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A seismic discontinuity in the upper mantle between the Eastern Alps and the Western Carpathians: Constraints from wide angle reflections and geological implications

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ABSTRACT

Seismic investigation of the lithosphere by means of active source experiments is mostly confined to the crust and the Moho. Structures in the upper mantle are more likely to be discovered by analyses of teleseismic data, although these methods are restricted in their resolution capabilities. The relatively rare evidence for upper mantle refractors or reflectors in active source data enables challenging and interesting studies of the lower and not so well known part of the lithosphere. We present such an example from the tectonically complex region between the Eastern Alps and the Western Carpathians. This area was covered by several extensive 3D wide-angle reflection/refraction experiments within the last decade, and their layout was designed to illuminate the crustal structure and in particular the Moho discontinuity. In some areas, reflections from below the Moho are also recorded. These reflections occur at recording offsets between 200 and 500 km, and they are particularly strong in cross line recordings. We derive a set of travel times from the data and perform a tomographic inversion for the depth and shape of the reflecting interface. The inversion makes use of an existing 3D crustal model which also includes the Moho topography. Since the upper mantle velocities are poorly constrained and the azimuthal distribution of the rays is biassed, several tests are applied to investigate the reliability of possible solutions. The results from the tomographic inversion indicate an overall horizontal and radially dipping reflector. The average depth of the reflector is 55 km, which is about 25 km below the crust–mantle transition, and amplitude modelling suggests that the reflecting interface represents a velocity increase. The investigated area is further characterised by deep sedimentary basins, high heat flow, high velocities in the lower crust, diffuse Moho signature and a strong positive Bouguer anomaly. Nearby xenolith outcrops exhibit a pronounced change in anisotropy and indicate the presence of two distinct layers in the lithospheric mantle, whereas the deeper layer is thought to present more juvenile lithosphere derived from thermal relaxation in the post-extension phase. Most likely the upper mantle reflector also represents this change in anisotropy, though other scenarios are also possible. We conclude that the entire lithosphere is significantly shaped by extensional processes which affect the area since the late Oligocene/early Miocene.

1. Introduction

The existence of seismic discontinuities in the uppermost mantle is demonstrated in several datasets throughout the world. A shallow lithosphere–asthenosphere boundary (LAB) may cause significant reflectivity (Posgay et al., 1990, 1995). Balling (2000) gives a fine example of subducted oceanic crust which, after the transformation to eclogite, represents a steeply dipping high-velocity/density contrast. A similar mechanism is assumed for the well-known Flannan Reflector (Brewer et al., 1983; Price et al., 1996). North- and south-dipping mantle reflectors are imaged in the MONA LISA dataset from the North Sea region (Mona Lisa Working Group, 1997). Abramovitz et al. (1998) interpreted these reflectors as a Caledonian subduction zone and a subsequently formed compressional shear zone. Carbonell (2004) found evidence for a reflective lithosphere and a less reflective asthenosphere from a high-density wide-angle shot gather in the Urals. Okure and McBride (2006) investigate a gently dipping mantle reflector below the Illinois Basin and provided two possible explanations. It either represents a deformation caused by a 1.6 Ga old subduction process or laminated lithosphere related to melting of proterozoic crust. Based on wide-angle data, Sŕoda et al. (2006) image a steeply north-dipping reflector (in a depth range from 40 to 60 km) below the Carpathian foredeep and interpreted it as a shear zone resulting from the collision of the European Platform and the ALCAPA unit. As shown, possible causes for reflectivity in the uppermost mantle are widespread. Steer et al. (1998) offer four different

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explanations (remnant subduction zones, shear zones, fluids and seismic anisotropy) and discuss their significance for geodynamic interpretations.

The presented study aims at the interpretation of wide-angle reflections from within the uppermost mantle in the area between the Eastern Alps and the Western Carpathians.

2. Tectonic and geological setting

The investigated area (Fig. 1) is situated in between four different geological provinces: The Bohemian Massif in the North West, the Eastern Alps in the West, the Pannonian basin in the South East and the Western Carpathians in the North East. While the genesis of the Bohemian Massif dates back to the Paleozoic (e.g. Matte et al., 1990), the other provinces are related to alpine orogeny and subsequent processes (e.g. Csontos and Vörös, 2004; Horváth et al., 2006; Schmid et al., 2004, 2008). During the Eocene, about 50 Ma ago, a continent–continent-collision started between the European and Adriatic–Apulian plates, leading to the formation of the Alps. The Eastern Alps were subject to eastward directed lateral extrusion starting from the Late Oligocene (i.e., Fodor and Csontos, 1999; Horváth et al., 2006; Ratschbacher et al., 1991). The extrusion was facilitated by the eastward directed retreat of the Carpathian subduction which was active from the Early Miocene to Pliocene times. Since this subduction ceased, the actual stress regime in the region has changed from extensional to compressional due to the ongoing movement and rotation of the Adriatic–Apulian plate (Bada and Horváth, 2007). The genesis of the Pannonian basin system is thought to be strongly related to the Carpathian subduction and its roll-back effect (i.e., Horváth et al., 2006). Cenozoic sedimentary fillings of this large basin system are up to 8 km thick. Its north-westernmost parts, the Vienna Basin, the Danube basin, and the Little Hungarian Plain represent the transition between the Eastern Alps and the Western Carpathians.

