The 2012 Ferrara seismic sequence: from a 1D reliable crustal structure for moment tensor solutions to strong implications for seismic hazard

CITATION
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Project S1 INGV-DPC

Sub-project S1a: "The Po Plain: Studies aiming at defining the crustal velocity structure and present-day deformation in the Po Plain and surrounding regions"

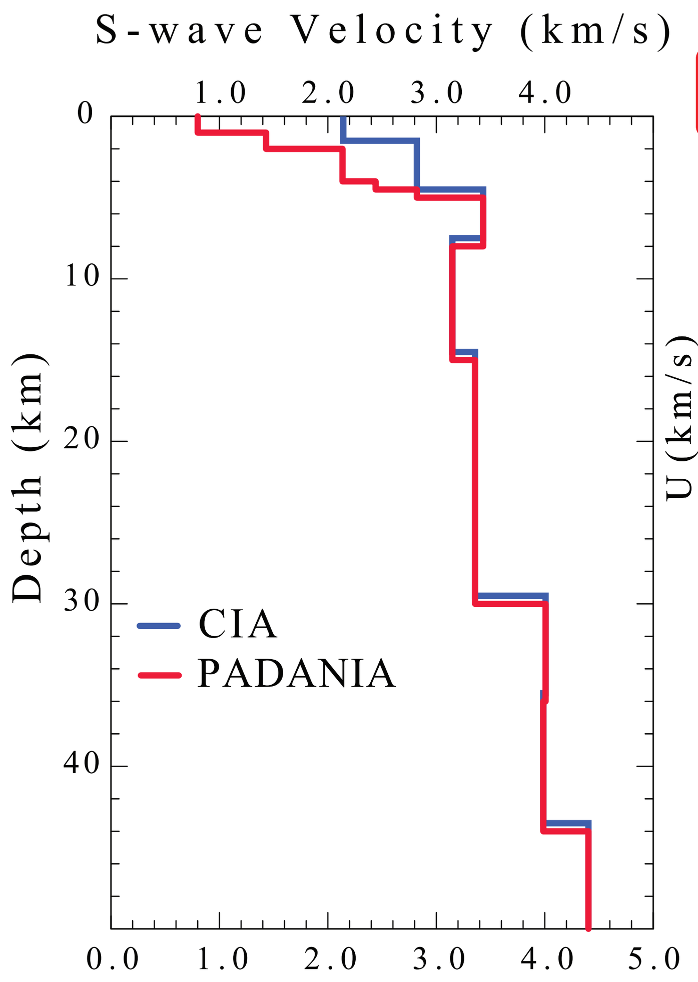
Task a.1.: "Crustal velocity structure of the Po Plain"

SAINT LOUIS UNIVERSITY

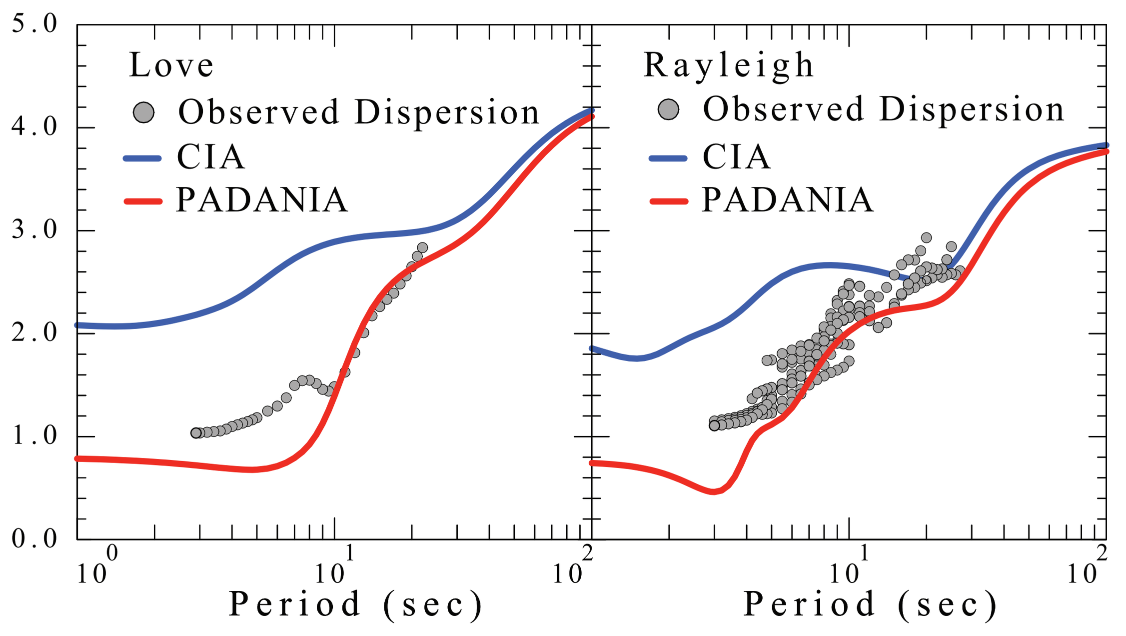
Istituto Nazionale di Geofisica e Vulcanologia

