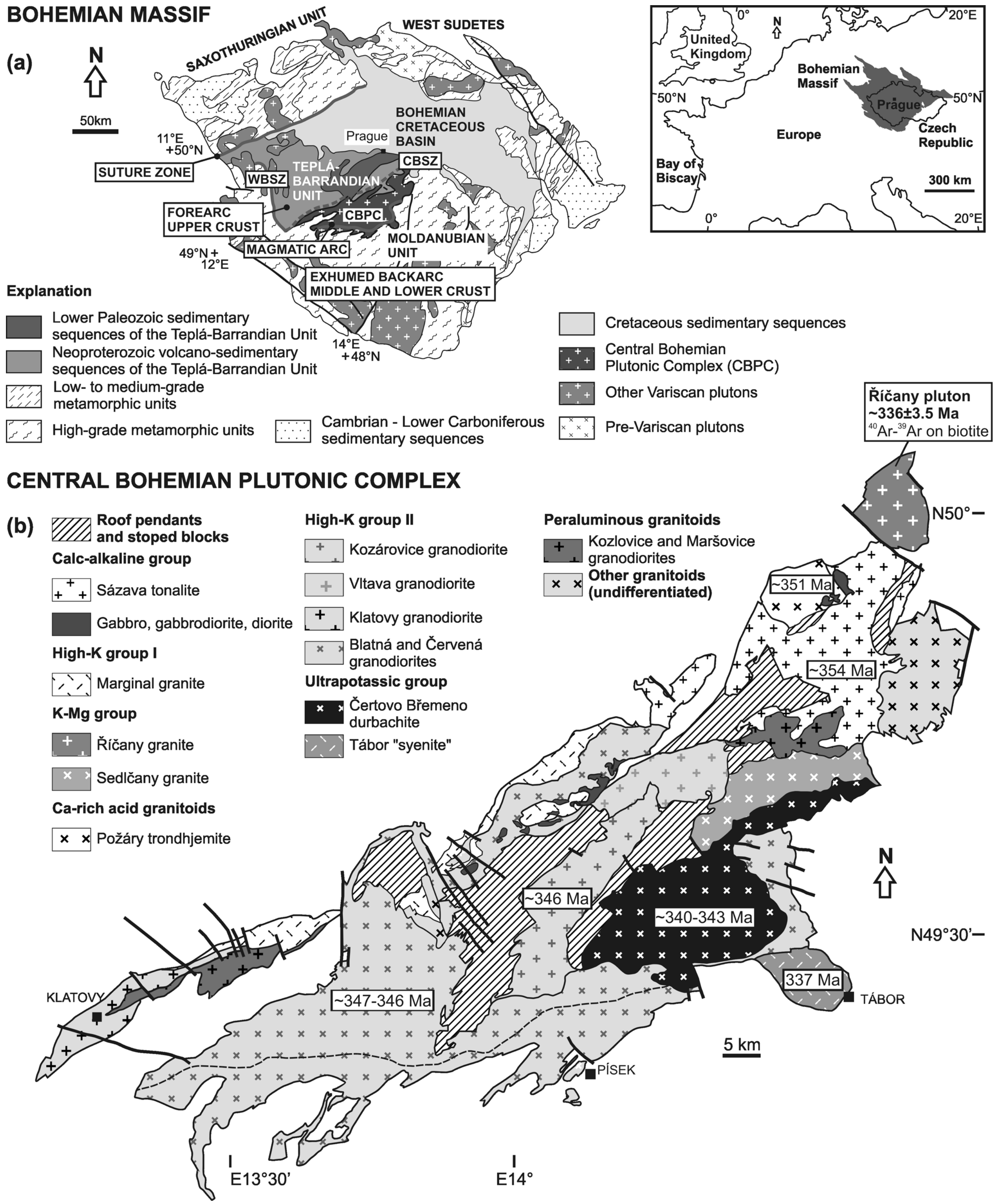

Figure 1. Simplified geological map of the Central Bohemian Plutonic Complex (b) and its position in the Bohemian Massif (a). The map is based on Czech Geological Survey 1:200 000 maps and Holub *et al.* (1997b). It shows the main intrusive units (or "types") with some recently published radiometric ages (Holub *et al.*, 1997a; Janoušek and Gerdes, 2003).

