Journal of Geodynamics 73 (2014) 100–117

Contents lists available at ScienceDirect

Journal of Geodynamics

journal homepage: http://www.elsevier.com/locate/jog

Formation of elongated granite–migmatite domes as isostatic accommodation structures in collisional orogens

Kryštof Verner[a,b,*], Jiří Žák[c], Josef Šrámek[d], Jana Paclíková[a,b], Alice Zavřelová[e], Matěj Machek[f], Fritz Finger[g], Kenneth Johnson[h]

[a] Czech Geological Survey, Klárov 3, Prague 11821, Czech Republic
[b] Institute of Petrology and Structural Geology, Faculty of Science, Charles University, Albertov 6, Prague, 12843, Czech Republic
[c] Institute of Geology and Paleontology, Faculty of Science, Charles University, Albertov 6, Prague, 12843, Czech Republic
[d] Czech Geological Survey, Leitnerova 22, Brno 60200, Czech Republic
[e] Department of Geological Sciences, Faculty of Science, Masaryk University, Kotlářská 2, Brno, 61137, Czech Republic
[f] Institute of Geophysics, Academy of Sciences of the Czech Republic, Boční II/1401, Prague, 14131, Czech Republic
[g] Division of Mineralogy, University of Salzburg, Hellbrunnerstraße 34, Salzburg, 5020, Austria
[h] Department of Natural Sciences, University of Houston-Downtown, 1 Main Street, Suite N813, Houston, TX 77002, USA

ARTICLE INFO

Article history:
Received 3 June 2013
Received in revised form 10 October 2013
Accepted 11 October 2013
Available online 19 October 2013

Keywords:
Anisotropy of magnetic susceptibility (AMS)
Bohemian Massif
Exhumation
Granite–migmatite dome
Metamorphic core complex

ABSTRACT

The mid-Carboniferous Pelhřimov core complex, Bohemian Massif, is a crustal-scale elongated granite–migmatite dome interpreted to have formed by gravity-driven diapiric upwelling of the metapelitic middle crust. The vertical diapiric flow is evidenced by outward-dipping foliation and lineation patterns, deformation coeval with the widespread presence of melt, rapid exhumation of the dome center from depths corresponding to pressure of about 0.6 GPa to shallow levels (pressure less than 0.2 GPa) within 2 M.y., and kinematic indicators of downward return flow of the mantling rocks. As compared to common diapirs, however, the Pelhřimov complex exhibits a more complicated inferred strain pattern with two perpendicular, irregularly alternating directions of horizontal extension in what is interpreted as the diapir head. Comparison of structural data from migmatites with anisotropy of magnetic susceptibility (AMS) data in granites also reveals that only final increments of strain are recorded in the granites. The map dimensions and gravity image of the complex suggest that the diapiric upwelling affected a large portion of the orogen's interior between two microplates brought together during continental collision. The northwesterly microplate (the upper-crustal Teplá–Barrandian unit) collapsed vertically as an 'elevator' at around 346–337 Ma whereas the easterly microplate (Brunia) was underthrust beneath the Moldanubian rocks during ∼346–330 Ma (the indentor). It is suggested that these microplates then acted as cold and rigid margins localizing mid-crustal diapirism and associated voluminous S-type granite plutons inbetween, parallel to the edge of the Brunia indentor.

We conclude that bringing together soft metapelitic middle crust with two rigid lithospheric blocks during collision resulted in significant lateral temperature and strength variations across the orogen's interior. A general conclusion from these inferences is that granite–migmatite domes delineating margins of collided microplates may form as crustal-scale structures accommodating late-orogenic isostatic reequilibration.

1. Introduction

Metamorphic core complexes, commonly containing granite–migmatite domes, form by multiple mechanisms in compressional, strike-slip, and extensional settings (e.g., Armstrong, 1982; Coney and Harms, 1984; Brown and Dallmeyer, 1996; Bregar et al., 2002; Teyssier and Whitney, 2002; Whitney et al., 2004, 2013; Yin, 2004; Brun and Sokoutis, 2007; McFadden et al., 2010; Rey et al., 2011). In many cases, their formation involves rapid crustal exhumation and decompression melting of originally deeply seated rocks, thereby facilitating advective heat transfer to upper crustal levels (e.g., Amato et al., 1994; Holm and Lux, 1996; Fayon et al., 2004; Whittington, 2004; Charles et al., 2011). Core complexes and domes are thus an expression of crustal flow driven by interactions between gravity and lateral tectonic forces during orogeny (e.g., Brun et al., 1981; Soula, 1982; Burg et al., 2004; Whitney et al., 2004; Teyssier et al., 2005). The key aspect

---

[*] Corresponding author at: Czech Geological Survey, Klárov 3, Prague, 11821, Czech Republic. Tel.: +420 737802447.
E-mail address: krystof.verner@geology.cz (K. Verner).

