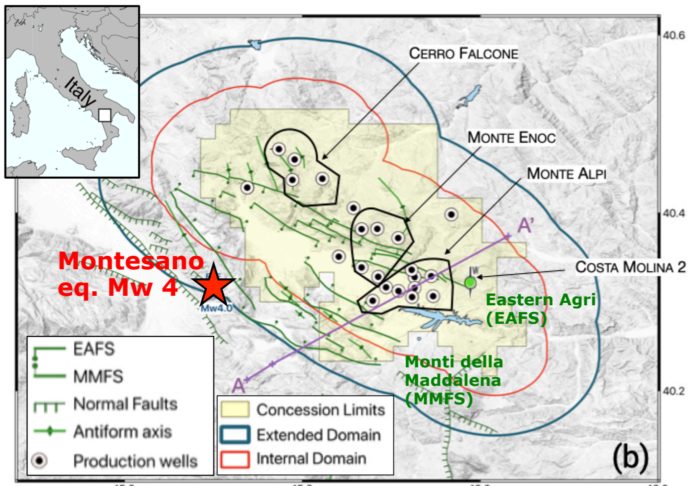
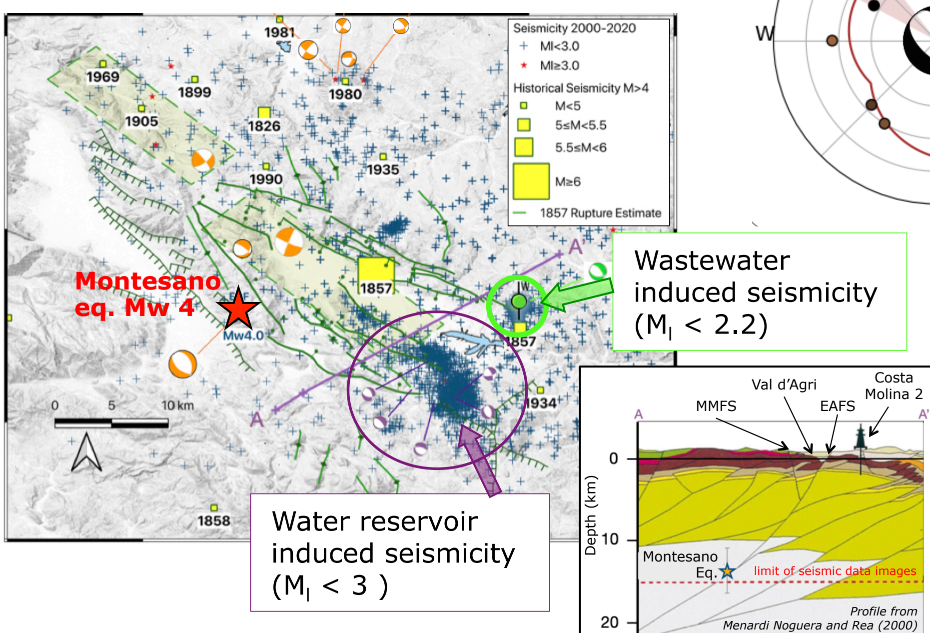
Deciphering the source parameters and genesis of the 2017, Mw 4 Montesano earthquake close to the Val d'Agri oilfield (Italy)

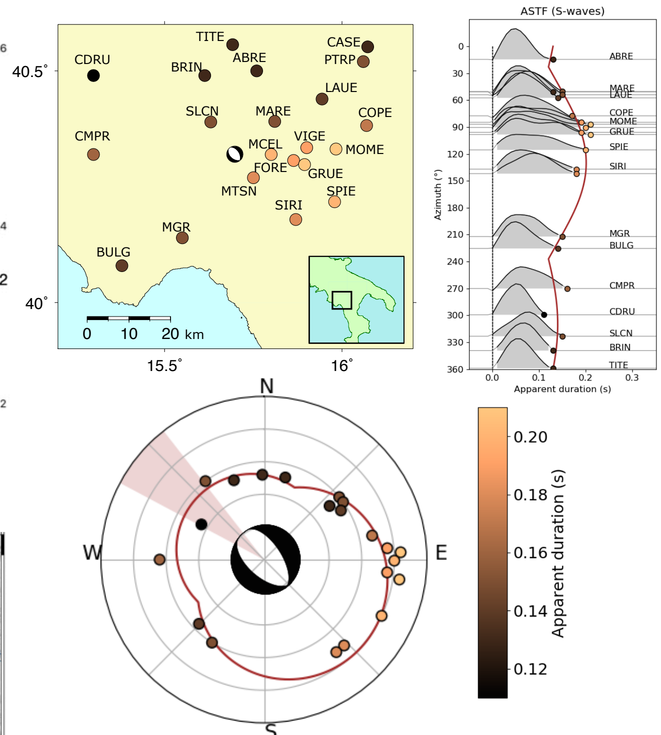
J. A. López-Comino, T. Braun, T. Dahm, S. Cesca & S. Danesi

Val d'Agri oilfield & Mw 4 Montesano eq.



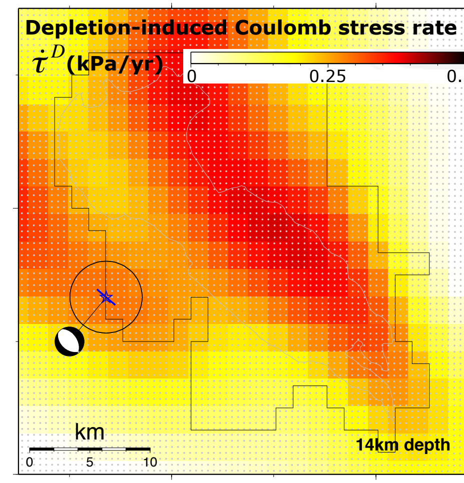


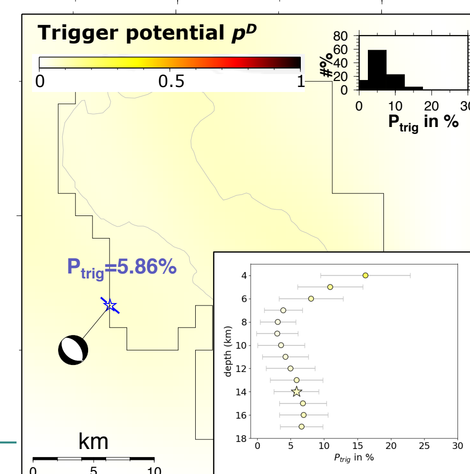
Directivity analysis



- Asymmetric bilateral rupture (70 % in N310°W).
- Apparent durations (0.11 - 0.21 s)
- Rupture length ~ 0.3 km.

Probabilistic discrimination (natural, triggered or induced)





Conclusions

- Montesano earthquake activated a deeper fault segment associated to the East Agri Fault Systems.
- Our results suggests a natural cause due to the local tectonic stress.