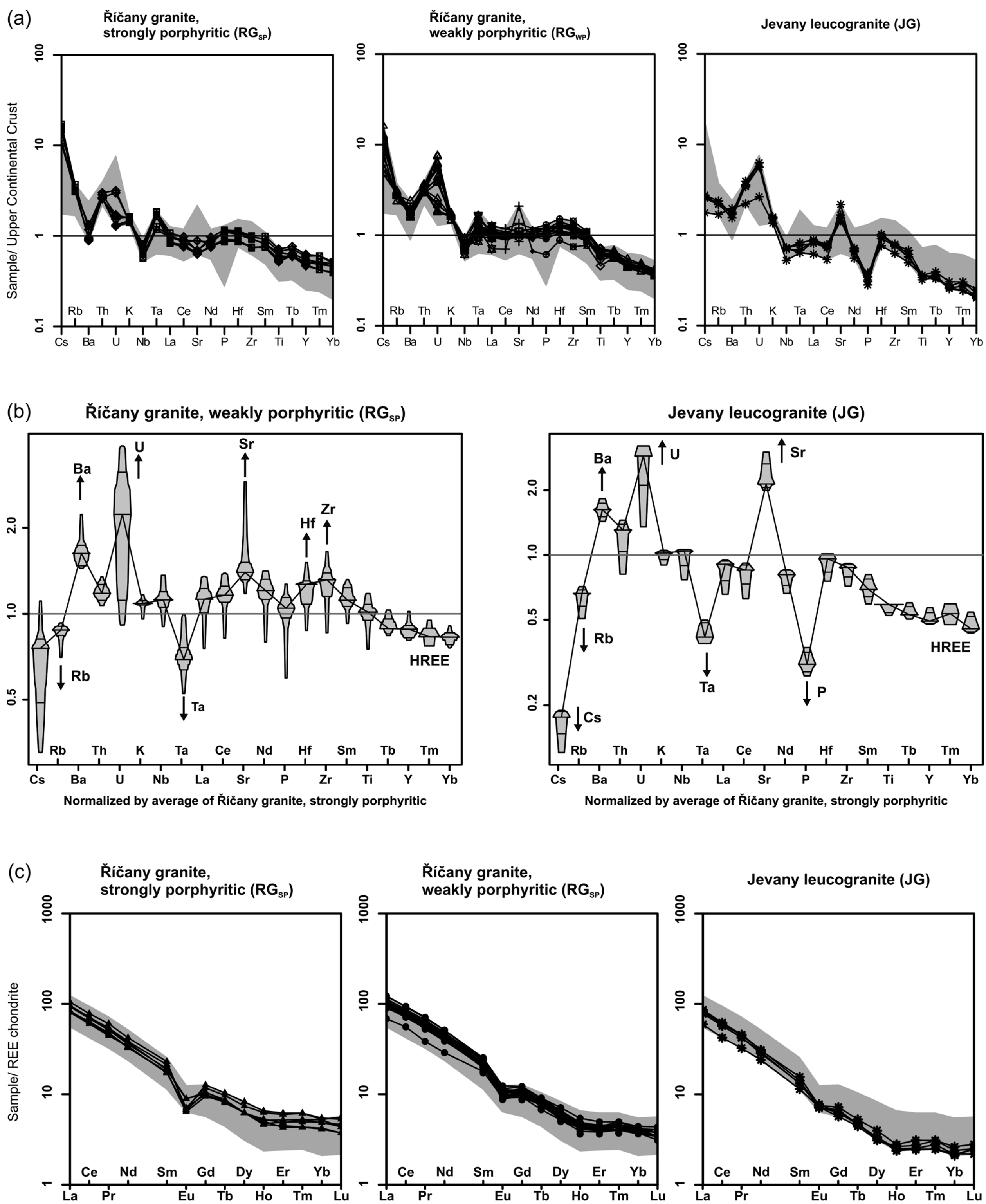

Figure 2. (a) Spider plots normalized by average composition of the upper crust (Taylor and McLennan, 1995) for the three main granite varieties of the Říčany pluton, (b) spider box and percentile plots (Janoušek and Holub, 2007) showing the statistical distribution of the trace-element abundances normalized by average contents in the outer, strongly porphyritic Říčany granite, (c) chondrite normalized (Boynton, 1984) REE patterns for the three main igneous pulses within the Říčany pluton.

a rarely documented flow mechanism in granitoid plutons.

