Mapping the lithosphere and asthenosphere in the Balkan Peninsula region

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Key words: lithosphere-asthenosphere, shear-wave velocity models, rift, subduction

Abstract
This study describes the Lithosphere-asthenosphere system in the region of Balkan Peninsula is obtained by non-linear inversion of the results from the tomography of surface-waves dispersion data. The three-dimensional model is constructed as a set of 133 cellular models, sized 1°x1°. The preferred cellular solutions, obtained by local smoothing optimization, are refined taking into account information from other independent geophysical studies. Several features are evidenced by the study: the lithospheric roots in southern Carpathians and Rhodope, high-velocity rigid lithosphere in the outer part of Eastern Carpathians, low-velocity zones under Pannonian basin with extension to the Serbian-Macedonian rift area, low-angle subduction under the Pindus (Greece) with high-velocity slab, low-velocity uppermost mantle under Aegean Sea, accompanied by significant seismicity.

Картиране на литосферата и астеносферата в района на Балканския полуостров.

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Ключови думи: литосфера-астеносфера, скорост на напречните вълни, рифт, субдукция

Резюме
Това изследване описва литосферно-астеносферната система в района на Балканския полуостров, получена чрез нелинейна инверсия на резултатите от томографията на дисперсионните данни за повърхностните вълни. Триизмерният модел на района е конструиран като набор от 133 клетъчни модела с размери 1 ° x 1 °. Предпочитаните клетъчни структури, избрани чрез локална изглаждаща оптимизация, са оптимизирани използвайки информацията от други независими геофизични изследвания. Изследването показва нямолко структурни характеристики: литосферичните корени в южните Карпати и Родопите, твърдата литосфера с висока скорост във външната част на Източните Карпати, зони с ниска скорост под Панонския басейн с преход към Сръбско-Македонския район, малък ъгъл на субдукция под района на Пинду (Гърция) с високоскоростен слаб, най-горната мантия с ниска скорост под Егейско море, но придружена със значителна сеизмичност.

Introduction

Estimations of Earth's structure have been performed using various methods and data sets: body wave, surface waves, noise correlation. The main problem remains the inversion methods since it is a strongly non-linear problem and consequently leads to no solution, solutions in local minima, multiple solutions, etc. To have a realistic three-dimensional model of the Earth's structure some additional information is necessary in order to constrain the solutions obtained by inversion.
This study describes the lithosphere-asthenosphere system in the region of Balkan Peninsula as obtained by non-linear inversion of surface-waves tomography data (absolute tomography). The three-dimensional model is constructed as a juxtaposition of representative cellular models, sized 1°x1°. The preferred cellular solutions,

obtained in Raykova and Panza (2015) by local smoothing optimization, are refined taking into account information from other independent geophysical studies.