López-Comino et al., (2021), Frontiers

Deciphering the source parameters and genesis of the 2017, Mw 4 Montesano earthquake close to the Val d'Agri oilfield (Italy)

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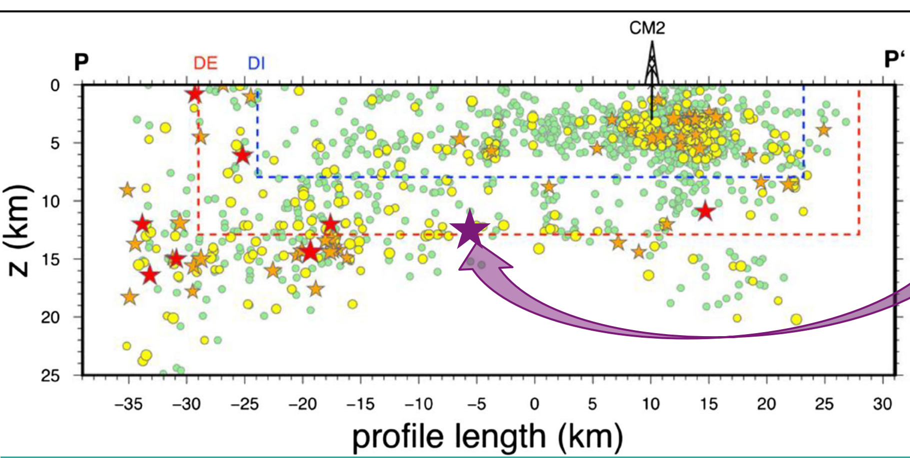
Motivation

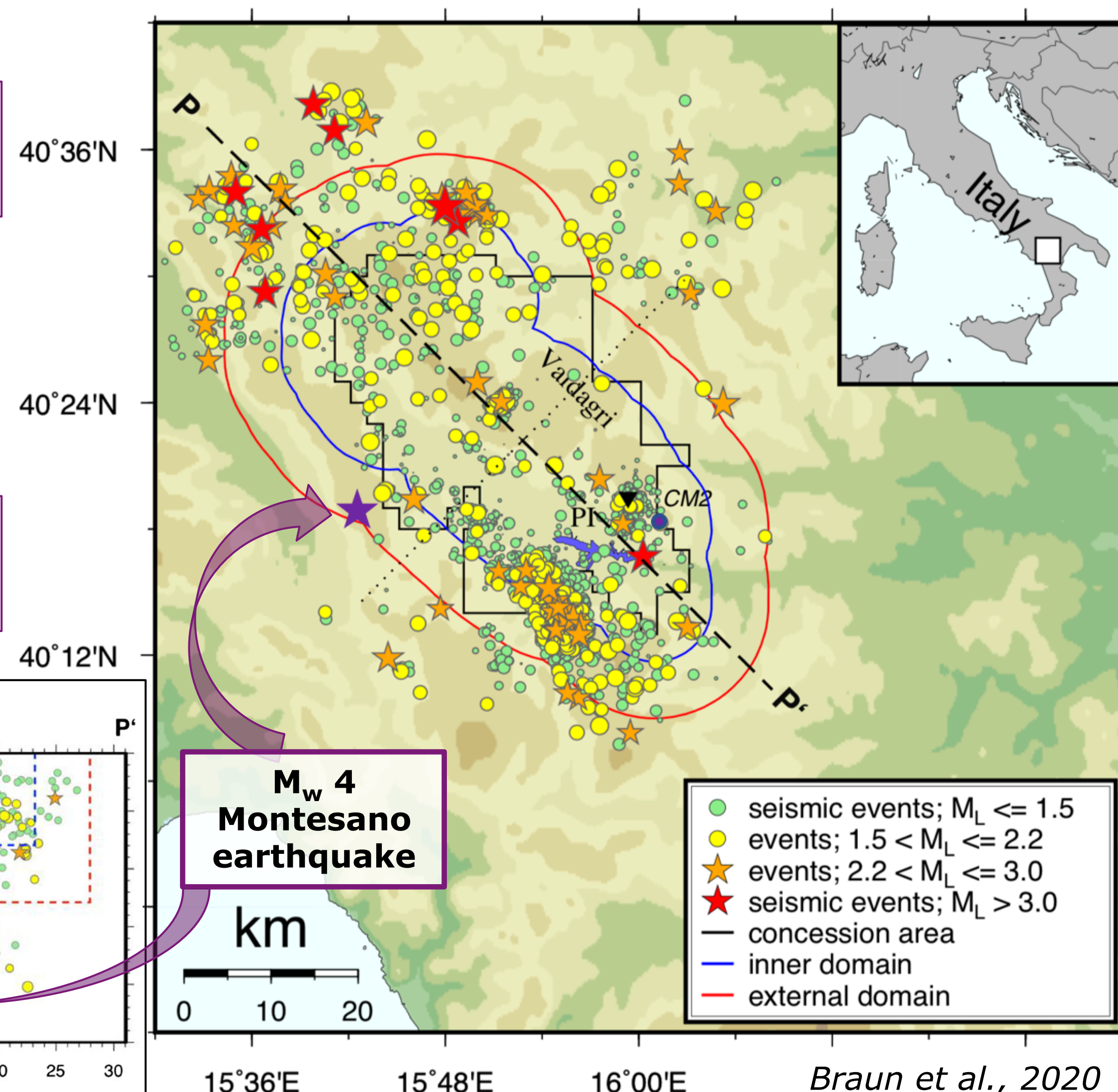
- Val d'Agri (VA) oilfield: largest European on-shore hydrocarbon reservoir.
- Our target: largest event in the last 20 years inside the Extended Domain (DE) of the VA oilfield.

October 27th, 2017,
Mw 4 Montesano earthquake

Natural, triggered or induced event ?

