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Seismic anisotropy and deformation patterns in upper mantle xenoliths from the central Carpathian–Pannonian region: Asthenospheric flow as a driving force for Cenozoic extension and extrusion?

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ABSTRACT

We review deformation fabrics in mantle xenoliths from the central part of the Carpathian–Pannonian Region (CPR) and, in combination with seismic shear wave splitting data, attempt to define patterns of upper mantle anisotropy. Our interpretations from both lines of evidence support a model for east–west oriented asthenospheric flow, decoupled (at least in part) from the overlying lithosphere. Mantle flow fields resulting from Tertiary indentation of Europe by the Adria micro-plate and the resulting Alpine orogen may thus have been an important factor in driving the eastward extrusion of lithospheric blocks in the CPR accompanied by lithospheric extension, rapid 'rollback' of the Carpathian subduction system, and its diachronous collision with the European craton. According to this model, eastward asthenospheric flow would add significantly to the effects of slab rollback and gravitational instability. Thus, opening of the Pannonian Basin, rather than being exclusively driven by 'slab pull' and gravitational instability, could have been resulted, at least in part, from mantle flow associated with the Adria–European collision and ensuing Alpine orogeny. Such models have also been proposed for analogous geodynamic scenarios such as the western and eastern Mediterranean, and western and southwestern Pacific regions, offering a potential generic model for back-arc basin opening.

1. Introduction

The Carpathian–Pannonian Region (CPR) is made up of young extensional basins enclosed by the Carpathian and Dinaride mountain chains, extending to the east and southeast of the Alpine orogenic belt (Fig. 1; e.g., Csontos and Vörös, 2004; Fodor et al., 1999; Horváth et al., 2006; Szabó et al., 2004). The complexity of its geodynamic history has long been recognized but, with a few exceptions (e.g., Kovács et al., 2007; Schmid et al., 2008), has not been evaluated in terms of syntheses of data bearing on mantle petrology, geophysics, magmatic activity and structural geology. Given the extensive bodies of information in each of these areas, and the relative youth and continuity of igneous and tectonic activity in the region, the CPR is an excellent natural laboratory for testing competing models for the generation of extensional basins and their possible association with mantle melting.

'Subduction type' geochemical signatures in the source regions of extension-related Miocene CPR magmas has been recognized by Seghedi et al. (2004) and Harangi et al. (2007) while recent reviews by Kovács et al. (2007) and Kovács and Szabó (2008) suggested that such type signatures may have been inherited from prior subduction episodes, related to Mesozoic stages of the Alpine orogeny. This is supported by evidence for slab-derived fluid interaction in mantle xenoliths from the central part of the CPR (Bakony–Balaton Highland; Bali et al., 2007, 2008), far removed, as interpreted from tomographic imagery (Grad et al., 2006; Koulakov et al., 2009), from any current or recently active subduction. These observations challenge previous views for the genesis of the Cenozoic Pannonian Basin and back-arc basins in general that invoke slab rollback and gravitational instability as the exclusive drivers of extension and lithospheric block extrusion in the CPR (see Flower et al., 1998; 2001).

However, our review of recent results on petrologic indications of tectonic deformation in upper mantle xenoliths from the Bakony–Balaton Highland (BBH) and Little Hungarian Plain (LHP) areas

