

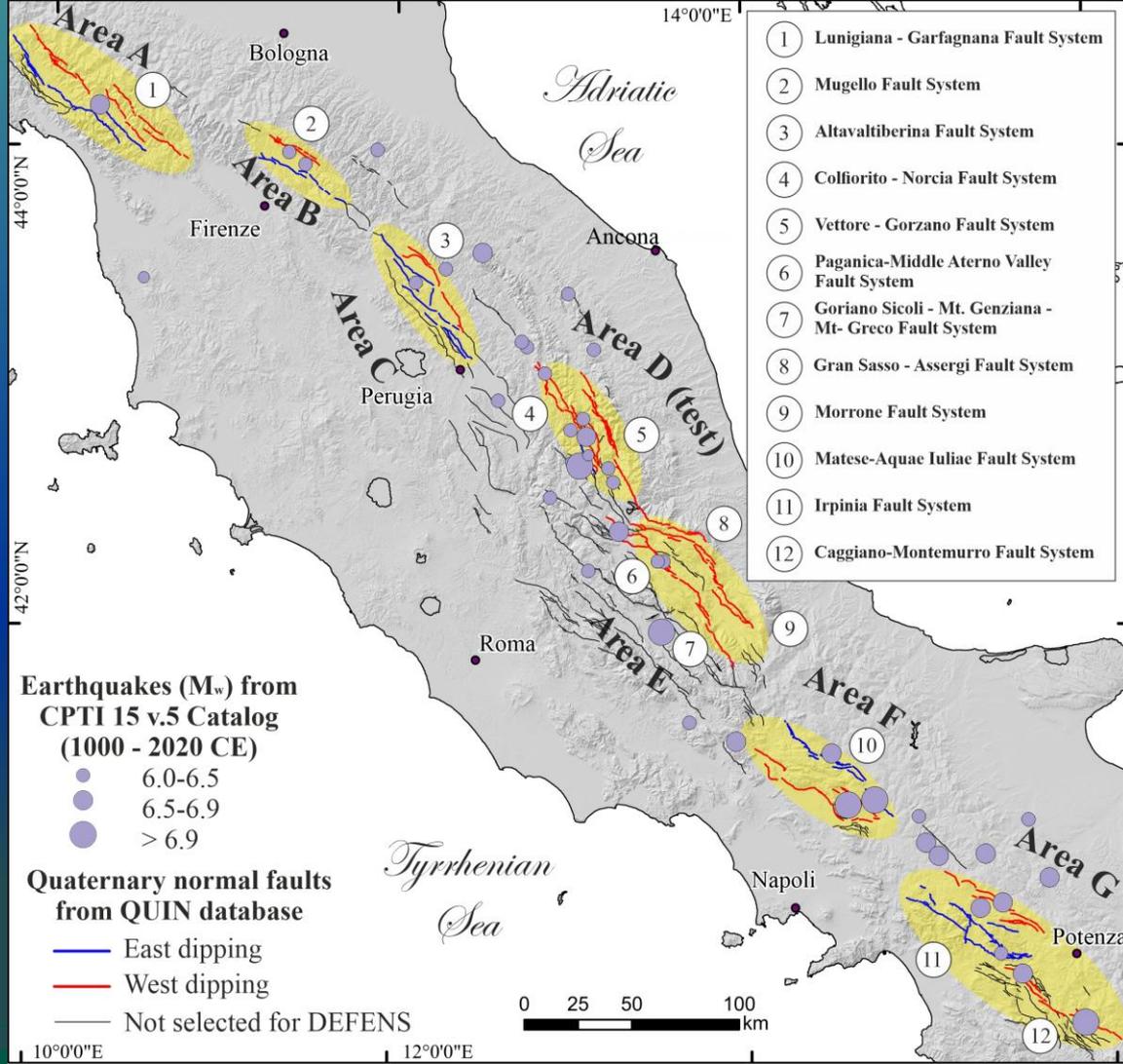


STRUCTURAL GEOLOGY for SEISMOTECTONICS

an interdisciplinary 3D approach to DEFENS case studies

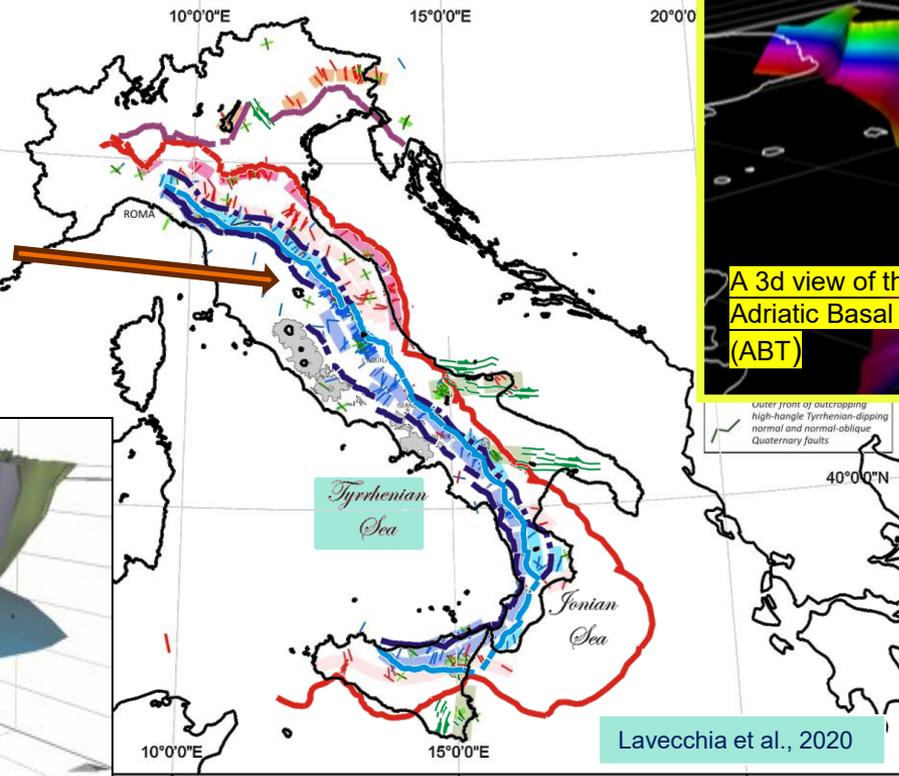
Giusy Lavecchia & Francesco Brozzetti

CRUST Interuniversity Center for 3Seismotectonics with territorial application
Ud'A University, Chieti , Italy

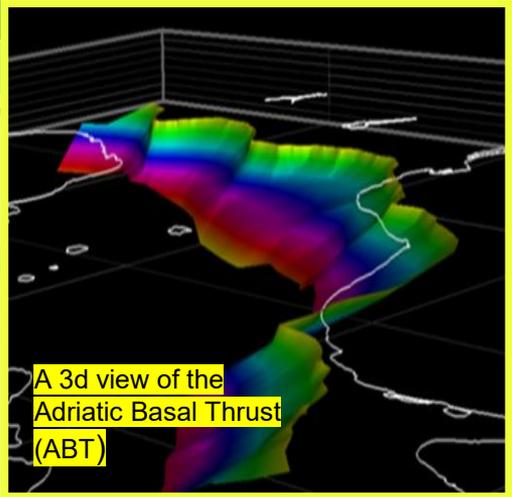


The seismotectonic provinces of Italy

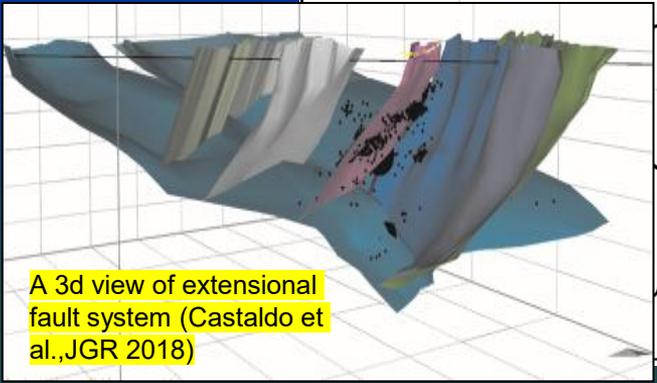
IEP
Intra-Apennine
Extensional Belt



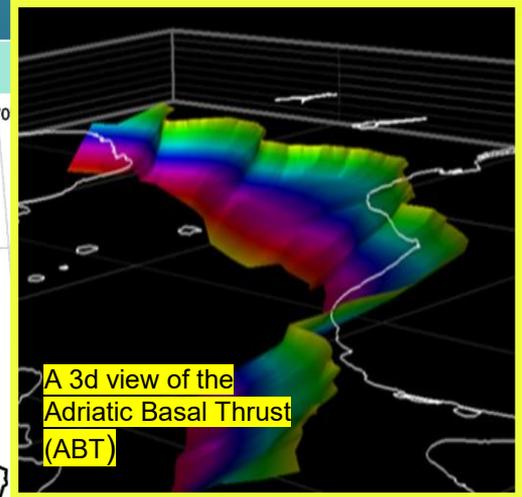
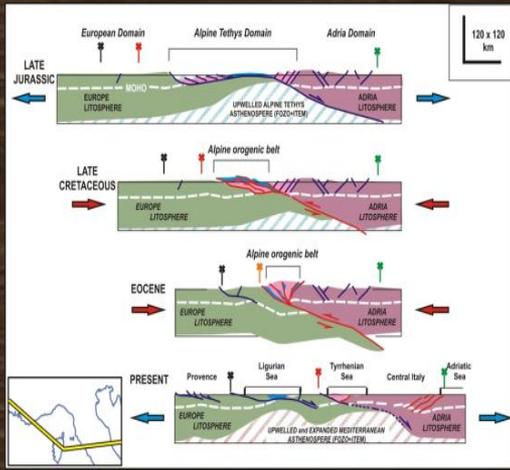
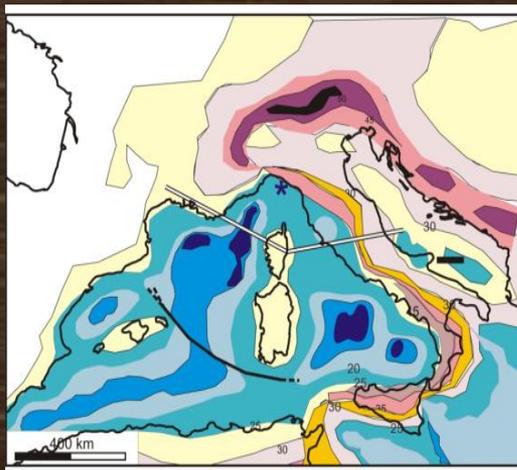
A 3d view of the
Adriatic Basal Thrust
(ABT)



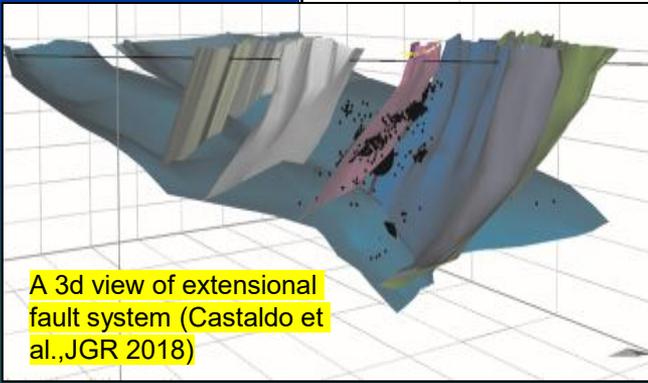
A 3d view of extensional
fault system (Castaldo et
al., JGR 2018)