Discrimination analysis to decipher the origin





M_w 4 Montesano earthquake

Braun et al., 2020

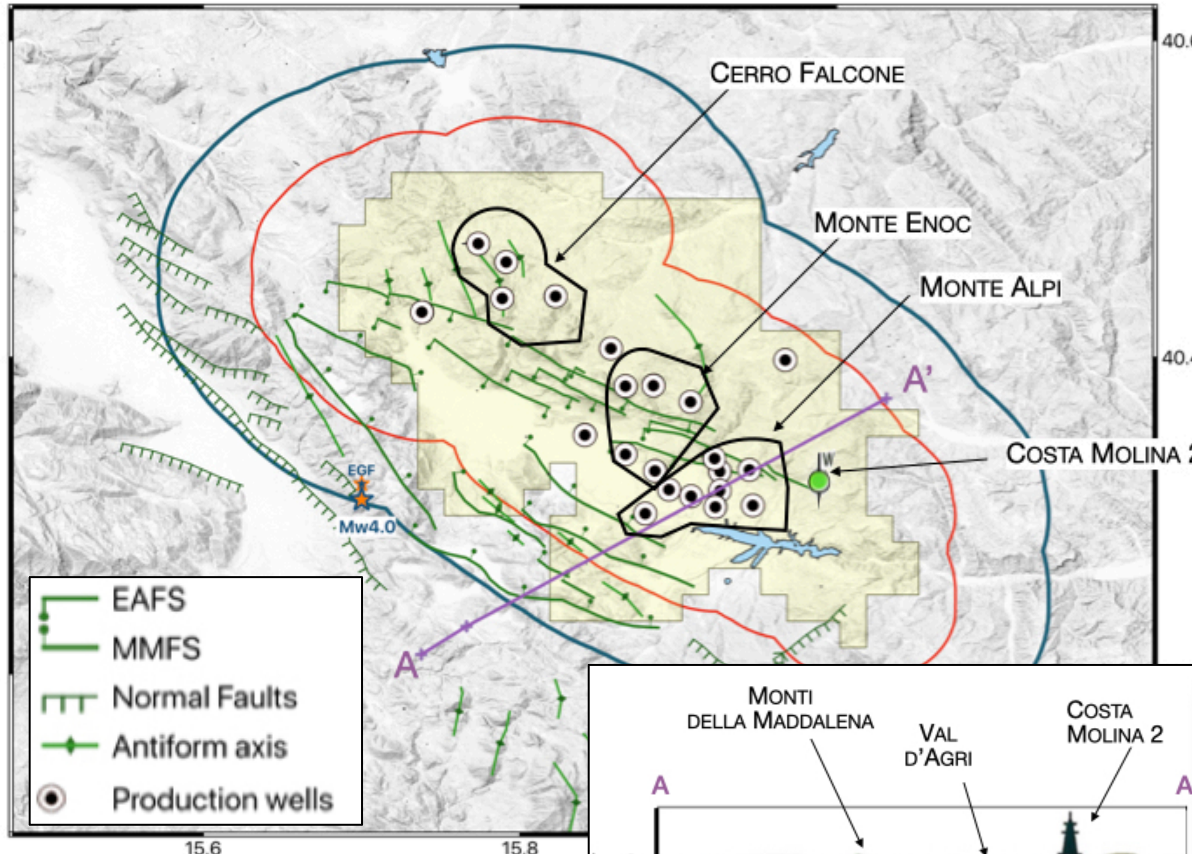
Val d’Agri oilfield

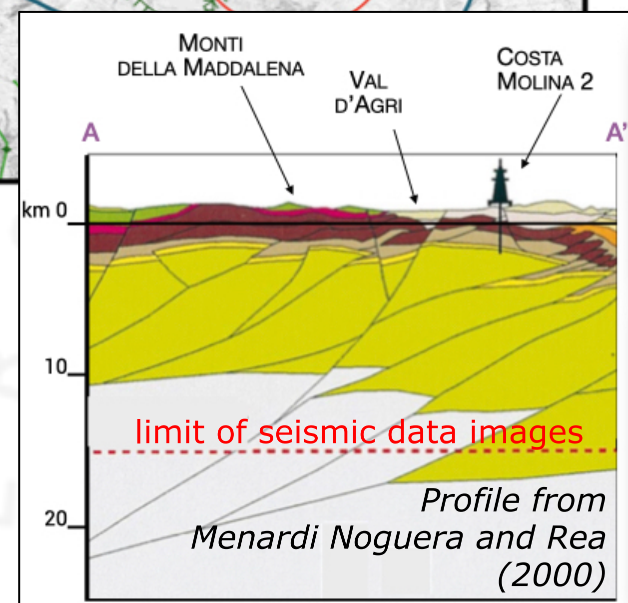
- Tectonics:

NE - SW extension accommodated by two main fault system:

- Monti della Maddalena (MMFS) on the SW edge, dipping to the NE.
- Eastern Agri (EAFS) on the NE edge, dipping to the SW.

Normal-faulting earthquakes

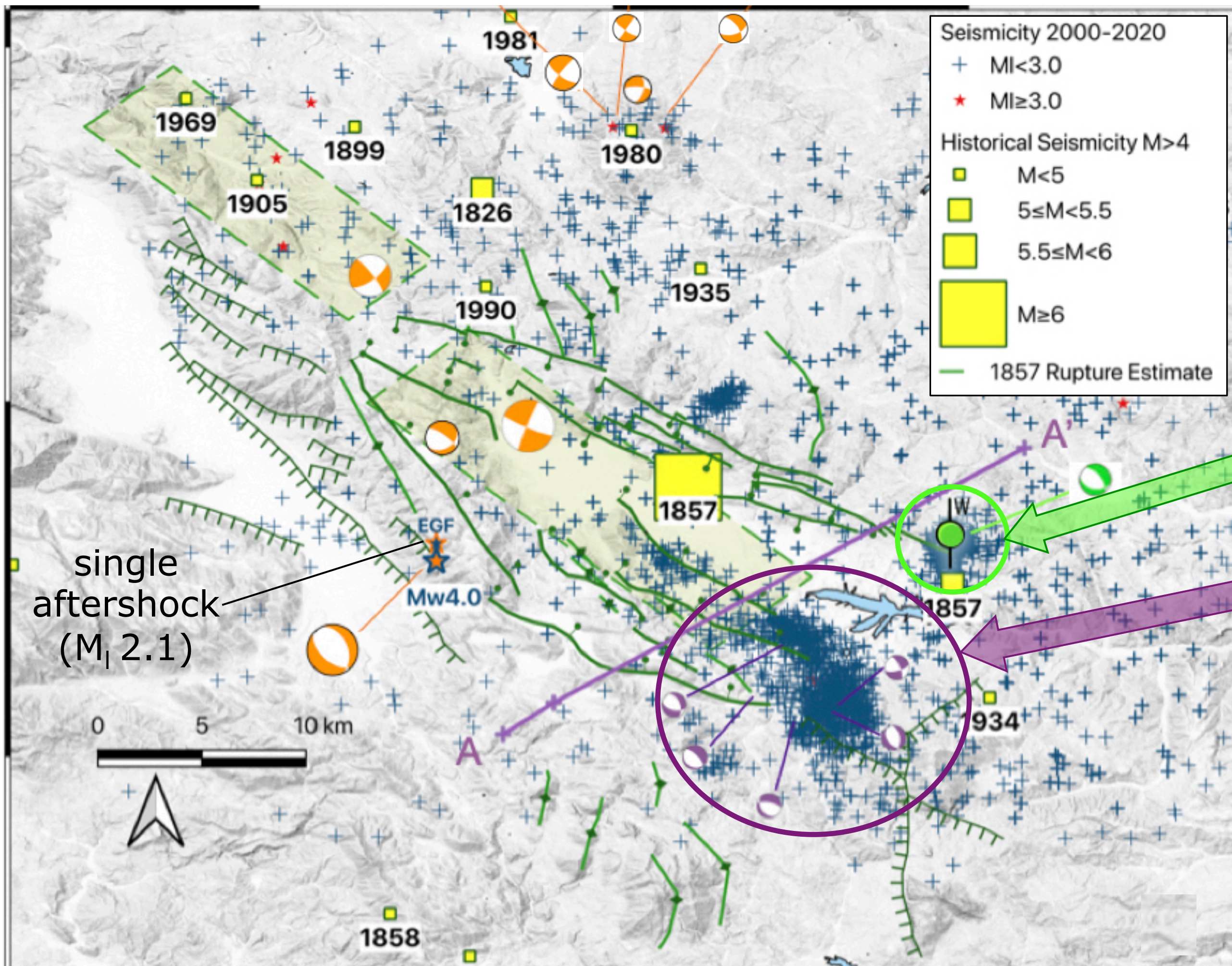




- Hydrocarbon exploitation started in 1996; full production in 2010.
- 24 production wells from 1.8 to 3.5 km depth.
- Costa Molina 2 (CM2): Wastewater disposal well in 2006, injection point at 3 km depth.

