Microstructural analysis of upper mantle peridotites: their application in understanding mantle processes during the formation of the Intra-Carpathian Basin System

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Precedents

The Intra-Carpathian Basin System was formed at late stages of the Alpine orogeny, the convergence of the Adriatic and European plates (e.g., Kázmér and Kovács, 1985; Balla, 1988; Csontos et al., 1992, Csontos, 1995; Fodor et al., 1999). The eastward escape of the orogenic wedge from the Alpine collision zone, followed by extensional collapse and the retreat and active pull of the Carpathian subduction zone by subduction rollback, are responsible for the formation of the Pannonian Basin. Significant quantity of lithospheric thinning accompanied the basin formation (e.g., Csontos, 1995; Török, 1995; Fodor et al., 1999; Tari et al., 1999; Falus et al., 2000; Huismans et al, 2001). Neogene-Quaternary alkali basalts, associated with deep seated earthquakes (Falus et al., 2004), occurring dispersed in the basin system with abundant mantle xenoliths provide spectacular opportunity to study the nature (both physical and chemical) of the underlying lithospheric upper mantle beneath the region.

Petrologic and geochemical studies on mantle derived xenoliths in the Intra-Carpathian Basin System are numerous and extensive (e.g., Embey-Isztin, 1976, Embey-Isztin et al., 1989, 2001ab; Kurat et al., 1991; Downes et al., 1992; Szabó and Taylor, 1994; Szabó et al., 1995ab Vaselli et al., 1995, 1996; Dobosi et al., 1999; Falus et al., 2000, Bali et al., 2001, 2002; Dobosi, 2003 and references therein) regarding their lithology, major-, trace-element and isotope geochemical compositions. These studies revealed that the lithospheric mantle beneath the region is similar to that observed world wide in the shallow subcontinental lithospheric mantle environment. Marked relation between the composition of mantle xenoliths and xenolith textures (interpreted as indicative of deformation state) was found (e.g., Downes et al., 1992; Szabó et al., 1995a). In fact, equilibrium temperature and oxygen fugacity also showed remarkable relationship with xenolith textures (Szabó et al., 1995a). However, no consistent kinematical model was found that was able to link texture-forming processes and those driving the evolution of geochemical characteristics.

Simultaneously to the evolution of geochemical exploration, but essentially independently from that, the analysis and interpretation of deformation and resulting textures and structures (together often addressed as "fabrics") also largely improved. In fact, not only a large evolution of analytical techniques (from U-stage to EBSD techniques) but also the modern kinematical interpretation of studied microstructures went through significant progress (e.g., Wenk and Christie, 1991). Specific attention has been paid to reveal and understand the behavior of olivine (e.g., Carter and Avé Lallemant, 1970, Mercier and Nicolas, 1975; Zhang et al., 2000), the most abundant mineral of the upper mantle, in lab experiments. Moreover, experimental results were successfully applied to interpret *olivine microstructures* (i.e., lattice preferred orientation) in some natural peridotites (e.g., Soedjatmiko and Christensen, 2000). Unfortunately, these works lack extensive geochemical data and thus the link between deformation, recrystallization and geochemical characteristics was not clarified.

The main aims of this study are:

1) To give a detailed textural, fabric and microstructural characterization of macroscopically deformed mantle peridotites from all xenolith locations of the Intra-Carpathian Basin System;
2) To quantify and to describe the mechanisms responsible for deformation in the upper mantle;
3) To provide a dynamic (more realistic) view of lithospheric evolution and response to the formation of the Intra-Carpathian Basin System.

Methodology

Almost 50 xenoliths from several hundred collected peridotite samples displaying macroscopic deformation features were selected from all well-known xenolith locations of the Intra-Carpathian Basin System. Petrographic thin sections were prepared from the selected samples. If possible xenoliths earlier studied geochemically in detail, fulfilling textural requirements were also selected for microstructural analysis.

The thin sections were analyzed in detail concerning their modal composition, texture (based on the methodology of Mercier and Nicolas, 1975) and microstructure using a Nikon Eclipse E600 POL microscope. Olivine crystallographic fabrics were analyzed with an Ernst Leitz Universal Stage mounted on a Laborlux polarization microscope (Eötvös University, Budapest, Lithosphere Fluid Research Lab). In each sample (where possible) the orientation of 100 olivine grains were analyzed. Results were plotted on lower hemisphere, equal area stereographic projections. Xenoliths with special textures were further analyzed concerning their misorientation pattern. These results were visualized in crystal co-ordinates. In both cases, spreadsheets for geometrical calculations were prepared.