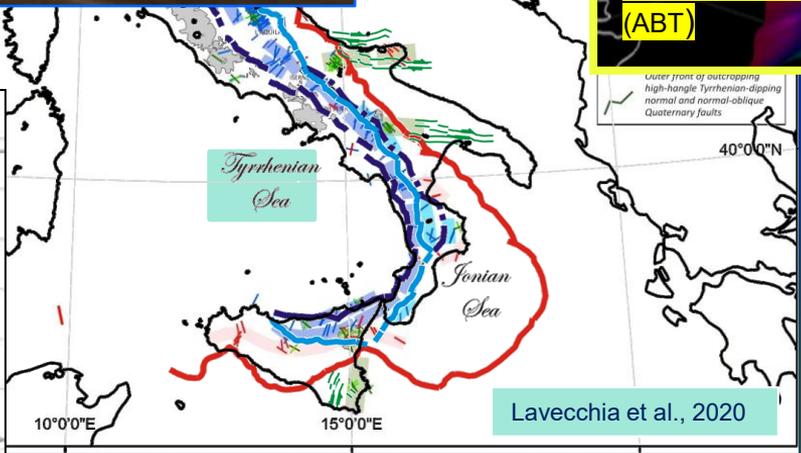
Lavecchia et al., 2020



A 3d view of the Adriatic Basal Thrust (ABT)



A 3d view of extensional fault system (Castaldo et al., JGR 2018)



Lavecchia et al., 2020

Peninsular Italy Over Time (PILOT) geometry, kinematics and dynamics

The term **"over time"** captures a continuous tectonic evolution, linking geological inheritance, progressive deformation, and present-day activity within a unified seismotectonic framework

PILOT stress database

to be submitted to Nature Communication



- 1- Fault traces, after QUIN1 and 2
- 2- Fault slip data, after QUIN 1 and 2
- 3- Multi-scale stress inversion



Two complementary elements are required:
A – fault-slip and fault trace data;

B – explicit choice of the scale of investigation, given the intrinsic scale-dependence of stress reconstructions.

PILOT 3D fault database

to be submitted to Earth System Science Data



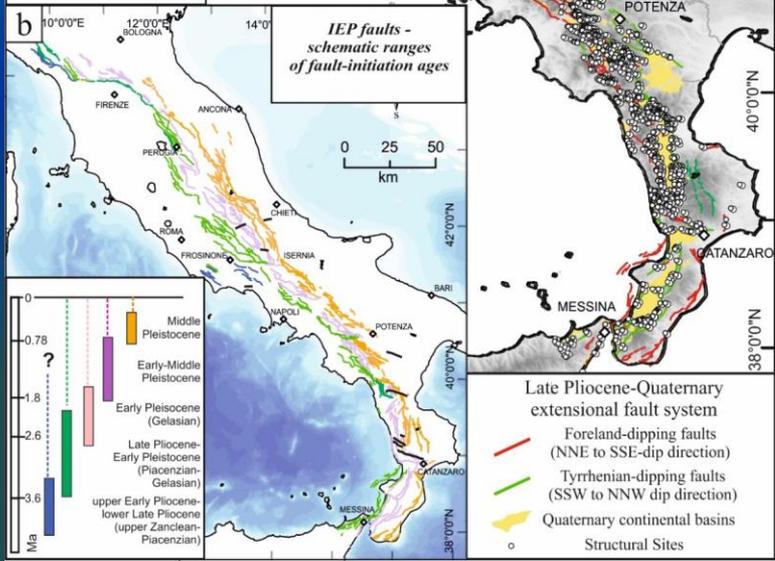
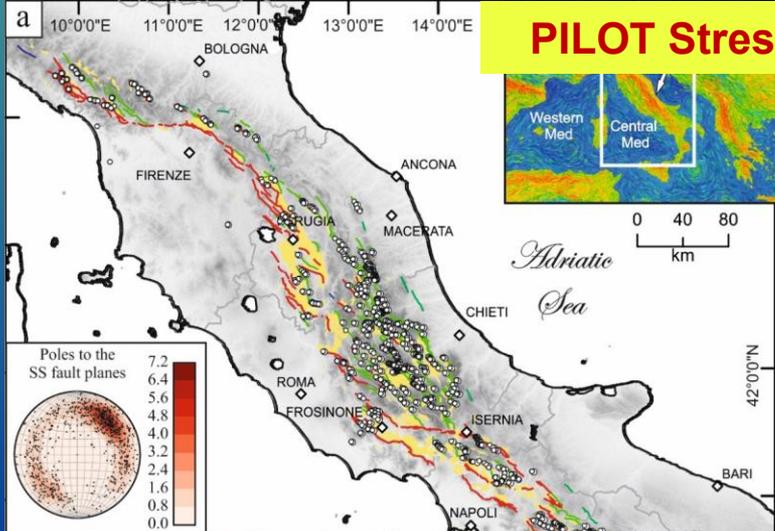
- 1-Km 0 curvilinear fault lines
- 2- «Ribbon» shallow fault models
- 3-Original non planar 3D fault models
- 4-Resampled 3D triangulated fault meshes



Two complementary elements are required:
A–multi-source, multi-depth, and multi-scale data;

B – explicit definition of the structural style, which provides the kinematic and mechanical framework for interpreting those data.

PILOT Stress Database Data Source



scientific **data**

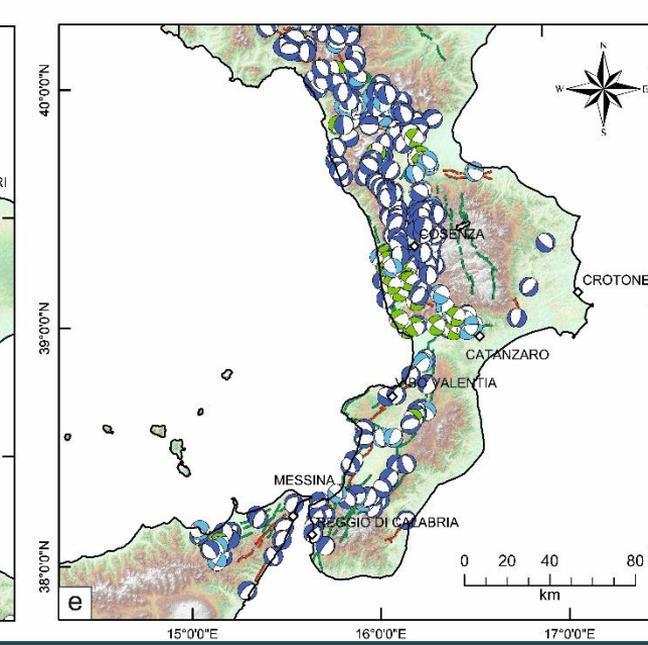
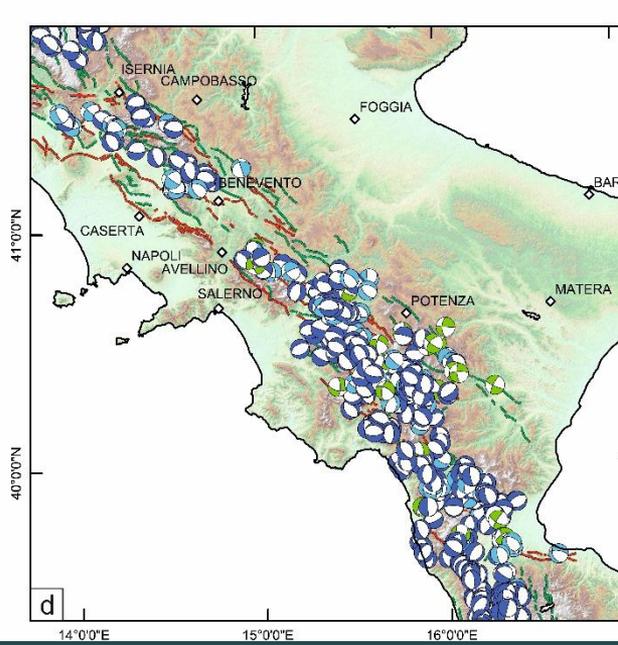
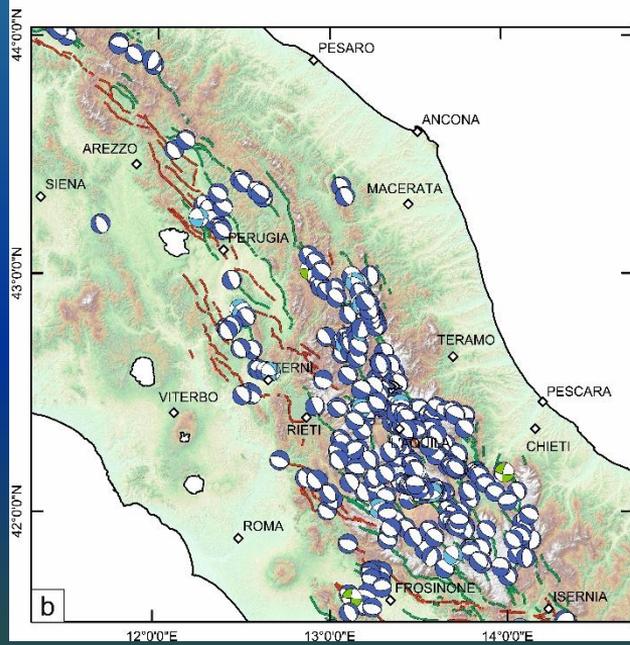
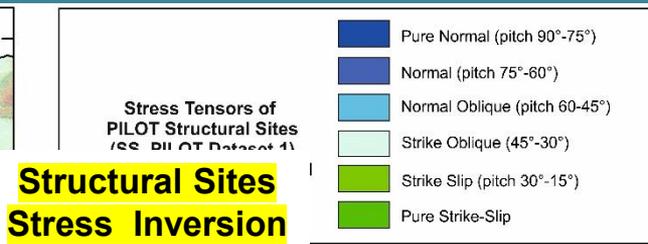
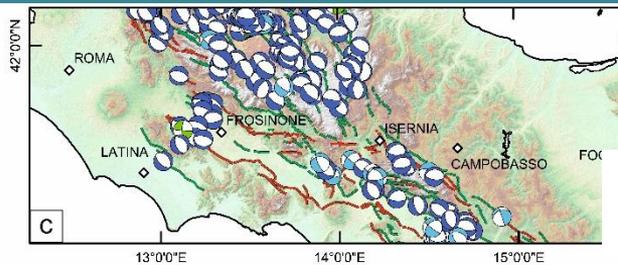
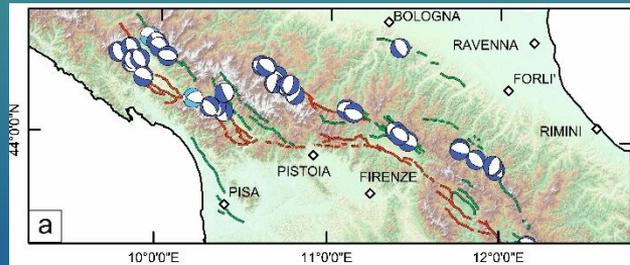
OPEN DATA DESCRIPTOR [QUaternary fault strain INDicators database - QUIN 1.0 - first release from the Apennines of central Italy](#)

