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Magma emplacement during exhumation of the lower- to mid-crustal orogenic root: The Jihlava syenitoid pluton, Moldanubian Unit, Bohemian Massif

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Abstract

In this study, we present structural and AMS data from the ~335 Ma ultrapotassic Jihlava syenitoid pluton, which intruded the lower- to mid-crustal orogenic root (Moldanubian Unit) in the Bohemian Massif, Central European Variscides. The emplacement of the pluton was accommodated by multiple processes, such as ductile host-rock shortening, formation of sheeted zones by magma wedging, magmatic stoping, and possibly host-rock displacement within a wide transtensional zone. Magmatic fabrics preserved in the pluton reflect both intrusive processes and regional strain. Margin-parallel and ~ENE–WSW foliations, which probably formed by strain during emplacement of inner magma pulses, were overprinted by tectonic strain within a zone of distributed wrench-dominated dextral transtension. This zone probably accommodated exhumation of different segments in the eastern part of the Moldanubian Unit during pluton emplacement. In contrast to existing models, we emphasize that the Jihlava pluton, as well as other ultrapotassic plutons widespread in the Moldanubian Unit, are structurally highly variable bodies emplaced by multiple intrusive processes. Our case study illustrates how careful documentation of structural relations around these ultrapotassic plutons may constrain the kinematic framework and local exhumation histories in different segments of the orogenic root during and shortly after the ~340 Ma mechanical event in the Central European Variscides.

Keywords: Anisotropy of magnetic susceptibility (AMS); Emplacement; Exhumation; Pluton; Transtension; Variscan orogeny

1. Introduction

One of the most intriguing aspects in evolution of orogenic belts and magmatic arcs is the exhumation of deeply buried high-grade rocks to the upper crustal levels. Recently, numerous studies focused on the mechanisms and driving forces of exhumation of lower- to mid-crustal segments and attributed the exhumation to various tectonic settings (e.g., Dewey, 1988; Allemand and Lardeaux, 1997; Thompson et al., 1997; Schulmann et al., 2002; Willner et al., 2002). The structural record of exhumation and the P-T-t paths of exhumed rocks are traditionally established using metamorphic petrology, geochronology, and structural analysis of metamorphic complexes. Interestingly, other studies (e.g., Paterson et al., 1998; Schofield and D'Lemos, 1998; Benn et al., 2001; Miller and Paterson, 2001) have also shown that the internal fabrics of plutons may record regional paleostrain fields in their metamorphic host rocks. Given that plutonic rocks are widespread, easy to date and, unlike metamorphic rocks, usually do not exhibit complex arrays of superposed structures (magmatic fabrics are easily reset; Paterson et al., 1998) we were interested in discovering whether populations of plutons emplaced episodically

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into originally deep-seated crustal segments could provide evidence for the kinematic framework, local exhumation histories and timing of exhumation events within orogenic belts.

In the European Variscides, which formed during the Devonian to Carboniferous collision of peri-Gondwana crustal segments and the Baltica (northern European plate; Ziegler, 1986; Franke, 1989; Rey et al., 1997), major crustal thickening was followed by the exhumation of the orogenic root domain (Behr et al., 1984; Medaris et al., 1995; Willner et al., 2002). The exhumed lower- to mid-crustal orogenic root referred to as the Moldanubian Unit is now exposed in the Bohemian Massif and forms the innermost part of the Variscan orogenic belt. During the later stages of the Variscan orogeny, the orogenic root (Moldanubian Unit) was intruded by geochemically specific ultrapotassic syenitoid (melasyenitic, melagranitic or monzonitic) plutons. In the Bohemian Massif, these plutons comprise two rock groups differing in assemblages of mafic minerals; the most widespread amphibole-biotite rocks are dominated by the durbachite series (mostly K-feldspar-phyric melasyenites to melagranites; see Holub 1997), while the subordinate biotite-two-pyroxene rocks make up the Jihlava pluton in the eastern part of the Bohemian Massif and the Tábor pluton at the southeastern margin of the Central Bohemian Plutonic Complex (Fig. 1a,b). These ultrapotassic plutons are spread over the entire orogenic root but their radiometric ages indicate that they were emplaced over a relatively short time span (Klötzli and Parrish, 1996; Holub, 1997; Holub et al., 1997; Schaltegger, 1997; Janoušek and Gerdes, 2003; Kotková et al., 2003). Although the petrogenesis and geochemistry of these plutons has been previously studied and interpreted as being the result of mixing of mantle-derived ultrapotassic magmas with acid crustal melts (Holub, 1997; Janoušek and Holub, in press), their internal fabrics, emplacement processes and structural relations to the exhumed host metamorphic complexes are unknown or poorly constrained.

