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3D SEISMIC IMAGING OF THE IRPINIA FAULT SYSTEM (SOUTHERN ITALY) FROM MULTI-SCALE VELOCITY AND ATTENUATION TOMOGRAPHY

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A 3D seismic imaging of the upper crustal structure of the Irpinia active fault system in southern Italy was obtained by combining P and S velocity models, earthquakes distribution, and Qp and Qs attenuation models.

The southern Apennines of Italy is a seismically active belt characterized by a complex crustal environment in response to a very intense geodynamic activity. The area has been interested by large earthquakes both in historic and recent time. The last destructive earthquakes was the 23 November 1980, M 6.9, Irpinia earthquake, which caused more than 3000 casualties and produced huge and widespread damage. The present-day seismicity is characterized by small-to-moderate magnitude earthquakes (M_L<=3.2). Although the actual seismicity does not represent a real threat for the region and its inhabitants, it can be a useful probe for a deeper knowledge of the fault structures on which the largest earthquakes occurred in the past.

The analyzed data set consists of 1311 events recorded in the period August, 2005 - April, 2011 at a total of 42 stations owned and operated by the research consortium AMRA scarl and Istituto Nazionale di Geofisica e Vulcanologia (INGV) (Figure 1).

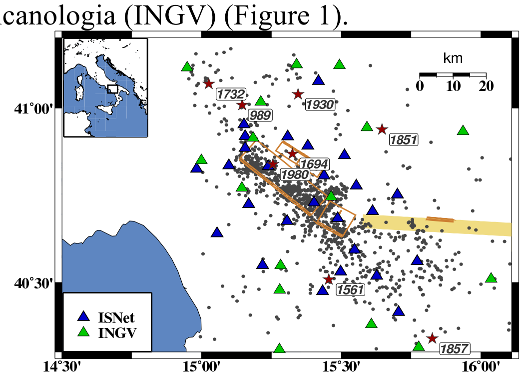

Figure 1. Map showing location of the studied earthquakes (grey dots), seismogenic sources (DISS Working Group, 2010), location of main historical earthquakes (red stars). Green triangles identify INGV stations, while blue triangle identify ISNet stations.

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The P and S phases were initially hand-picked on three-component ground velocity recordings. The seismic events were preliminary located in a 1D reference velocity model (Matrullo et al., 2013). In order to improve the S-phase identification, a technique which combines polarization analysis of single three components recording of a seismic event with the analysis of lateral waveform coherence in a trace gathers (Amoroso et al., 2012) was applied. As a further improvement, a refined re-picking algorithm (Rowe et al., 2002) based on the waveforms cross-correlation was applied providing with a high-accurate observed travel-times data set.

The used tomographic method performs a simultaneous inversion of P and S arrival times to estimate the event location coordinates, the origin times, and P and S velocities at the nodes of a 3D discretized volume. The forward problem, e.g., the travel-time calculation, is solved by using the finite-difference solution of the eikonal equation and a re-calculation by integration of slowness along the ray path. We used a multi-scale inversion approach, according to which a series of inversion runs are performed by progressively decreasing the velocity model grid spacing. This allowed us to first estimate the large wavelength components of the velocity model and then to progressively introduce the smaller-scale components for model reconstruction. The complete procedure consisted of three different inversions in which the grid spacing was decreased from $12x12x4km^3$ to $3x3x1km^3$. The smallest grid space has been chosen based on the spatial resolution as inferred from specific checkerboard-type resolution tests. As a quantitative measure of model resolution, the semblance between the true and recovered checkerboard anomalies has been computed which allowed to delineate the optimal resolved regions. Moreover, we performed a numerical estimation of the resolution matrix from which we calculated the spread function and resolution contouring. For both the parameterizations 6x6x2 km^3 and 3x3x1 km^3, the extent of the resolved areas increases with depth and the best resolution is obtained for depths ranging between 4 and 14 km for the first parameterization and 4-10 km for the second one (Amoroso et al., 2014).