Giusy Lavecchia^{1,2}, Simone Bello^{1,2,3,4}, Carlo Andrenacci^{1,2}, Daniele Cirillo^{1,2}, Federica Ferrarini^{1,2}, Noemi Vicentini^{1,2}, Rita de Nardis^{1,2}, Gerald Roberts⁵ & Francesco Brozzetti^{1,2}

scientific **data**

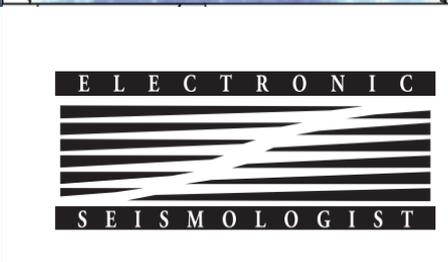
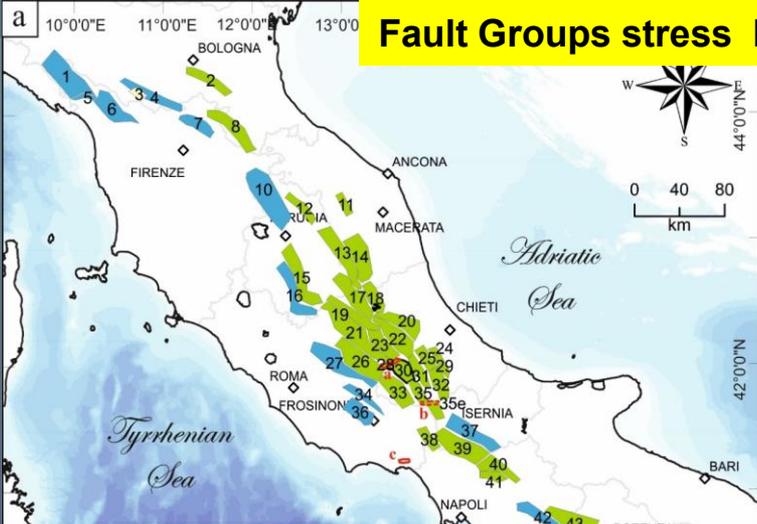
OPEN DATA DESCRIPTOR [QUIN 2.0 - new release of the QUaternary fault strain INDicators database from the Southern Apennines of Italy](#)

Giusy Lavecchia^{1,2,16}, Simone Bello^{1,2,3,14}, Carlo Andrenacci^{1,2}, Daniele Cirillo^{1,2}, Federico Pietrolungo^{1,2}, Donato Talone^{1,2}, Federica Ferrarini^{1,2}, Rita de Nardis^{1,2}, Paolo Galli^{1,2}, Joanna Faure Walker^{1,2}, Claudia Sgambato^{1,2}, Marco Menichetti^{1,2,8}, Carmelo Monaco^{1,9,10}, Salvatore Gambino^{1,9}, Giorgio De Guidi^{1,9}, Giovanni Barreca^{1,9}, Francesco Carmemolla^{1,9}, Fabio Brighenti^{1,9}, Salvatore Giuffrida^{1,9}, Claudia Pirrotta^{1,9}, Filippo Carboni^{1,11,12}, Luigi Ferranti^{1,12}, Luisa Valoroso¹⁴, Giovanni Toscani^{1,15}, Massimiliano R. Barchi^{1,11}, Gerald Roberts⁷ & Francesco Brozzetti^{1,2}



A statistical PBT inversion (Turner, 1953; Angelier, 1979; Sperner et al., 1993) was applied to the kinematically compatible FSP of each SS dataset, using a 3×3 matrix based on the direction cosines of the P and T axes.

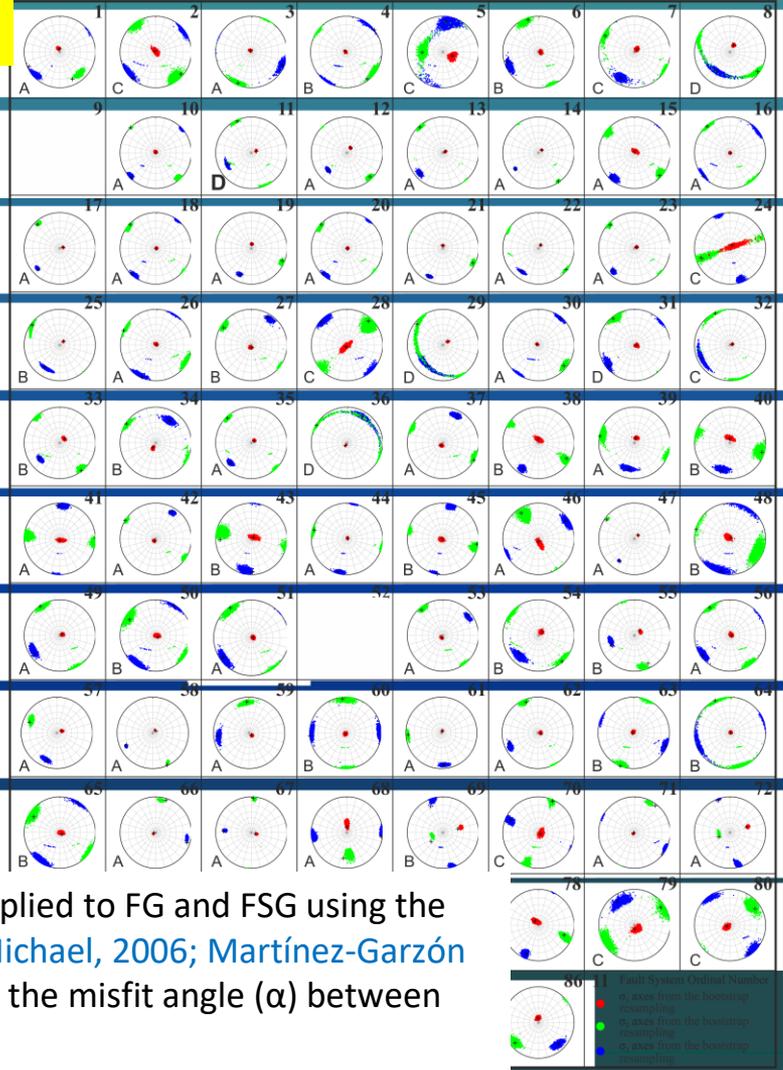
Fault Groups stress Inversion



MSATSI: A MATLAB Package for Stress Inversion Combining Solid Classic Methodology, a New Simplified User-Handling, and a Visualization Tool

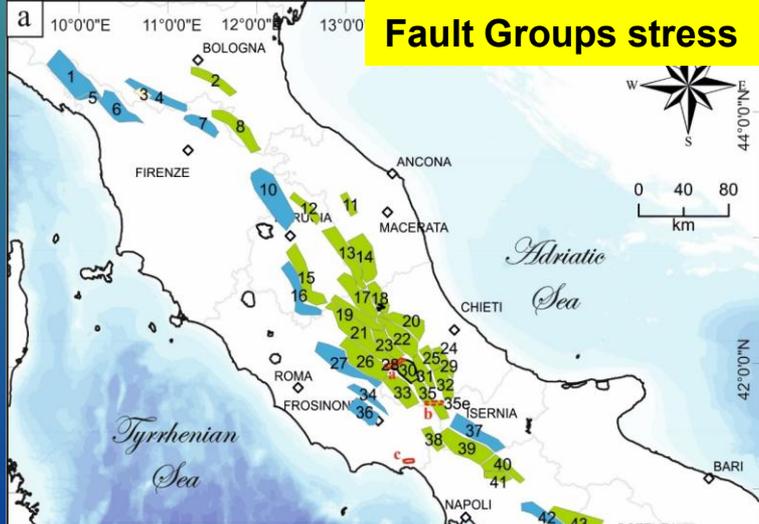
by Patricia Martínez-Garzón, Grzegorz Kwiatek, Michèle Ickrath, and Marco Bohnhoff

Online Material: Figures of complete stress inversion results.



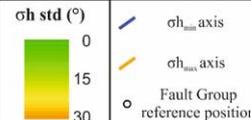
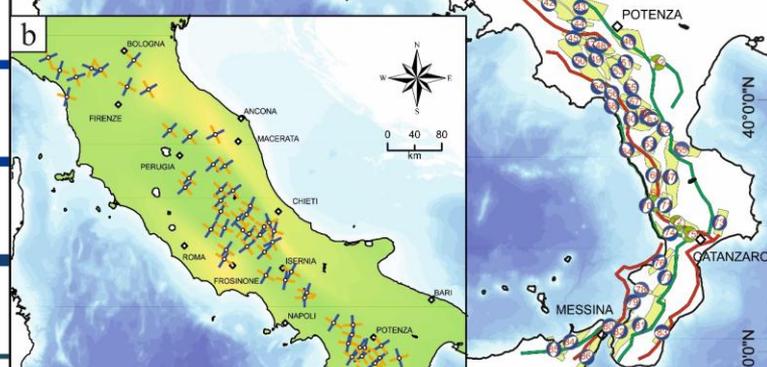
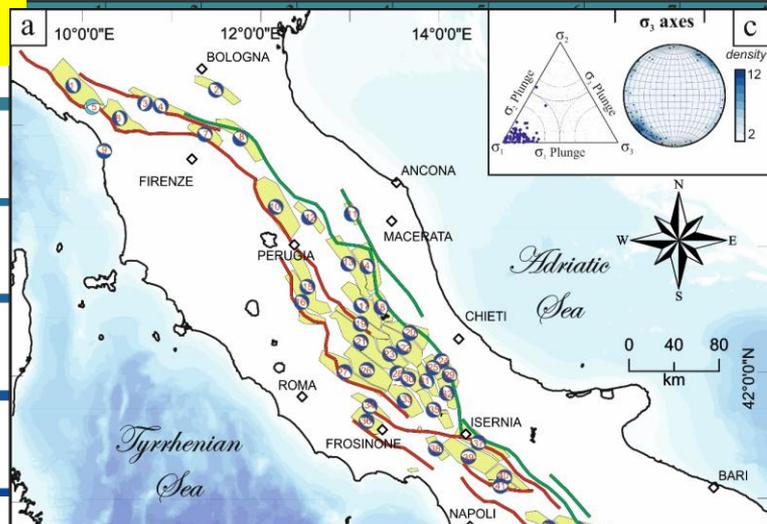
A full-tensor inversion was applied to FG and FSG using the MSATSI code (Hardebeck & Michael, 2006; Martínez-Garzón et al., 2014), which minimises the misfit angle (α) between shear stress and slip vectors.

