Clues of Post-seismic Relaxation for the 1915 Fucino Earthquake (Central Italy) from Modeling of Leveling Data

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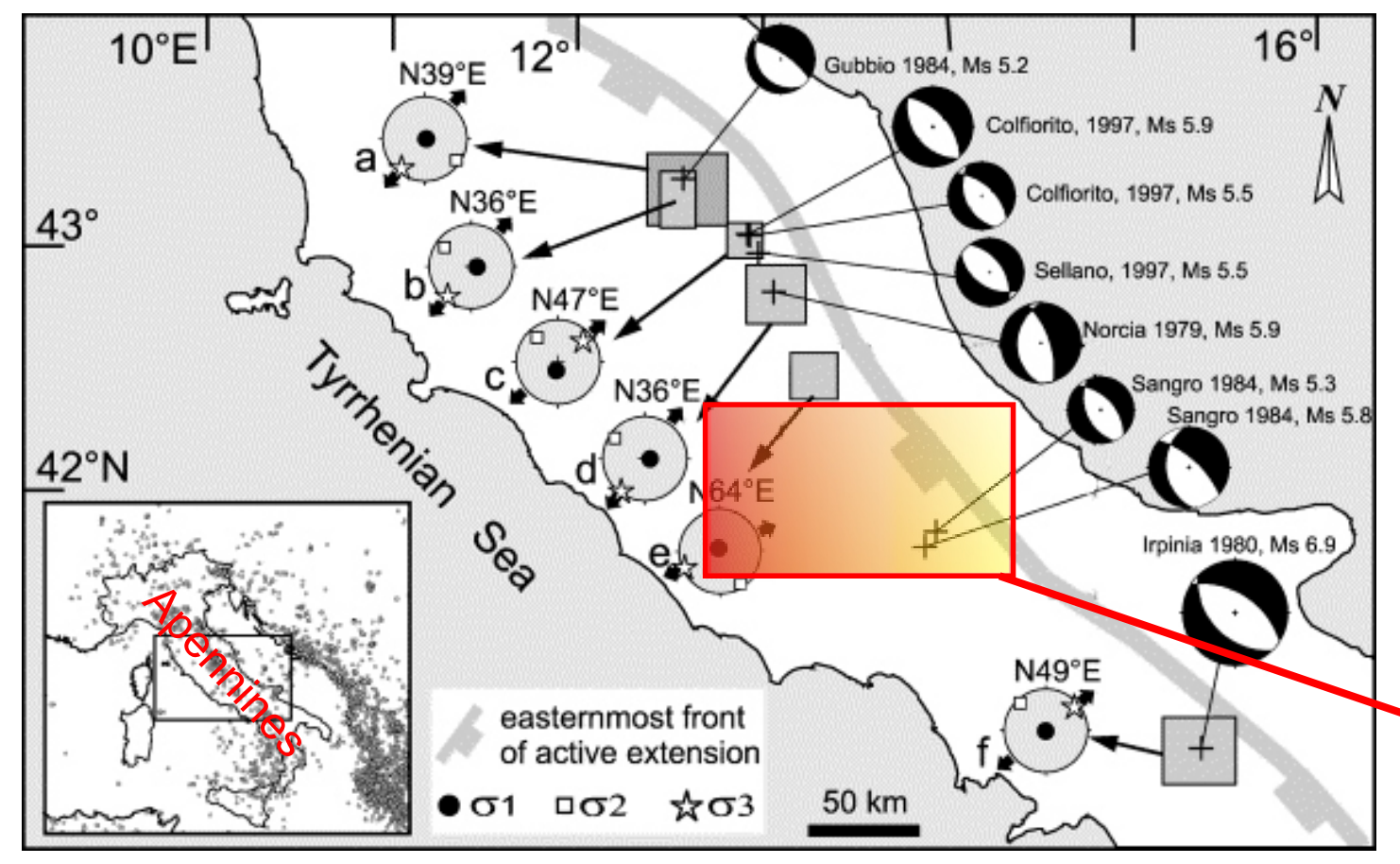
Introduction