The inner Western Carpathians (i.e. south of the Penninic units) and the intervening portion of the Pannonian basin north of the Middle Hungarian zone (MHZ) are usually referred to as the ALCAPA block because of lithologic and stratigraphic similarities (e.g., Csontos and Vörös, 2004; Haas and Mioc, 2000; Kovács and Szederkényi, 2000). To its south, the ALCAPA block is separated from the Tisza–Dacia unit by the MHZ. While the ALCAPA block is derived from the Adriatic–Apulian Domain, the Tisza–Dacia unit is believed to have rifted off the European margin during the Late Jurassic.

Kovács and Csontos (2007) and Kovács and Szabó (2008) provide an overview of concurring ideas on the tectonic evolution of the area. Previous interpretations are in favour of a southward subduction of the European plate beneath the Western Carpathians. However, recent geophysical investigations (Grad et al., 2006; Szafian and Horváth, 2006) could not show significant crustal thickening or southward dipping reflectors in the crust beneath the Western Carpathians. The volcanic rocks in the northern part of the Pannonian Basin (referred to as the “Western segment” in Kovács and Szabó, 2008) do not show a spatial and temporal pattern which would be

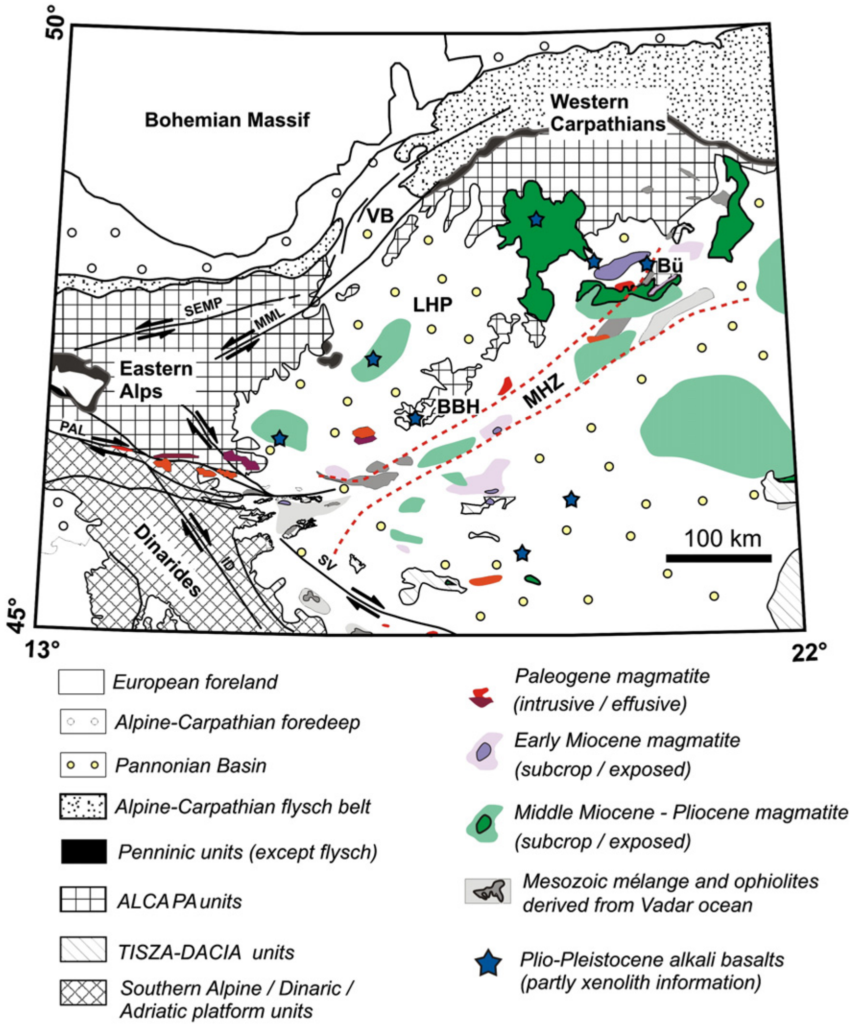

Fig. 1. Tectonic map of the investigated area. Solid lines: Major faults, active since early Miocene. SEMP: Salzachtal–Ennstal–Mariazell–Puchberg – line. MML: Mur–Mürz – line. PAL: Periadriatic line. SV: Sava fault. ID: Idria fault. MHZ: Mid-Hungarian zone. VB: Vienna Basin. LHP: Little Hungarian Plain. Bü: Bükk Mountains. BBH: Bakony–Balaton Highlands.