Fault Groups stress Inversion



Fault Group Polygons

- ▬ Tyrrhenian-dipping
- ▬ Adriatic - dipping
- ▬ Early Stage
- ▬ Double stage



- ▬ σ_{max} axis
- ▬ σ_{min} axis
- Fault Group reference position

- ### Stress Tensor Kinematics (Pitch [°])
- PN 90-75
 - NF 75-60
 - N-SS 60-45
 - SS-N 45-30
 - SS 30-15
 - PSS 15-0
 - ▬ Foreland-dipping faults
 - ▬ Tyrrhenian-dipping faults
 - ▬ Fault Group Polygon

ELECTRONIC

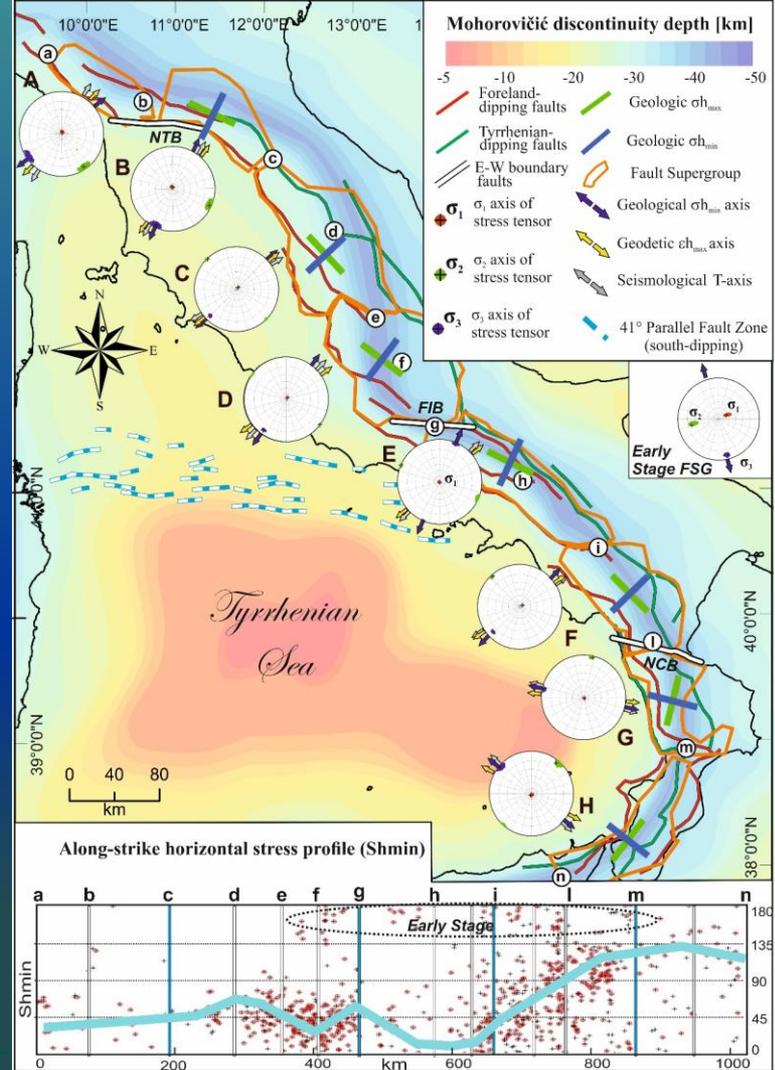
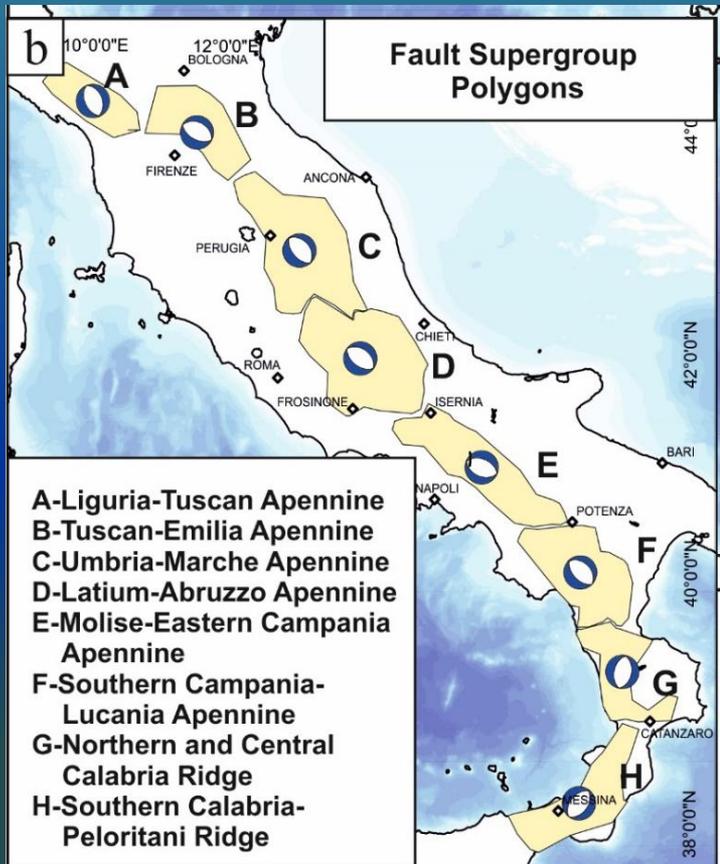
SEISMOLOGIST

MSATSI: A MATLAB Package for Stress Inversion Combining Solid Classic Methodology, a New Simplified User-Handling, and a Visualization Tool

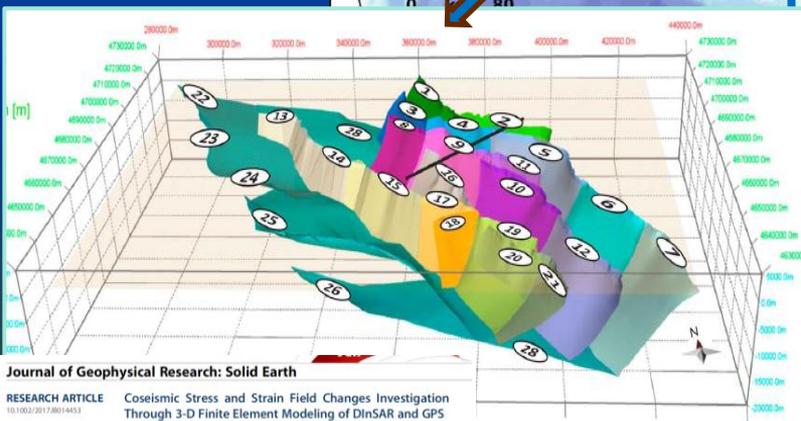
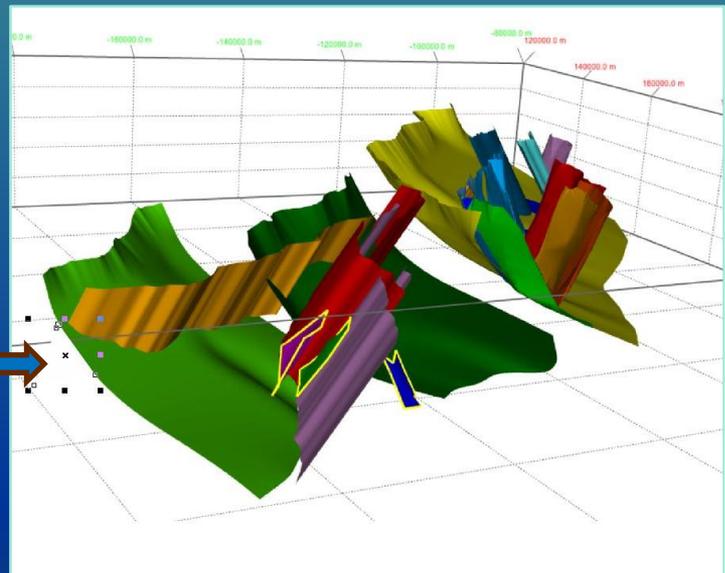
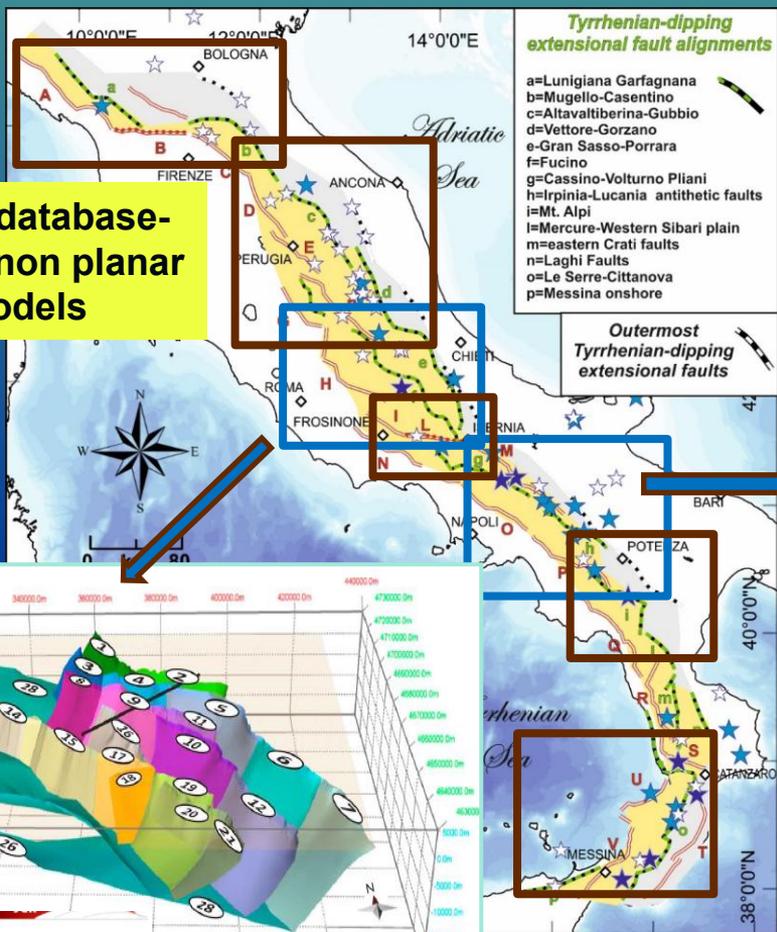
by Patricia Martínez-Garzón, Grzegorz Kwiatek, Michèle Ickrath, and Marco Bohnhoff

Online Material: Figures of complete stress inversion results.