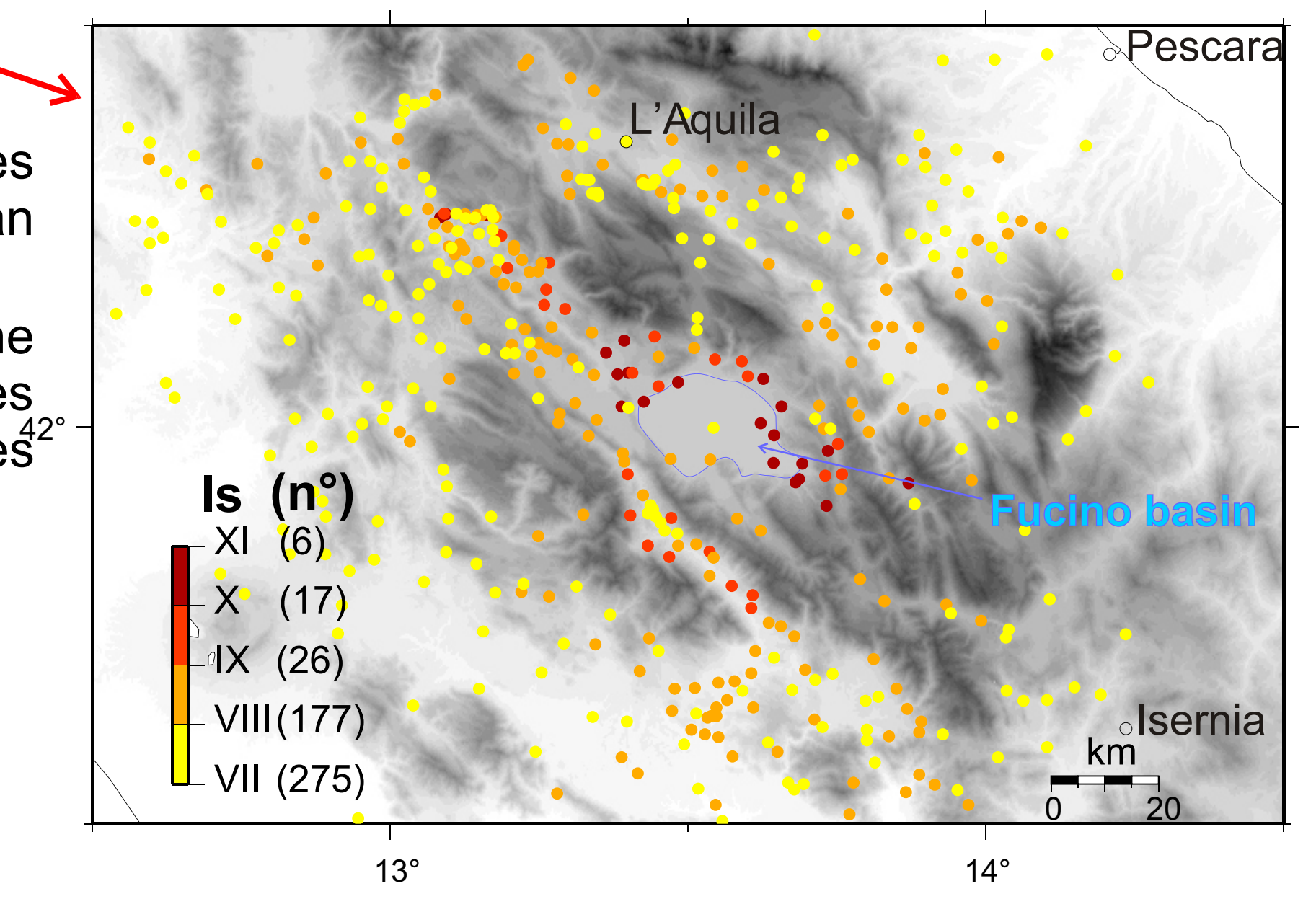
The principal aim of this study is to evaluate, by means of geodetic leveling data analysis, possible postseismic movements related to the January 13th, 1915 Fucino earthquake (Ms = 6.9). It was one of the largest and most destructive events occurred in Central Italy during the last century.

We use data from high precision leveling lines located around the epicentral area and measured 35 and 85 years after the earthquake. This work concerns our approach to the modeling of postseismic movements recorded by leveling benchmarks and the implications for the lithospheric layering in Central Italy.

