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A DETAILED TOMOGRAPHIC APPROACH ON WESTERN GREECE CRUSTAL VELOCITY STRUCTURE. COMPARATIVE STUDY BASED ON RECENT EARTHQUAKE CRISES

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The broader area of Western Greece is characterized by the highest rates of seismicity of the Hellenic peninsula, since it is dominated by complex tectonic structures which result in intense deformation. The northern part of this area is dominated by a continental collision zone, while the southern is characterized by the subduction zone, where the Eastern Mediterranean oceanic and Aegean continental lithospheres converge. In between lies the Cephalonia Transform Fault Zone (CTF), related to right-lateral strike–slip motion that constitutes a transition zone between these regions along with minor strike-slip faults triggered in the recent seismic activity in Cephalonia Island.

A regional scale tomography study was performed, using regional body-wave (P and S) travel-time phases of earthquakes with magnitude M≥3.7 derived for the time interval of 2006-2014, in order to investigate some medium to large scale related anomalies such as the Hellenic Trench (HT) and the Cephalonia-Lefkas Transform Fault Zone (CLTFZ). The seismic events were located with HYPOINVERSE (Klein, 2000) and then selected for the inversion with specific criteria of spatiotemporal errors and geographic distribution in order to provide the greatest possible resolution. The resulting 3D tomographic model reveals some main discontinuities of regional scale that could be attributed to the remnant oceanic lithosphere of Tethys which is subducted beneath the continental Aegean one to the SE of Zakynthos Island and the CLTFZ that intersects between the northern and southern branch of the Hellenic Trench.

Along with Regional Tomography, Local Earthquake Tomographic Inversion was performed in sub-areas of Western Greece where some important aftershock sequences such as the cases of Zakynthos (2006), Andravida (2008), Aigion (2013) and Cephalonia (2014) took place. Phase data from stations of the Hellenic Unified Seismological Network and a temporary deployed local network by the Earthquake Planning and Protection Organization (E.P.P.O) in Zakynthos were merged and jointly used as a primary catalogue.

The LOTOS-10 algorithm (Koulakov, 2009) was applied in order to perform an iterative tomographic inversion for 3-D seismic V_P and V_S in the cases described above. The LOTOS code requires as input the data of station coordinates and the arrival times from the recorded seismicity. The hypocenter coordinates and origin time are not essential, since they are determined during the execution of calculations. However, if preliminary hypocentral locations are available, they can be used in order to increase the speed of the operation processing time. Additionally, a 1-D starting

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velocity model and a set of input parameters for performing the convergence iteration steps, including parameterization, grid dimensions and damping parameter, are considered.

Model parameterization of the velocity field should be able to delineate, according to the local characteristics, the shape and position of heterogeneities. A nodal representation is employed, since the velocity field that is reconstructed by a three-dimensional grid does not assume a specific geometry of heterogeneities (Toomey and Foulger, 1989). The spacing between the nodes of the grid must be kept considerably smaller than the expected size of the anomalies for each case in order to reduce the bias of the resulting models due to the grid configuration. The optimal grid mesh is being determined in co-ordinance of the stations/events geometry. In the present study, the checkerboard method (Humphreys and Clayton, 1988) is applied as indicator of the resolution and errors associated with the inversion in order to define the fidelity area. This method uses alternating anomalies of high and low velocity, evenly spaced throughout the model in a three-dimensional checkerboard pattern. Data resolution is mainly controlled by ray-path distribution, model parameterization and smoothing (Lees and Crosson, 1989). Checkerboard tests are performed in order to reproduce the procedure of real data processing. In the initial synthetic model, the size of cells corresponds to the expected anomalies. The inversion variance is controlled by errors in the data, including a) mis-picks, b) mis-locations and c) incorrectly determined ray-paths.

In the case of Zakynthos, four events (5.3≤Mw≤5.7) occurred south of the island and on its SE part that were followed by significant seismic activity. More than 3500 microearthquakes were mainly recorded by the local temporary network installed by EPPO during April and May of 2006. During the inversion process, more than 1500 located events were included in the iterative tomography scheme, with their focal locations, P- and S-wave travel-times used as input data. Some major anomalies that came up through this procedure, at the center of the island and to its SE, were linked to the local fault system in an approximate direction of NW-SE.