Val d'Agri oilfield: seismicity

- Since 1990, only few seismic events with $M_w > 3$ (*Cucci et al., 2004*).
- Most destructive earthquake: 1857, M_w 7 (event source still under debate).
- Two significant induced seismic clusters:



Wastewater induced seismicity linked to the CM2 in June 2006 (*Improta et al., 2015*)

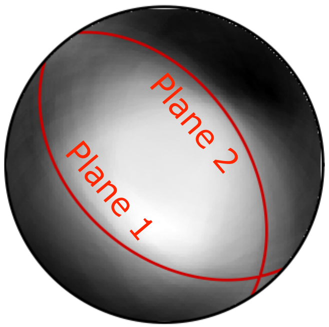
- Depth range: 1.5 -5.5 km
- $M_l < 2.2$

Water reservoir induced seismicity linked to the artificial Pertusillo lake. (*Valeroso et al., 2009*)

- Depth range:1 -5 km
- $M_l < 3$

Moment tensor inversion

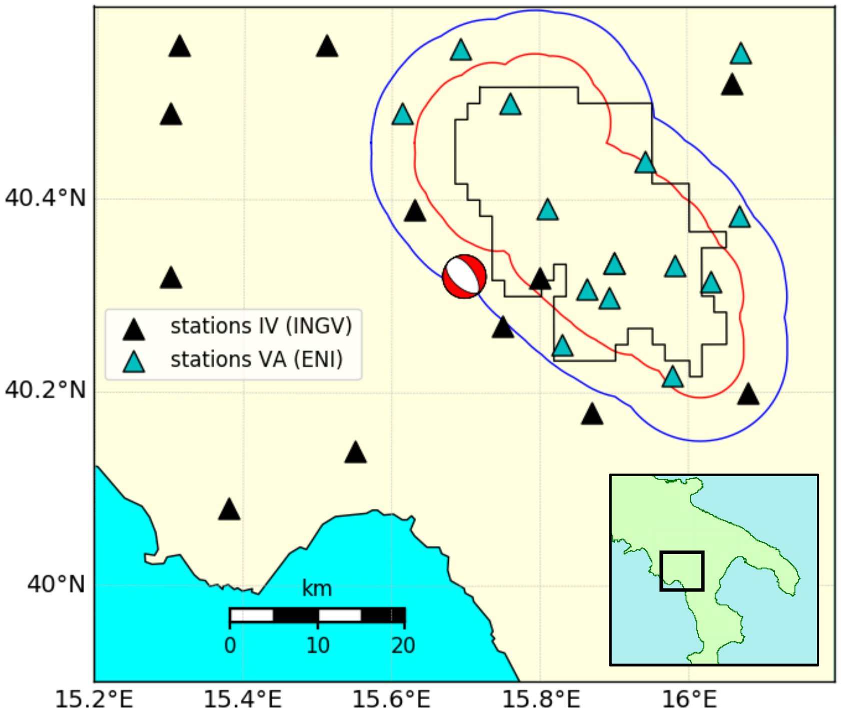
- GROND (*Heiman et al., 2018*)

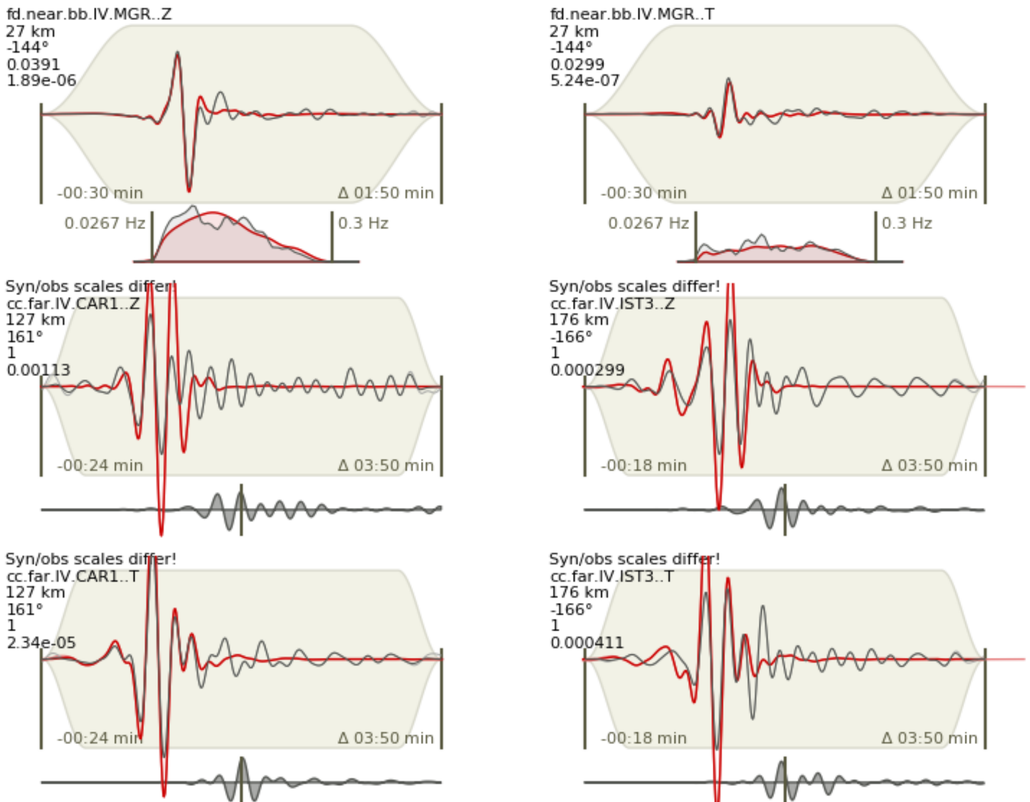


NW-SE oriented normal faulting

$M_w = 4.0 \pm 0.2$

depth = 14 ± 2.8 km





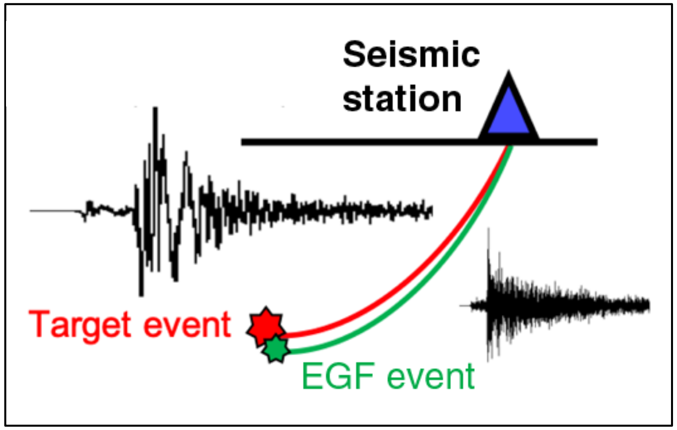
	Plane 1 dipping SW	Plane 2 dipping NE
Strike (°)	131	327
Dip (°)	43	48
Rake (°)	-102	-79

