# Pore pressure control on the thickness of the seismogenetic crust in continental extensional regimes:

## insights from recent earthquake and swarm sequences in the Apennines

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# Continental extensional regime

- Transition from localised frictional behaviour on faults to creep processes in more distributed ductile shear zones (Scholtz, 1988; Sibson, 1982) is temperature-controlled

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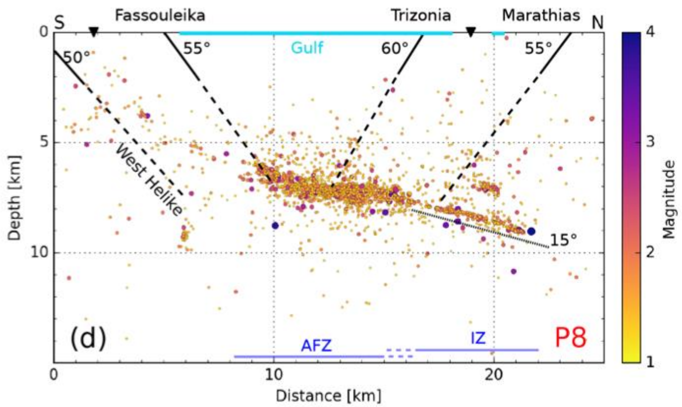
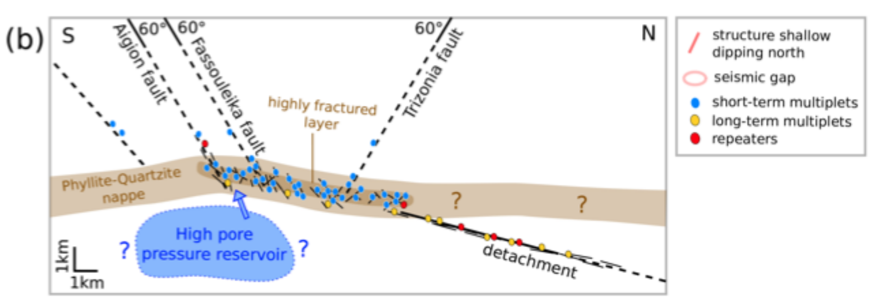
- Transition from localised frictional behaviour on faults to creep processes in more distributed ductile shear zones (Scholtz, 1988; Sibson, 1982) is temperature-controlled
- Low-dipping alignments of seismicity