Geological setting

The Říčany pluton of the Central Bohemian Plutonic Complex (Bohemian Massif; figure 1) represents a post-tectonic, shallow-level intrusion emplaced into low-grade Neoproterozoic and Lower Paleozoic siliciclastic rocks in Early Carboniferous times (figure 1; 336±3.5 Ma, unpublished ^{40}Ar-^{39}Ar biotite data of H. Maluski, cited in Janoušek *et al.*, 1997). In map-view, the pluton has a roughly elliptical outline (13×9 km) and is made up of three distinct granite varieties: (i) outer, strongly porphyritic, (muscovite-) biotite Říčany granite, (ii) inner, weakly porphyritic, (muscovite-) biotite Říčany granite, and (iii) a small, poorly exposed body of fine-grained, equigranular, two-mica Jevany leucogranite in the south-central part of the pluton. These granite varieties define a concentric pattern. The contact between the two porphyritic granites is gradational over several hundreds of meters; the nature of the outer contact of the Jevany leucogranite is unclear due to a poor exposure.

All varieties are fairly fractionated, peraluminous (A/CNK = 1.01-1.13), S-type granites enriched, if compared with average crustal composition (Taylor and McLennan, 1995), in Large Ion Lithophile Elements (LILE: Cs, Rb, Th, U, Sr) and depleted in some High Field Strength Elements (HFSE: Nb, Ti, HREE) (Fig. 2a). In general, the major-element compositions are comparable and do not vary greatly between the two facies of the Říčany granite.