Fault Supergroups Stress Inversion



PILOT 3D fault database- pre-resampling non planar 3D fault models



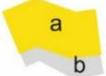
ical seismicity
00 aD.-2020

IEP

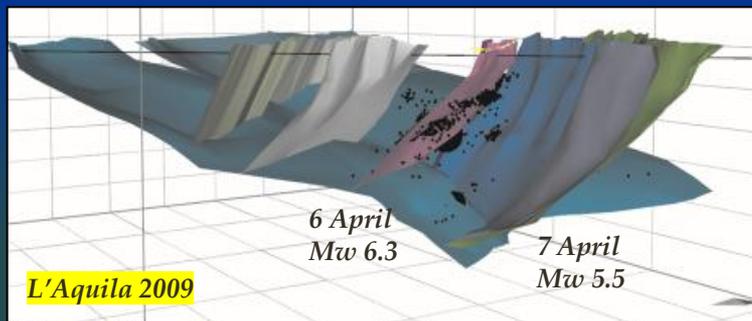
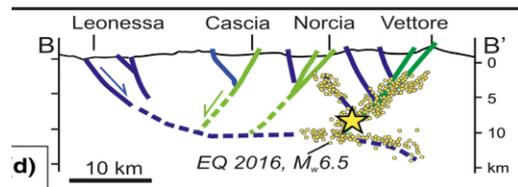
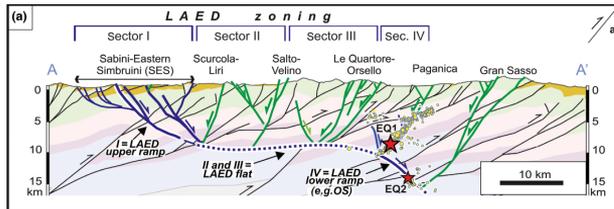
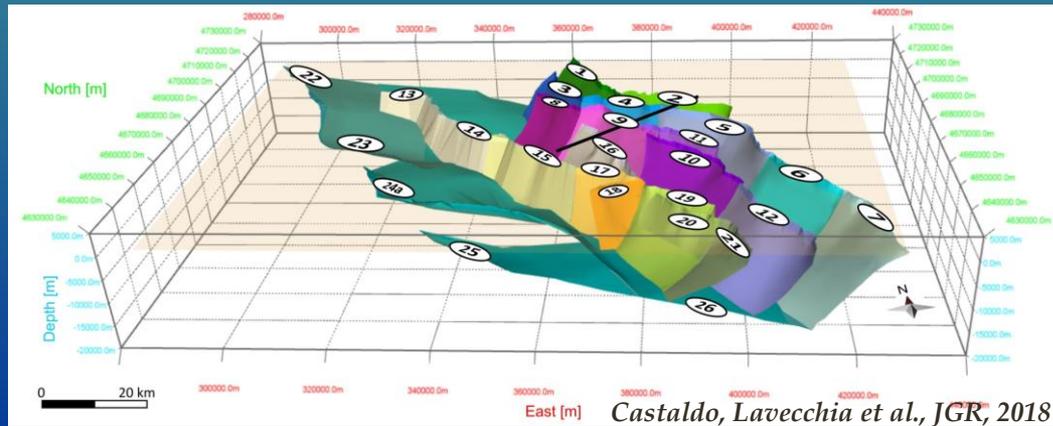
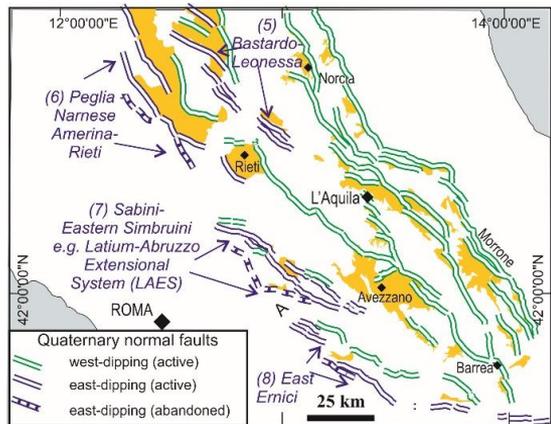
- ☆ Mw 5.5-6.0
- ★ Mw 6.0-6.5
- ★ Mw 6.5-7.3

5 OSCA

U= Sant'Eufemia-Capo Vaticano offshore
V= Sant'Eufemia-Scilla -Messina

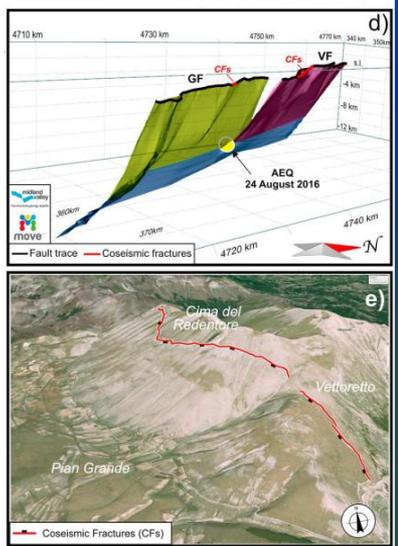
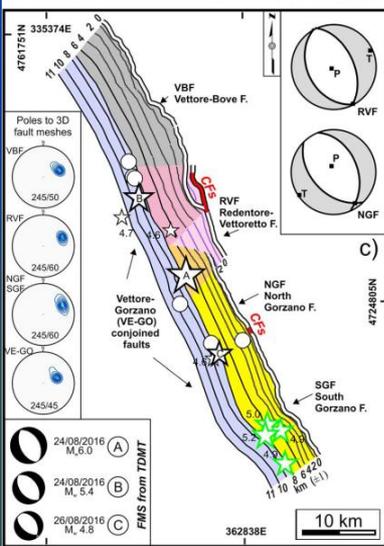
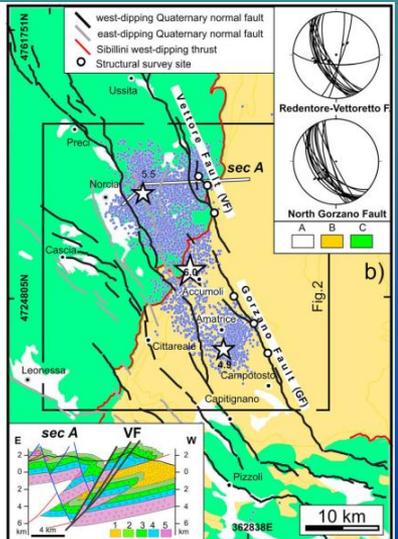
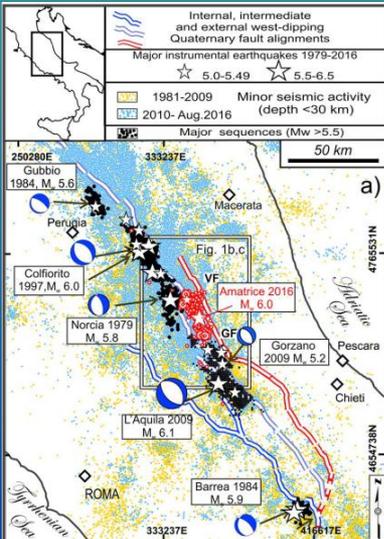


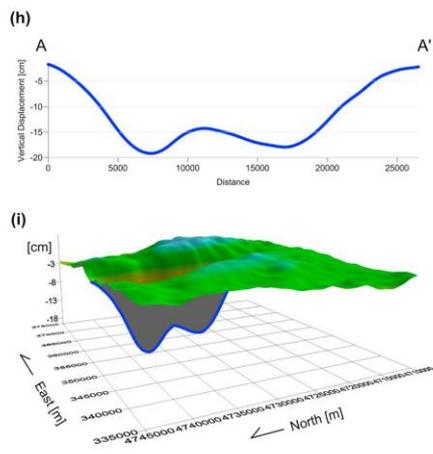
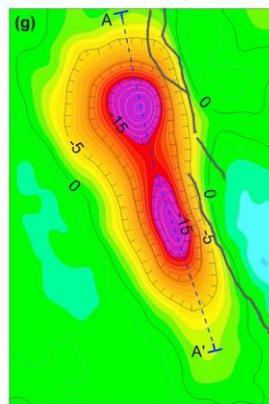
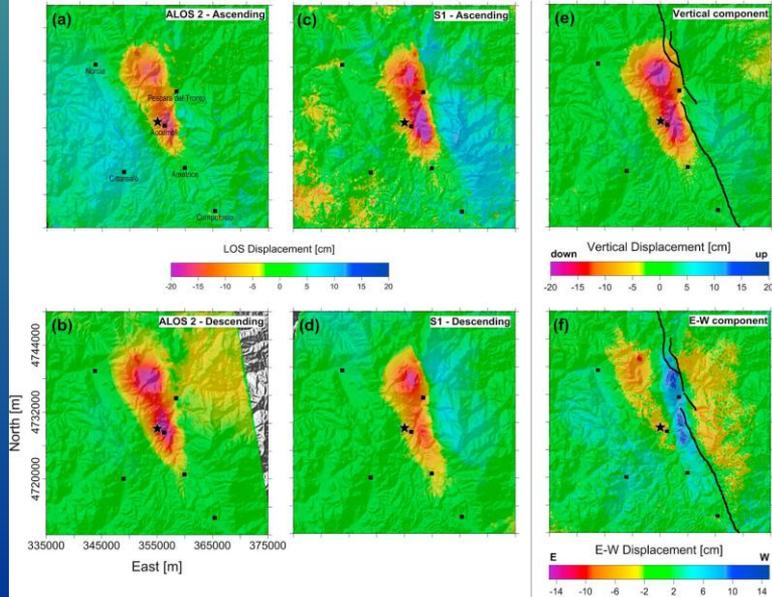
Structural style of the seismogenic intra-Apennine belt of Central Italy



6 April
Mw 6.3

7 April
Mw 5.5





RESEARCH LETTER
10.1002/2016GL071723

Ground deformation and source geometry of the 24 August 2016 Amatrice earthquake (Central Italy) investigated through analytical and numerical modeling of DInSAR measurements and structural-geological data

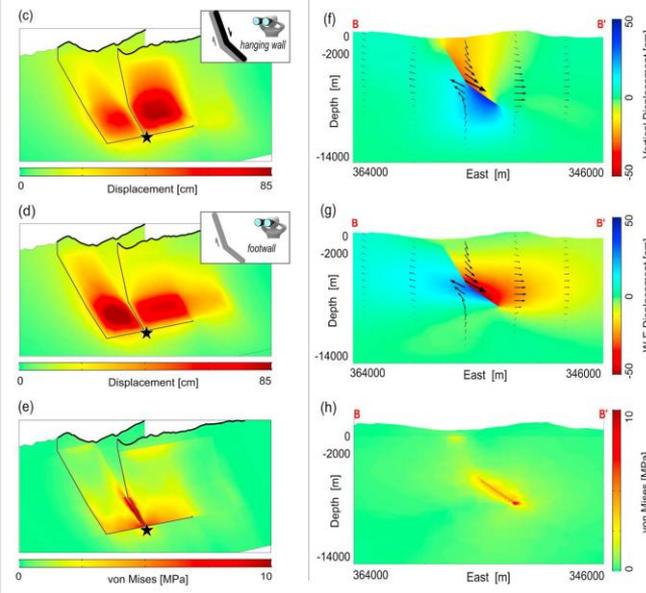
Key Points:

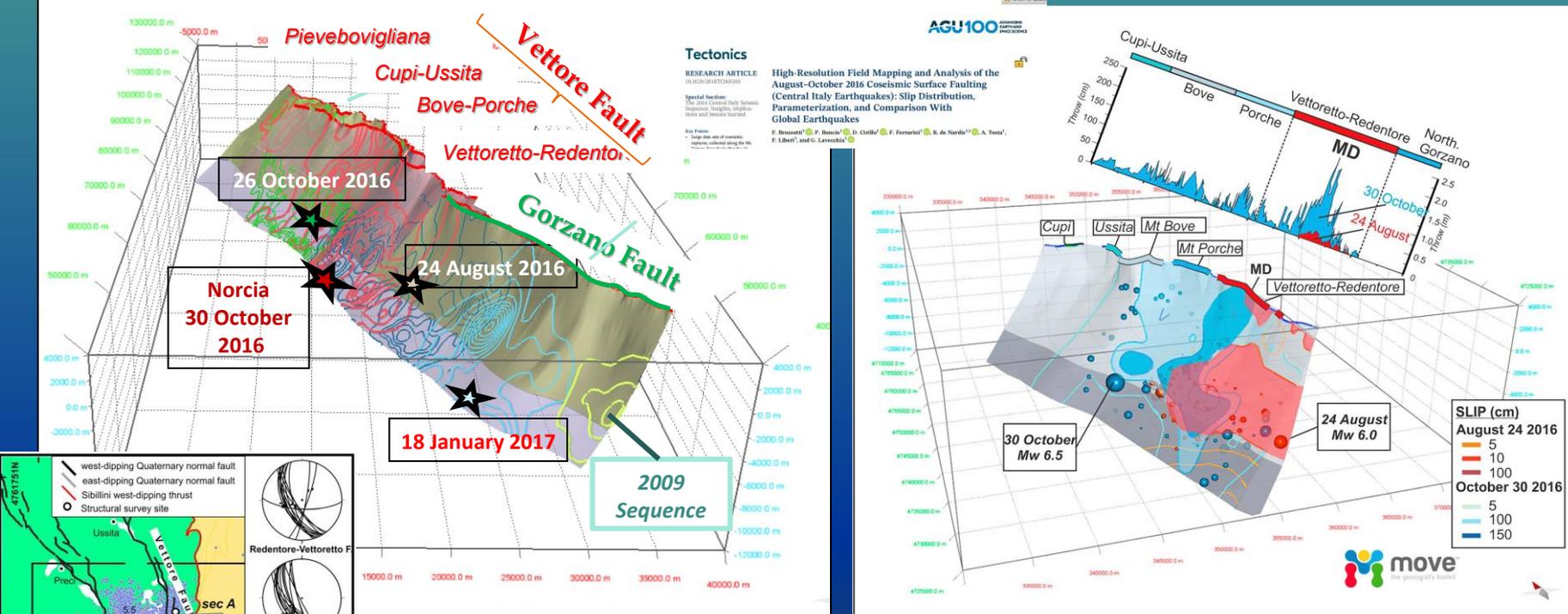
- Investigation of the ground deformation and source geometry of the 2016 Amatrice earthquake (Central Italy)
- Cosismic displacements modeling through 3-D finite elements approach jointly exploiting DInSAR measurements and a 3-D fault model
- Evidence of a bilateral rupture propagating along two en echelon normal faults conjoined at the hypocenter