0264-3707/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.jog.2013.10.002

in understanding the cause and mechanics of formation of core complexes and gneiss domes is thus a rigorous assessment of the relative contribution of gravity and tectonic forces. Fortunately, as documented by both field and numerical modeling studies, much of this information, though sometimes ambiguous, may be extracted from geometry of and finite strain patterns in and around core complexes and granite–migmatite domes (e.g., Brun and Pons, 1981; Lagarde et al., 1994; Burg et al., 2004; Kruckenberg et al., 2011).

This contribution addresses this issue on the example of the Pelhřimov granite–migmatite core complex, Bohemian Massif (Fig. 1), largely utilizing structural and anisotropy of magnetic susceptibility (AMS) data. Elsewhere, the AMS analysis has revealed a great potential in quantifying magnetic fabric parameters, such as orientation, intensity, and symmetry, in migmatites and gneiss domes (e.g., Ferré et al., 2002; Borradaile and Gauthier, 2003; Teyssier et al., 2005; Charles et al., 2009; Schulmann et al., 2009; Kruckenberg et al., 2011; Viegas et al., 2013) and is also used here to characterize in detail the inferred strain pattern of the granite–migmatite dome. On the basis of the AMS and structural data, we then interpret the internal dynamics and formation of the core complex as resulting from gravitational instability of the metapelitic middle crust that postdated juxtaposition of two contrasting continental microplates. Finally, we present a new model invoking lateral rheological variations inherited from continental collision and underthrusting as a driving mechanism for the formation of metamorphic core complexes, crustal exhumation, and associated voluminous S-type granite plutonism.

2. Geology of the Pelhřimov complex

2.1. Tectonic setting, ages, and metamorphic evolution

The Pelhřimov complex is by far the largest domal structure in the Bohemian Massif (e.g., Suess, 1926; Tollmann, 1982), stretching along the ~NNE–SSW direction across the high grade core of the orogen (the Moldanubian unit; Fig. 1). The complex divides this high grade unit into two segments (Fig. 1b). Although these segments have broadly similar composition, dominated by amphibolite-facies metapelitic lithologies with intercalations of eclogite and granulite facies rocks, and were exhumed at approximately the same time, they differ in the inferred geodynamic setting driving this exhumation.

To the east of the Pelhřimov complex, the Moldanubian unit is thrust over the Brunia microplate (also referred to as the 'Brunovistulicum'; Fig. 1b), which is an exotic terrane of presumably Avalonian affinity (e.g., Dudek, 1980; Schulmann et al., 1991, 2005; Fritz and Neubauer, 1993; Štípská and Schulmann, 1995; Fritz, 1996; Fritz et al., 1996; Finger et al., 2000, 2007; Schulmann and Gayer, 2000; Racek et al., 2006; Kalvoda et al., 2008). Geophysical data indicate that Brunia continues ~70 km westward beneath the Moldanubian rocks (Fig. 1c; Schulmann et al., 2008; Guy et al., 2011; this study) and that its westernmost edge at depth coincides with the Přibyslav mylonite zone on the present-day surface (PMZ in Fig. 1c). Indeed, this zone, which also delimits the eastern margin of the Pelhřimov complex, was recognized as an important crustal-scale geophysical and tectonic boundary (Blížkovský et al., 1975; Verner et al., 2006; Lenhardt et al., 2007; Žák et al., 2011). The highly oblique Moldanubian/Brunia collision and underthrusting commenced prior to ca. 346 Ma in the northeast (Štípská et al., 2004; Jastrzebski, 2009) and ceased at around 335 Ma in the southwest (Verner et al., 2006). This process resulted in a ~NNE–SSW-trending belt of imbricated nappe stacks along the eastern margin of the Bohemian Massif (Fig. 1c) and also in mixing and extrusion of lower- and mid-crustal rocks over the top of Brunia (Štípská et al., 2008). The existing U–Pb monazite and ^{40}Ar/^{39}Ar hornblende and muscovite cooling ages from Moldanubian rocks east of the Pelhřimov complex suggest metamorphism, exhumation, and cooling below ~400 °C during ~341–325 Ma (Dallmeyer et al., 1992; Fritz et al., 1996; Friedl, 1997). The minimum exhumation and cooling ages are also constrained by pegmatite dikes which cross-cut the Moldanubian paragneisses and were dated at 334 ± 6 Ma and 332 ± 3 Ma (U–Pb on columbite–tantalite; Melleton et al., 2012).