ABSTRACT

On May 20 2012, an event of Ml 5.9 (Mw 5.6) stuck the southern edge of the Po river plain (Pianura Padana). The earthquake was preceded by a foreshock of Ml 4.1 (Mw 3.8), less than 3 hours before the Mw 5.6 main. Hypocentral depths were 6.3 km for both events. Centroid depths were 5 and 6 km, respectively. The activated fault was a reverse one, dipping to the south. Then a complex seismic sequence started, in which more than six earthquakes with Ml greater than 5 stuck the area, the last one on June 3, 2012. Aftershocks delineated a 50 km long and 10-15 km wide zone, approximately elongated in the WE direction. More than 2100 events were located between May 19 and June 25 2012 by the INGV National Seismic Network, 80 of them with Ml greater than 3.5. The damage due to the Ml 5+ earthquakes was widespread, as they severely hit historical towns and industrial infrastructures. However, a striking inconsistency exists between the relatively small moment magnitudes and the corrisponding high level of damage. In order to define a velocity structure for the crust beneath the Pianura Padana, to be used for waveform inversion of moment tensors, we gathered all the geophysical and geological information available for the area. The model is characterized by very thick and shallow Quaternary sediments, to be used for the inversion of broadband waveforms for moment tensor (MT) solutions, in the frequency band between 0.02-0.1 Hz. We calculated moment tensors for 20 events down to Mw~3.2. We demonstrate how surface waves dominate the seismograms in the region, which may have played a major role in enhancing the damage to industrial structures observed in the epicentral area. Synthetic seismograms computed using the developed model well reproduced the anomalous durations of the ground motion observed in Pianura Padana, also highlighting important implications for the seismic hazard in the entire area. The present seismic hazard assessment as well as the size of the historical earthquakes in the region (and so their recurrence times), may need to be re-evaluated in the light of this new results.

