Assessing fault-earthquake relationships for low-grade seismic sequences (M_L<4.5): examples from the extensional belt of central Italy

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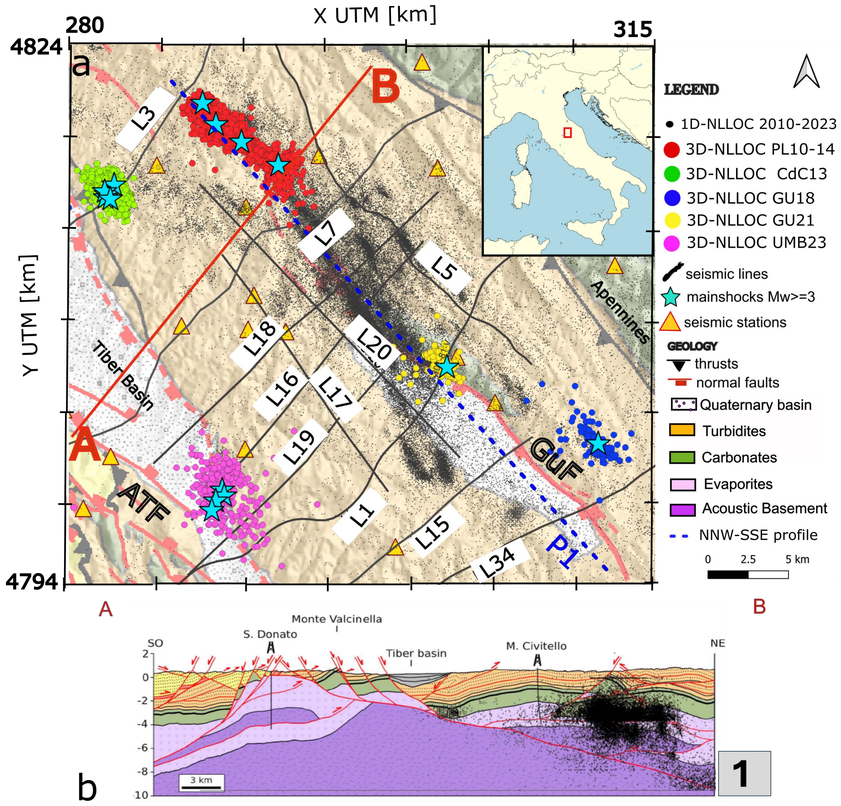
INTRODUCTION

The study area is located in Umbria, in the northern sector of the Apennines and is dominated by two major geological structures: the Alto Tiberina Fault (ATF) and the Gubbio Fault (GuF). The region is characterized by diffuse microseismicity (M_L<3) and by shallow low-magnitude sequences (ML< 4.5) not associated with surface-exposed faults, widely felt by the population and locally damaging (Figure 1).

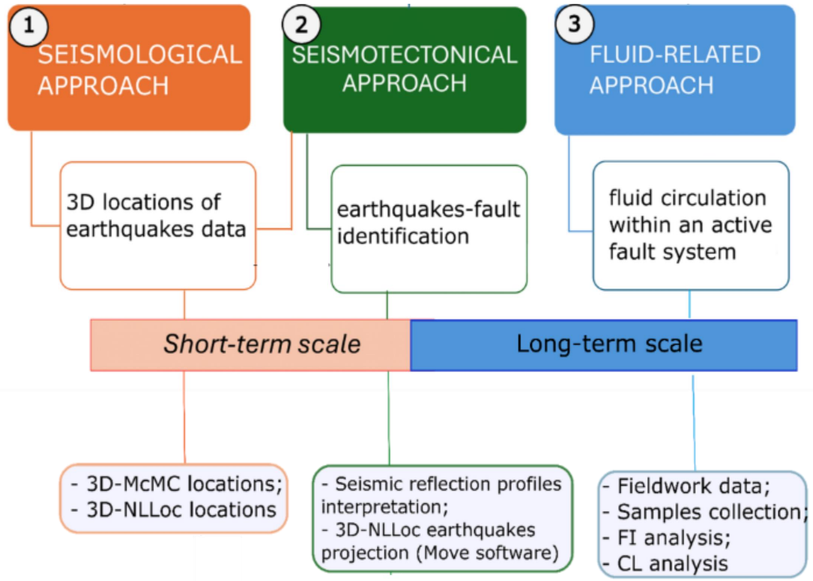


RESEARCH QUESTIONS

1. What is the geometry and kinematics of the causative faults ? Are they imaged in available 2D seismic reflection profiles?
2. How do fault architecture and crustal heterogeneity control the spatial distribution of present seismicity and past fluid processes in active tectonic systems?