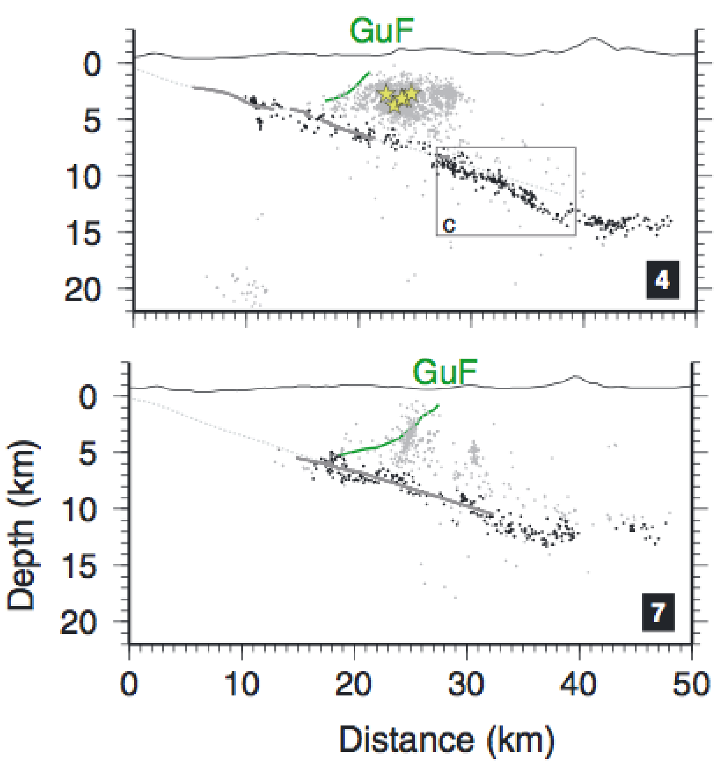
**Gulf of Corinth**




Duverger et al., GJI 2018

**Alto Tiberina Valley**

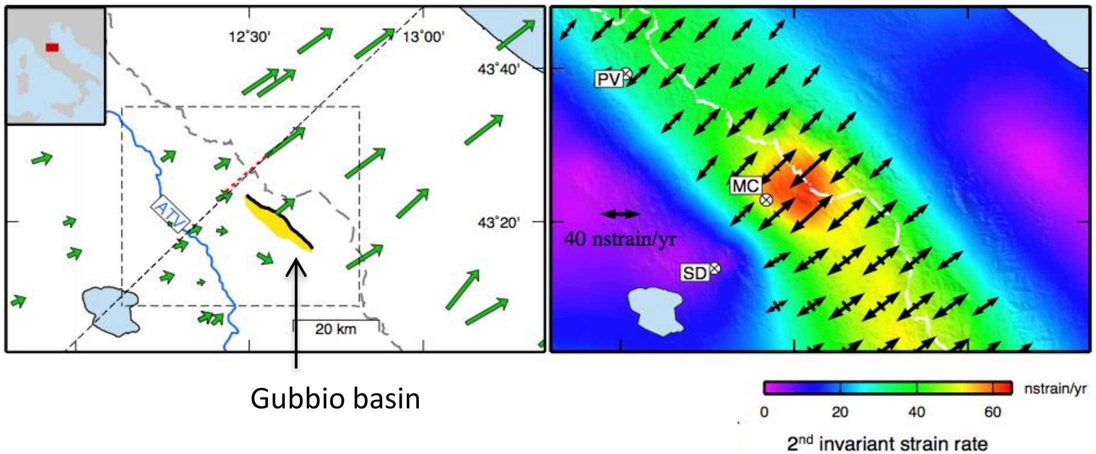


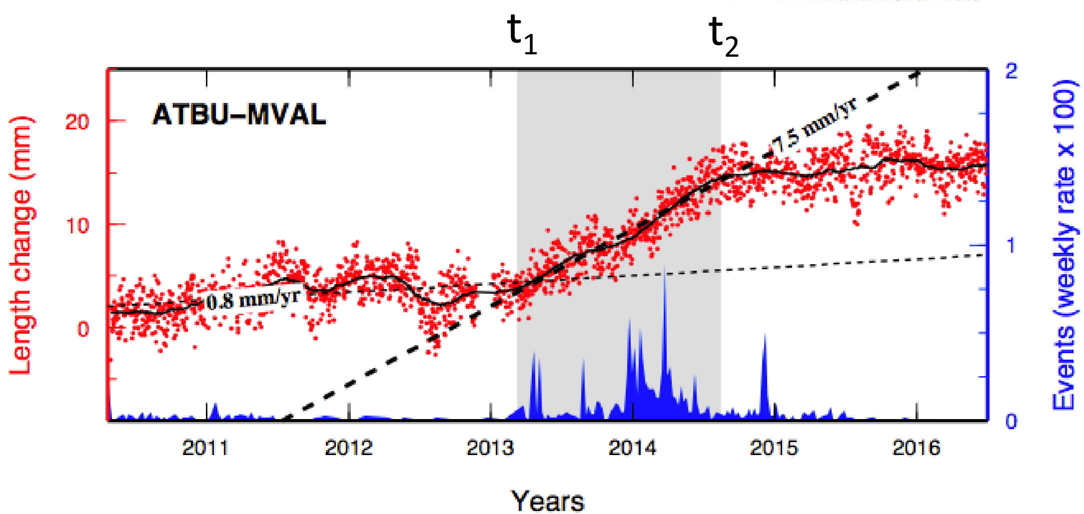

Valoroso et al., JGR 2017

# Plan of the talk

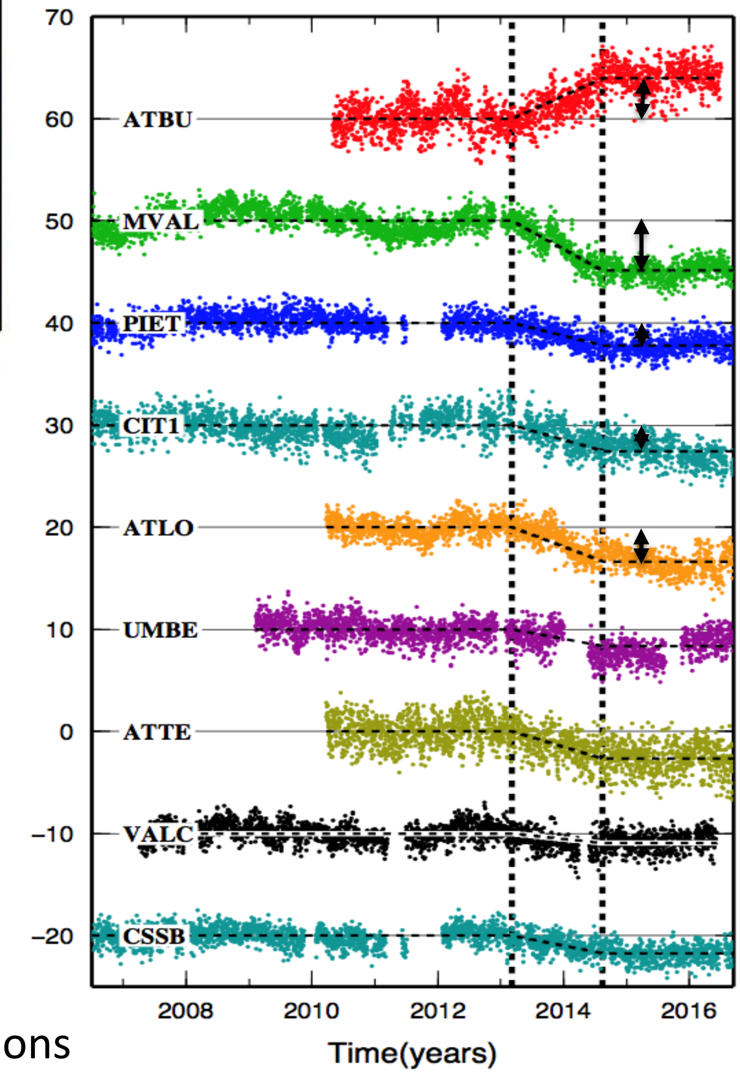
- Seismic/Aseismic slip from Amatrice-Norcia sequence (2016-2017) and Gubbio swarm (2013-2014)
- Role of distinct stratigraphic horizons and permeability boundaries to control depth of frictional localized slip (seismic/aseismic)
- Modelling of interseismic deformation (relation with seismicity distribution, fluid overpressures)

