Geometry and structure of a fault-bounded extensional basin by integrating geophysical surveys and seismic anisotropy across the 30 October 2016 Mw 6.5 earthquake fault (central Italy): the Pian Grande di Castelluccio basin

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Outline

• The 2016-2017 seismic sequence in central Italy

• Surface faulting following the 30 October 2016 Mw 6.5 Norcia earthquake

• The Pian Grande di Castelluccio basin: need for a better subsurface knowledge

• Integration of near-surface geophysical investigations and shear-wave splitting analysis
The 2016-2017 seismic sequence and the study area
Surface faulting following the 24 August (Mw 6.1), 26 October (Mw 5.9) and 30 October 2016 (Mw 6.5) earthquakes:

- marked heterogeneity
- striking asymmetry
Coseismic surface throw following the 24 August (Mw 6.1), 26 October (Mw 5.9) and 30 October 2016 (Mw 6.5) earthquakes:

- segmentation at different scales (> 800 small individual strands)
- integrated contribution from multiple active normal fault splays (> 15)
- >40% of total surface slip accomplished by Cordone del Vettore Fault
Surface faulting also affected the Pian Grande di Castelluccio basin during the 30 October 2016 earthquake.

- Good knowledge of bedrock geology surrounding the basin
- Poor knowledge of the shallow subsurface structure
- Long-term Quaternary activity of basin-bounding faults lacks constraints
Surface faulting within the PGC basin: present-day and past evidence

Villani & Sapia, Tectonophysics. (2017)

Active fault splay within the PGC basin (Valle delle Fonti – Prate Pala): comparison between coseismic and short-term fault throw
Active fault splay within the PGC basin (Valle delle Fonti – Prate Pala): comparison between coseismic and short-term fault throw

Average coseismic throw: **0.05 m**
Post-12 ka morphologic throw: **2.3-2.8 m** (0.23 ± 0.08 mm/yr throw-rate)
Evidence of strain localization: coseismic throw peaks match the locus of long-term throw
Previous studies

Biella et al., GNGTS (1981)
- 18 SEV
- Smooth basin-bottom geometry
- 1 main depocenter
- Max infill thickness 500-800 m

Calamita & Pizzi, Studi Geol. Cam. (1992)
2-stage development:
1) N60°E extension (VBFS)
2) Local N20°E extension (pull-apart like basin)
Why studying the PCG basin?

- Defining the subsurface structure of the active fault splay(s)
- Recovering the pre-Quaternary top-bedrock depth to reconstruct the large-scale basin geometry
- Constraining a geological profile across the PGC basin
- Inferring the long-term evolution and throw-rates of the basin-bounding faults

Methods (multi-disciplinary approach):

- **Electrical Resistivity Tomography** (ERT): high-resolution fault imaging
- **Time-Domain Electromagnetic sounding** (TDEM): inferring top-bedrock depth through 1-D resistivity modelling
- **Horizontal-to-Vertical Spectral Ratio** (HVSR): constraining subsurface basin geometry through ambient vubration and micro-earthquakes spectra
- **Shear-wave Splitting**: defining the spatial pattern of fractures related to the active stress-field in the area
New geophysical dataset

Villani et al., Tectonics (2018b)

- **5 ERTs**: 3 x 630 m length, 1 x 315 m length, 1 x 126 m length (64 electrodes)
- **30 TDEM soundings** (50x50 m loop-size)
- **43 ambient vibration recordings** (0.2 Hz velocimeters, 1-3 hr rec. length)
- **138 micro-earthquakes waveforms** (ML < 2)
- **2 geophysical transects**: A-A’ and B-B’

**Survey dates:**
9,13-14,21 December 2016
27-29 March 2017
6-7 April 2017
15-16 June 2017
25 May 2018
8 August 2018
Calibration of geophysical data: Test profile A-A'
High-resolution multi-scale ERT:

the Valle delle Fonti (VF) splay
Western Fault F2 (unit Fz1)
- Displaces the topmost deposits
- > 30 m total throw
- 0.22 ± 0.07 mm/yr long-term throw-rate

Valle delle Fonti fault VF (unit Fz2):
- Displaces the topmost deposits
- > 30 m total throw
- 0.22 ± 0.07 mm/yr long-term throw-rate

Eastern Fault F1 (unit Fz3):
- the main basin-bounding fault of the PGC basin seems sealed by thick resistive layer (alluvial fan)

High-resolution ERT across the main faults (profile B-B’)

ERT T2
ERT P1
ERT T1
TDEM soundings across the PGC basin (profile B-B’)

- Drastic changes of top-bedrock depth
- Maximum depth of 280-300 m
- Constraints for VF fault total throw: about 100 m
- Two possible additional buried splays: F5 and F6
Ambient vibrations and micro-earthquake recordings in the PGC

- About 50 micro-earthquakes suitable for HVSR analysis
- High-frequency content
- Sensitive to shallow interfaces and small-scale heterogeneities
Ambient vibrations and micro-earthquake recordings in the PGC

- Complex HVSR curves
- Different response from ambient vibrations and micro-earthquakes
- Several recordings exhibit low-frequency amplification (< 0.3 Hz)
- The pattern of $f_0$ is quite consistent with the retrieved top-bedrock depth from TDEM soundings
- The deepest parts of the PGC basin (> 240 m) display $f_0 \approx 0.4$-0.5 Hz or even lower
Ambient vibrations and micro-earthquake recordings in the PGC (profile B-B')
Seismic anisotropy in the PGC basin

- 57 $\phi$ and $\delta t$ pairs, 33 good measurements, 24 null
- 2 principal fast direction orientations (N130°-150°, N20°-30°), parallel to faults VF, F1 and to F2, F3, respectively: structure-induced anisotropy?
Tentative geological section across the PGC basin: transect B-B’
(working hypothesis!)
Conclusions

• The PGC basin displays a rough top-bedrock topography.
• Maximum infill thickness is nearly 280-300 m.
• ERT images indicate low degree of activity of the basin-bounding faults F1 and F3.
• TDEM results suggest the existence of two additional buried splays (F5 and F6).
• The VF fault has nearly 100 total throw, probably accrued in the last 0.4 Myr.
• Seismic anisotropy highlights the interplay of two different fault-systems (N130°-150° and N20°-30°).
• Inception age of the PGC basin is possibly Early Pleistocene.

Open questions

• Are faults F5 and F6 reliably constrained?
• What’s the southernmost evidence of fault VF?
• What’s the age of the infilling deposits???

Coming soon...

High-resolution seismic reflection and non-linear refraction-tomography images along three seismic profiles! Will unravel details of the depositional architecture and geometry of fault splays.
References


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