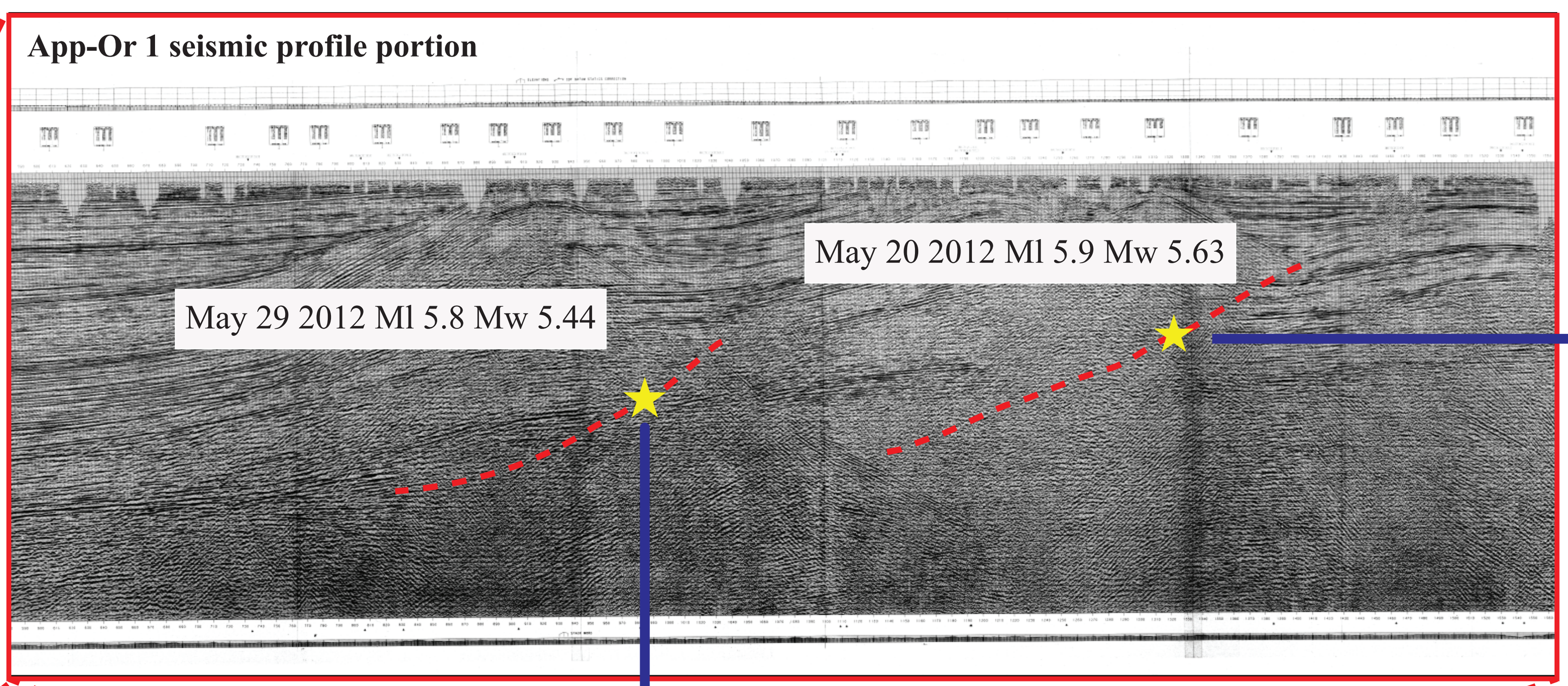


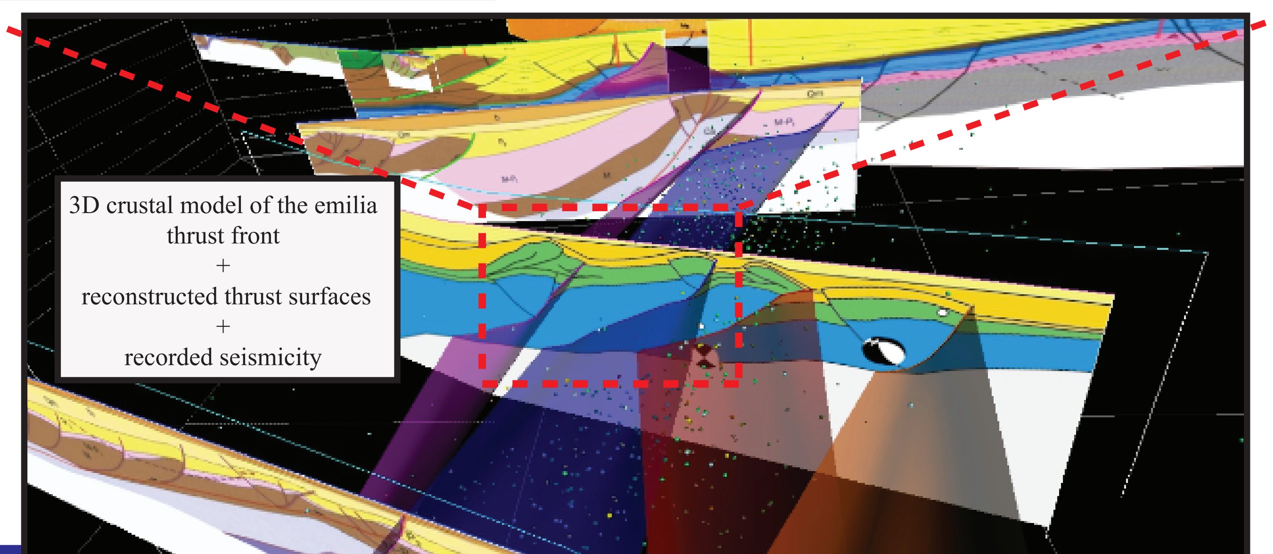
VELOCITY MODEL

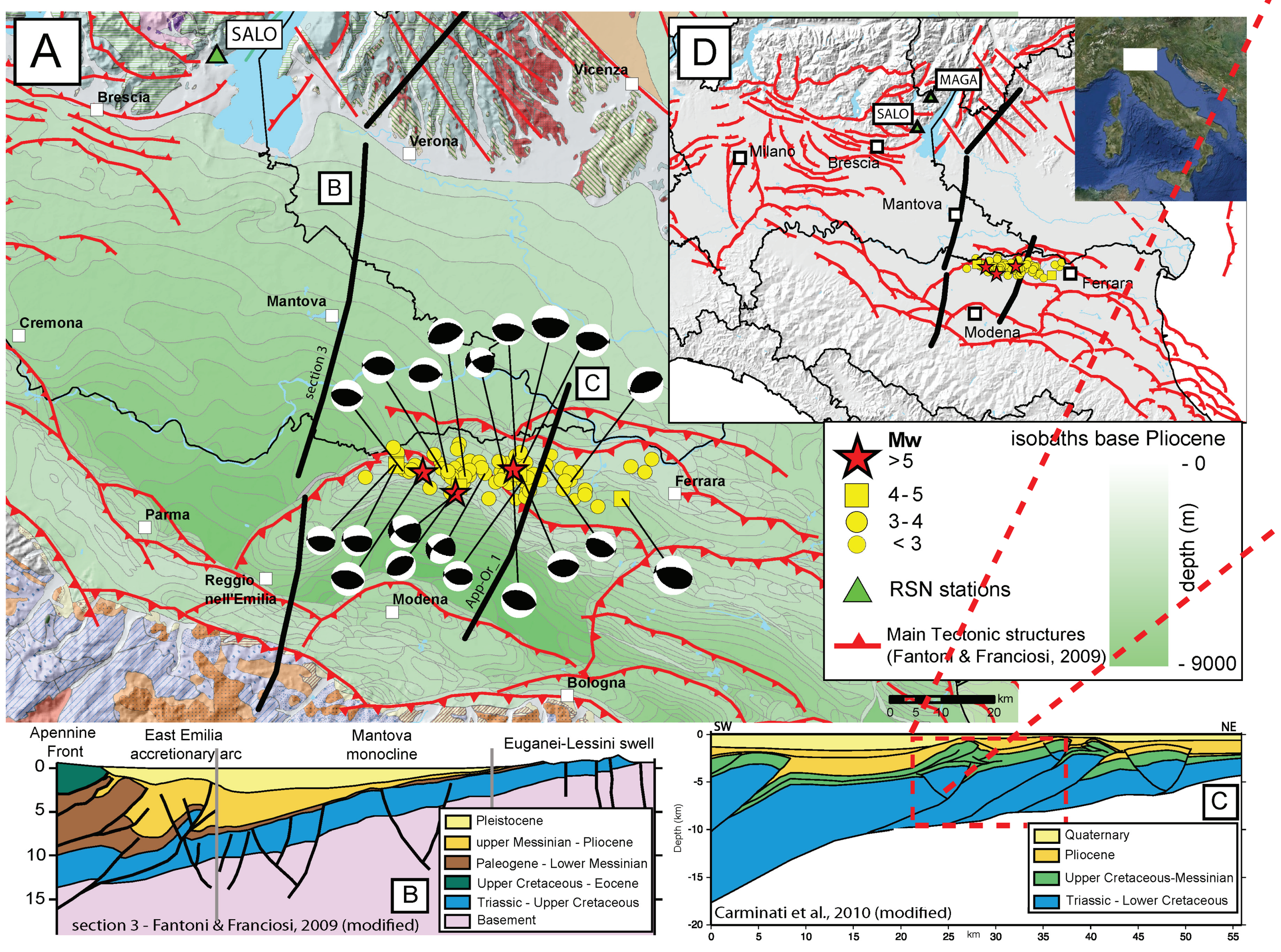


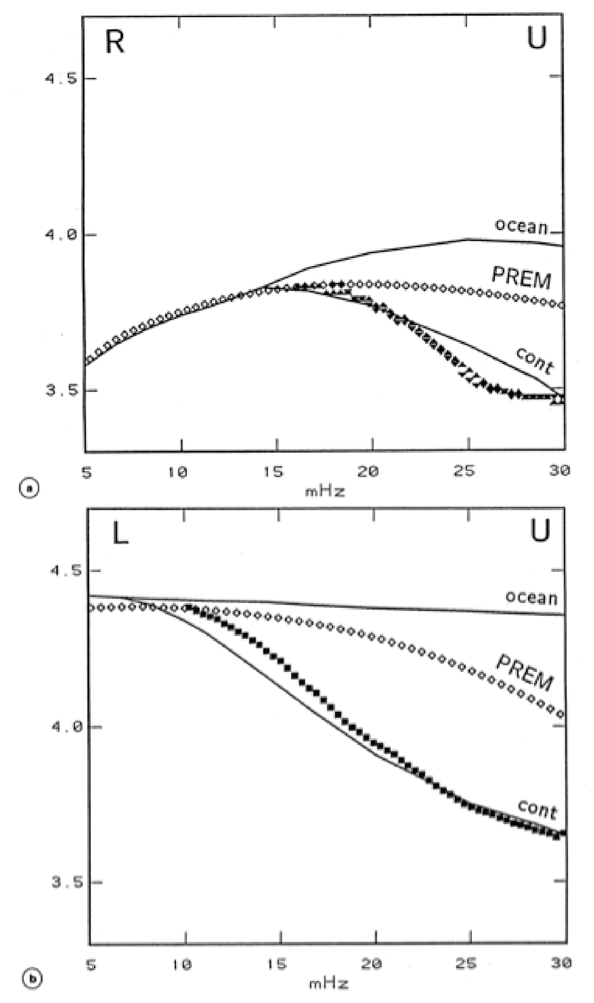
Love and Rayleigh dispersion observations obtained at stations MAGA and SALO, compared to theoretical predictions from the crustal models nCIA and PADANIA. Most of the source receiver paths are within the sediments.