# 2013-2014 Gubbio swarm



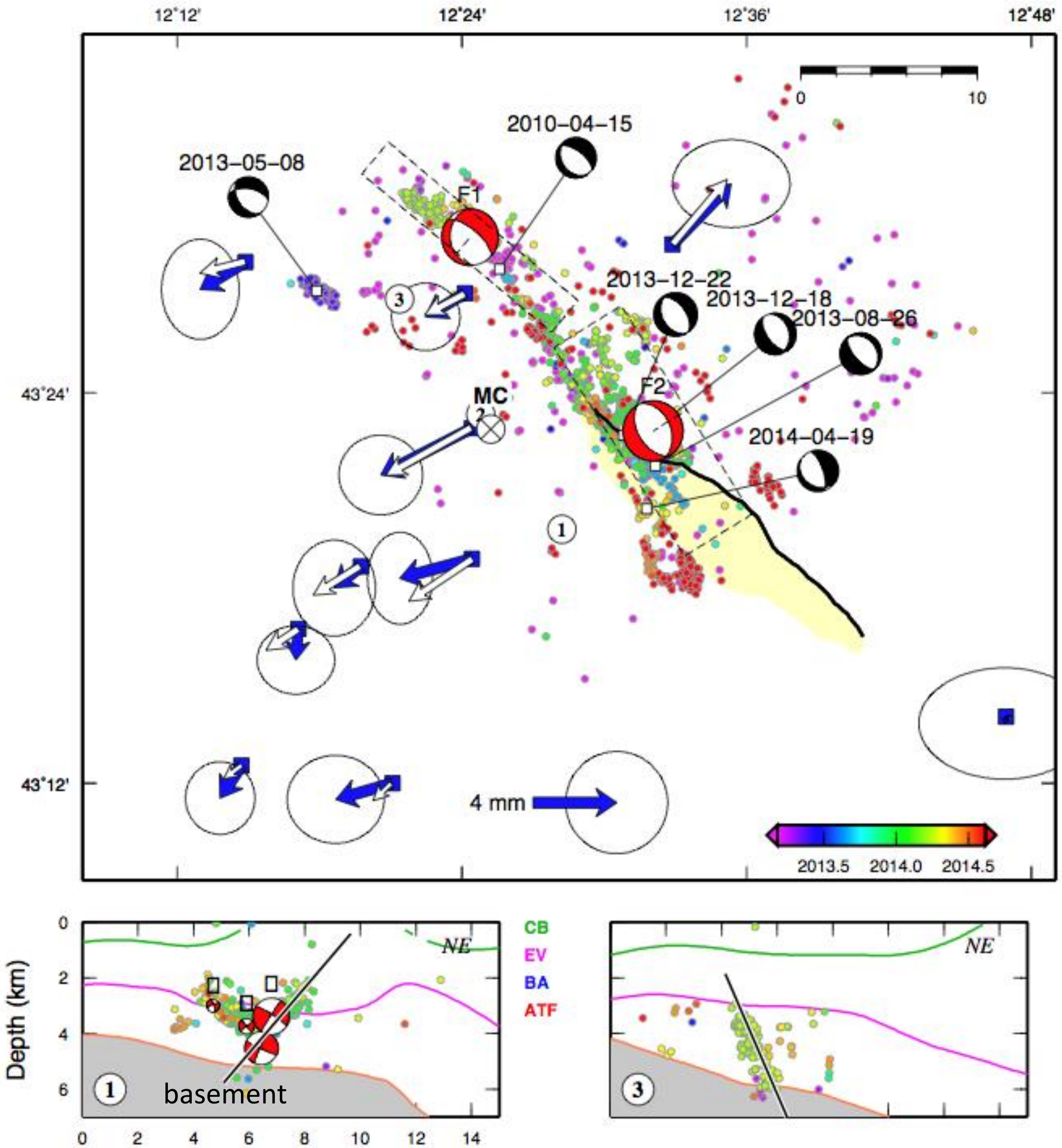




GPS offsets during the swarm



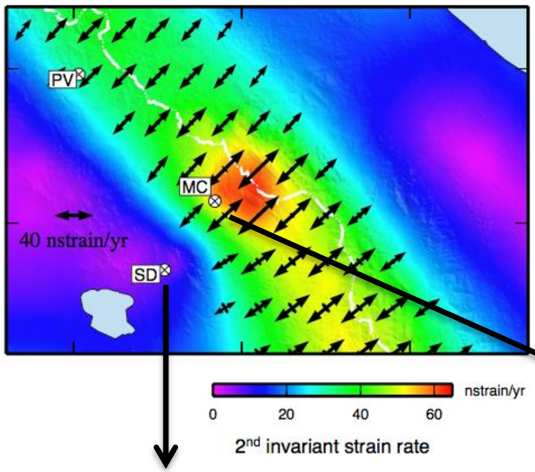

- Time evolution of displacement = ramp funtion
- t1 , $t_2$ simultaneously inverted from all the GPS stations

# 2013-2014 Gubbio swarm

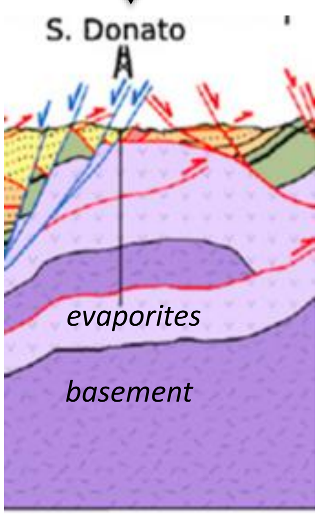



- Transient deformation modelled with two dislocations (read beachballs) aligned with seismicity
- Released seismic/geodetic moment ~25%
- Slipping faults confined above basement/evaporites boundary

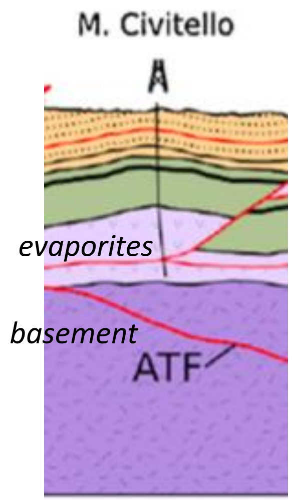
# Fluid overpressures in the Northern Apennines




- Good coverage of seismic reflection lines and deep boreholes
- Large deep $CO_2$ release (Chiodini et al., 2004)
- Basement(phyllites)/evaporites boundary as a regionally-important permeability boundary?
- High overpressure controlled by basement phylites ?

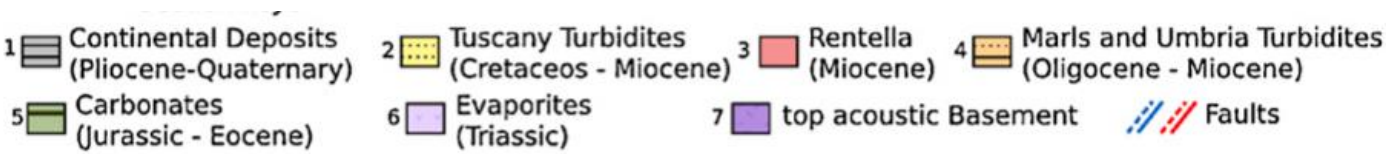



- At borehole's bottom (4800 m) $CO_2$ $P_f$ = 99 MPa ($\lambda$ = 0.85)
- Within evaporite beneath basement thrust sheet