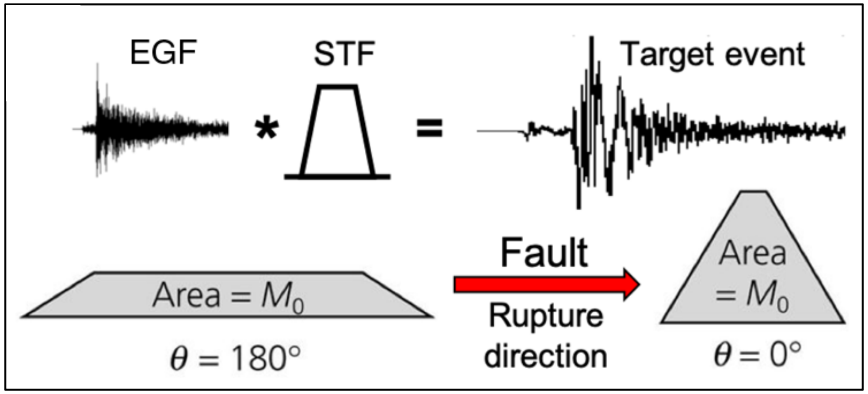
Plane dipping to SW or NE ?

Directivity analysis

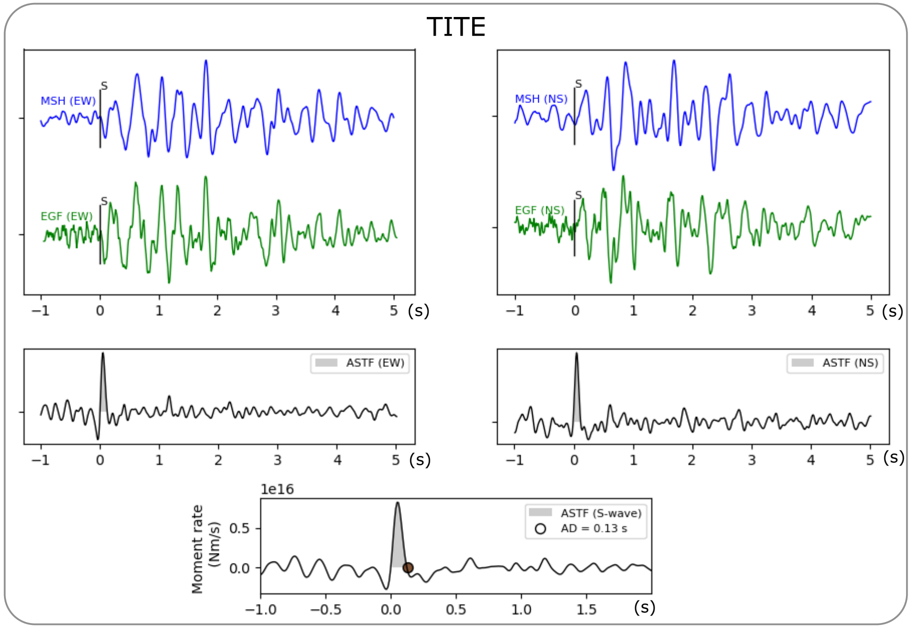
- Empirical Green's Function (EGF) technique to obtain:

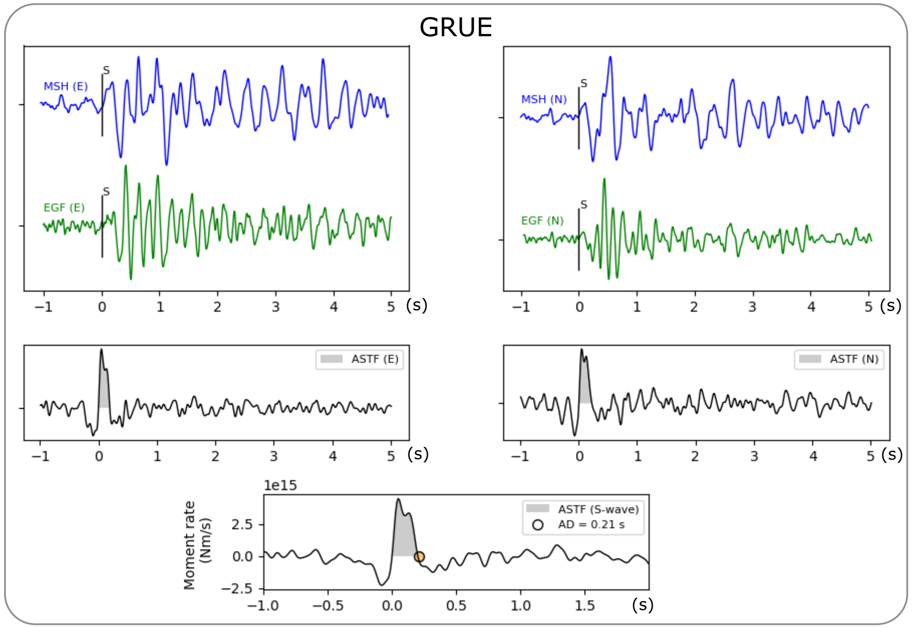
Apparent Source Time Functions (ASTFs) using S-wave windows from the horizontal components.





Figures from Lui & Huang, 2019, BSSA





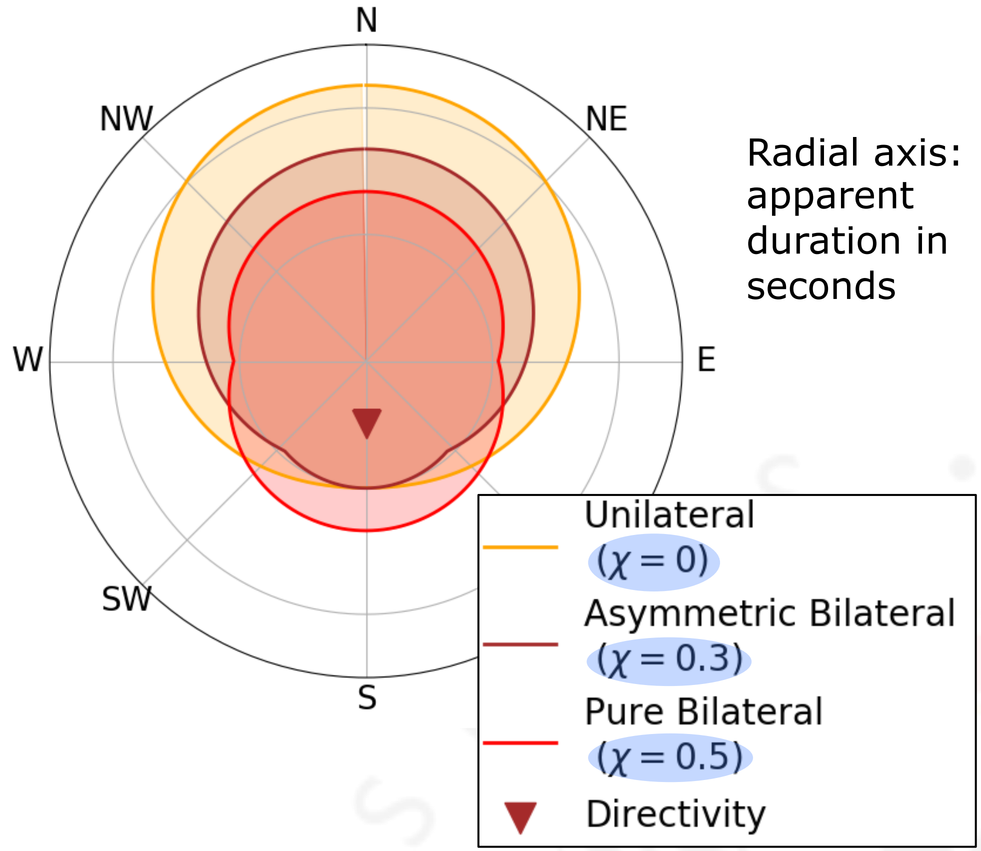
Directivity analysis

$\tau(\phi)$ = Apparent duration as a function of the azimuth (ϕ)