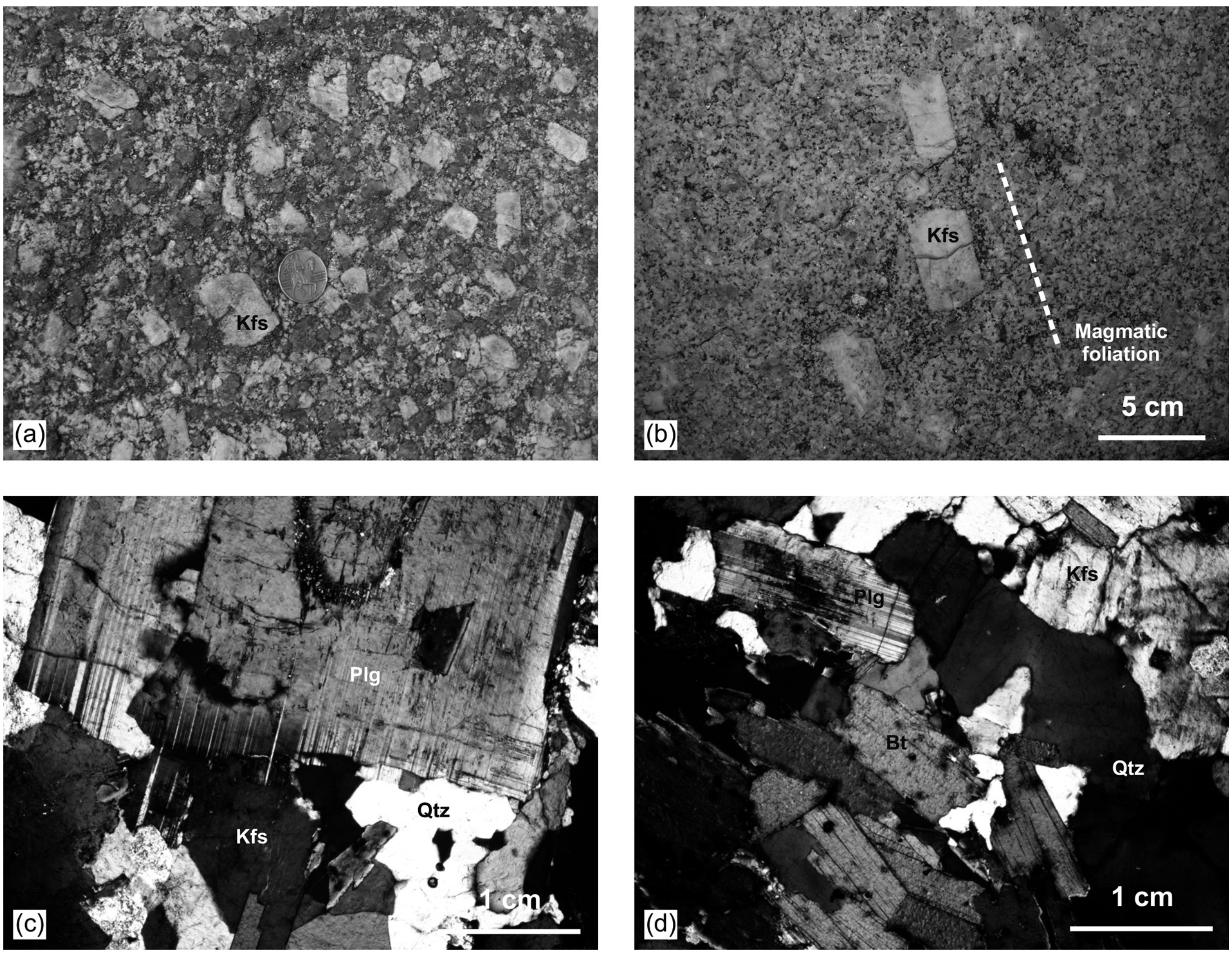

Figure 3. (a) K-feldspar phenocrysts (up to 4 cm in size) in the strongly porphyritic Říčany granite; coin for scale, (b) magmatic foliation defined by K-feldspar phenocrysts in the weakly porphyritic Říčany granite, (c) photomicrograph of a magmatic texture of strongly porphyritic muscovite-biotite Říčany granite, (d) photomicrograph of magmatic texture of weakly porphyritic muscovite-biotite Říčany granite. Crystals of main rock-forming minerals do not exhibit internal solid-state deformation. The magmatic textures are typical of all granite varieties in the Říčany pluton.