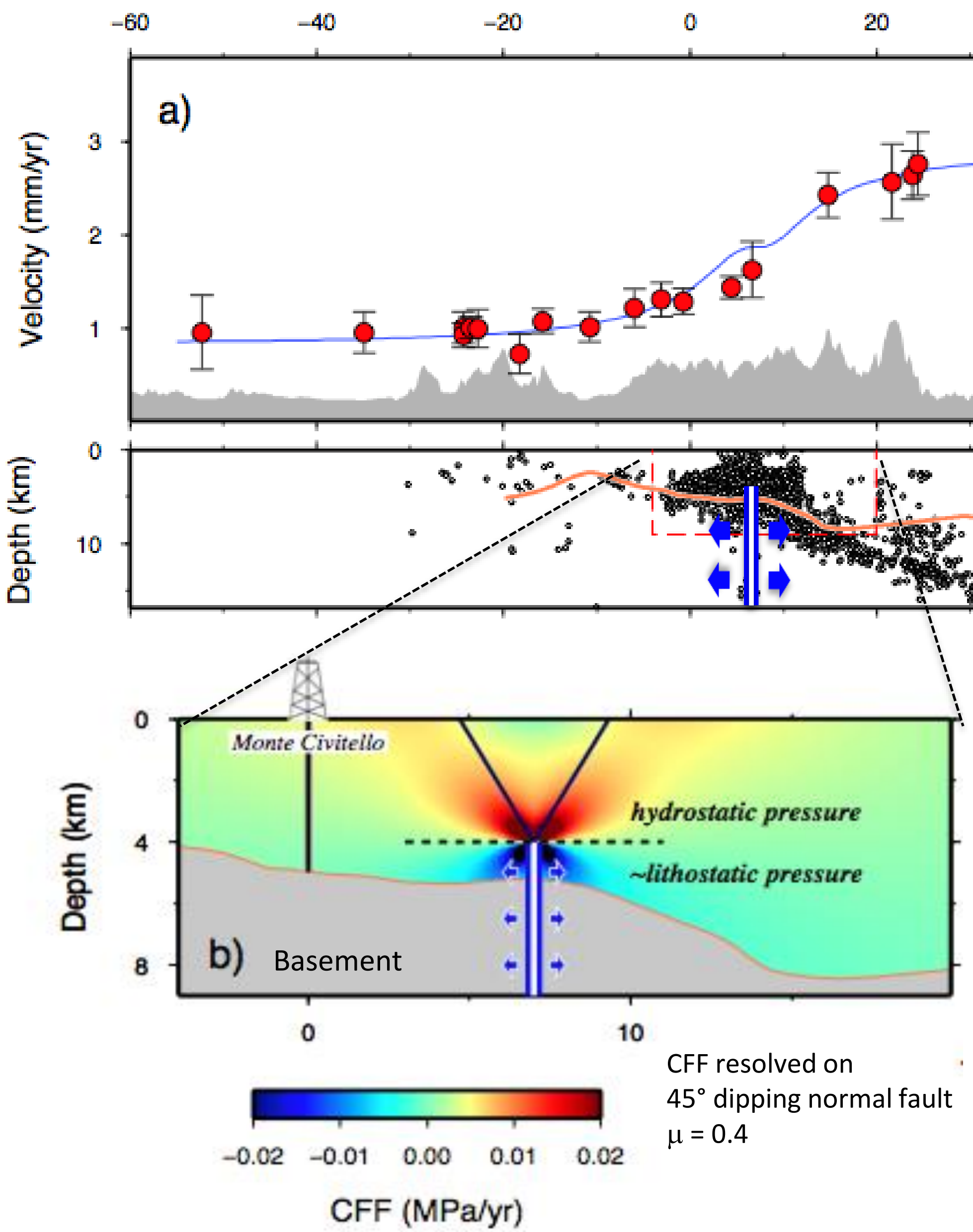



- Bottom of borehole (~5500 m)
- Hydrostatic pore pressure

Trippetta et al., 2013



# Gubbio: interseismic modelling

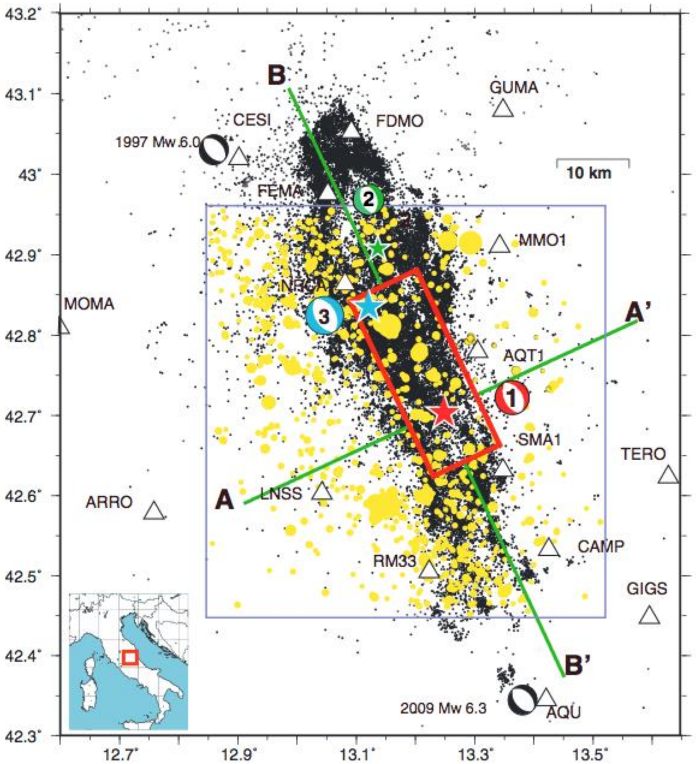



CFF resolved on
45° dipping normal fault
$\mu = 0.4$

- Buried tensile dislocations (depth 4 km)
- Geometry: **fixed** below slipping faults; amplitude: **adjusted**
- Good fit to GPS velocities

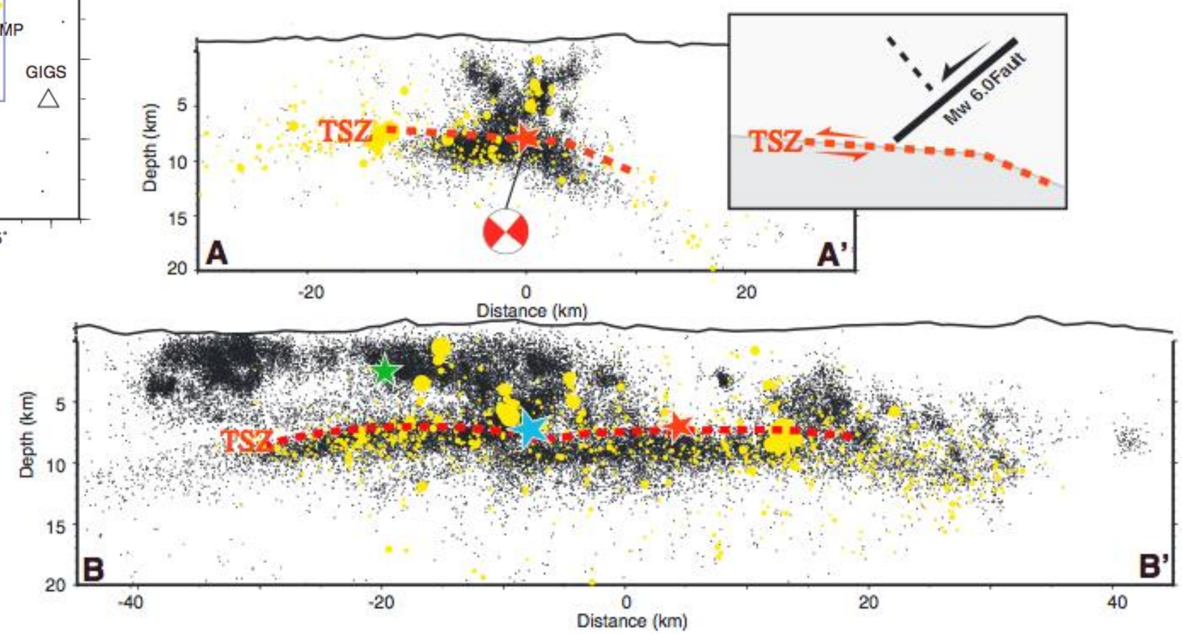
- High differential stress above the tip of the tensile dislocation
- Low differential stress in the basement

# 2016-2017 Amatrice-Norcia sequence




Vuan et al., 2017

- **Main shocks:**
  24 August Mw 6.1
  26 October Mw 5.9
  30 October Mw 6.5
- **> 90k relocated aftershocks (iside.rm.ingv.it)**
- **Shallow dipping low-magnitude alignment beneath coseismicall-active faults**