- Unilateral ruptures

$$\tau(\phi) = t_R + \frac{L}{v_r} - \frac{L}{v_{P,S}} \cos(\phi - \alpha)$$

t_R = Rise time
L = Rupture length
v_r = Rupture velocity
a = Azimuth of rupture directivity
$V_{P,S}$ = P or S wave velocity



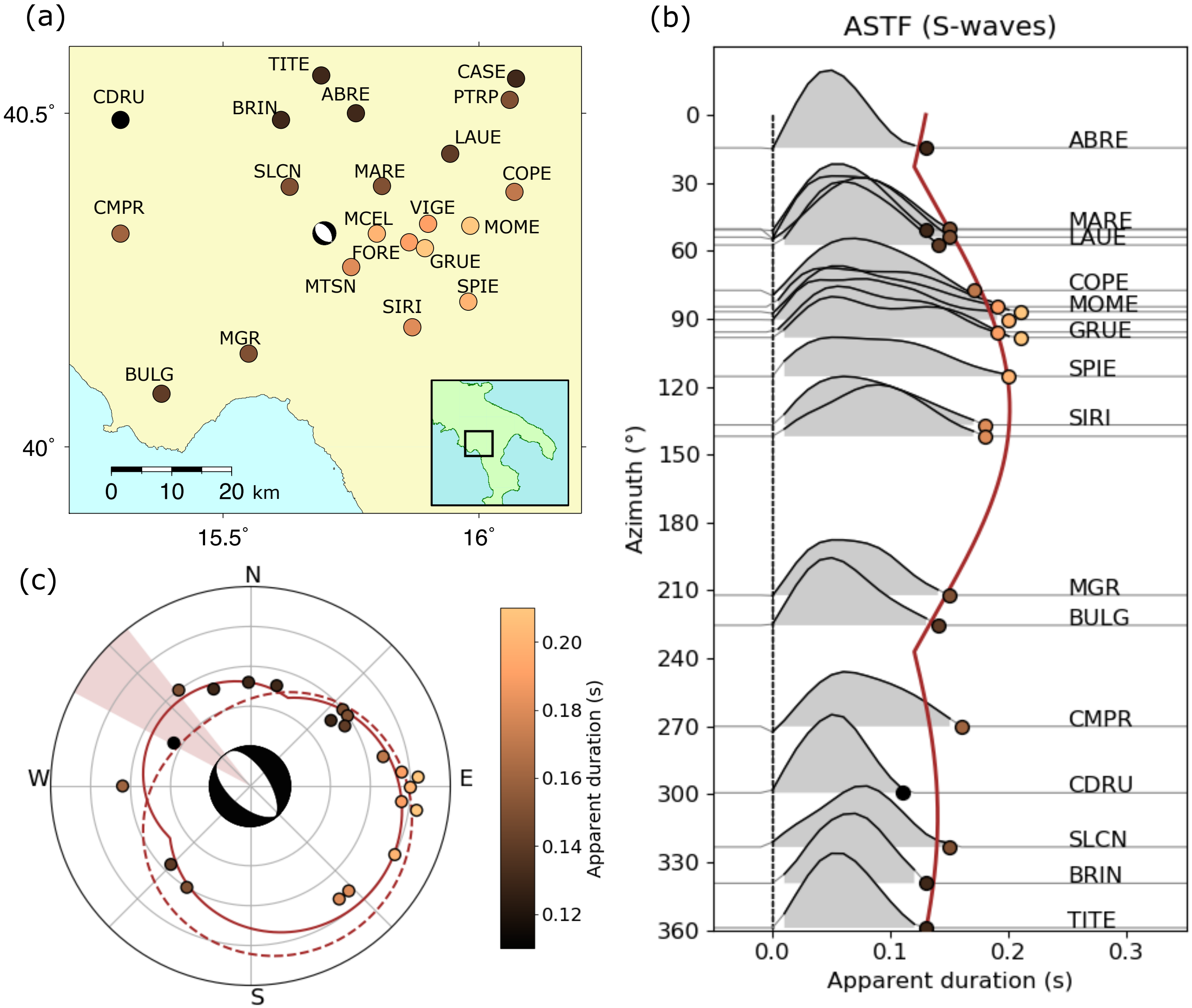
Radial axis: apparent duration in seconds

- Asymmetric bilateral ruptures

$$\tau(\phi) = \max\left[t_R + (1-\chi)\left(\frac{L}{v_r} - \frac{L}{v_{P,S}} \cos(\phi - \alpha) \right), t_R + \chi\left(\frac{L}{v_r} + \frac{L}{v_{P,S}} \cos(\phi - \alpha) \right) \right]$$