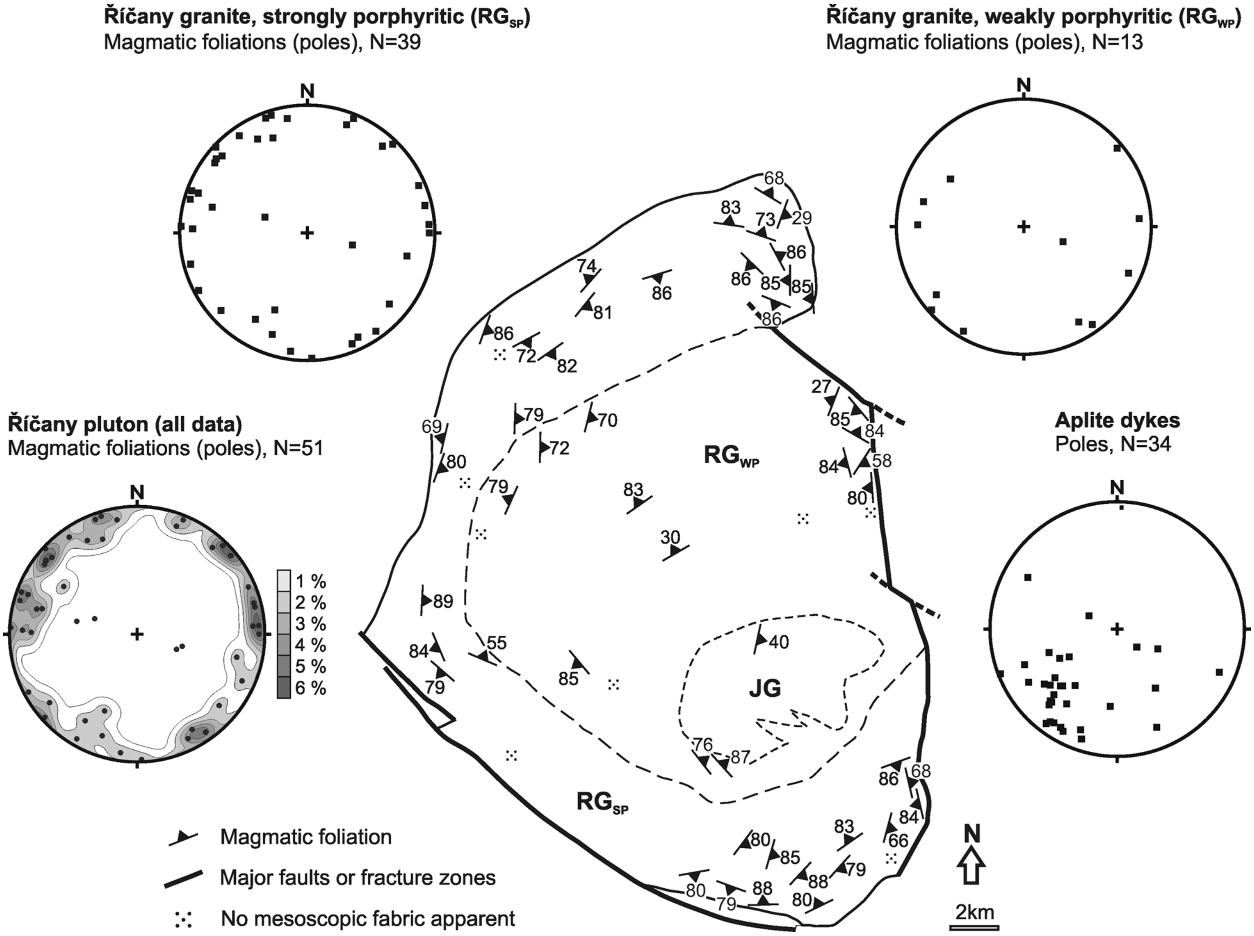

Figure 4. Structural map to show mesoscopic magmatic foliation pattern. Stereonets (lower hemisphere, equal area projection) show orientation of magmatic foliations in each granite variety.

However, there are some conspicuous differences in the trace-element signatures. For instance, the central, weakly porphyritic facies shows markedly lower Rb, Sr, Ta and HREE contents at elevated Ba, U, Sr, Hf and Zr if compared with the outer, strongly porphyritic facies (Fig. 2b). All the rocks are characterized by fractionated REE patterns with a high degree of LREE/HREE enrichment. Typical is also the presence of Eu anomalies, the magnitude of which increases outwards, reaching its maximum in the strongly porphyritic Říčany granite (Fig. 2c). The degree of fractionation decreases from the pluton margin inwards, the outer, strongly porphyritic granite being more evolved than the central, weakly porphyritic granite (Janoušek *et al.*, 1997). The position of the Jevany leucogranite is, to a large extent, independent and its genetic relationship to both the Říčany granite varieties still poorly constrained (Němec, 1978).

Magmatic fabric and anisotropy of magnetic susceptibility (AMS) of the granite

Mesoscopic foliation in the porphyritic granites is defined by a planar shape-preferred orientation of biotite and K-feldspar phenocrys, lineation being mesoscopically indiscernible (Figs. 3a and 3b). At the micro-scale, no evidence for sub-solidus deformation was observed throughout the pluton (Figs. 3c and 3d). The foliation dips steeply (70-80°), is subparallel to the outer contact of the pluton and is thus clearly discordant with the regional host rock structures (Fig. 4).

We used the anisotropy of magnetic susceptibility (AMS) method to investigate the magnetic fabric of the Říčany pluton in order to corroborate the structural data and to quantify the fabric parameters in the pluton. 71 oriented samples were collected using a portable drill at 31 sampling sites. The AMS was measured with the KLY-4S Kappabridge apparatus and statistical analysis of AMS data was performed using the ANISOFT package of programs.

The AMS data are represented by the k_m, P, and T parameters defined as follows $k_m = (k_1 + k_2 + k_3)/3$; $P = k_1/k_3$; $T = 2ln(k_2/k_3)/ln(k_1/k_3)–1$. The k_m parameter represents the mean bulk magnetic susceptibility reflecting the qualitative and quantitative contents of magnetic minerals in the rock. The P parameter, called the degree of AMS, reflects the eccentricity of the AMS ellipsoid and thus indicates the intensity of the preferred orientation of the magnetic minerals in the rock. The higher the P parameter, the stronger the preferred orientation. The T parameter indicates the symmetry of the AMS ellipsoid. It varies from –1 (perfectly linear magnetic fabric) through 0 (transition between linear and planar magnetic fabric) to +1 (perfectly planar magnetic fabric). The orientations of the magnetic foliation poles and the magnetic lineations are presented either in a contour diagram in the geographic (*in situ*) coordinate system or as locality means in a map.