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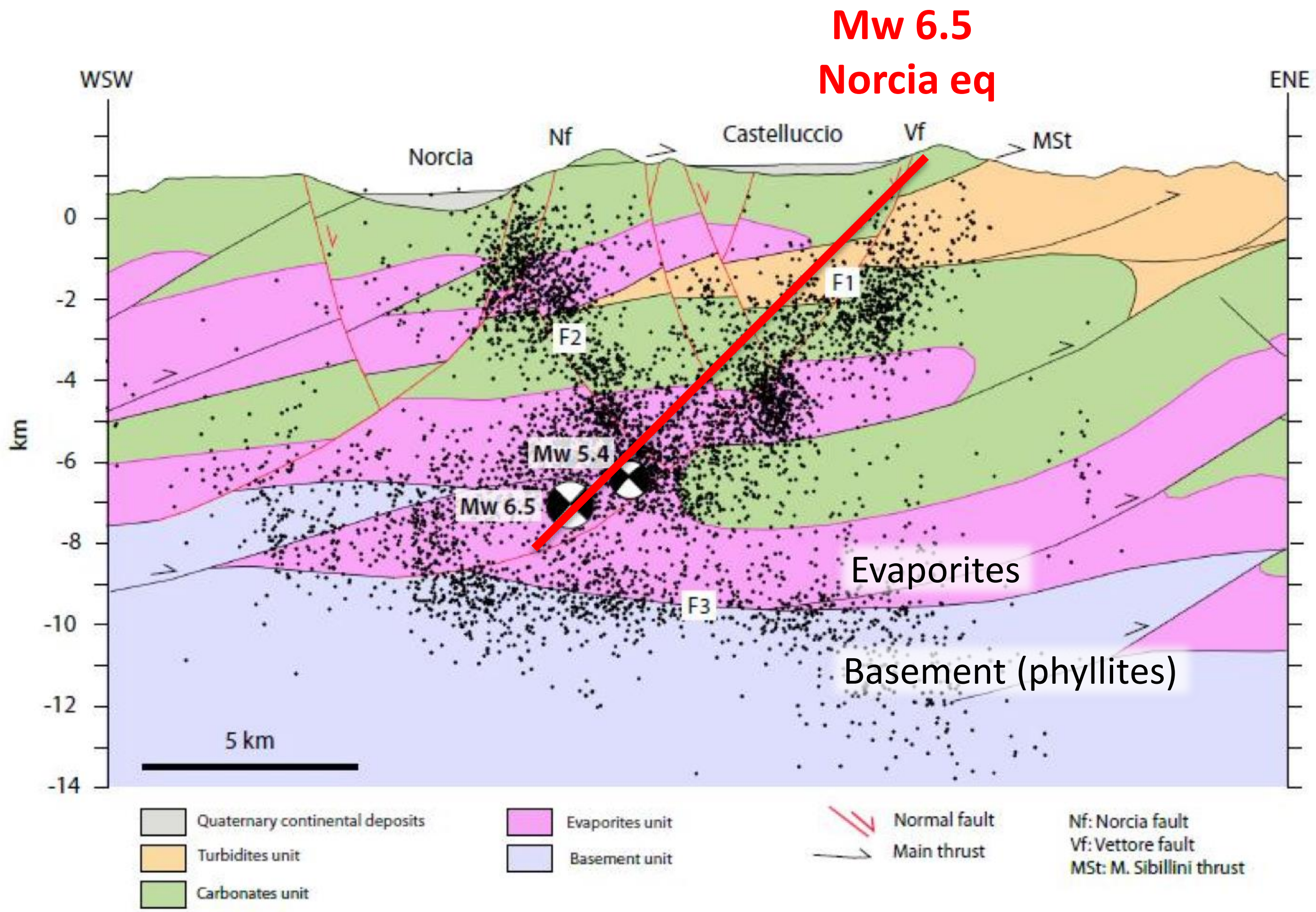
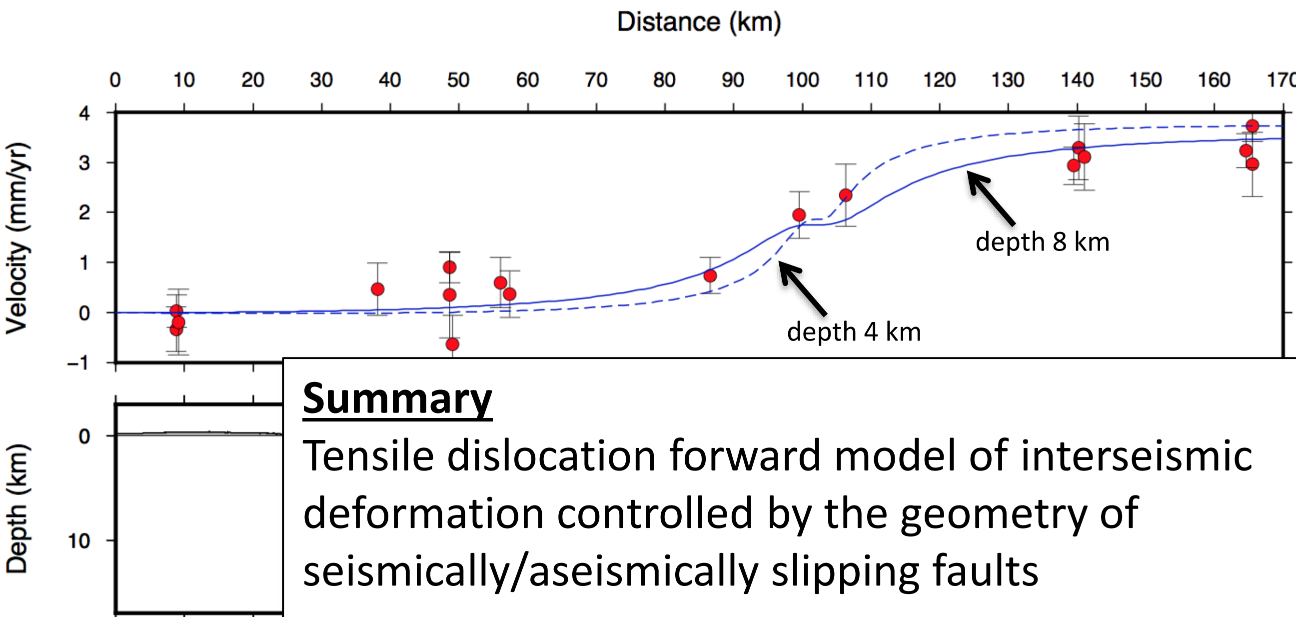



Porreca et al., 2018

# Amatrice-Norcia interseismic




**Summary**

Tensile dislocation forward model of interseismic deformation controlled by the geometry of seismically/aseismically slipping faults