Similarly, the Moldanubian rocks west of the Pelhřimov complex were exhumed above the brittle–ductile transition between ~346 and 337 Ma (Fig. 1b; Holub et al., 1997, 2011; Žák et al., 2005, 2012). Although there are no existing cooling ages for this area, the upper age limit for its exhumation is bracketed by structural relations around a melasyenitoid pluton dated at 336.6 ± 1.0 Ma (Tábor melasyenite, U–Pb on zircons; Janoušek and Gerdes, 2003) and comparable melagranite porphyry dikes dated at 337.9 ± 0.2 Ma (locality Nihošovice, U–Pb on zircons; Holub et al., 2011). These intrusions cut discordantly across the ductile foliation in their mid-crustal metapelitic host rocks. In contrast to the continental indentation and horizontal channel flow proposed for the Moldanubian rocks east of the Pelhřimov complex, recent studies invoked gravity-driven collapse of a rigid upper crustal block (the Teplá–Barrandian unit) as the principal cause driving the crustal exhumation to the west (e.g., Zulauf et al., 2002; Dörr and Zulauf, 2010; Franěk et al., 2011; Žák et al., 2012).

The Pelhřimov complex itself differs from the neighboring eastern and western segments of the Moldanubian unit in the presence of large volumes of crustally derived S-type two mica granites that constitute part of the extensive Moldanubian batholith and are in close association with biotite–sillimanite (±cordierite) migmatites and migmatized paragneisses (e.g., Krupička, 1968; Fig. 1c). The metapelitic rocks also contain volumetrically minor lenses of serpentinized peridotites and eclogites preserving an earlier HP/UHP exhumation history (Faryad and Kachlík, 2013; Faryad et al., 2013, in press). On the basis of U–Pb monazite and zircon ages and *P*–*T* estimations, it was shown that the Pelhřimov complex underwent anatexis at around 330–329 Ma at 0.6 GPa and 730 °C and was then nearly isothermally decompressed to shallow depths corresponding to about 0.2 GPa within 2–3 M.y. (Žák et al., 2011). These inferences point to an exhumation history significantly different from the Moldanubian rocks along both flanks of the Pelhřimov complex.

2.2. S-type granites of the core complex

The two-mica granites, referred to as the 'Eisgarn-type', exhibit only subtle petrographic, compositional, and textural variations in the core complex, but have variable intrusive geometries including multiple ~NNE–SSW-elongated sheets, highly irregular plutons, and elliptical steep-sided stocks. The westernmost of these intrusions is the Klenov pluton (Fig. 2) composed of fine to medium grained equigranular monzonite to syenogranite characterized by muscovite prevailing over biotite and low contents of Zr and Th (René et al., 1999, 2003). The granite also contains magmatic andalusite and cordierite in some places and hosts rare biotite schlieren, in some cases associated with sillimanite. The Klenov granite was dated at 328.4 ± 0.2 Ma and 327.1 ± 0.2 Ma (U–Pb on monazite; K. Verner, unpublished data).

The inner part of the complex was intruded by the extensive Mrákotín composite pluton (Fig. 2) which includes several textural varieties of fine to medium grained, both equigranular and porphyritic, two-mica andalusite-bearing granites. Field relationships indicate that the granite varieties are broadly coeval. The major- and trace-element geochemical signature of these granites is characteristic of peraluminous high-K granites formed by partial melting of a crustal metasedimentary source (René, 2000; René