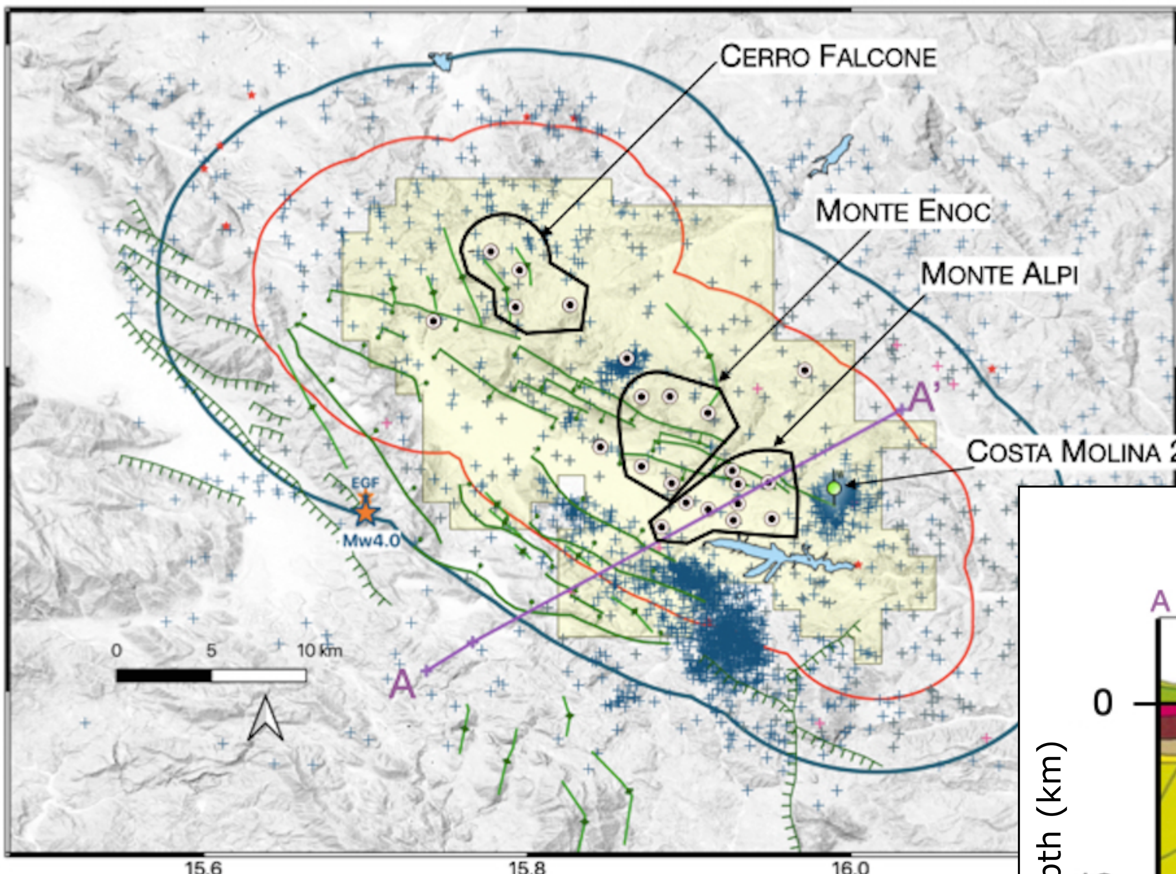
Directivity analysis

- Asymmetric bilateral rupture (70 % in N310°W).
- Apparent durations from 0.11 to 0.21 s ; Rupture length ~ 0.3 km.

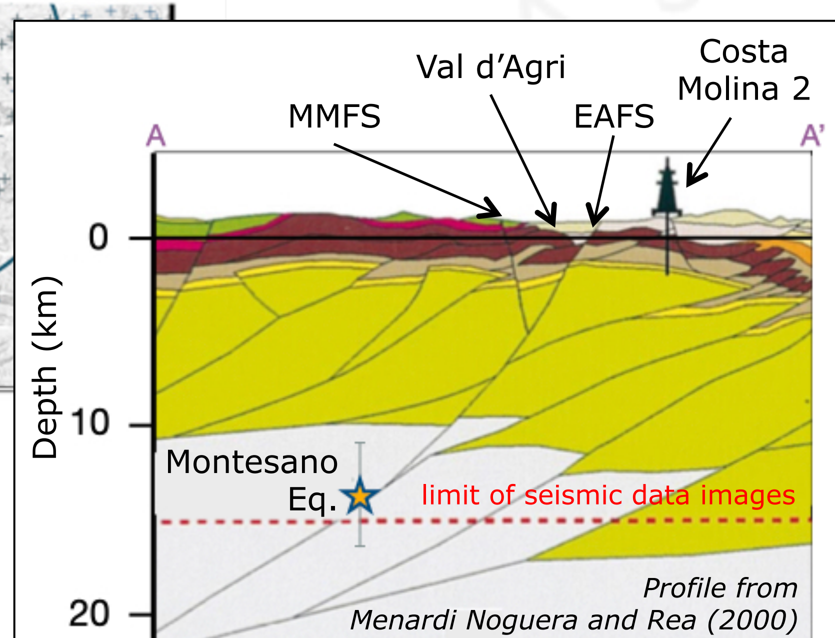


Fault identification

- These results identify a deeper fault segment associated to the East Agri Fault Systems.



East Agri Fault Systems (EAFS)
Monti della Maddalena Fault Systems (MMFS)



Probabilistic discrimination analysis

- Discrimination problem between natural, triggered or induced event.

p^D Trigger potential: probability to be triggered by the stressing rate induced from the depletion of the oil field (*Dahm et al., 2015*).

$$p^D = \frac{H(\dot{\tau}^D)\dot{\tau}^D}{H(\dot{\tau}^D)\dot{\tau}^D + \dot{\tau}^T}$$

$\dot{\tau}^T$ Tectonic stress rate: from the background seismicity.

$$\dot{\tau}^T = 10^{a+9.1} \frac{b}{1.5-b} \frac{10^{(1.5-b)M_{\max}}}{AD}$$

A = area of the seismogenic zone (8354 km^2)
D = seismogenic width (10 km)
M_{max} = 7.06

$\dot{\tau}^T$ ~ 2.3 kPa/yr (a = 1.95; b = 0.557; *Iervolino et al., 2011*)
~ 6.1 kPa/yr (a = 2.72; b = 0.72; *Convertito et al, 2009*)

*Note: $\dot{\tau}^T$ ~ 0.7 kPa/yr in the regions of Emilia and Aquila earthquakes.

$\dot{\tau}^D$ Depletion-induced Coulomb stress rate: from the long-term hydrocarbon extraction.

Probabilistic discrimination analysis

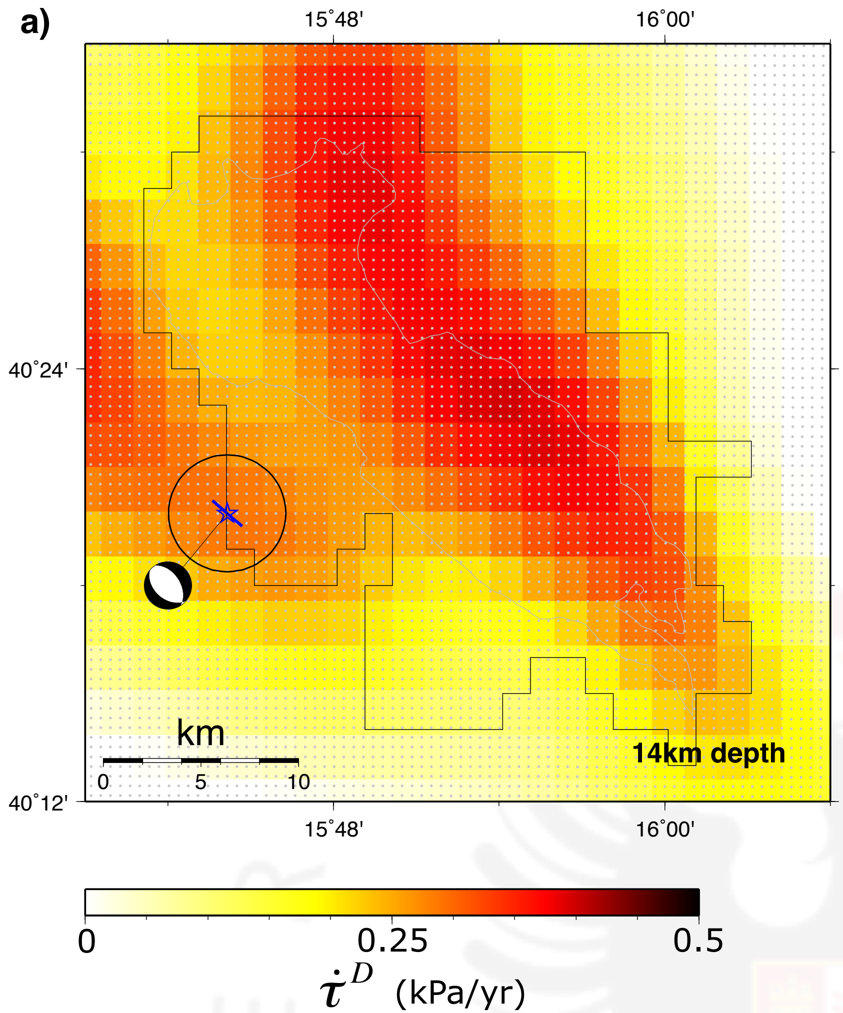
$\dot{\tau}^D$ Depletion-induced Coulomb stress rate: from the long-term hydrocarbon extraction.