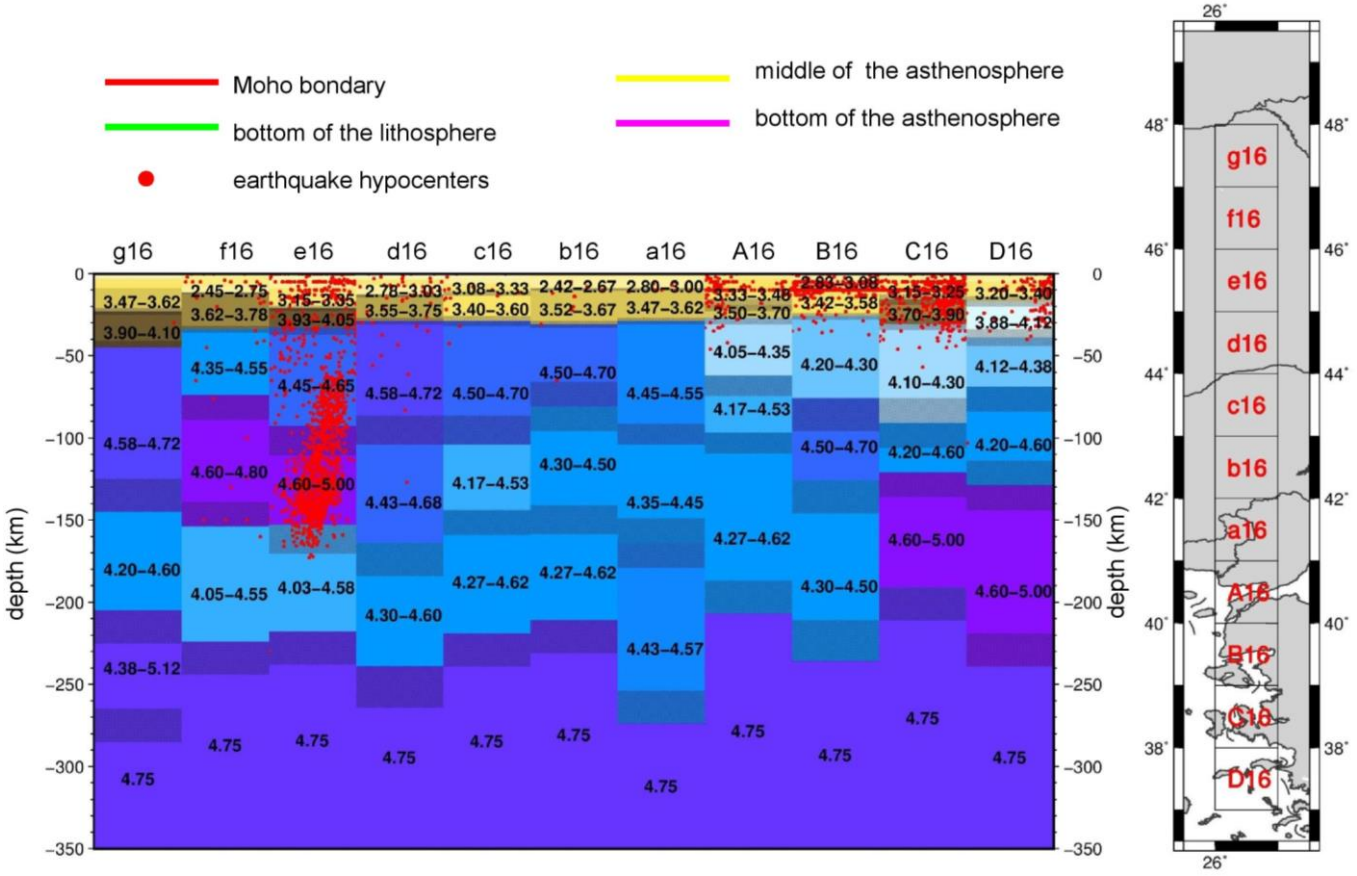


Figure 1. Shear-wave velocity section along longitude 26.5°E. The velocity range is given for each layer. The uncertainties of layer thickness are given by filled rectangles. Location of the cells is given in the right graph.

Methods

The data set consists of Rayleigh wave dispersion curves (group velocities and phase velocities) with period ranges from about 5-10 s to 150 s. The two-dimensional tomography (Yanovskaya, 1991) was used to determine the local values of the group and/or phase velocities in a grid sized 1°x1°. Local dispersion curves were assembled for each cell. The non-linear "hedgehog" inversion (Panza, 1981) of cellular dispersion curves has been applied to obtain the shear-wave velocity models for every cell in the Balkan Peninsula region. The applied inversion method is a trial-and-error optimized Monte Carlo search and a set of models is obtained as the solution for each cell. The number of solutions, with the used parameterization, in general does not exceeded 15 models per cell. An optimized smoothing method (Boyadzhiev et al., 2008), which follows the Occam's razor principle, is used to define, with a formalized criterion, the representative model for each cell. This method decreases the effect of the introduction of artificial vertical discontinuities in VS models between neighboring cells and keeps the 3D structure as homogeneous as possible, minimizing the lateral velocity gradient and the dependence of the final model from the predefined grid.
Since the non-linear inversion and its smoothing optimization guarantee only the mathematical validity of the solution of the inverse problem, we analyzed and tuned the results from optimization (Raykova and Panza, 2015) to additional independent geophysical constrains, such as Moho boundary depth, seismicity, heat flow, etc.

Results

In the Balkan Peninsula region 133 cells have been processed. The representative solutions, selected by optimization, are analyzed, constructing longitudinal and latitudinal sections with the aim to tune the mathematical model to known independent information like (a) depth of Moho boundary from Grad et al. (2009) and Tesauro et al. (2010), (b) depth distribution of seismicity (ISC, 2006), used to resolve some ambiguities in layer's definition and (c) heat flow maps (Cloetingh et al., 2010), used to guide the definition of lithosphere and/or asthenosphere layers.