1. The 1915 Fucino earthquake

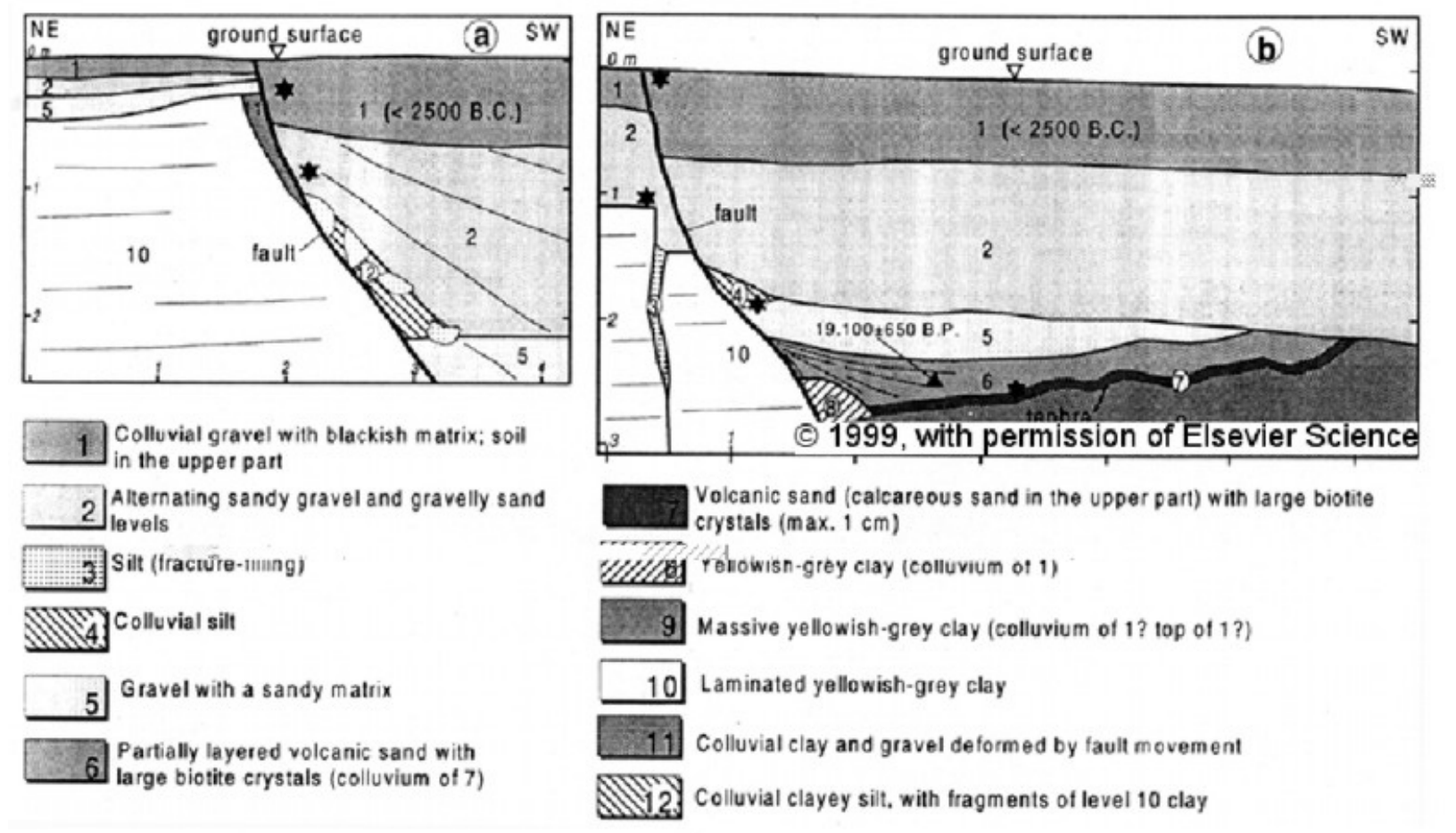


The 1915 earthquake epicentral area is centered in the Abruzzi region (Central Italy), where seismotectonic studies suggest a NE-SW oriented active extension (e.g.: Anderson & Jackson, 1987). Present state of stress in Central Apennines for past 25 years, CMT solution of largest earthquakes and minimum principal stress vectors, derived from background seismicity and aftershock sequences, are shown on the left (figure from Pace et al., 2002).



The 1915 earthquake caused more than 30,000 casualties and strong damages (shown in the two pictures below) over an area of about 500 km^2.
A compilation of January 13th, 1915 intensity data (Is) from the DOM4.1 catalogue extents all over Central Italy, with values up to XI (in figure we plotted only intensity points with values above VII).

The 1915 earthquake fault produced detectable coseismic surface ruptures for about 20 km along NW-SE striking structures (Oddone, 1915). The related fault scarp is well visible in the Fucino basin area (picture from Valensise & Pantosti, 2001).



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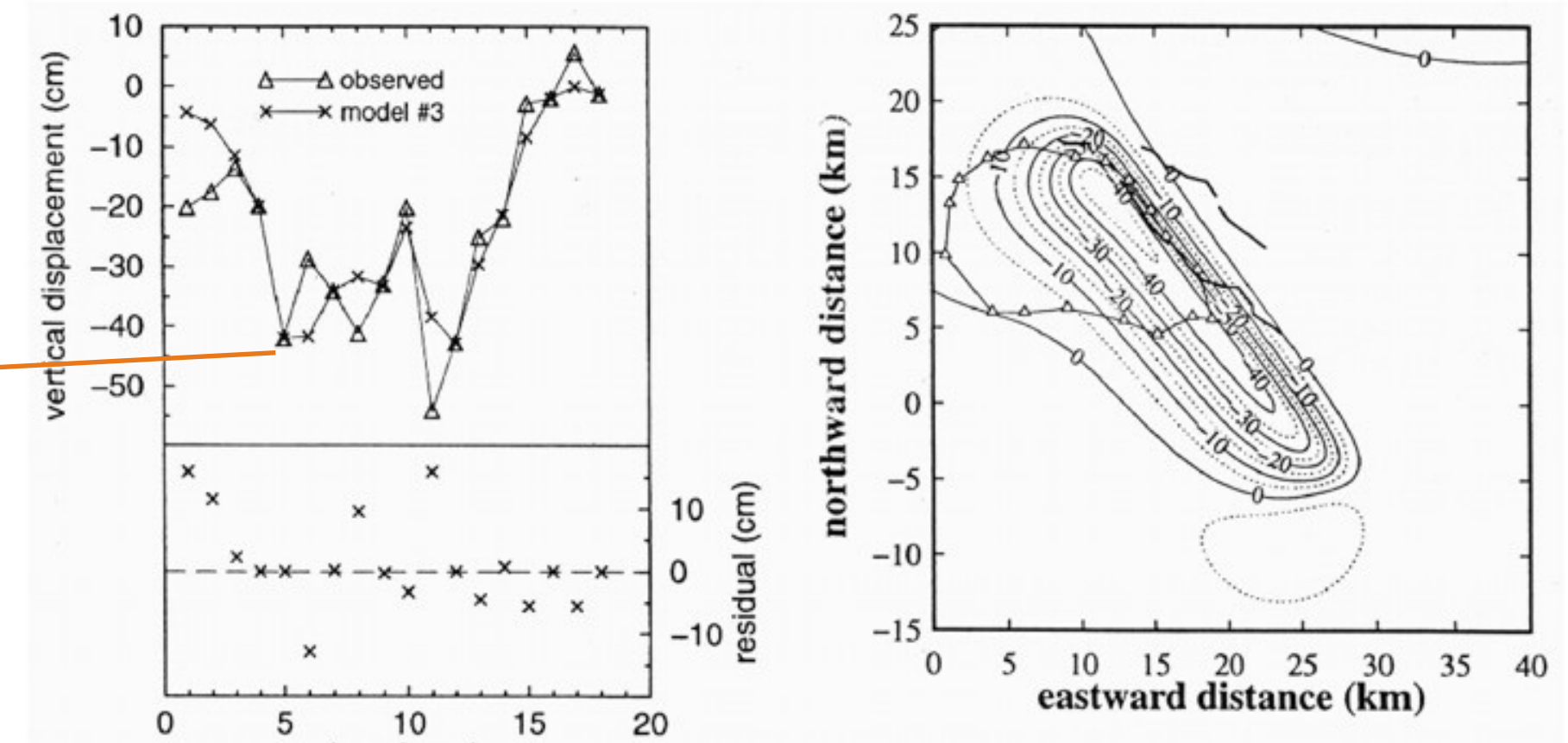
The rupture extended to ground surface, as evidenced also by several paleoseismological studies (figure from Galadini and Galli, 1999).