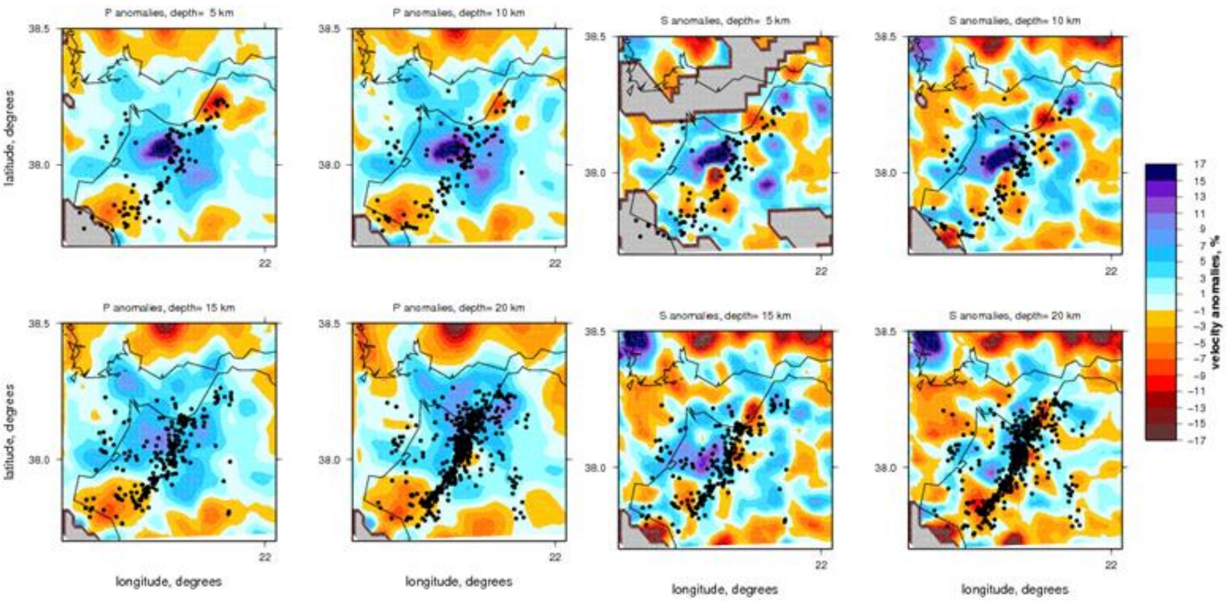

Figure 1. Horizontal tomographic slices for depths of 5, 10, 15 and 20 km of P and S waves in the case of 2008 Andravida earthquake sequence

Two years after the Zakynthos seismic sequence, on 8 June 2008, a large (Mw=6.4) event occurred about 22 km E-NE of Andravida town at Western Peloponnese. More than 2500 events were located, using the obtained 1D velocity model. In the framework of the tomographic study, events with residuals of more than 0.5 sec for P and 0.7 sec for S rays were rejected. Following, earthquakes with at least 10 P- and 3 S- phases and ratio of S to P residual < 3.2 were selected. The final dataset that was used for the iterative tomographic inversion and source location in the 3D velocity model consisted of 1895 earthquakes, with 13944 P- and 10601 S-arrival times. In depths between 10 km and 20 km, where important seismic activity was evident and rays were dense, positive anomalies were observed. Most earthquake hypocenters in these depths were located in regions of relatively high velocity oriented approximately in a NE-SW direction. In the cross-section performed perpendicular to the northern branch of the activated fault (N295°E), a sudden change of the V_P and V_S anomalies was observed, at about 40 km to the SE of the city of Patras. This quasi vertical discontinuity separates two major anomalies, one with high V_P and V_S values and the other with low respective values. Similar results were also seen in the N330°E striking tomographic transection perpendicular to the southern part of the fault.

In the Aigion earthquake crisis (July-August 2013), more than 2200 events were recorded by the stations of the Hellenic Unified Seismological Network and CRL Network, and analyzed using a local 1-D layered velocity model (Kaviris, 2003). In order to perform a LET, events with temporal residuals of more than 0.4 and 0.8 sec for P and S rays respectively were rejected. Following, earthquakes with at least 10 P- and 3 S- phases and ratio of S to P residual < 2.2 were selected. The final dataset that was used for the iterative tomographic inversion and source location in the 3D velocity model consisted of 1937 earthquakes, with 56254 P- and 36353 S-arrival times. Most of the seismic activity was concentrated in the depth range between 7 to 14 km, giving a denser ray coverage than the one in superficial depths (<7 km) and below 16 km. Most of the earthquake hypocenters were located in regions of relatively high velocity oriented approximately in an E-W direction. More specifically, a major cluster was located in a positive anomaly (V_P=+8%, V_S=12%) near the city of Aigion. A negative anomaly (V_P=-4 to -8%, V_S=-12%) seems to be elongated eastward in a direction parallel to the Gulf and the faults that control its extension.

For the time interval of January-March of 2014, a moderate earthquake sequence occurred, numbering more than 3000 earthquakes. This seismic activity was recorded by both local and regional stations of the Hellenic Unified Seismological Network (HUSN) and analyzed using a minimum 1D velocity model obtained through an error minimization technique (Kissling et al., 1994). In this case, earthquakes with at least 12 P- and 4 S- phases and ratio of S to P residual < 2.5 were selected. The dataset that was used for the iterative tomographic inversion and source location in the 3D velocity model consisted of 2803 earthquakes, with 60749 P- and 33705 S-arrival times. Velocity variations for the superficial layers generally range between +12 and -14% for P and S waves, with some spikes that reach ±20% that reveal important tectonic characteristics for this earthquake sequence. More specifically, the area seems to be formed by a strike-slip fault system which was activated gradually by the three largest earthquakes occurred in the Paliki peninsula giving rise to the complex hypocenter distribution.

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