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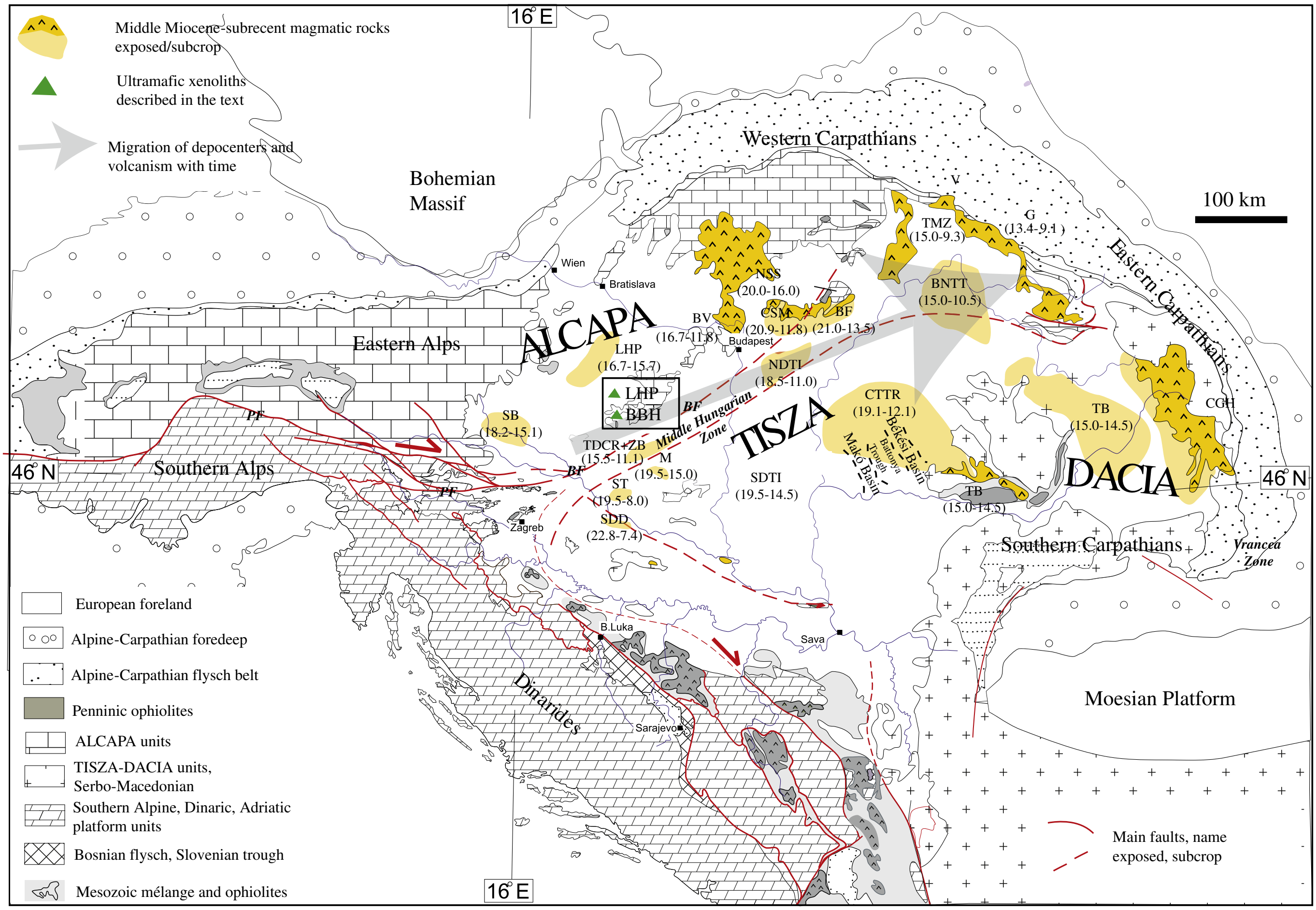