CRUSTAL STRUCTURE & MOMENT TENSOR SOLUTIONS

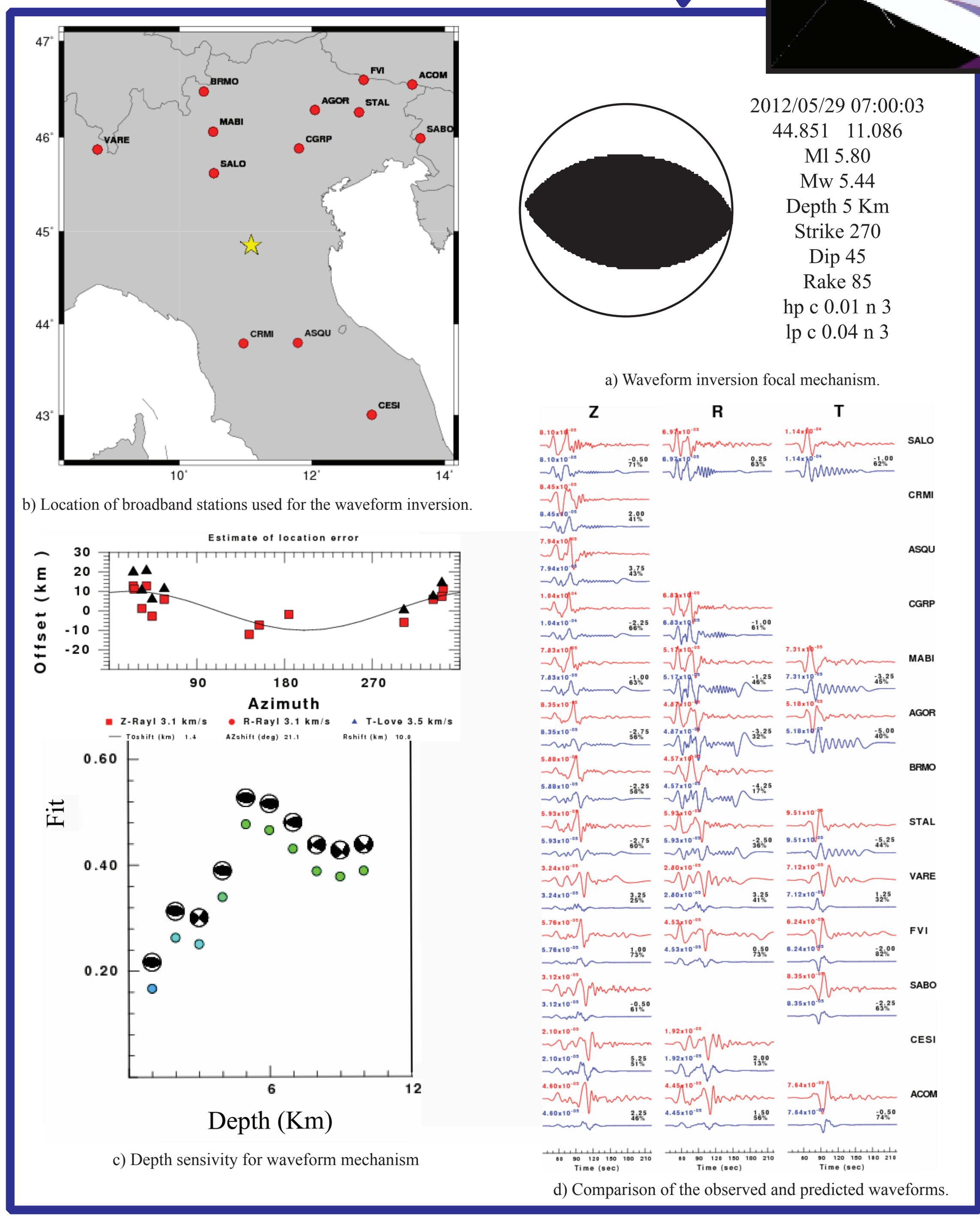




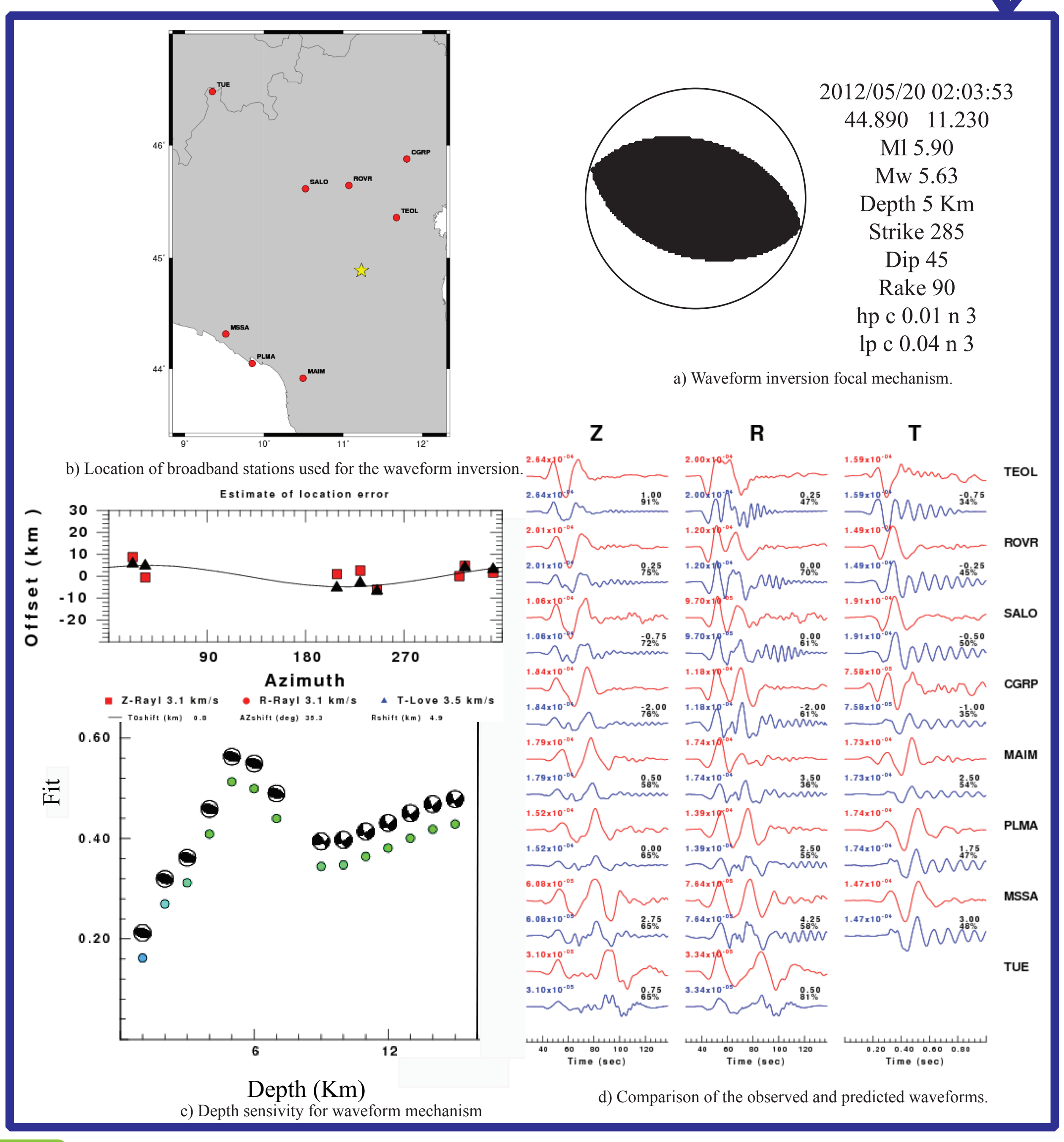




Strong differences exist between the observed surface waves dispersion curves and their theoretical prediction obtained with global earth model like PREM. The problem is well known, as it was pointed out by Giardini et al. (1994) almost 20 years ago. The plots show the group velocity dispersions for the fundamental Rayleigh (a) and Love (b) waves from PREM (diamonds) for typical oceanic and continental paths, compared to those derived using the VSL recordings of the 1990 NW Iran earthquake. In the region of the Pla- nura Padana, differences are way more severe than what shown by Giardini et al (1994).



a) Waveform inversion focal mechanism.
b) Location of broadband stations used for the waveform inversion.
c) Depth sensivity for waveform mechanism
d) Comparison of the observed and predicted waveforms.