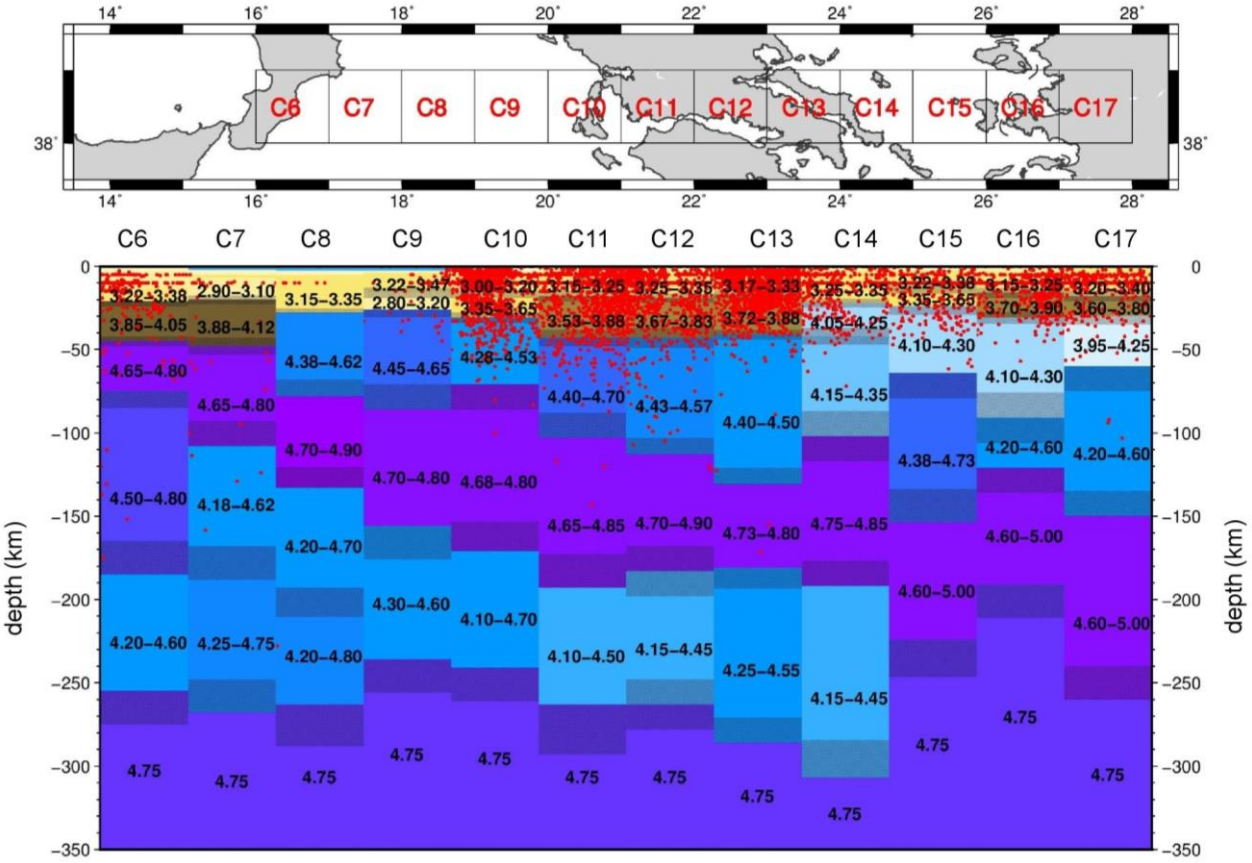


Figure 2. Shear-wave velocity section along longitude 38.5°N. See Fig. 1 for used symbols.

Two shear-wave velocity sections are shown in Fig. 1 (for longitude 26.5°E) and Fig. 2 (for latitude 38.5°N). The shear-wave in the layers is color-coded. The Moho discontinuity is marked by a red line, while the bottom of the lithosphere is evidenced by a green line. The middle of the asthenosphere (low velocity channel) is presented as a yellow line and the bottom of the asthenosphere is outlined by a purple line. Dashed lines are used to denote some alternative possibilities for the boundaries. In both figures is visible hot uppermost mantle under the Aegean Sea and the western coast of Turkey. In almost all cells that underlie the Aegean Sea the observed seismicity is extends also in the hot mantle layers down to depths of about 50-60 km and may indicate the presence of rigid layers with magma intrusion associated with the ongoing process of thinning of the crust (Tirel et al., 2004). In Fig. 1 is visible the area of the Vrancea seismic zone - cell e6. The velocity model of this cell is in accordance with registered seismicity. Hypocenters of the earthquakes are not deeper than about 170 km and the low velocity asthenosphere is located below the rigid, high velocity body. In Fig. 2 is notable the high velocity layer dipping from west (cell C7) to east (cell C14). A high velocity body (Vs ~4.8 km/s) down of depths of about 10 km is detected under cells C15, C16 and C17, in central Aegeas Sea and west coast of Turkey.
The thickness of the lithosphere is shown in Fig. 3. Well notable are rifting properties in the Aegean Sea, Serbian-Macedonian rift and south margins of Pannonian basin (cells, marked by vertical segments). Several cells have complex feature: hot uppermost mantle layer, followed by high velocity rigid layer that overlies low-velocity asthenosphere layer (cells, marked by vertical and horizontal segments). The thickness of the lithosphere is not easily identifiable in several cells where the velocity in the mantle is almost constant (about 4.4 km/s) down to depth of about 300 km (cells, marked by horizontal segments). In some cases this feature can be interpreted as lithospheric roots of the mountains as south Carpathians and Rhodope. The deepest lithosphere is detected under Greece - more than 220 km deep.