G. Lavecchia¹, R. Castaldo², R. de Nardis¹, V. De Novellis³, F. Ferrarini¹, S. Pepe², F. Brozzetti¹, G. Solaro², D. Cirillo⁴, M. Bonano⁵, P. Bondi⁶, F. Casu⁷, C. De Luca², R. Lanari², M. Manunzi², M. Manzo², A. Pepe², L. Zinno², and P. Tizzani²

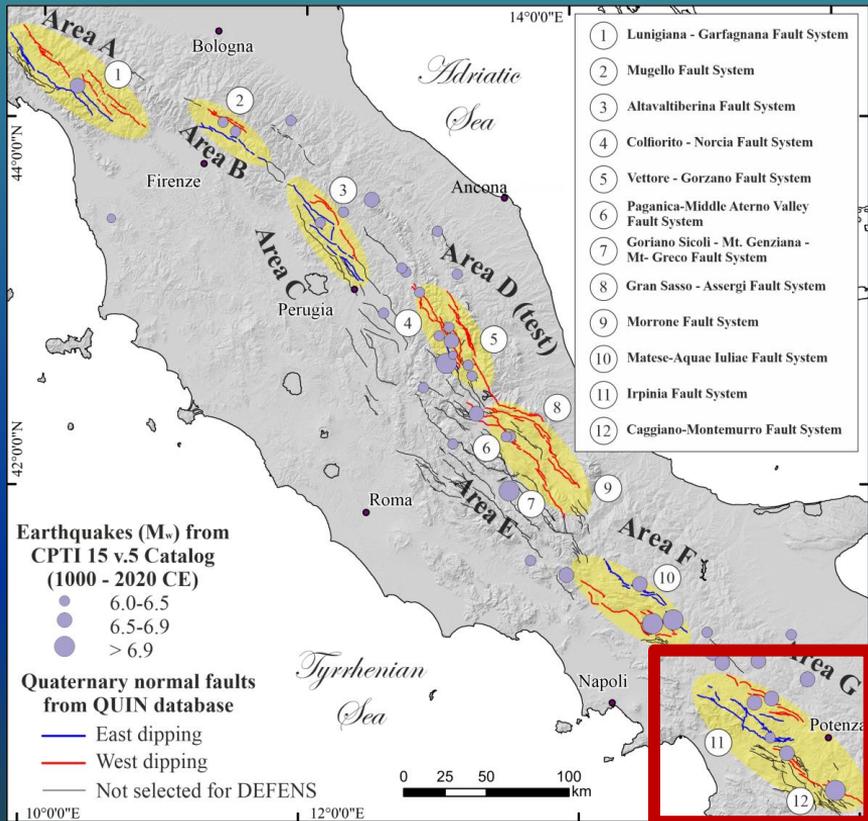
¹CRUIST-DISPUter-Università di Chieti-Pescara "G. d'Annunzio", Chieti Scalo, Italy, ²Istituto per il Rilievo Elettromagnetico dell'Ambiente-Consiglio Nazionale delle Ricerche, Naples, Italy

Three-dimensional FE modeling results.

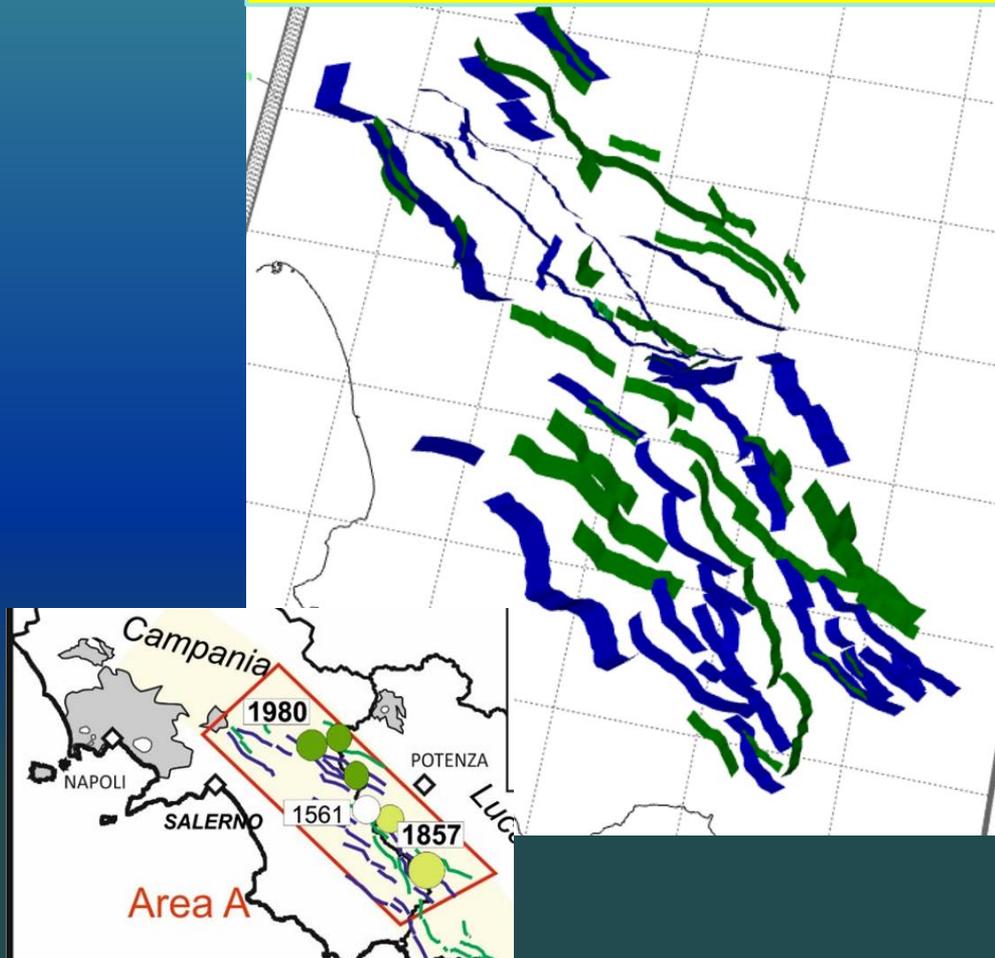




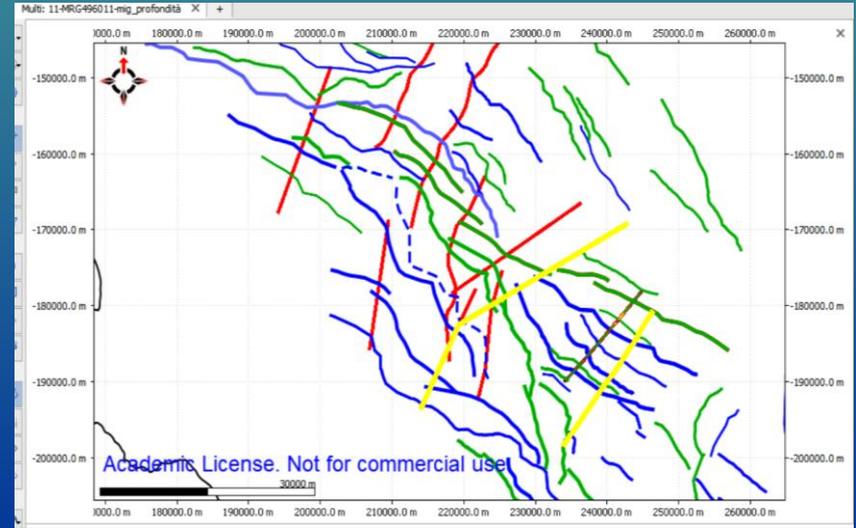
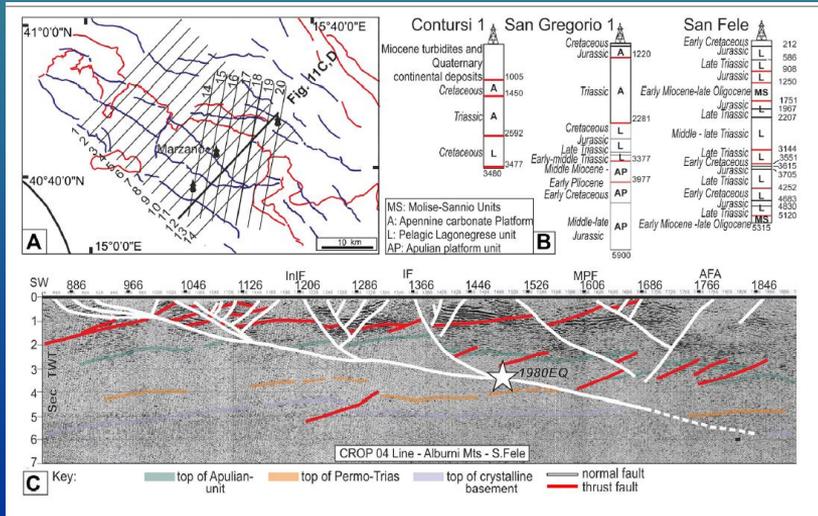
- 1- Vettore-Gorzano shallow interconnection: step-over zone or hard linkage?
- 2-What controls the localization of maximum surface coseismic slip at the same position during the 24 August and 30 October 2016 Central Italy earthquakes, despite hypocenters being more than 10 km apart? Persistent shallow slip patches may reflect inheritance of a structurally controlled rupture corridor.
- 3-Decoupling between rupture nucleation and persistent shallow slip localization may be controlled by intersection with the Sibillini thrust at a few kilometers depth?