The mean bulk magnetic susceptibility of the analyzed samples is low, ranging from 13.13×10^{-6} (SI) to 10.53×10^{-6} (SI). Such a low susceptibility (in the order of 10^{-5}) is characteristic of paramagnetic granites (Bouchez, 1997), in which the main carriers of AMS are paramagnetic minerals. The degree of AMS (represented by parameter P) ranges from 1.009 to 1.149 in the strongly porphyritic granite and from 1.014 to 1.363 in the weakly porphyritic granite. The T parameter ranges from –0.754 to 0.904 in the strongly porphyritic granite and from –0.667 to 0.970 in the weakly porphyritic granite. No significant spatial variations in the degree of anisotropy or shape of the AMS ellipsoid were revealed in the pluton. In the Jevany leucogranite, the P parameter ranges from 1.07 to 1.27 and the T parameter ranges from 0.1 to 0.9.

The magnetic fabric pattern (AMS) of the Říčany pluton is characterized by margin-parallel, moderately to steeply dipping magnetic foliation (Fig. 5); its geometry is consistent with the orientation of mesoscopic magmatic foliation. Foliation poles tend to concentrate along the periphery of the stereonet (Fig. 5). Magnetic lineation steepens significantly as a function of distance from the pluton margin. In the outer part of the pluton, the lineation plunges shallowly (0-20°) and is subparallel to the contact whereas in the center lineation dips steeply (60-70°) with variable trends (Fig. 5).

Discussion and conclusions

Our structural and AMS data do not comply with existing models proposed for the emplacement of elliptical, onion-skin plutons (e.g. single-blob or nested diapirism, ballooning, laccolith-like emplacement). We interpret the mesoscopic and magnetic fabrics in the Říčany granite as a result of helical flow (as defined by Fowler, 1996). In our model, we consider the strongly and weakly porphyritic granites as two nested magma batches having different viscosities during emplacement. We envisage that the difference in K-feldspar phenocryst content in the two granites caused significant difference in their viscosities: the

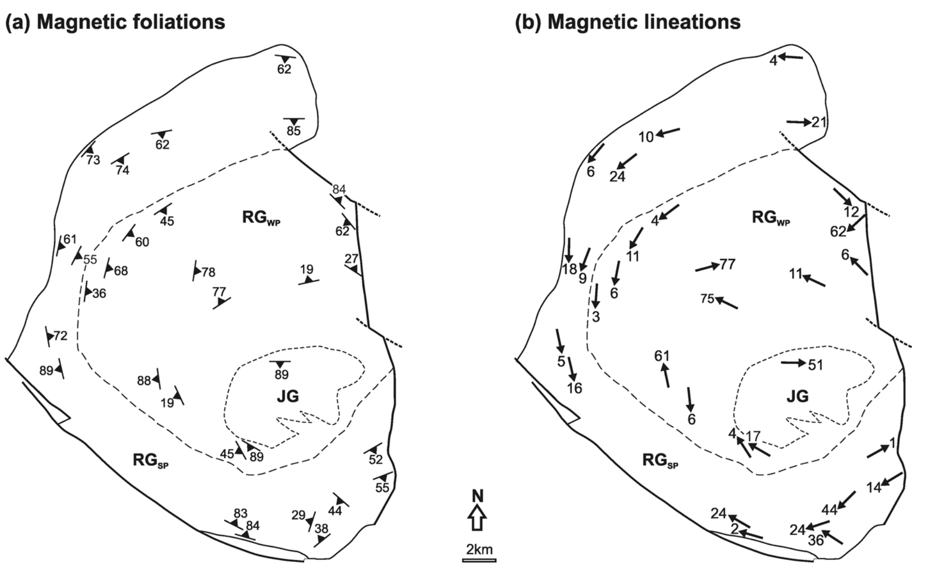

Figure 5. Map of magnetic foliations (a) and lineations (b) in the Říčany pluton (AMS).