Good first-order fit of GPS velocities

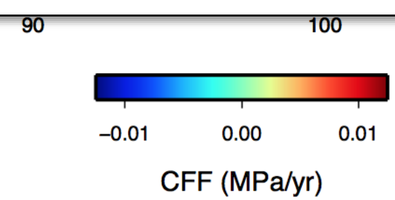
High differential stress, hydrostatic pore pressure above the tip of tensile dislocation

Low differential stress, ~lithostatic pore pressure below the tip of the tensile dislocation

tensile dislocation
the 30 October Mw 6.5
epth 8 km)

PS interseismic
es (adjust amplitude)

he depth at 4 km
es the fit in the high-
gradient zone

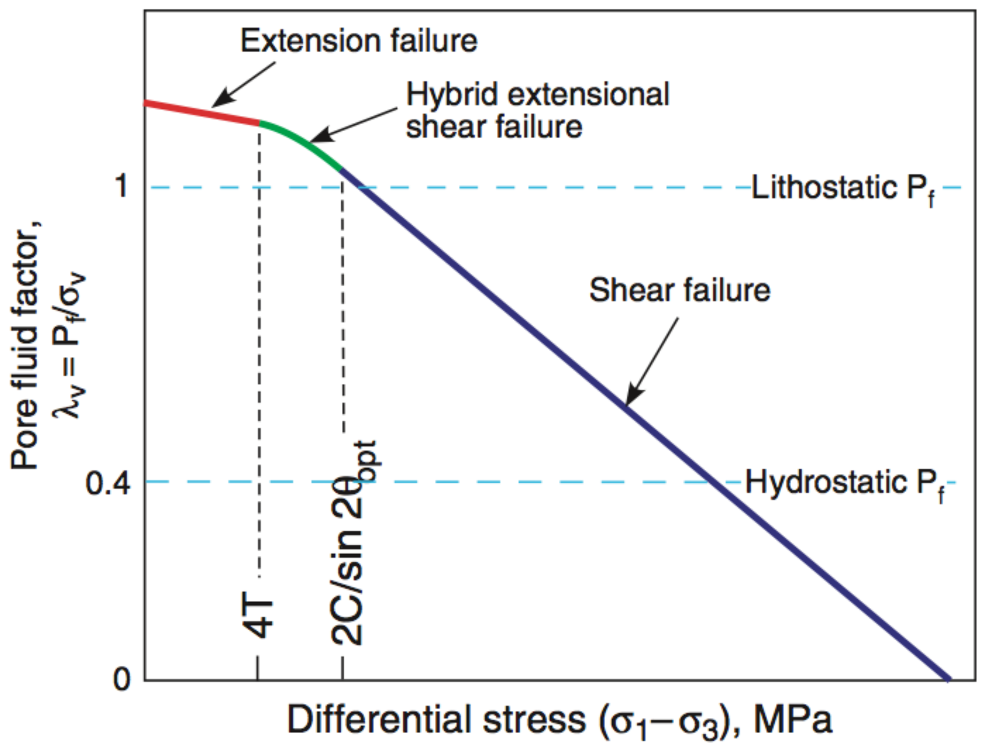


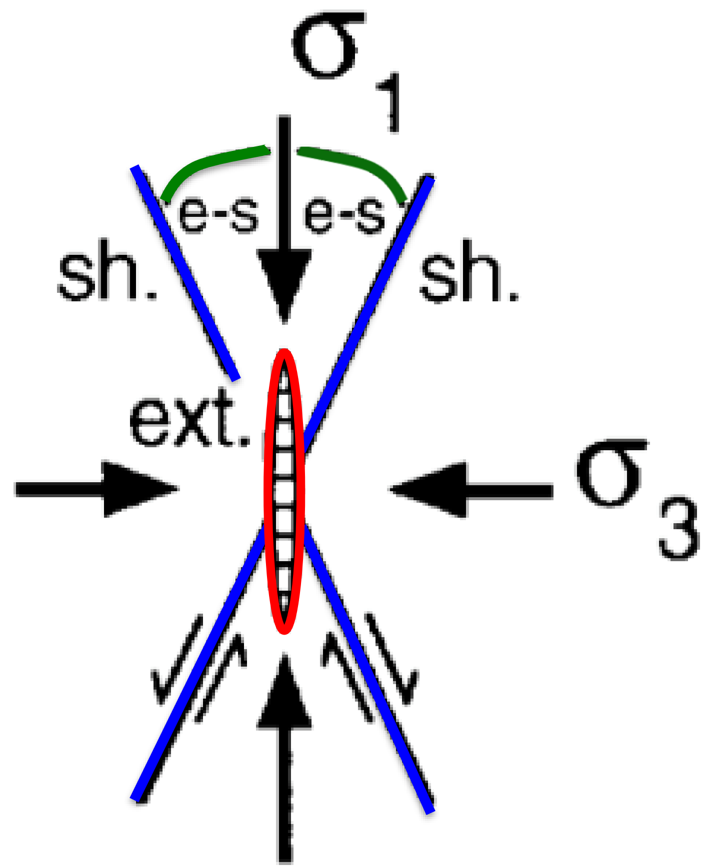
# Failure mode diagrams

*Define different failure modes in $\lambda_v$ - $\sigma$ space*

$$\lambda_v = P_f/\sigma_v$$

*extensional failure* *hybrid failure* *shear failure*




(Sibson, 1988; Cox, 2010)