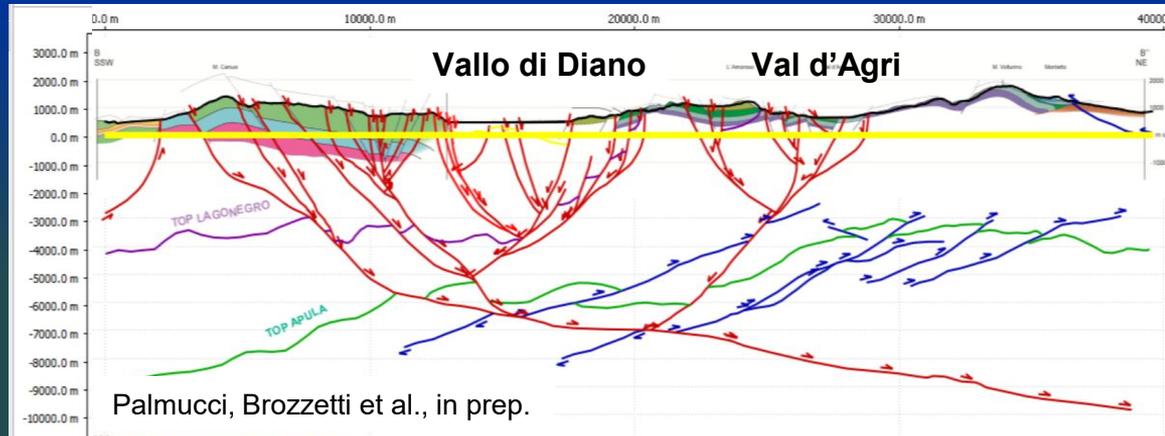
Irpinia-Vallo di Diano-Val d'Agri «Ribbon» PILOT database



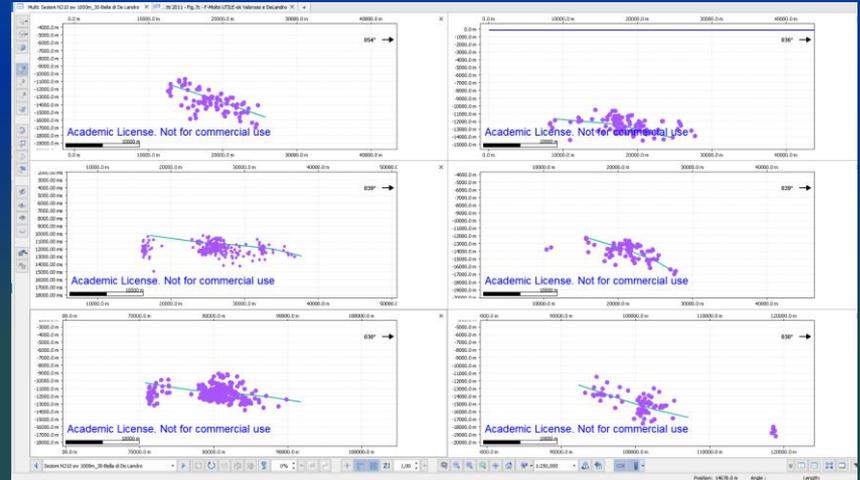
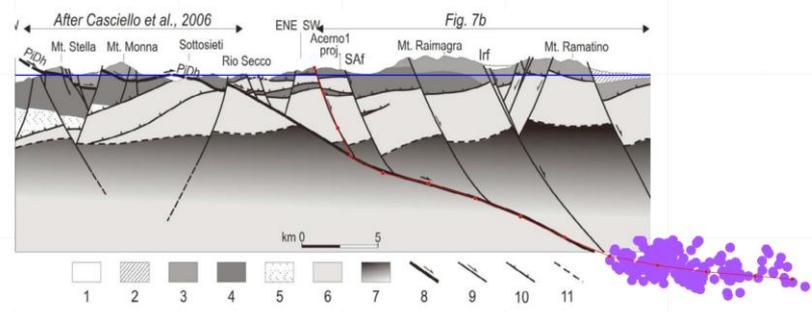
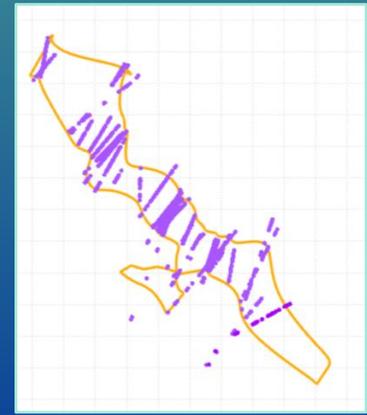
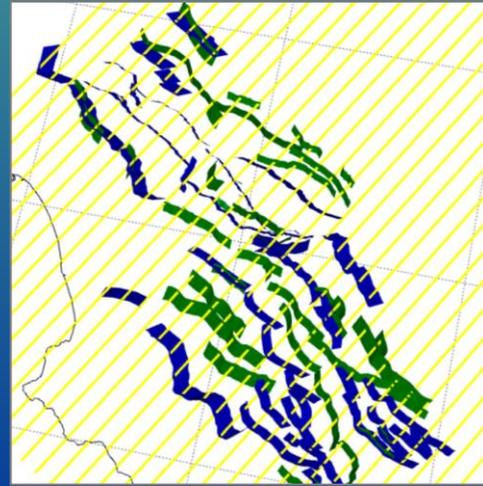
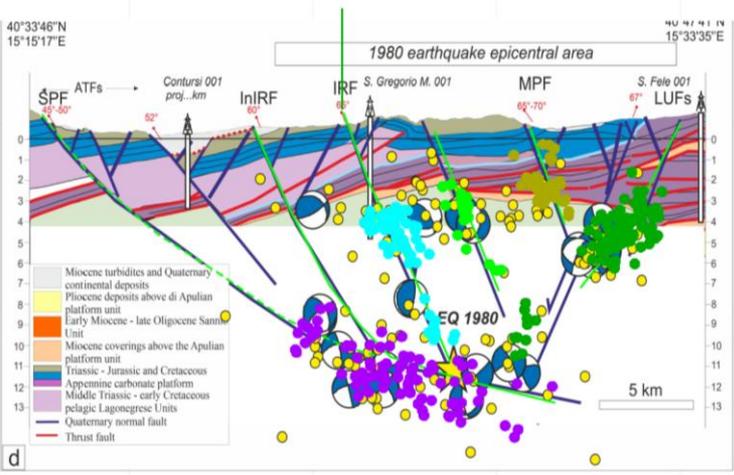
The choice of the deformation style



CROP 04 (Bello et al., 2021)

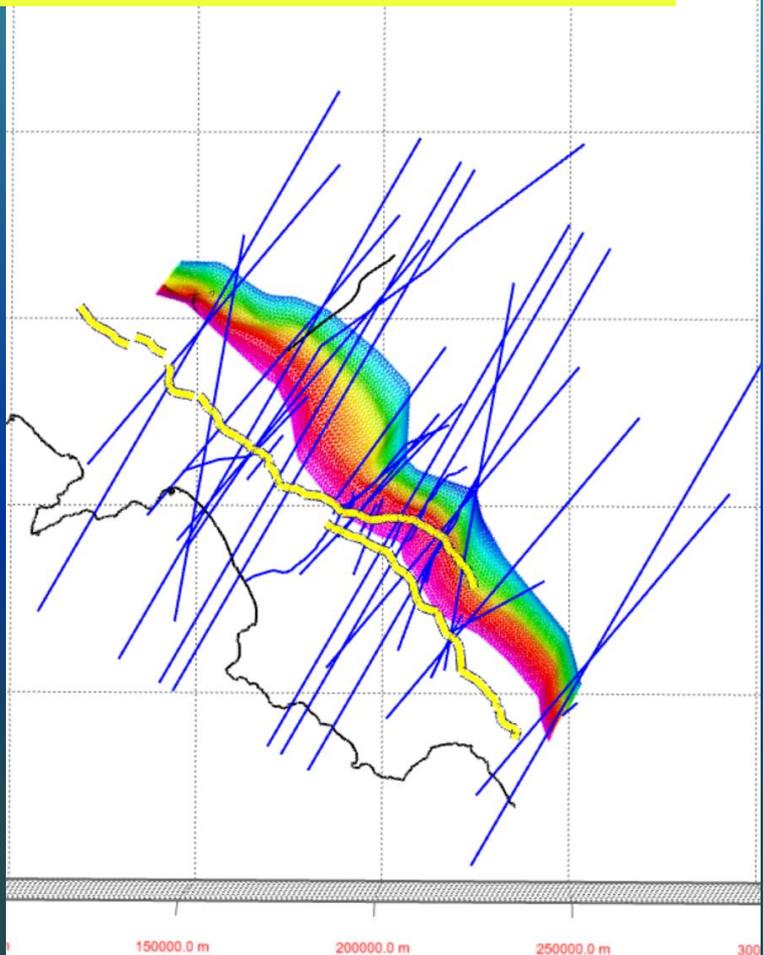
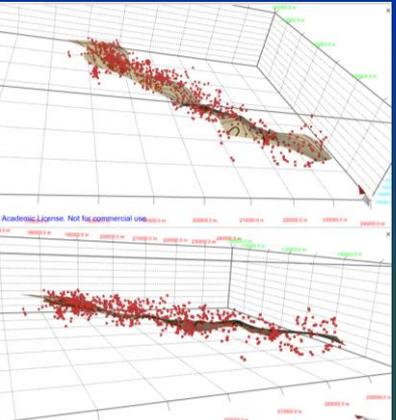
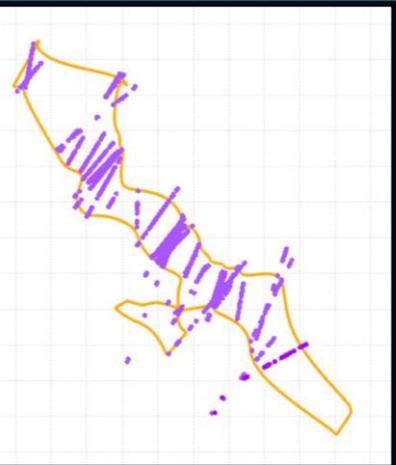


Palmucci, Brozzetti et al., in prep.