Major element composition of the analyzed peridotites was either taken from earlier geochemical studies (e.g., Kurat et al., 1991; Downes et al., 1992; Szabó and Taylor, 1994; Szabó et al., 1995b Vaselli et al., 1995, 1996; Falus et al., 2000, Embey-Isztin et al., 2001; Bali et al., submitted) or were carried out using a JEOL Superprobe JXA-8600 WDS at the Department of Earth Sciences, University of Florence and University of Bristol. In both laboratories natural and synthetic standards were used for the analyses, and the method of Bence & Albee (1968) was applied for correction. For the determination of average compositions 2 to 5 points were analyzed in each constituent.

Results

1) Formation of the Intra-Carpathian Basin System was the consequence of Alpine collision, subsequent extrusion, subduction and rollback of the European oceanic lithosphere beneath the African plate. The Intra-Carpathian Basin System is constituted of two main lithospheric units (ALCAPA and TISZA) with different pre-Miocene history, but with similar tectonic/structural/geodynamic and geochemical evolution after their docking in early Miocene times. Basin formation was associated with deformation and geochemical evolution of the lithospheric mantle.

2) Equilibrium temperatures of mantle xenoliths are suggested to represent their relative stratigraphic position within the lithospheric mantle within one xenolith location. Xenoliths with higher equilibrium temperatures correspond to deeper portion of the lithospheric mantle whereas xenoliths with lower equilibrium temperature represent shallower lithospheric depth.

3) Systematic variance in the depletion of basaltic major elements in the peridotite xenoliths with decreasing depth (decreasing equilibrium temperatures) is believed to be the consequence of more superimposed mantle processes:
   - ancient depletion related to increasing partial melting during adiabatic decompression and mantle upwelling associated with continental crust formation,
   - reaction of the peridotite with migrating melts/fluids resulting in pyroxene breakdown and olivine precipitation.

4) Enrichment, mostly observed in the composition of incompatible trace elements, was subsequent to the ancient depletion. Migration of metasomatic fluids occurred along veins, shear zones, however melt percolation along grain boundaries could have also been an important feature in the overall metasomatism of the shallower part of the upper mantle.

5) Deformation features observed in the lithospheric mantle beneath the region are mostly attributed to the formation of the Intra-Carpathian Basin System, although the preservation of older deformation features cannot be excluded.

6) The formation of the Intra-Carpathian Basin System was associated with considerable lithosphere thinning evidenced by garnet symplectites from the SBVF, ETBVF and LHPVF. According to geobarometric estimations, the lithosphere before basin formation was at least 40-50 km thicker than at recent times.

7) Olivine orientation distribution in the mantle xenoliths, despite relatively low number studied, imply that deformation in the mantle beneath the northern and eastern marginal portions of the basin system was dominantly accommodated by intracrystalline slip on the (010)[100] slip system regardless of equilibrium temperatures. Conversely, deformation in the xenoliths from the central portion of the Intra-Carpathian Basin System displays clear relation to equilibrium temperatures (~ depth of origin). Xenoliths from the deep lithospheric mantle display evidence for intracrystalline slip on the (010)[100] slip system, whereas those from the shallow mantle display clear evidence for the activation of multiple slip systems beside the (010)[100], most likely the (100)[001] slip system and the occurrence of twist walls on the (010). It is strongly suggested that this remarkable feature is a consequence of deformation in different stress regimes with respect to mantle depth. In the shallow mantle deformation was characterized by considerable flattening also recognized in surface processes. Whereas, the deep lithosphere deformed by asthenospheric flow and was only attached to the bottom of the lithosphere after cooling and the cessation of deformation.

8) Mylonites among the xenoliths of the ETBVF are unique features. Localization of deformation is attributed to melt infiltration. The driving force for deformation is suggested to be related to the proximity of the subducting slab.

9) The development of annealed and statically recrystallized textures is the consequence of young processes associated with the heating of the asthenospheric upwelling and melt/fluid percolation, triggering subgrain rotation, static recrystallization and grain growth. However, the effect of static recrystallization on developed mantle fabric is suggested to be subordinate.

10) The remarkable anisotropy observed in the fabric of mantle xenoliths should have considerable effect on the migration of fluids and melts. In fact, it could be an important factor in controlling the spatial distribution of the surface manifestation of magmatic activity.
Anisotropy features and the evidence for the occurrence of structural domains within the subcontinental lithospheric mantle beneath the Intra-Carpathian Basin System demonstrated by the fabric analysis of deformed mantle xenoliths implies that these features should be detectable, as they are worldwide, by seismic sounding methods. The mutual application microstructural and geochemical analysis together with geophysical methods could reveal the nature of the upper mantle in regions where the volcanic activity did not sample these portions of the lithosphere. Moreover, this way of the research would significantly contribute to the understanding of basin formation, associated with deformation and melt/fluid migration processes.

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