(top) Measured (triangles) and predicted (cross, model 3) vertical displacements; (bottom) residuals. The mean absolute deviation of residuals is about 4.8 cm.

Contour map of surface vertical displacements from model 3. The region of maximum strictly corresponds to the Serrone fault, and values are in agreement with those reported by Oddone [1915].

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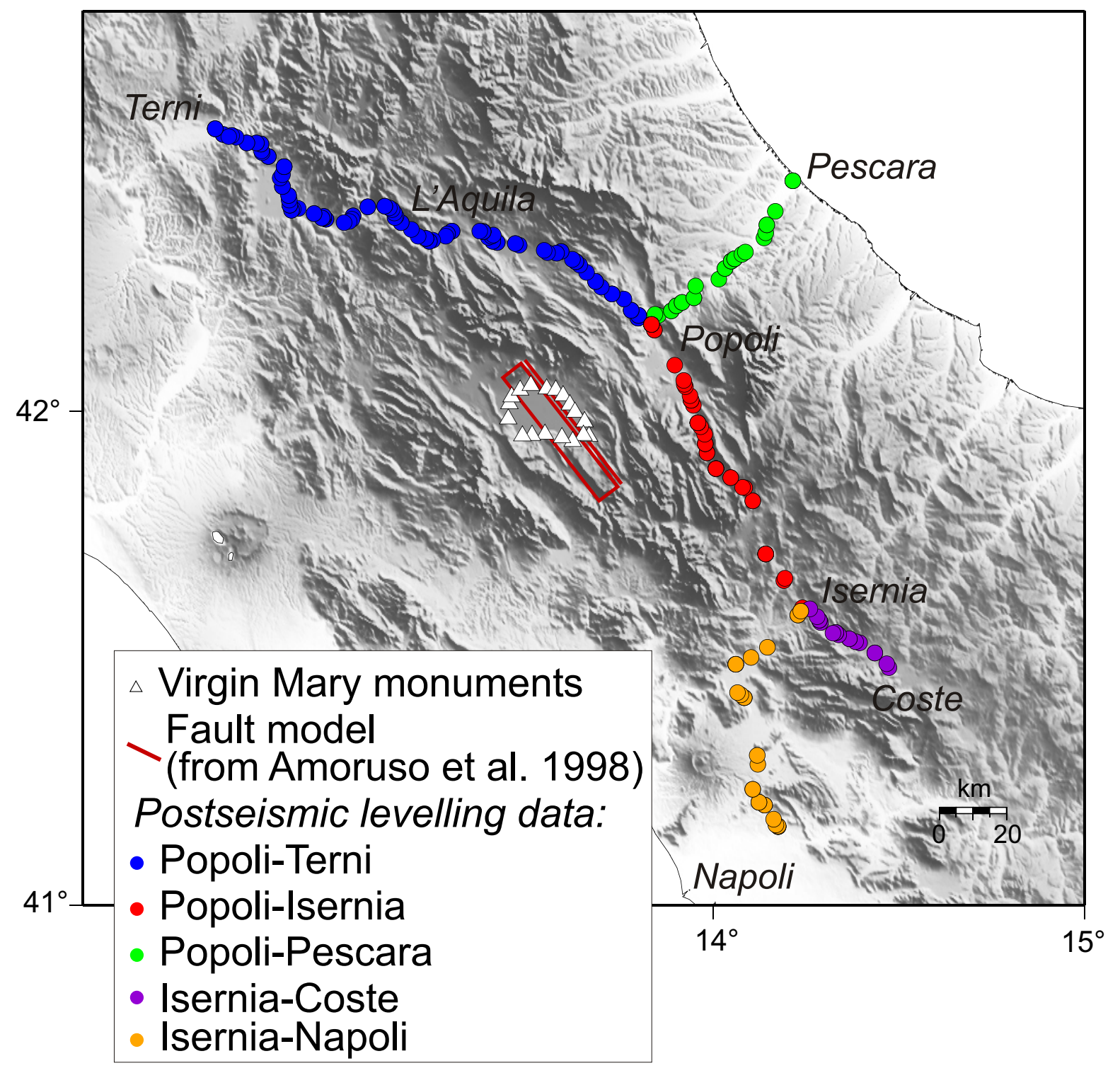
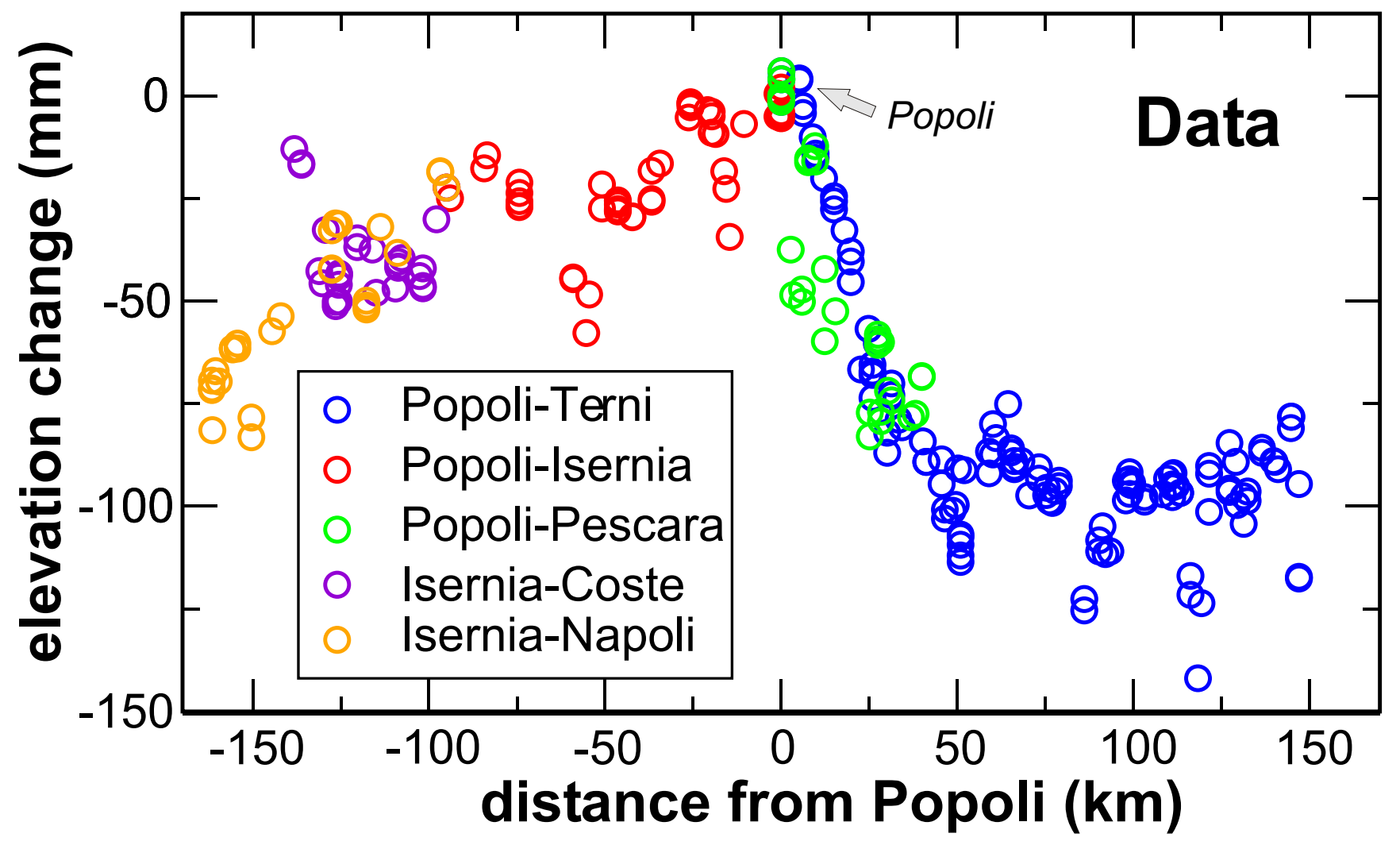
Coseismic movements have been recorded in the epicentral area by 18 statues of the Virgin Mary (picture from Valensise & Pantosti, 2001; location is shown in panel 2), leveled in 1862 and 1915.

