Nature of the Deep Vrancea Seismic Zone – New Constraints from Dispersion of First-Arrival P-Waves

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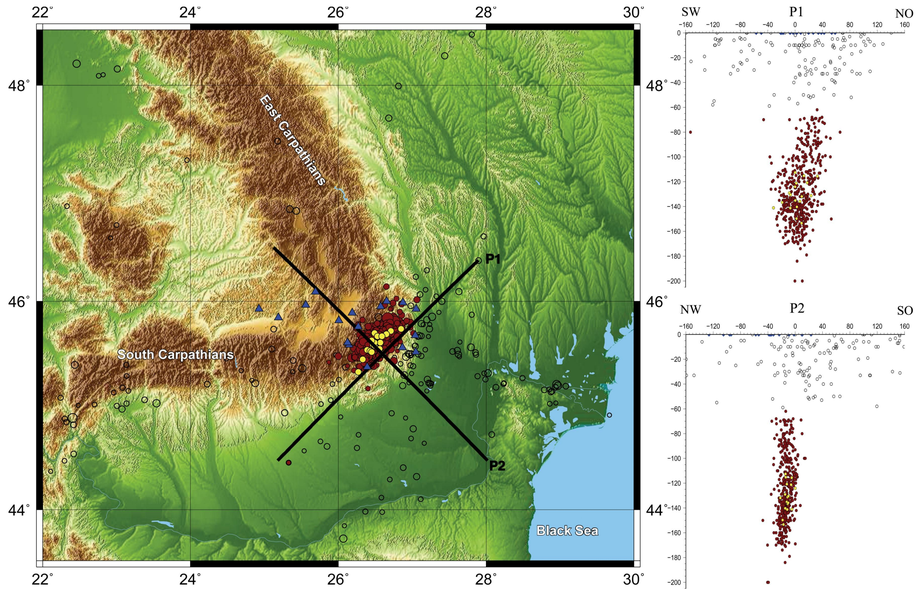
Abstract

The Vrancea region of the south-eastern Carpathians is one of the most active seismic zones in Europe and is known for its intermediate depth seismicity (70-180 km). Seismic tomography revealed a high-velocity body beneath Vrancea and the Moesian platform that extends to a depth of at least 350 km and can be interpreted as descending lithosphere. The many regional geodynamic models that have been proposed for this area can be split into two main categories: The high-velocity anomaly is associated with (a) descending relic oceanic lithosphere beneath the bending zone of the SE-Carpathians, either attached or already detached from the continental crust, or (b) continental lithosphere that has been delaminated, after continental collision and orogenic thickening. In order to shed more light on the nature of the seismic anomaly under the Vrancea region, as well as that of the origin of the intermediate depth seismicity in the Vrancea zone, we investigate the waveform character of P-waves from local earthquakes excited beneath this area, and in particular the dependence of group arrival times on frequency. A natural explanation for that effect is that it is caused by the presence of a low-velocity channel at the top of the seismic anomaly, which is too thin to be resolved by classical seismic tomographic techniques. This is similar to observed low-velocity layers with a thickness of several kilometers that is found to exist atop many slabs in subduction zones around the world. The presence of subducted oceanic crust suggests that the seismic anomaly under the Vrancea region consists of subducted oceanic lithosphere rather than continental lithosphere, at least above the seismically active zone.

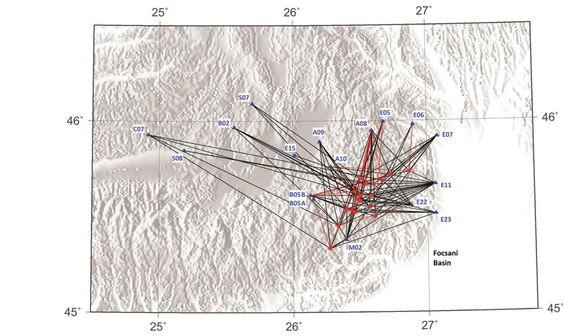
Study Region

The earthquake distribution in the South-Eastern Carpathians shows a strong concentration of intermediate-depth seismicity (70-180 km) in the Vrancea region. In 1999 the CALIXTO field experiment (Carpathian Arc Lithosphere X-Tomography) with 143 seismic stations was conducted in south-eastern Romania. Data inversion revealed a high velocity body interpreted as a descending lithospheric slab [1]. We examine waveforms of direct P-waves for 61 local events with magnitude > 2, recorded at a subset of the CALIXTO network of 17 stations (blue triangles) situated in the area above the supposed near-vertical slab. Events > 70km depth that show dispersion are represented by yellow circles. (right) Vertical cross-sections of hypocenter distribution on the SW-NE profile P1 (top) and the NW-SE Profile P2 (bottom). Events with M>2 are taken from the NEIC Event Database between 1980 and 2013.

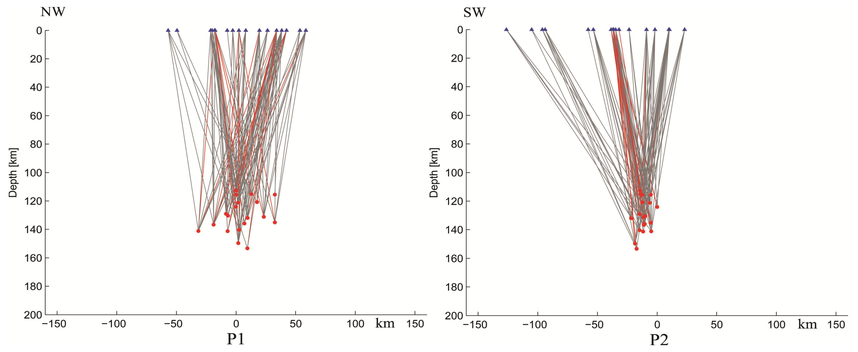


Ray paths

Map view (top) and vertical cross-sections of ray paths for the two profiles P1 and P2 (bottom) from events-station pairs, where dispersion was observed for 18 events (red lines), and not observed at others (black lines). Dispersion observations occur mainly at stations sited a view kilometers north-east of the event epicenter. The table shows the number of observations at each station that do and do not show dispersion.