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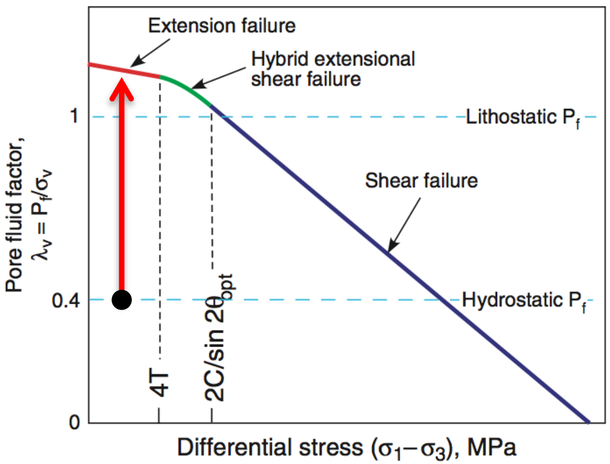
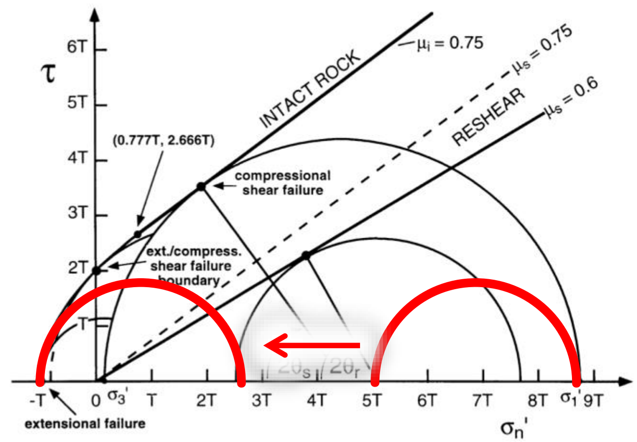
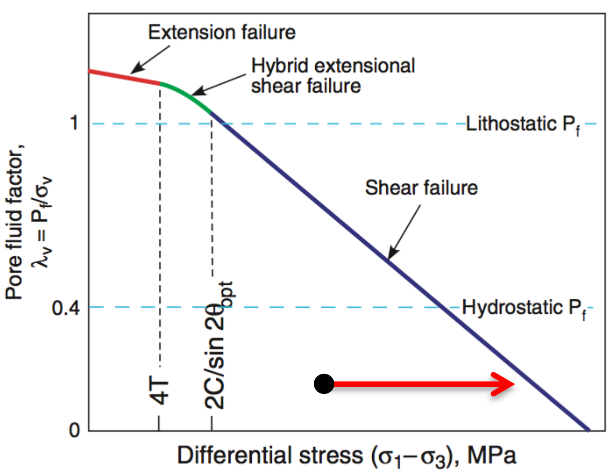
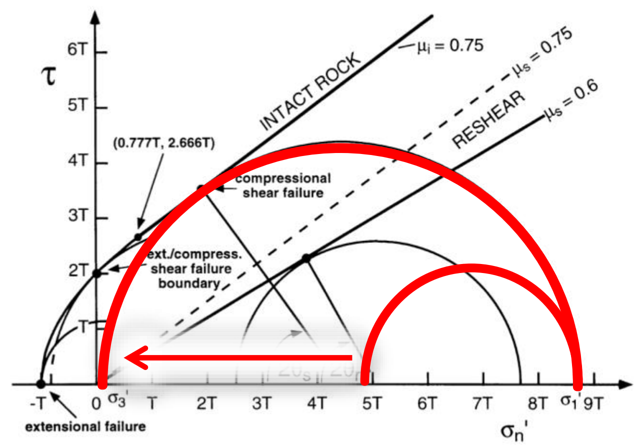