Inversion of this geodetic dataset suggests a causative fault dipping at moderate angle toward SW, with normal and not negligible left-lateral component (Amoruso et al. 1998).
This fault geometry has been used herein to model the hypothesized postseismic deformation.

2. Postseismic Leveling Data



Our dataset consists of three unpublished high precision leveling lines located in a wide sector around the Fucino basin. These routes were measured in 1950 and 1997-2000 by IGM (*Istituto Geografico Militare*) and their total length is about 360 km with a mean benchmark density higher than 0.5 bm/km.



We calculate elevation changes referring them to the nodal benchmark of Popoli. Relative elevation changes show maximum values between 5 and 12 cm, with a signal wavelength of 40-70 km. The elevation changes stand significantly above the calculated total error of 1.13 sqrt(L), in mm (where L is the distance between benchmark, in km) (D'Anastasio, 2004). A sharp gradient can be noticed between km 0 and 40, along the Popoli-Terni and the Popoli-Pescara lines.

3. Postseismic Modeling

We use Pollitz (1997) code for computing gravitational-viscoelastic postseismic relaxation on a layered spherical Earth.

Computed postseismic benchmark elevation changes are compared with observed ones, by means of a L1-norm misfit function including correlated and uncorrelated uncertainties.

Observed elevation changes in the Fucino earthquake area seem to comprise both regional tectonic deformation and post-seismic relaxation. The former and the latter effects are expected to dominate along sections of the leveling lines which are respectively about perpendicular and parallel to the Apennines, thus in the misfit function we multiply observed benchmark vertical movements along the Popoli-Pescara and the Popoli-Terni lines by two free parameters (P1 and P2). The two free parameters are optimized in the misfit minimization procedure.

Reference source fault (from Amoruso et al., 1998)
Location (lat, lon of corner on lower fault edge closest to strike direction): 41°49'12'' N, 13°41'31'' E
Length: 35 km; width: 9 km; upper side depth: 2 km; strike: 143°; dip: 55°
Three rake values: -90°, -60°, -42°
Slip: 0.5 to 3 times 1.23 m