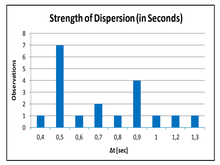


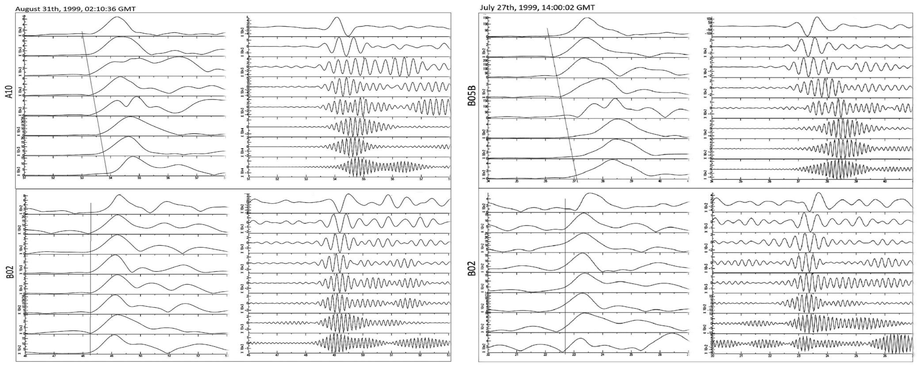
Station	yes	no	%
A08	8	45	18
B05B	4	20	20
A10	3	5	60
E05	2	6	30
E06	1	2	50
B05A	1	4	25
E22	1	12	8
E11	0	30	0
A09	0	12	0
B02	0	9	0
C07	0	7	0
E07	0	19	0
E15	0	5	0
E23	0	16	0
M02	0	19	0
S07	0	5	0
S08	0	4	0



Waveform Examples

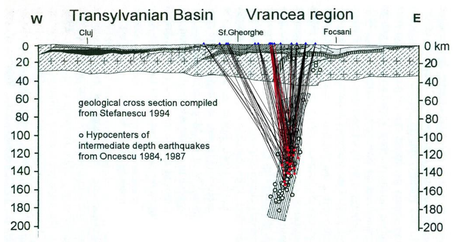
To measure dispersion we characterize the dependence of group velocity arrival times on frequency. Vertical-component seismograms are band-pass-filtered in 1Hz intervals between 0.5 – 8.5 Hz. The figure shows narrow-band seismograms and their envelopes for the same event recorded at stations A10 and B05 respectively and station B02. The difference in arrival time at stations A10 and B05 between 0.5 and 8.5 Hz is about 1 second whereas at station B02 all frequencies arrive at the same time. All observations correspond to high-frequencies at 8 Hz being delayed relative to 0.5 Hz by an average of 0.7 seconds in the sense of “normal dispersion” (see the histogram on the right).



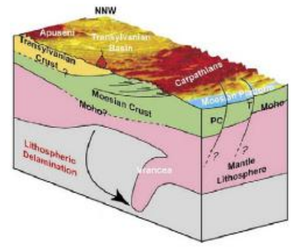


Interpretation

We found that dispersion is only observed for rays that travel nearly vertically. This is consistent with the supposed position of the slab under Vrancea [2]. A similar effect has been observed at subduction zones around the world where a thin low-velocity layer on top of the slab acts as a waveguide for high frequencies but is too thin to be “recognized” by long wavelengths [3, 4]. Attenuation, multipathing, scattering and site effects are unlikely to explain the observed effect.



Model of subducting oceanic lithosphere underneath Vrancea after (Linzer et al. 1998) overlaye by our raypath obsevations.



Top: 3-D perspective lithosphere-scale block model (view towards NNW), illustrating a continental lithospheric delamination scenario (after Knapp et al., 2005). Vrancea is located in the lower front corner of the model.

Conclusion

This suggests that the high-velocity anomaly under Vrancea consists of subducted oceanic lithosphere, at least the zone above the seismically active portion.

References

[1] Martin, M., Wenzel, F., the CALIXTO working group, 2006. High-resolution teleseismic body wave tomography beneath SE-Romania — II. Imaging of a slab detachment scenario. Geophysical Journal International 164, 579–595.

[2] Linzer, H. G., Frisch, W., Zweigel, P., Girbacea, R., Hann, H. P., and Moser, F., 1998. Kinematic Evolution of the Romanian Carpathians. In: PANCARDI; the Lithospheric Structure and Evolution of the Pannonian/ Carpathian/ Dinaride Region. (eds Decker, K., Lillie, R., and Tomek, C.). Tectonophysics, p. 133-156.

[3] Abers, G., 2004. Seismic low-velocity layer at the top of subductiong slabs: observations, predictions, and sysematica, Physics of the Earth and Planetary Interiors 149, 7-29

[4] Bokelmann, G. and E. Maufroy, 2007. Mantle structure under Gibraltar constrained by dispersion of body waves, Geophysical Research Letters, VOL. 34, L22305.

[5] Knapp, J.H., Knapp, C.C., Raileanu, V., Matenco, L., Mocanu, V., Dinu, C., 2005. crustal constraints on the origin of mantle seismicity in the Vrancea Zone, Romania:
the case for active continental lithospheric delamination. Tectonophysics 410, 311–323.