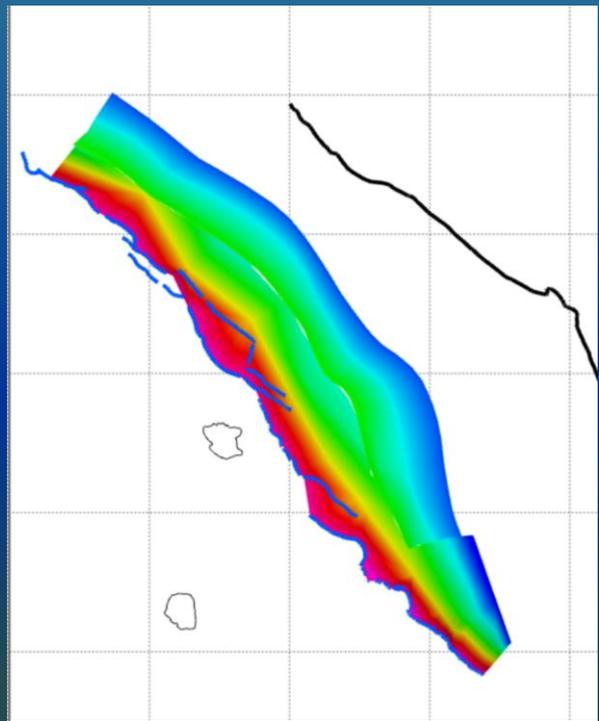


ISNET Dataset Camanni, De Landro et al., 2023

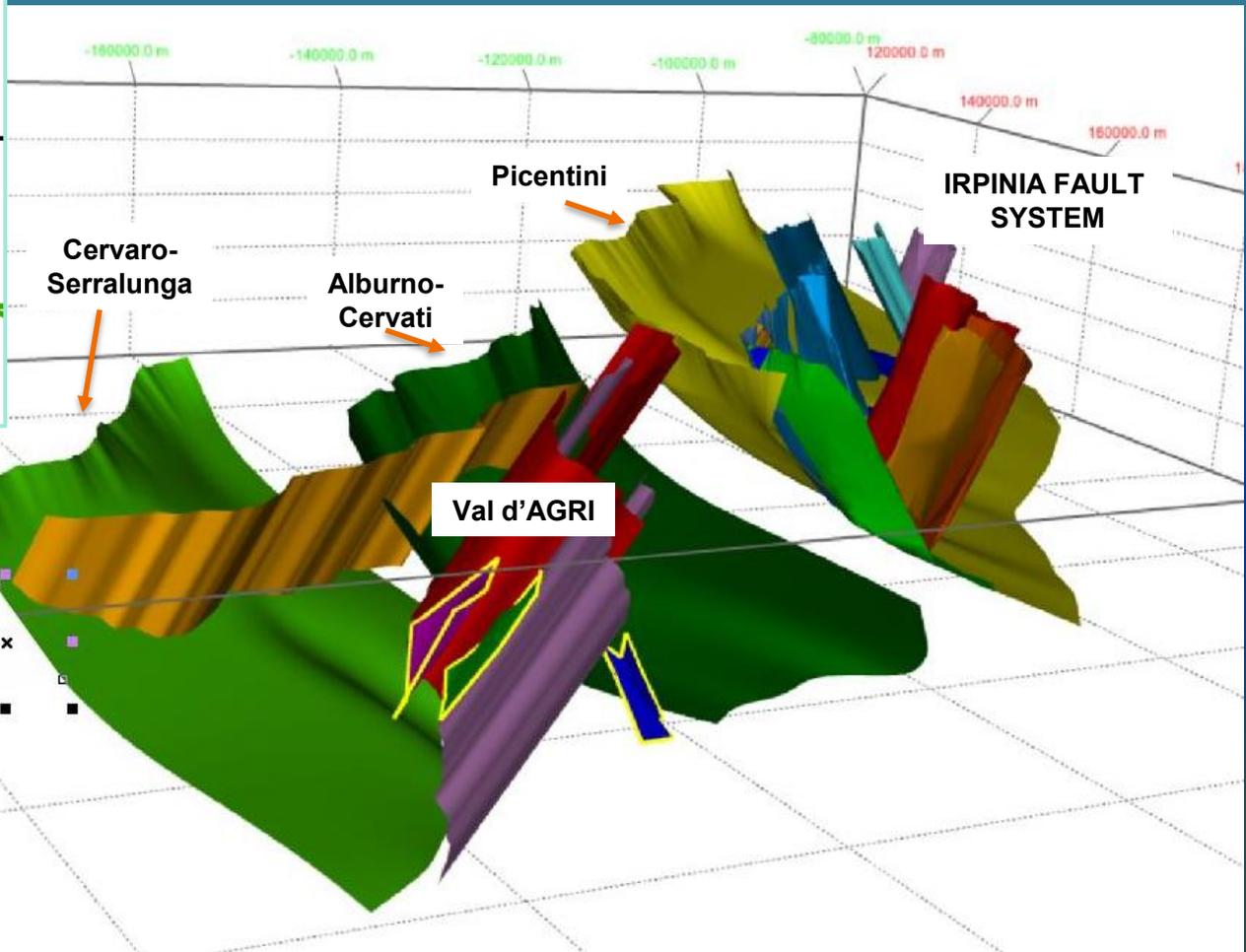
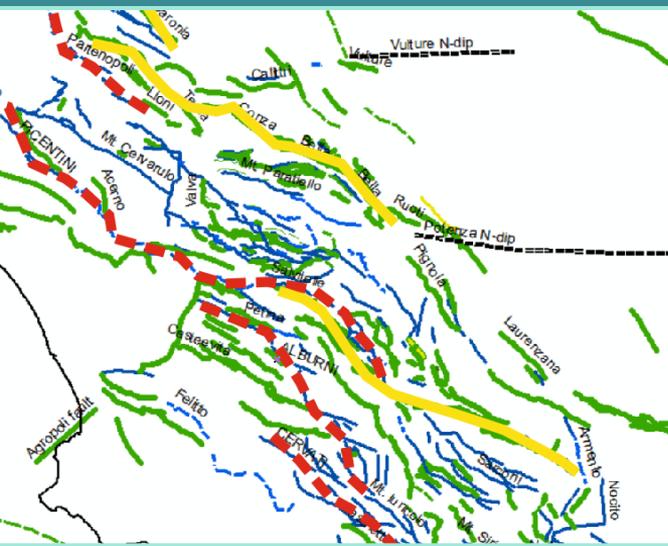
Picentini-Melandro Pergola Alburno-Cervati east-dip basal detachment



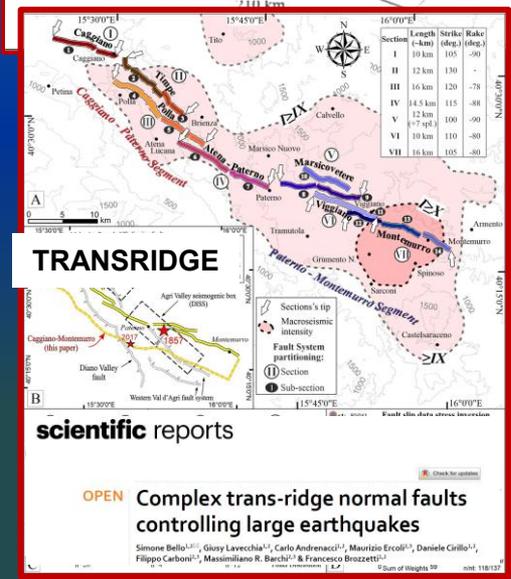
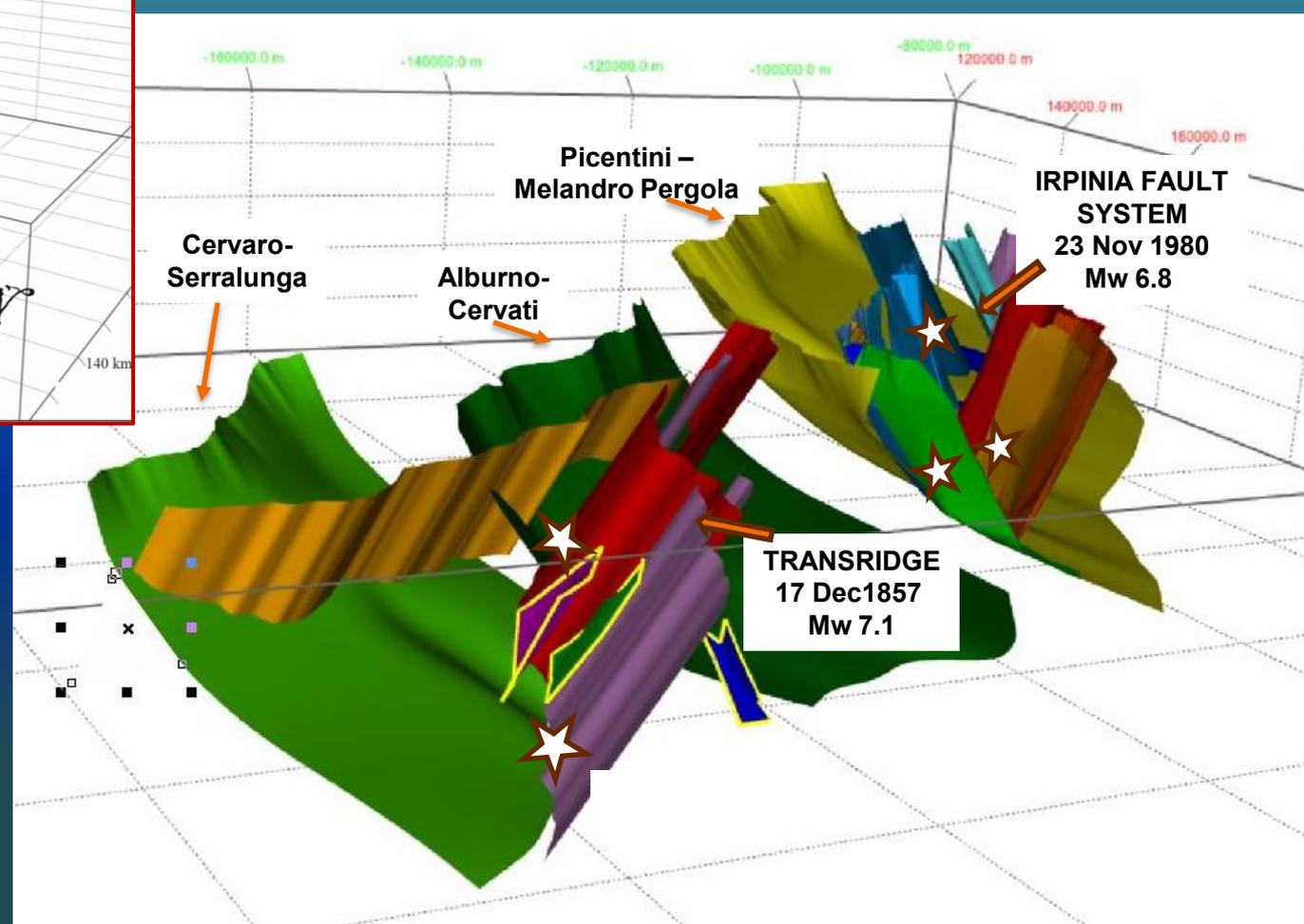
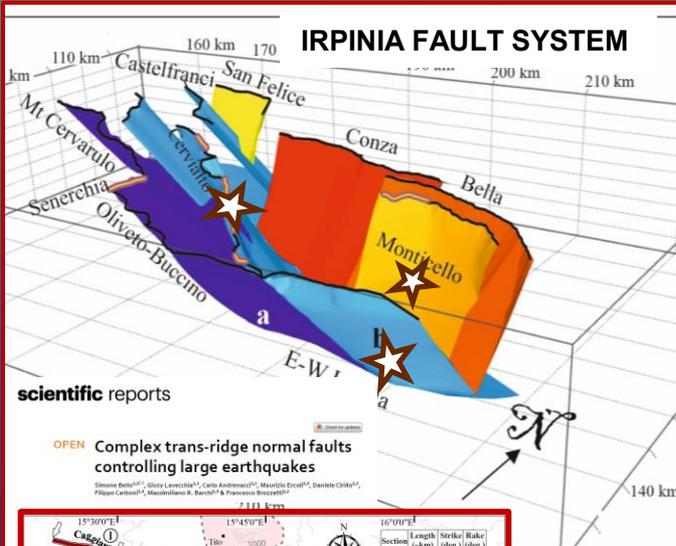
Altavaltiberina- Bastardo – Spoleto-Leonessa east-dip basal detachment



Irpinia, Vallo di Diano and Val d'Agri 3D fault model



Irpinia, Vallo di Diano and Val d'Agri 3D fault model



Take-home message

- Data are fundamental and indispensable: the more data you have, the more robust your interpretations become. Data do not speak by themselves, but insight grows through careful and repeated analysis.
- Build your own structural style vision: expert judgment cannot be replaced.
- Think multi-scale: only continuity across scales gives geological meaning.
- Inherit the past, but go beyond it with your own questions.
- Be intellectually independent: listen, but do not be led.
- Doubt fuels understanding; rigor gives it strength.
- Work hard. Time devoted to research is never wasted.

Final recommendations for seismotectonists

- Interdisciplinarity is not optional. Seismotectonics cannot be done in isolation.
- A structural geologist is not required to locate earthquakes, but must be able to critically analyze seismic data, fully aware that data quality, resolution, and uncertainties control interpretation.
- Likewise, a geophysicist does not need to master structural mapping, but must understand the geological meaning, assumptions, and limits of structural models.
- Remaining rooted in your own discipline is essential, but fluency in the language, constraints, and data logic of adjacent fields is what enables robust interpretation