a) Waveform inversion focal mechanism.
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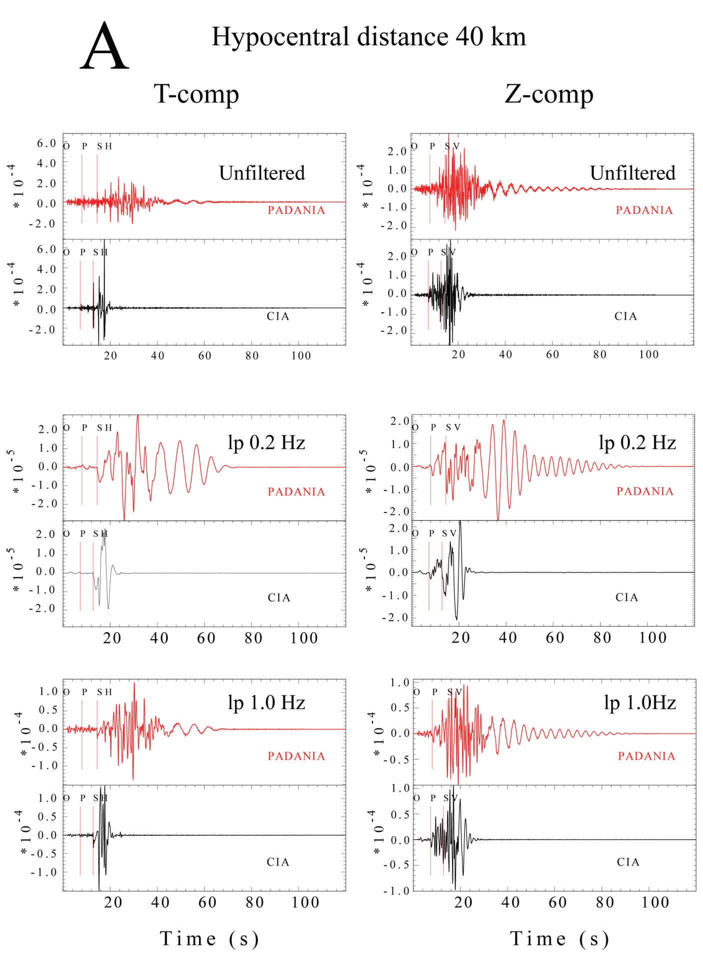
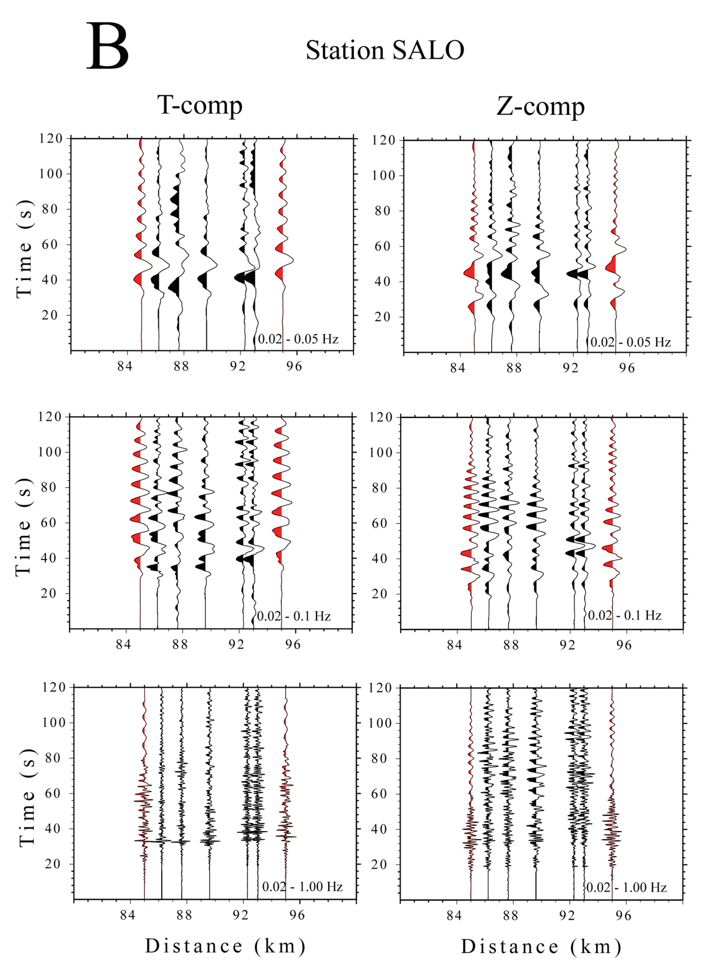
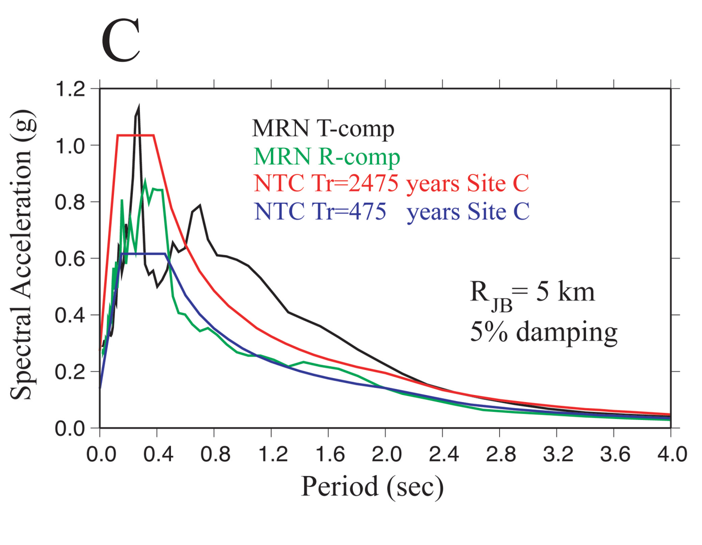
GROUND MOTION ANALYSIS & IMPLICATIONS FOR SEISMIC HAZARD