Conclusions

The obtained structural model for the lithosphere-asthenosphere system of the Balkan Peninsula region is based on the Vs-depth distribution. A multidisciplinary approach is used to constrain the obtained mathematical model using additional geological, geophysical and petrological information. The reconstructed picture of the lithosphere-asthenosphere system evidences the following features: the lithospheric roots in southern Carpathians and Rhodope,

high-velocity rigid lithosphere in the outer part of Eastern Carpathians, low-velocity zones under Pannonian basin with extension to the Serbian-Macedonian rift area, low-angle subduction under the Pindus (Greece) with high-velocity slab, low-velocity uppermost mantle under Aegean Sea, accompanied by significant seismicity.

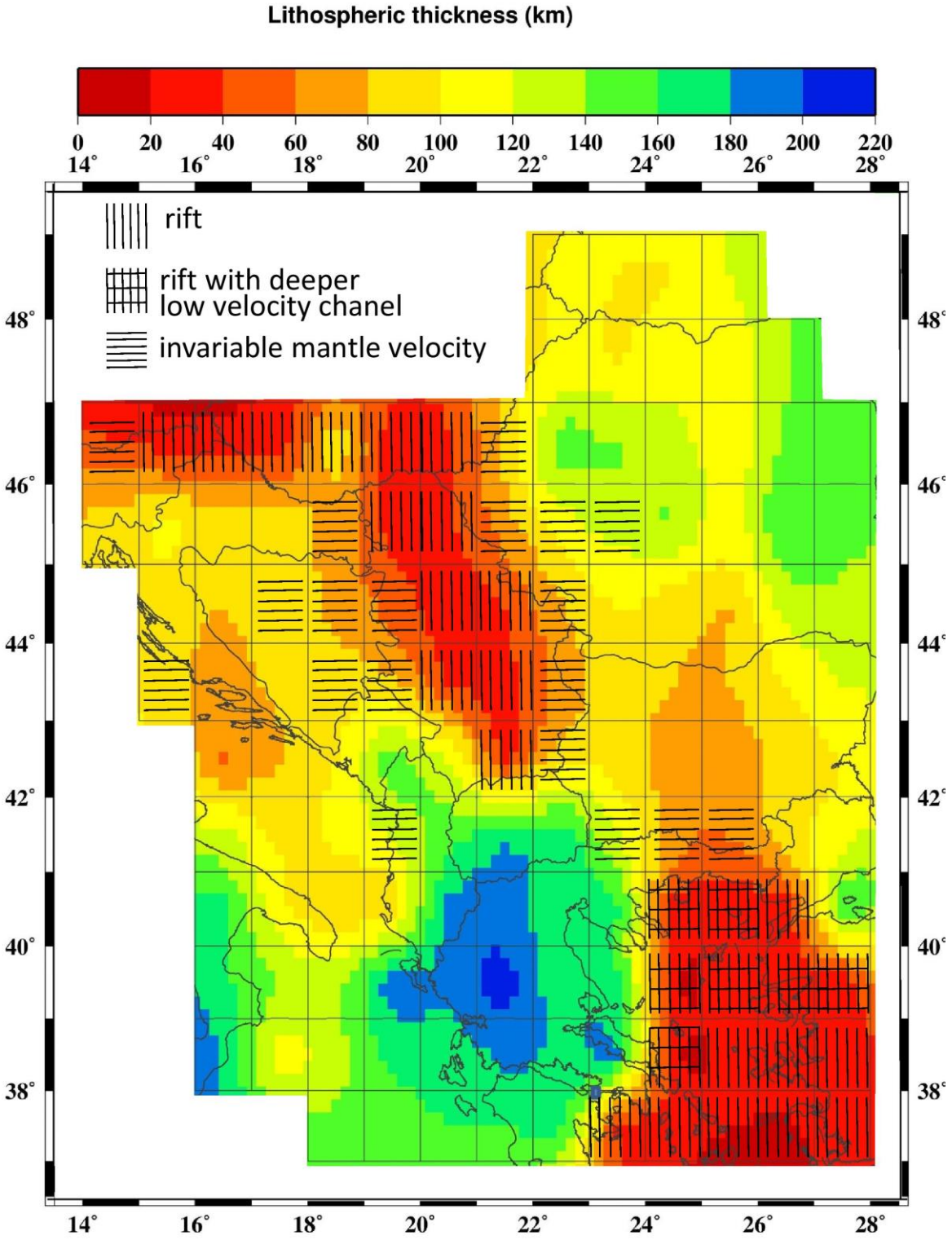


Fig. 3. Thickness of the lithosphere in the Balkan Peninsula region.

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