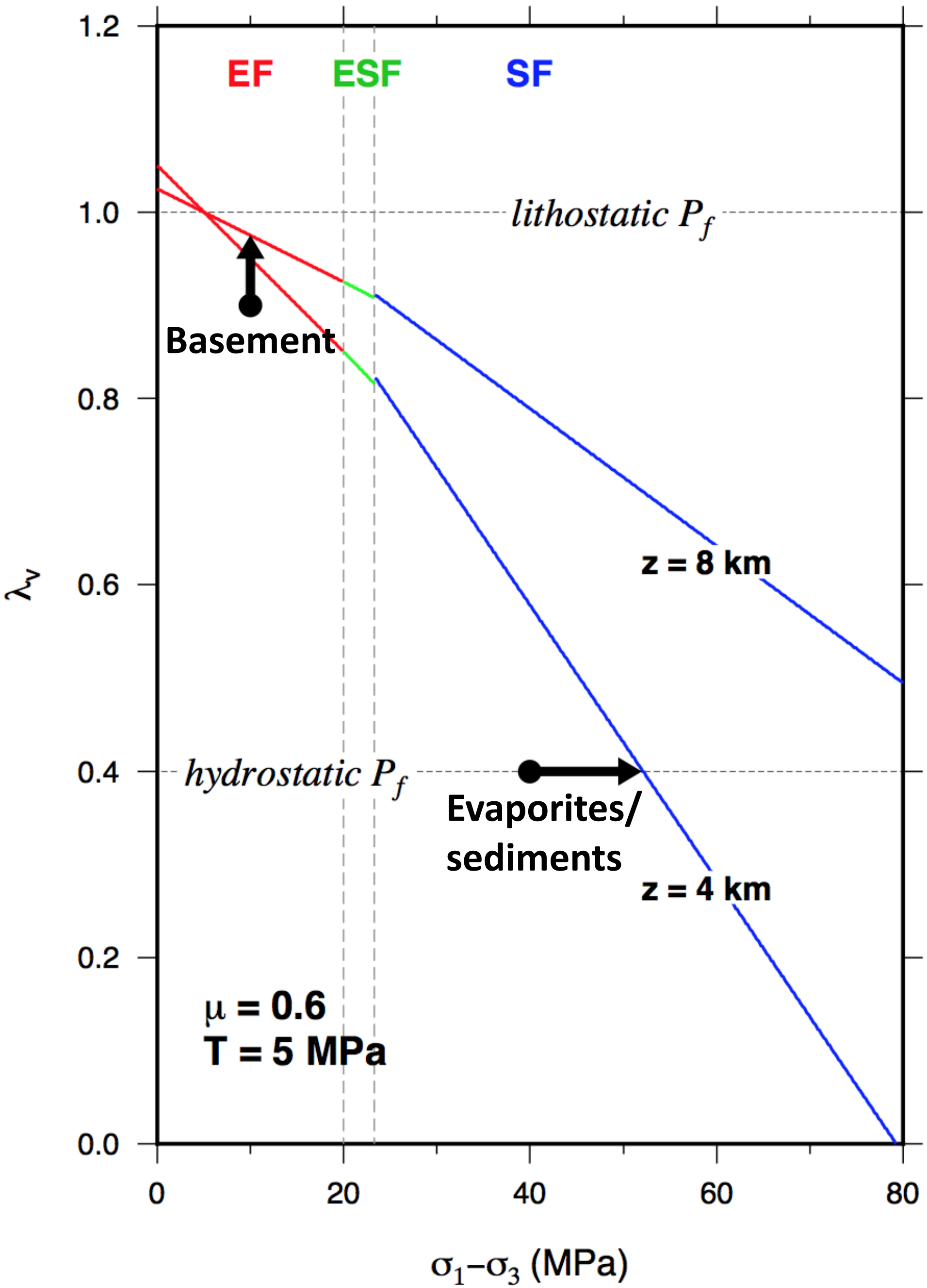




Extensional failure by pore pressure increase




Compressional shear failure by differential stress increase



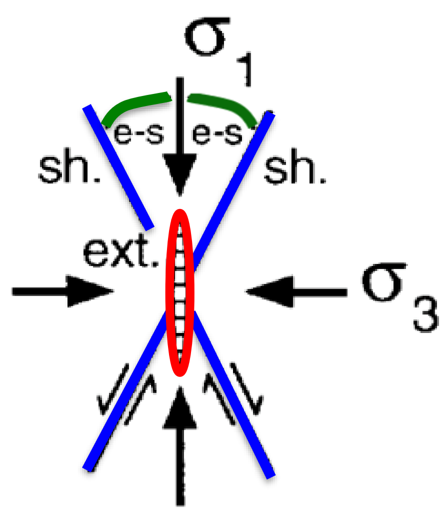

# A possible scenario ?

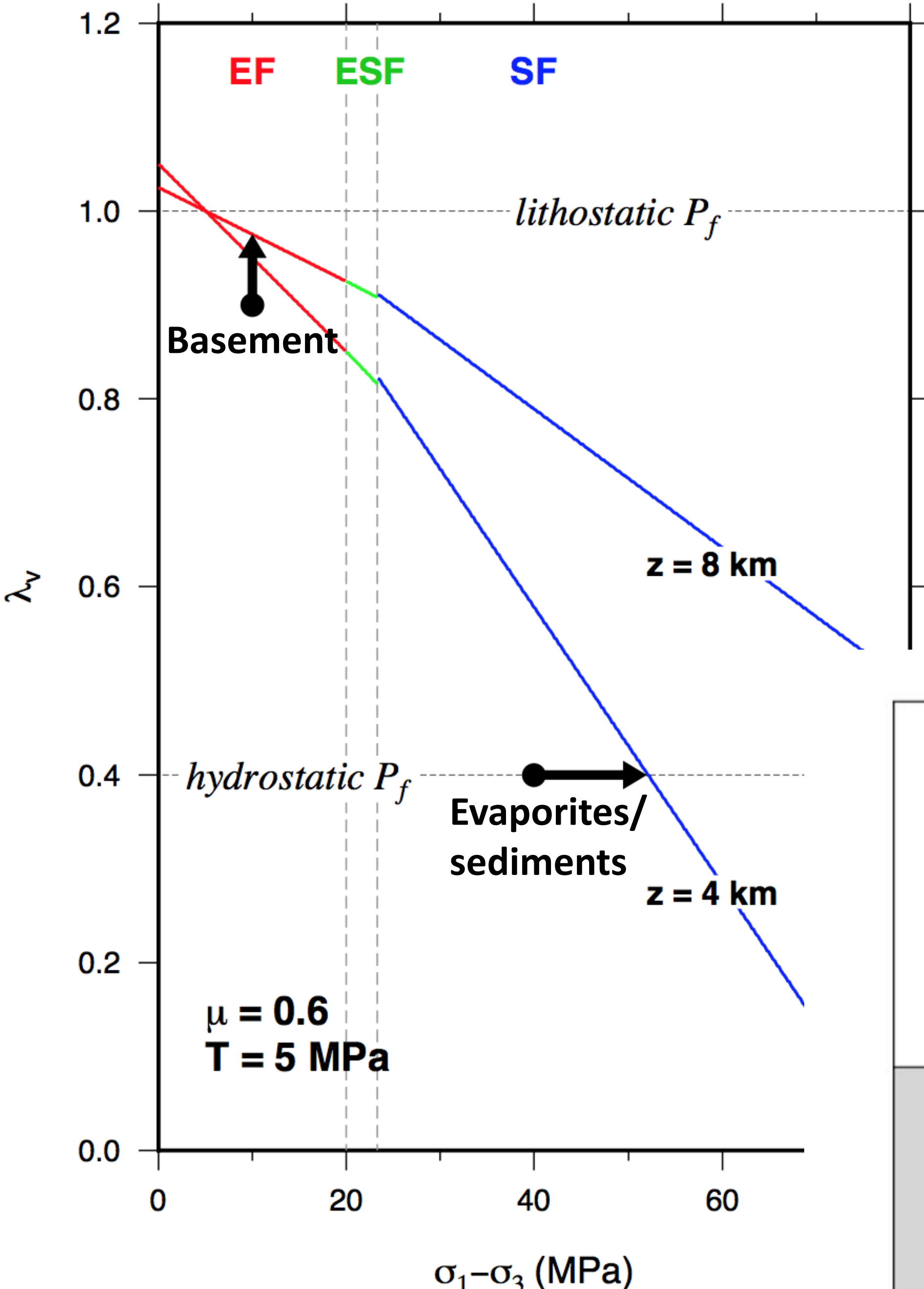
**Evaporites (depth ~4 km):**

- Hydrostatic $\lambda$, high differential stresses
- Increase of $(\sigma_1 - \sigma_3)$ or $P_f$ leads to **SF** (seismic/aseismic)

**Basement (depth ~8 km):**

- High $\lambda$ (0.85), low differential stresses
- Small increase of $P_f$ leads to **EF**
- Volumetric deformation by fracturing/veining



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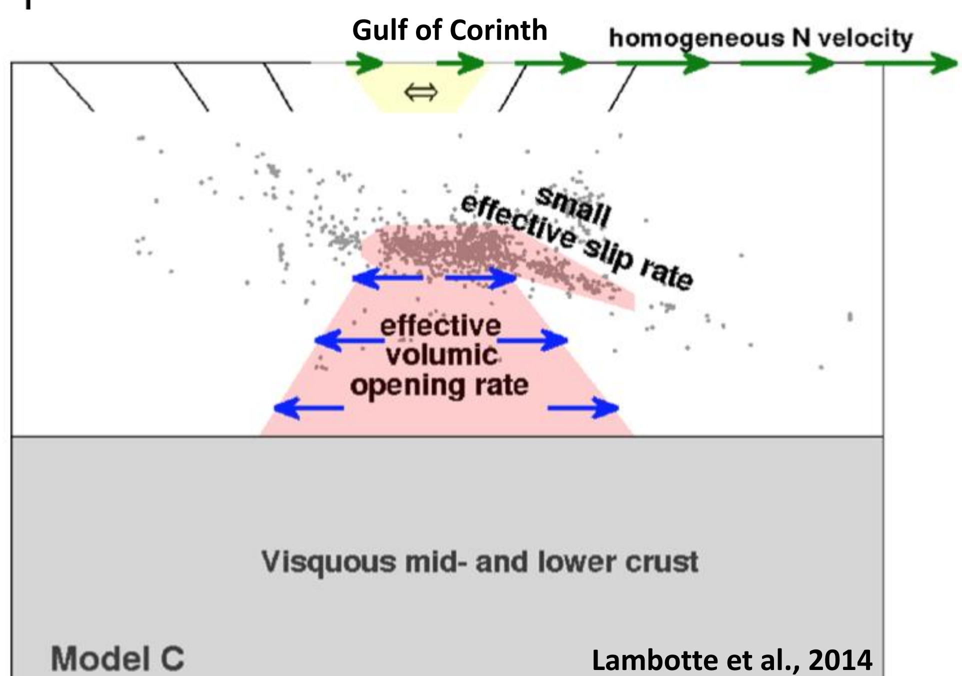

# Conclusions

- High pore pressure horizons limit the depth of frictional faulting (seismic/aseismic) ?
- Similar settings in Northern Apennines, Gulf of Corinth
- Volumetric deformation, significant fracturing/veining. Geological analogues ?