Mw 4; Strike=105; Dip=40; Rake=100; Depth=5 km; AZ=330







(a) Synthetic seismograms (left: transverse components; right: vertical components) calculated at 40 km distance and at an azimuth of 300° over the PADANIA and CIA crustal models (red and black, respectively), for an earthquake of Mw 4, strike = 105°; dip = 40°; rake = 100°. From top to bottom: i) unfiltered; ii) bandpass filtered between 0.02 and 0.2 Hz; iii) bandpass filtered between 0.02 and 1.0 Hz.
(b) Waveforms recorded at SALO (T and Z components of the ground motion, black shading) during five earthquakes (events marked with footnote b in Table 2), compared with synthetic waveforms (red shading) calculated around the same hypocentral distances. Parameters are the same as before. Amplitudes are normalized to their peak values. Waveforms are bandpass filtered in the following frequency bands: top 0.02–0.05 Hz; middle 0.02–0.1 Hz; bottom 0.02–1.0 Hz.
(c) Transverse and radial Spectral Acceleration (black and green, respectively) recorded at station MRN (Mirandola, EC8 site C) during the main event of 05/20/2012 (Mw 5.63, 5 km Joyner-Boore distance). SAs are plotted against 475 and 2475 years return time estimates (blue and red, respectively) for an EC8 C site.

REFERENCES

Carminati, E., D. Scrocca, and C. Doglioni (2010), Compaction-induced stress variations with depth in an active anticline: Northern Apennines, Italy, *J. Geophys. Res.*, 115, B02401, doi:10.1029/2009JB006395.

Fantoni, R., and R. Franciosi (2010), Tectono-sedimentary seting of the Po Plain and Adriatic foreland, *Rend. Fis. Accad. Lincei*, 21, suppl. 1, 197-209, doi:10.1007/sl2210-010-0102-4.

Giardini, D., L. Malagnini, B. Palombo, and E. Boschi (1994), Broad-band moment tensor inversion from single station, regional surface waves for the 1990, NW-Iran earthquake sequence, *Annali di Geofisica*, VOL. XXXVII, N° 6.

CONCLUSIONS

- 1-D crustal structure (PADANIA model) allowing the inversion of moment tensor solutions for 20 events of the Ferrara seismic sequence, from Mw 5.63 (the largest main event, occurred on May 20 2012), down to Mw 3.2. PADANIA represents a major improvement for the investigation of the seismicity along the southern edge of the Pianura Padana.
- PADANIA model in order to perform a numerical study on the characteristics of the ground motion in the thick sediments of the flood plain, in the frequency band between 0.02 and 1.0 Hz. Predicted Spectral Accelerations (SA) at 5% damping for a return period of 2475 years were exceeded at station MRN by the spectral acceleration observed during the largest main event of May 20 2012.
- Predicted SAs are somehow controlled by the maximum magnitude chosen for the area (Mwmax = 6.14 , which is 0.5 magnitude units larger than that of the main event that struck Ferrara. The inconsistency between observed SA and UHS (Uniform Hazard Spectra), indicates the necessity of including the regional characteristics of the ground motion into the tools used for the calculation of the UHS, at least in this region of Italy. Although the work on regional Ground Motion Predictive Equations (GMPEs) in Italy was included in the logic tree of the hazard map, no high-quality digital waveforms from substantial earthquakes in the Pianura Padana were available until now, and no regional GMPE from this specific area could be inclu- ded in the logic tree.
- Because the fundamental characteristics of earthquake induced ground motion are not taken into account in current estimates of seismic hazard, it is likely that, within the thick sedimentary body of the Pianura Padana, seismic hazard got substantially underestimated until now. The issue may be especially important at low- frequencies, with a substantial impact on the expected response of very tall structures.