Reference layering

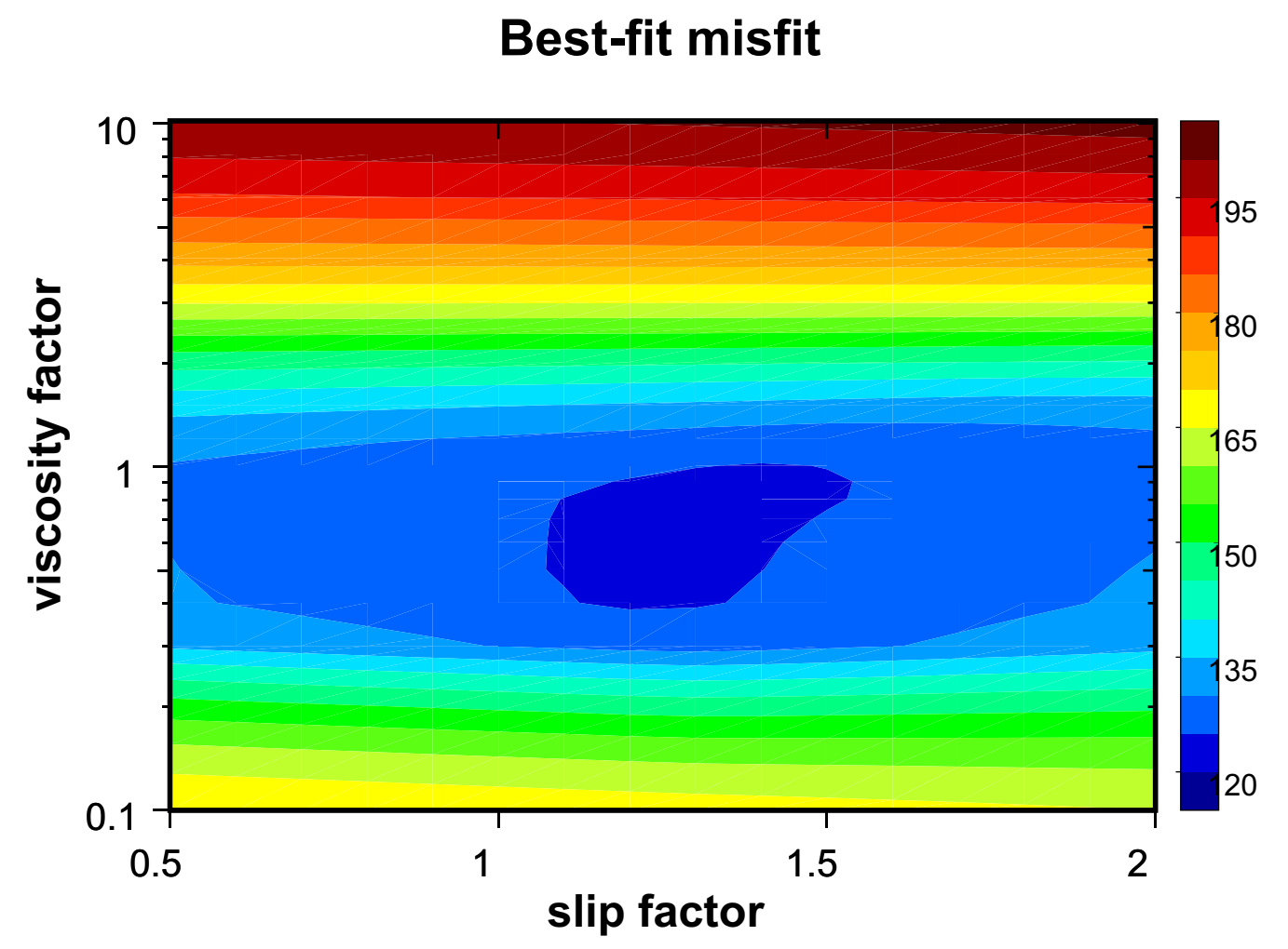
Layer	Density (kg/m^3)	Bulk modulus (Pa)	Shear modulus (Pa)	Viscosity (Pa s)
surface layer (4km-thick)	2800	6.50×10^{10}	3.60×10^{10}	10^{29}
upper crust	3030	7.36×10^{10}	4.08×10^{10}	10^{29}
transition zone	3190	7.36×10^{10}	4.08×10^{10}	10^{19}
lower crust	3384	9.51×10^{10}	5.27×10^{10}	10^{18}
mantle	3384	15.00×10^{10}	7.00×10^{10}	10^{21}

We assign various depths to the layers of the Reference layering. For each layer configuration, we multiply all viscosities by a common "viscosity factor" ranging 0.1 to 10 and the reference fault slip (1.23 m) by a "slip factor" ranging 0.5 to 3, thus gridding the (slip, viscosity) plane.

4. Postseismic Modeling Results

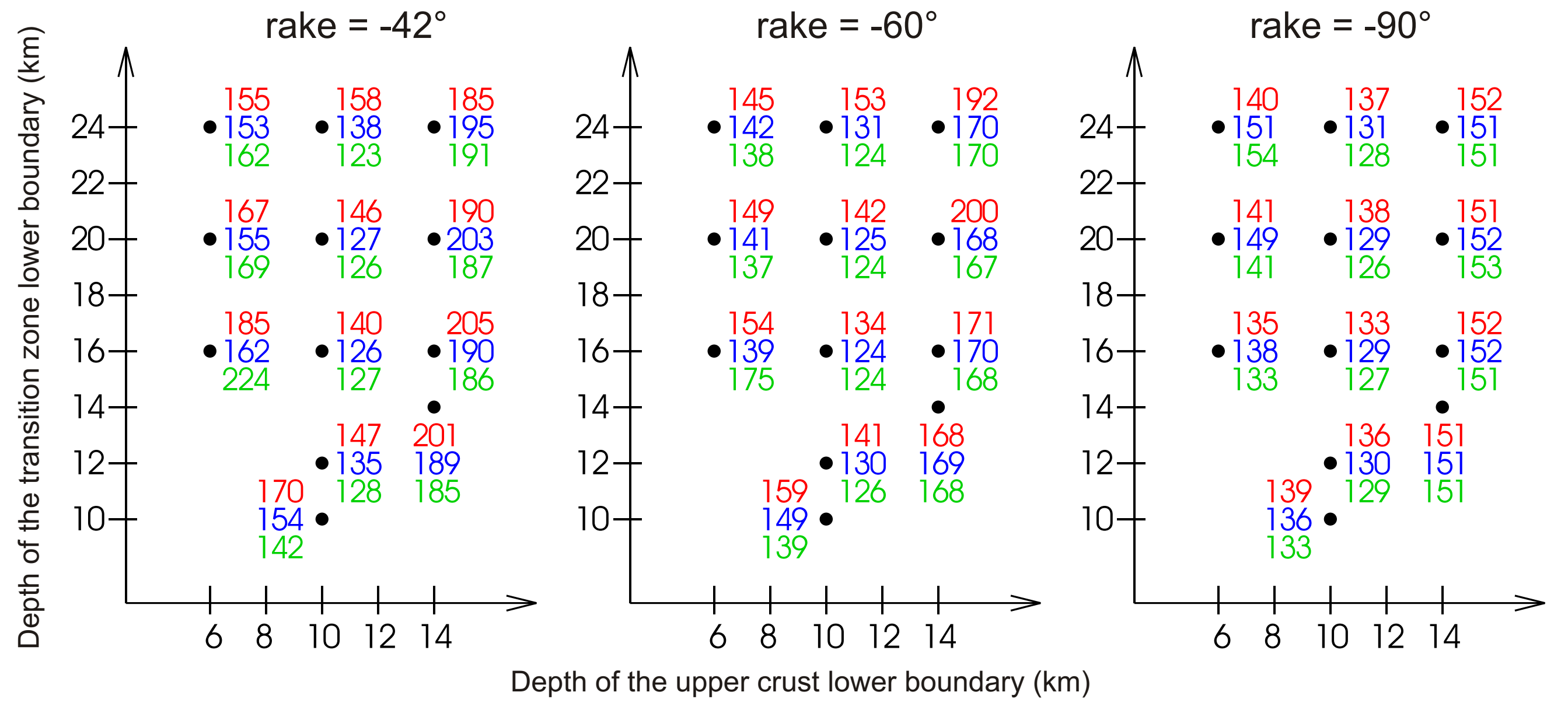
For each (slip, viscosity) point we compute the best-fit misfit optimizing P1 and P2 .