In order to estimate the attenuation model, the used data are the quantities t^*, which are defined as the ratio of the travel time and quality factor (Q). The t^* measures for both P and S wave were obtained from the analysis of the displacement spectra of microearthquakes in the moment range $4x10^9$ - $2x10^{14}$ Nm has been analyzed. In particular, two are the adopted approaches: the first one based on the estimation of t^* from the low-frequency spectral decay of small magnitude ($M_L \leq 1.0$) earthquakes; the second one based on the multi-step, iterative inversion of spectral parameters for the larger events in the data set (Zollo et al., 2014). In the present study, we inverted t^*_P and t^*_S for 3D Qp ad Qs values on the same grid spacing as used for the velocity inversion, i.e., keeping the rays fixed. Starting from a homogeneous attenuation model, we obtained some preliminary results that were interpreted in terms of massive presence of fluids (water) that produces partial or complete saturation of the rock medium. In addition, we carried out an analysis to investigate the dependence of the attenuation model on the background velocity model and to assess the robustness and resolution of the retrieved model.

Both the P and S wave velocity models indicate the presence of a strong lateral variation in the seismic velocity pattern along a direction orthogonal to the Apeninic chain in the 4-8 km depth range (Figure 2). This variation defines two geological formation domains, which are characterized by a relatively low and high P velocity, respectively. The zone where the sharpest lateral transition occurs in the NE direction is well correlated with the location of the NW-SE oriented, primary normal fault associated with the 1980, Ms 6.9 earthquake. This fault cuts at SW the outcrops of the carbonatic Campanian platform, and separates at NE the older Mesozoic limestone formations from the younger Pliocene-Quaternary basin deposits.

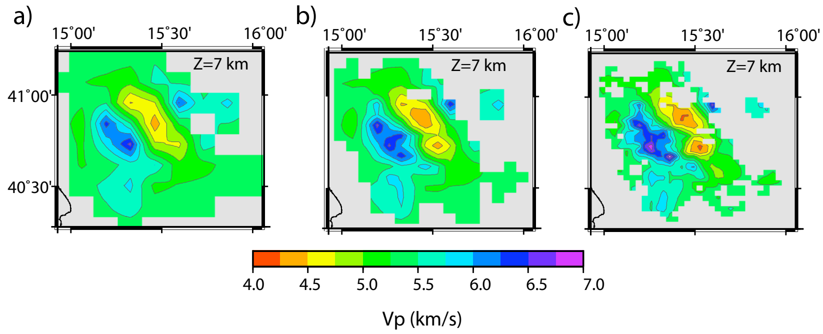

Figure 2. Map view of Vp velocity models at 7 km depth for each parametrization: (a) 12x12x4 km^3, (b) 6x6x2 km^3, and (c) 3x3x1km^3

The spatial distribution of seismicity delineates at south-west the possible border of the Irpinia master fault, while at north-east it shows a more diffused pattern due to the presence of a system of highly organized, sub-parallel normal faults as it has been inferred from the fault mechanisms and the coherent orientation of the tensional axes, consistently with a NE-SW dominant extensional stress regime (De Matteis et al 2012).

We have extracted two 1D P-wave velocity models from the final 3D model in correspondence of two deep wells. We note that the velocities inferred from the tomographic analysis are generally consistent with the expected velocities of litho-stratigraphic units for the studied area.

The Vp/Vs ratio shows a large lateral and vertical variability. It ranges from a value of 1.7-1.8 at shallow depths and increases up to 2.0-2.2 between 5 km and 12 km depth in the volume where most of present microseismicity occurs. The 3D spatial distribution of Qs/Qp reveals vertical and lateral variability. In particular at 4-8 km depth we observe a variation of Qs/Qp around 1 along a trend parallel to the Apennine chain.

The observed Vp/Vs ratio values and Qs/Qp variability suggest a contribution of partial to total fluid–saturation in controlling seismic attenuation within the crustal volume embedding the Irpinia fault system. The evidence for a predominant microearthquakes activity confined within the highest Vp/Vs volume, indicates that pore pressure changes induced by fluid flow/diffusion in a highly fractured medium, may be the primary mechanism controlling and driving the background seismic activity along the Irpinia fault zone.

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