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
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

• Low-dipping alignments of seismicity

Gulf of Corinth

Alto Tiberina Valley

Duverger et al., GJI 2018

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

- Time evolution of displacement = ramp function
- $t_1$, $t_2$ 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 CO₂ 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) CO₂ $P_f = 99$ MPa ($\lambda = 0.85$)
- Within evaporite beneath basement thrust sheet

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

Trippetta et al., 2013

Diagram showing strain rate and geologic layers.
Gubbio: interseismic modelling

- 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

- 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 coseismic-all-active faults

Vuan et al., 2017
2016-2017 Amatrice-Norcia sequence

Norcia eq

Mw 6.5

Evaporites

Basement (phyllites)

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, \(\sim\) lithostatic pore pressure below the tip of the tensile dislocation
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)
Failure mode diagrams
(Sibson, 1988; Cox, 2010)

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
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

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Lambotte et al., 2014

**Diagram:**
- A graph showing stress vs. strain with critical points indicating SF and EF conditions.
- A map highlighting the Gulf of Corinth and model parameters such as viscosity and slip rate.
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 ?