In this paper, we present structural and AMS data from the Jihlava pluton, which intruded the eastern part of the Moldanubian Unit (Figs. 1b, 2), as the first case example to show the importance of these ultrapotassic plutons for the interpretation of the kinematic framework and timing of exhumation in the orogenic root domain. Based on structural data, we interpret the formation of magmatic fabrics in the pluton, its relationship to the host-rock structures and regional tectonics, and we evaluate the material transfer processes during emplacement (i.e. MTPs of Paterson and Fowler, 1993a). Finally, we discuss the more general implications of our study for the exhumation and tectonic evolution of the orogenic root during the later stages of the Variscan orogeny.

2. Geological setting

The Jihlava pluton crops out in the eastern part of the Moldanubian Unit, which represents the exhumed lower- to mid-crustal orogenic root in the Central European Variscides (Fig. 1a,b; e.g., Medaris et al., 1995; Vrána et al., 1995; Schulmann et al., 1997; Konopásek and Schulmann, 2005). The Moldanubian Unit (Fig. 1b) comprises two major units with contrasting tectonometamorphic evolution, exhumed from different depths: the mid-crustal Drosendorf and the lower-crustal Gföhl Units. The Drosendorf Unit consists of metasedimentary sequences of problematic protolith age, dominated by sillimanite-biotite (±cordierite) paragneisses (referred to as the Monotonous Group) with abundant lens-shaped bodies of metaquartzites, marbles and amphibolites (summarily referred to as the Varied Group). Estimations of the PT conditions of regional metamorphism of the Drosendorf Unit range from 630 to 720 °C and 3–6 kbar (Petrakakis, 1997; Vrána et al., 1995), the age of HT-LP metamorphism was estimated as 337–333 Ma using the U-Pb method (Friedl et al., 1993). The high-grade Gföhl Unit, the protolith age of which was estimated at ∼482 ± 2 Ma (Friedl et al., 1993), is structurally the uppermost unit (Vrána, 1988; Matte et al., 1990) and comprises orthogneisses, migmatites, granulites, eclogites and peridotites. Estimations of the PT conditions of peak metamorphism in the Gföhl Unit correspond to ∼950–1050 °C and ∼14–20 kbar (in crustal peridotites) dated at ∼351 ± 6 (Carswell and O'Brien, 1993; Wendt et al., 1994) and ∼345 ± 5 (Van Breemen et al., 1982), followed by retrograde metamorphism ($T \sim 600$–800 °C and ∼6–8 kbar; Owen and Dostal, 1996) at ∼337–333 Ma (Friedl et al., 1993; Wendt et al., 1994; Gebauer and Friedl, 1994).

In the studied area (Fig. 2), pluton host rocks are dominated by sillimanite-biotite (±cordierite) paragneisses of the Monotonous Group, which are commonly migmatized at variable degrees of partial melting. Numerous lens-shaped bodies of amphibolites, quarzitic rocks and graphite-bearing gneisses are scattered over the area. The Moldanubian paragneisses were also intruded by leucogranite sheets prior to the emplacement of the Jihlava pluton. The map-scale pattern of these bodies is parallel to the pluton margin forming a sigmoidal deflection as does the outcrop shape of the pluton. In contrast to other studies (Urban and Synek, 1995 and references therein; see also Fig. 2 in Schulmann et al., 2005), which place the presumed ∼N–S trending boundary thrust of the Varied Group over the Monotonous Group as intersecting the central part of the Jihlava pluton (the pluton would thus discordantly cut across the thrust plane), our detailed mapping revealed that the paragneisses of the Monotonous Group are juxtaposed against the Gföhl-like migmatites and orthogneisses along a NE–SW trending boundary located to the SE of the pluton (Fig. 2). The migmatites and orthogneisses resemble the Gföhl gneisses; however, the nature of the boundary and interpretation of this unit remains problematic.

The Jihlava pluton has a ∼NW–SE elongated sigmoidal shape (Fig. 2). Its contacts with the Moldanubian host rocks of the Monotonous Group are intrusive, only locally affected by post-emplacement brittle faulting. In general, the intrusive contacts dip steeply (∼70°) to the east. The pluton is composed of mafic syenitoid to granitoid rocks ranging from the most widespread quartz monzonite to (mela)syenite and melagranite. Their color index varies from 25 to 35, although it