Depth of the upper crust lower boundary: 10 km
Depth of the transition zone lower boundary: 20 km
Depth of the mantle upper boundary: 35 km
Rake angle: -60°



Misfit minima for all choices of layer depths allow to put constraints on local crustal structure.

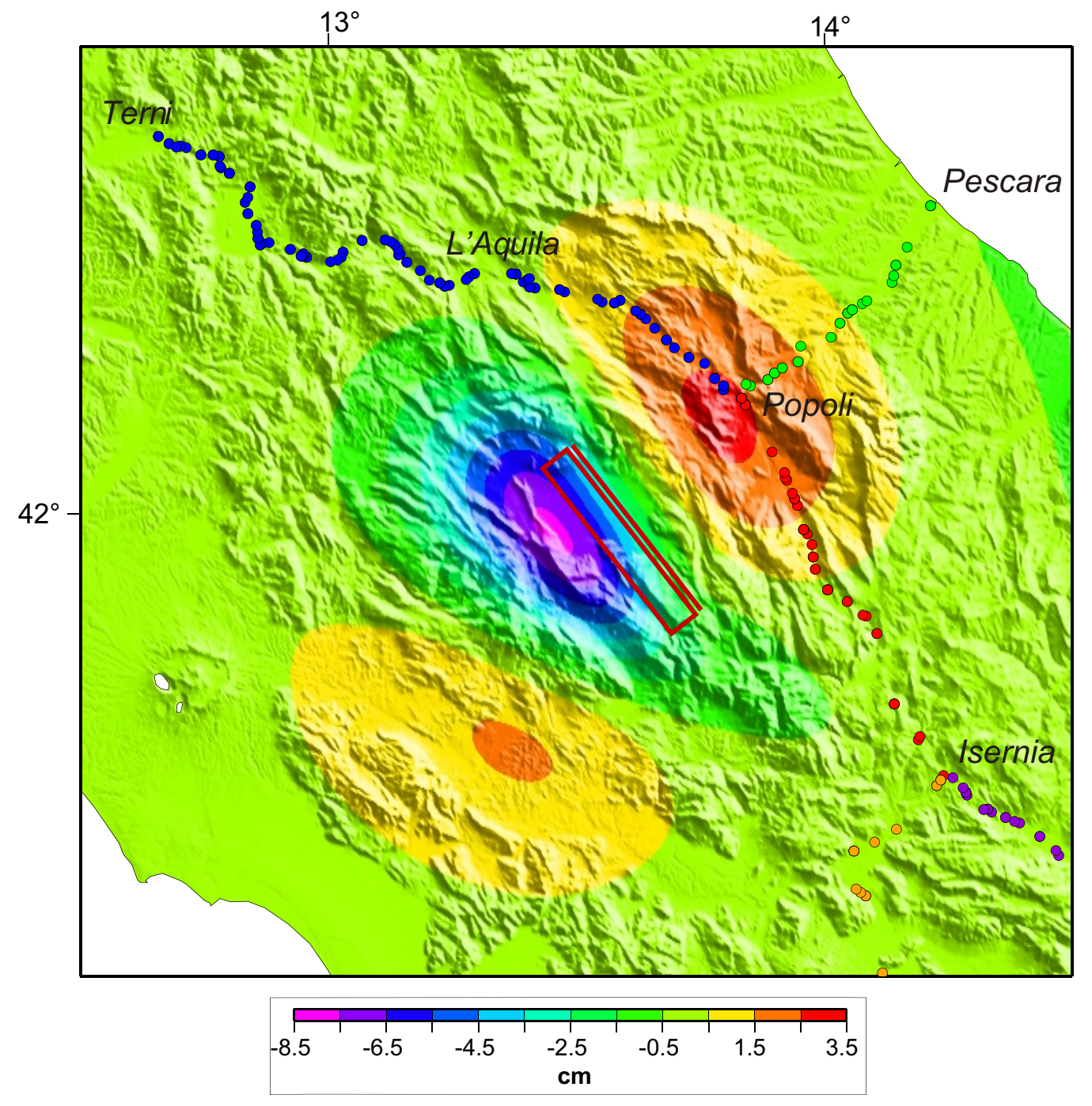
Best-fit misfits for three values of the mantle upper boundary depth: 25 km, 30 km, 35 km