A significant pressure depletion started at the end of 2001 and the pore pressure continuously decreased until the end of the simulation period in 2017.

We assume a pressure drop on the range between 4.5 – 18 Mpa through 16 years over the whole field.

Other parameters:

- Fault geometry of plane 1
- Reservoir thickness = 800 m
- Biot constant = 0.1
- Poisson ratio = 0.25
- Friction coefficient = 0.6



$\dot{\tau}^D$ ~ 0.25 kPa/yr at 14 km depth

Probabilistic discrimination analysis

p^D Trigger potential: probability to be triggered by the stressing rate induced from the depletion of the oil field (*Dahm et al., 2015*).

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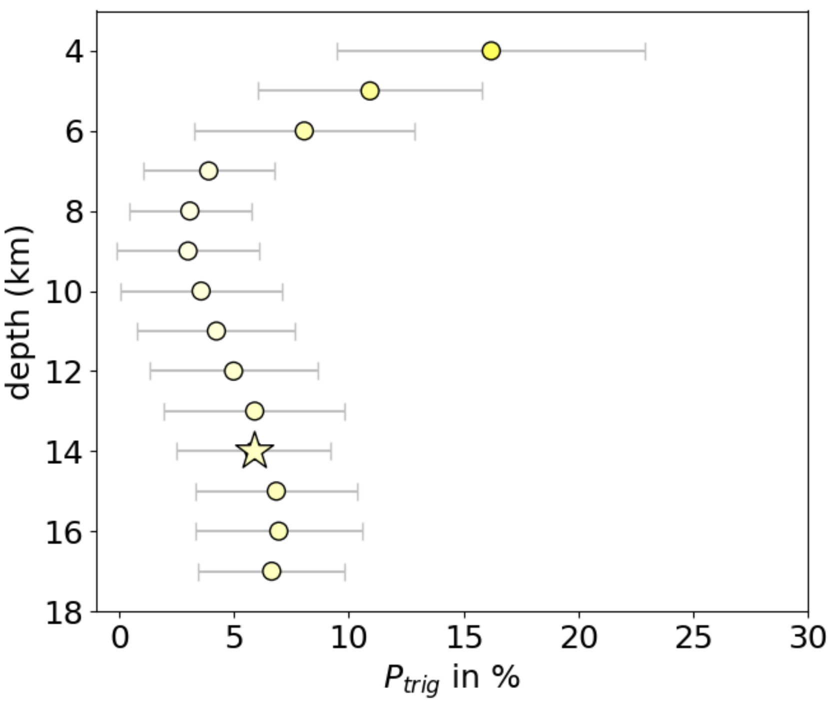

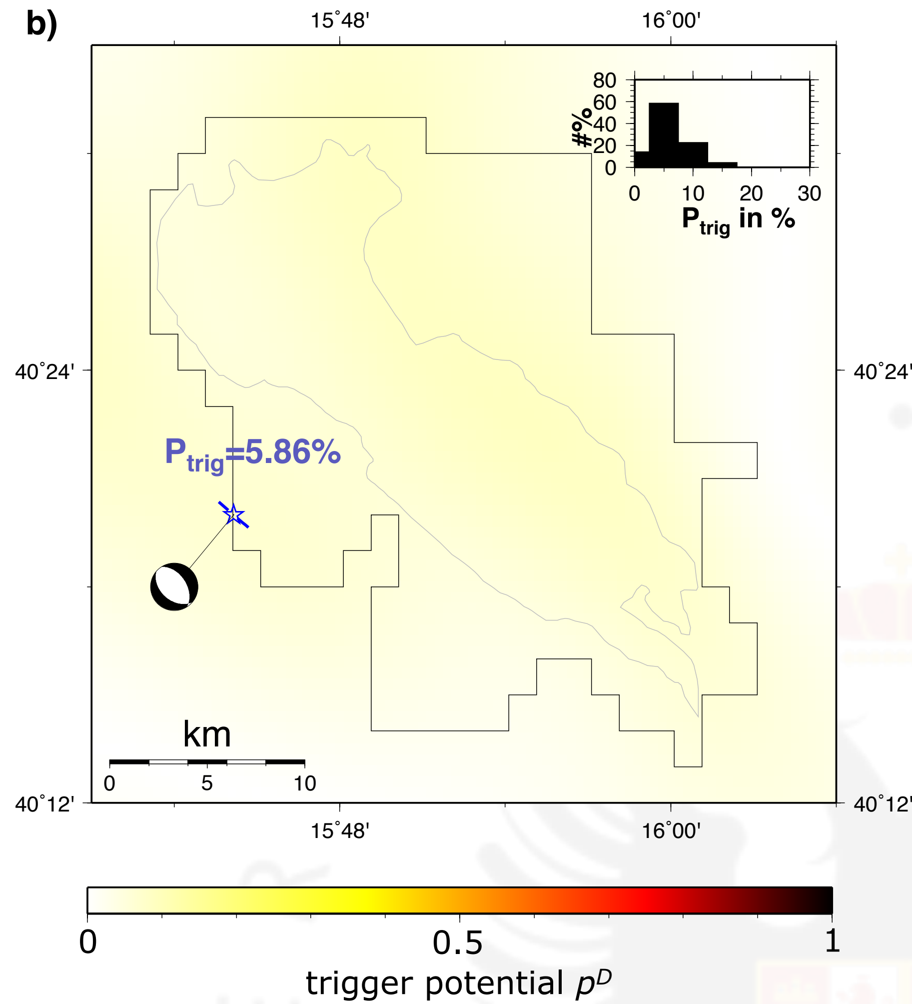

Conclusions

A detailed seismological procedure is described to discriminate between natural, triggered or induced earthquakes in the VA oilfield, which should be also applied together with the previous traffic light system protocols.

We analyze the source parameters of the Mw 4 Montesano earthquake, revealing an asymmetric bilateral rupture with the 70 % of the rupture propagation in N310°W.

Our results conclude that the Montesano earthquake activated a deeper fault segment associated to the East Agri Fault Systems.

An induced or triggered event can be discarded due to the long-term hydrocarbon extraction in the VA oilfield, which suggests a natural cause due to the local tectonic stress.

Reference

- López-Comino, J. A., Braun, T., Dahm, T., Cesca, S. and Danesi, S. (2021). On the source parameters and genesis of the 2017, Mw 4 Montesano earthquake in the outer border of the Val d'Agri oilfield (Italy), *Frontiers Earth Sci., 8:617794.*