Fig. 1. Spatial distribution of basement rocks and major tectonic units in the Carpathian–Pannonian Region. Map is compiled and modified after Channell and Kozur (1997), Csontos (1995), Fodor et al. (1999), Haas et al. (2000), Kovács et al. (2000), Szabó et al. (1992), Tari et al. (1993). Paleogene–Early Miocene, Middle Miocene to subrecent calk-alkaline, alkaline volcanic rocks and Plio-Pleistocene alkali basalts are also highlighted with the respective age data (modified after Kovács et al., 2007 and Pécskay et al., 2006). Light gray arrow indicates the diffuse youngening of volcanic activity and basin formation (Meulenkamp et al., 1996; Pécskay et al., 2006). Abbreviations for the major calc-alkaline, alkaline volcanic provinces are as follows (with capital letters): PZ — Periadriatic zone, MHZ — Middle Hungarian zone, SVZ — Sava–Vardar zone. Abbreviations for the major alkaline basaltic occurrences are: SB — Styrian Basin; LHP — Little Hungarian Plain; BBH — Bakony–Balaton Highland; NG — Nógrád–Gömör; ETB — East Transylvanian Basin (also referred to as Persanyi Mts.). Abbreviations for the major calc-alkaline occurrences are (with capital letters): SDD — Sava–Drava Depression, ST — Southern Transdanubia, M — Mecsek, TDCR + ZB — Transdanubian Central Range + Zala Basin, SDTI — Southern Danube–Tisza Interfluves, NDTI — Northern Danube–Tisza Interfluves, BV — Börzsöny–Visegrád Mts., CSM — Cserhát–Mátra Mts., BF — Bükk Foreland, NSS — Nógrád–Southern Slovakia, BNTT — Beregovo–Trans-Tisza Region, TMZ — Tokaj–Milic–Zemplén Mts., CTTR — Central Trans-Tisza Region, G — Gutin range, TB — Transylvanian Basin, CGH — Calimani–Gurghiu–Hargita; V — Vihorlat. Abbreviations for major faults are (with bold italic): PF — Periadriatic Fault, BF — Balaton Fault. For the more accurate location of xenolith bearing alkaline basalts please refer to Fig. 6.

(Fig. 1.; Falus, 2004; Hidas et al., 2007), and seismic shear-wave splitting directions (e.g., Dricker et al., 1999; Ivan et al., 2008; Kummerow and Kind, 2006; Meissner et al., 2002; Stuart et al., 2007; Vinnik et al., 1994), offer strong evidence in support of asthenospheric flow beneath the CPR. In this paper, the temporal and spatial dimensions of such a process are discussed in the light of the data derived from mantle xenoliths and seismic shear-wave splitting studies, structural geology and spatio-temporal patterns of Cenozoic magmatic activity. Our provisional conclusion is that a combination of asthenospheric flow, slab rollback and gravitational instability allows for a comprehensive explanation of the Cenozoic geodynamic evolution in the CPR. We highlight some key points for future research with a view to reconciling the temporal and spatial contributions of slab rollback and gravitational instability to CPR evolution and the role of the proposed asthenospheric flow.

The association of the proposed asthenospheric flow model with continental collisions and their conjugate orogenic belts has been invoked as a significant factor for analogous scenarios elsewhere (e.g., in Southeast Asia and Anatolia). There is no widely accepted term to describe asthenospheric flow occurring in orogenic belts, however in many papers the notion of 'Collision-Driven Asthenospheric Flow' (CDAF) has been adopted (Flower et al., 1998; Hoang and Flower, 1998; Hoang et al., 1996; Liu et al., 2000). However, such models have not been widely adopted with respect to similar scenarios, such as the southwest Pacific marginal basins and the Mediterranean and Caribbean Seas (etc.), despite its potential ability to explain a number of puzzling, but (seemingly) similar features. A brief overview of the asthenospheric flow model is presented based on the basis of seismic shear-wave splitting data and (a new, independent line of evidence) fabric studies of basalt-hosted mantle xenoliths, that record upper mantle anisotropy, bearing mantle convective flow histories.

2. Geological background

The central (largest) part of the CPR per se is the Pannonian Basin. This is characterized by significantly thinned continental crust, dominated by Middle to Late Miocene sedimentary formations (Fig. 1), which are punctuated by a number of smaller isolated mountainous features. Based on Mesozoic tectonostratigraphy and structural geological analysis, this area been shown to comprise two micro-plates, referred to, respectively, as 'Alcapa' (Fig. 1; *Al*ps–*Ca*rpathians–*Pa*nnonian) and 'Tisza–Dacia' (Csontos, 1995; Csontos and Vörös, 2004; Haas et al.,