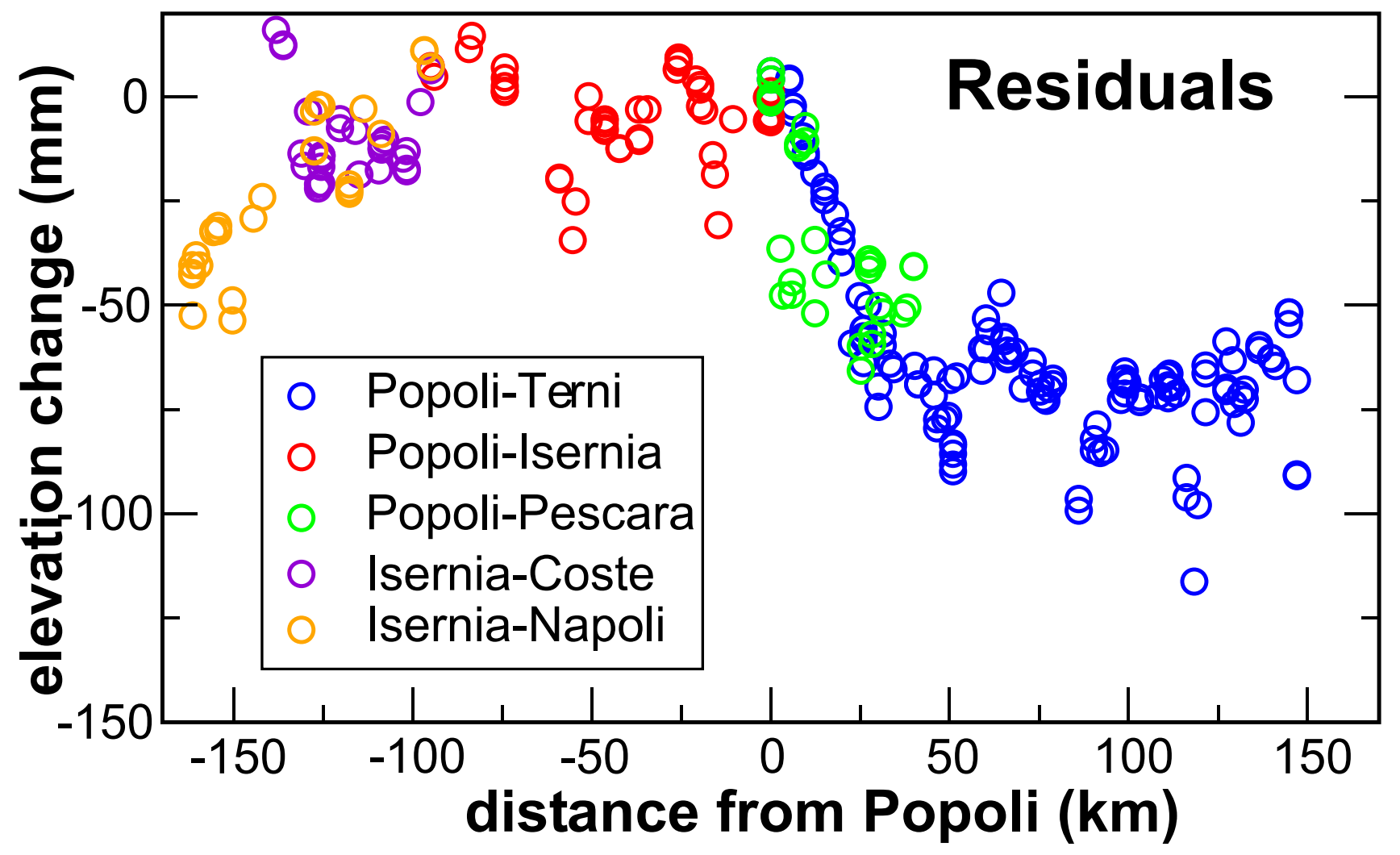
Results indicate that:
1. upper crust thickness is about 10 km, in agreement with rupture geometry (Amoruso et al. 1998)
2. the existence of a transition zone (Aoudia et al. 2003) is here confirmed
3. total crust thickness is larger than about 25 km
4. rake angle is not well constrained, but the existence of a left-lateral component (Amoruso et al. 1998) seems confirmed.

Misfit maps in the (slip, viscosity) plane show that acceptable viscosity values are well inside the ranges suggested by Aoudia et al. (2003) and slip is fully consistent with Amoruso et al. (1998).

Best-fit P1 and P2 indicate that postseismic relaxation contributes to Popoli uplift with respect to benchmarks out of the Apennines by about 30%.



Residual plot is about flat for benchmarks along the Apennines and decreases aside the Apennines, showing a quasi-symmetric shape toward the Adriatic Sea and the Tyrrhenian Sea. Numerical values and shape are fully consistent with expected regional tectonic deformation in Central Apennines (D'Anastasio, 2004).



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Conclusions

The elevation changes observed between 1950 and 1997-2000 along leveling lines around the epicentral area of the 1915 Fucino earthquake comprise both post-seismic relaxation and regional tectonic deformation. Since we compare measurements performed 35 and 85 years after the earthquake, relaxation effects refer to a late stage of the process, accounting for about 30% of the observed geodetic signal. Even if S/N ratio of expected post-seismic effects is not high, comparison between predictions and observations allowed us to constrain regional crustal structure. Residuals are fully consistent with expected regional tectonic deformation in Central Apennines.

Acknowledgments

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