outer, strongly porphyritic granite presumably had viscosity of a higher order of magnitude than the central, weakly porphyritic granite. This assumption is in agreement with an exponential increase in viscosity with crystal content as predicted by the Einstein-Roscoe equation for solid-liquid mixtures. Considering the Říčany pluton as a steep-sided cylindrical body, we can apply the Hagen-Poiseuille equation for fluid flow through a pipe to infer the flow mechanism within the pluton. Contrasting viscosities of the two magmas then would cause their different velocities during ascent. Consequently, faster subvertical flow of low-viscosity (phenocryst-poor) magma in the pluton center may have generated helical (subhorizontal) flow in the outer, high-viscosity and phenocryst-rich layer. This two-layer model explains well the finite fabric pattern, with concentric, steep foliations and magnetic lineation being subhorizontal along the pluton margin and subvertical in the center. Taking into account the shallow emplacement level of the Říčany pluton, the pluton may be viewed as a conduit linking a deeper magma chamber with a volcanic system at the surface.

Acknowledgements

We would like to acknowledge comments by L. G. Corretgé which helped to improve the original version of the manuscript. This research is funded by a grant from the Grant Agency of Charles University in Prague (GAUK) No. 131607 (to J. Trubač).

References

BOUCHEZ, J. L. (1997): Granite is never isotropic: an introduction to AMS studies of granitic rocks. In: J. L. BOUCHEZ, D. H. W. HUTTON and W. E. STEPHENS (eds): *Granite: From Segregation of Melt to Emplacement Fabrics*, Kluwer Academic Publishers, Amsterdam: 95-112.

BOYNTON, W. V. (1984): Cosmochemistry of the rare earth elements: meteorite studies. In: P. HENDERSON (ed): *Rare Earth Element Geochemistry*, Elsevier, Amsterdam: 63-114.

FOWLER, T. J. (1996): The properties and geological environments of helicoids: axially symmetric surfaces in torsional and non-torsional deformations. *J. Struct. Geol.*, 18: 505-517.

HOLUB, F. V., COCHERIE, A. and ROSSI, P. (1997a): Radiometric dating of granitic rocks from the Central Bohemian Plutonic Complex: constraints on the chronology of thermal and tectonic events along the Barrandian-Moldanubian boundary. *C. R. Acad. Sci. II A.*, 325: 19-26.

HOLUB, F. V., MACHART, J. and MANOVÁ, M. (1997b): The Central Bohemian Plutonic Complex: geology, chemical composition and genetic interpretation. *Sbornik Geologickych Ved: Loziskova Geologie, Mineralogie - J. Geol. Sci. Econ. Geol., Mineral.*, 31: 27-50.

JANOUŠEK, V., ROGERS, G., BOWES, D. R. and VAŇKOVÁ, V. (1997): Cryptic trace-element variation as an indicator of reverse zoning in a granitic pluton: the Říčany granite, Czech Republic. *J. Geol. Soc. London*, 154: 807-815.

JANOUŠEK, V. and GERDES, A. (2003): Timing the magmatic activity within the Central Bohemian Pluton, Czech Republic: conventional U-Pb ages for the Sázava and Tábor intrusions and their geotetonic significance. *J. Czech Geol. Soc.*, 48, 1-2: 70-71.

JANOUŠEK, V. and HOLUB, F. V. (2007): The causal link between HP-HT metamorphism and ultrapotassic magmatism in collisional orogens: case study from the Moldanubian Zone of the Bohemian Massif. *Proc. Geol. Assoc.*, 118: 75-86.

NĚMEC, D. (1978): Genesis of aplite in the Říčany massif, central Bohemia. *Neues Jb. Miner. Abh.*, 132: 322-339.

PATERSON, S. R., VERNON, R. H. and TOBISCH, O. T. (1989): A review of criteria for identification of magmatic and tectonic foliations in granitoids. *J. Struct. Geol.*, 11, 3: 349-363.

PATERSON S. R., FOWLER T. K., SCHMIDT K. L., YOSHINOBU A. S., YUAN E. S. and MILLER R. B. (1998): Interpreting magmatic fabric patterns in plutons. *Lithos*, 44: 53-82.

TAYLOR, S. R. and MCLENNAN, S. M. (1995): The geochemical evolution of the continental crust. *Rev. Geophys.*, 33: 241-265.