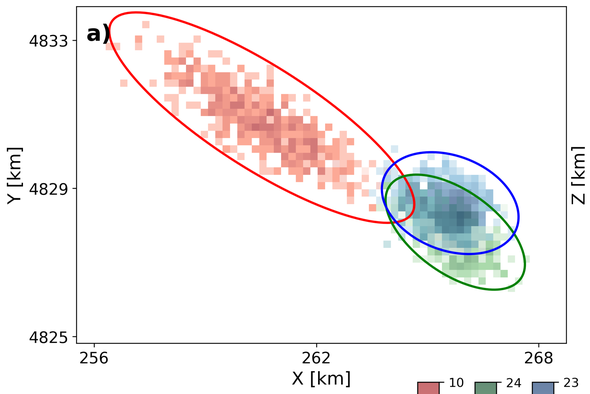
***Figure 1**. (a) Umbria-Marche 1D seismic catalog (Cattaneo et al., 2019). (b) zoom into the study area. (c) geological cross section modified after Mirabella et al. (2011)*

METHODS



RESULTS

1. SEISMOLOGICAL APPROACH : The 3D velocity model reduces location uncertainties by up to 90%, especially in depth (Figure 2) → The sequences previously located with a 1D model are relocated using the 3D model of Latorre et al. (2016).



SCAN ME

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***Figure 2**. Epicentral (a) and hypocentral (b) Posterior Density Function (PDF) cloud resulting from the location of an earthquake with a homogeneous (red), 1D (green) and 3D (blue) velocity model.*

2. SEISMOTECTONIC APPROACH : The newly relocated sequences are successfully associated with minor normal faults at the hanging wall of the ATF imaged in seismic profiles (Figure 3). The larger spatial extend occupied by the aftershocks suggest fluid migration.

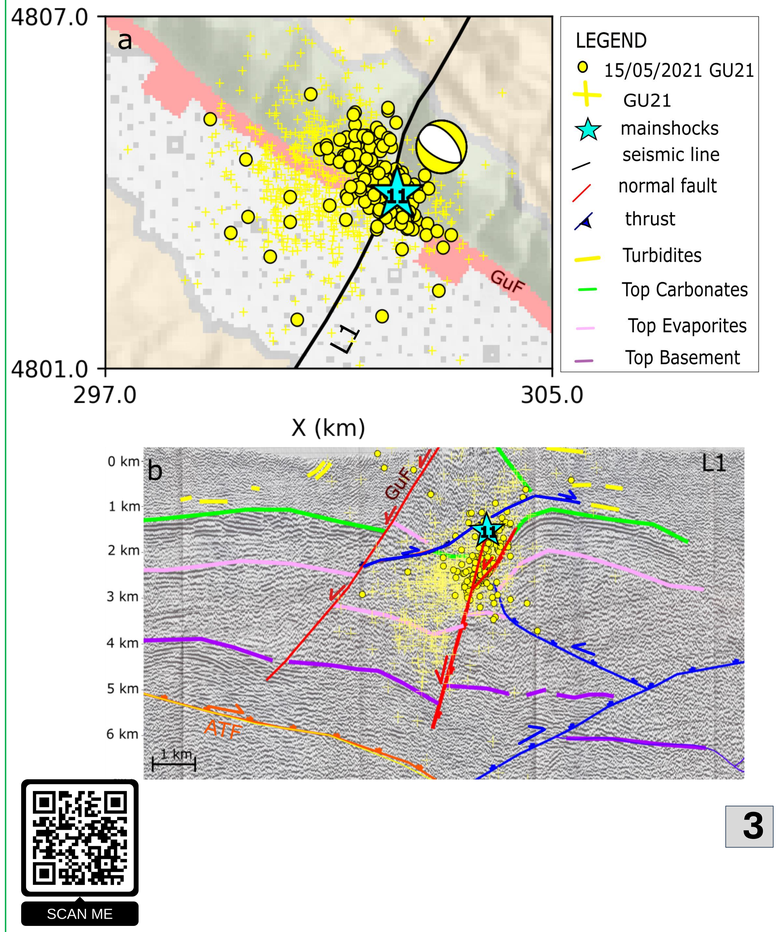

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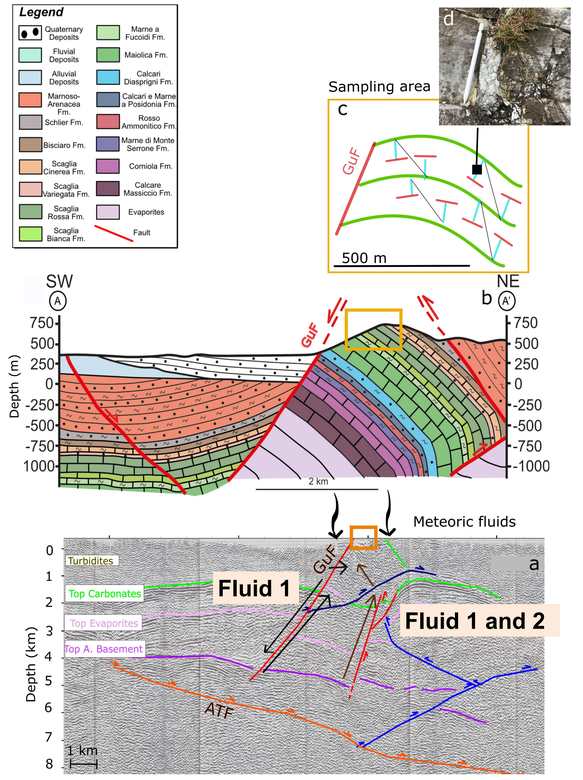
***Figure 3**. Example of a seismic sequence (GU21) occurred near Gubbio town, succesfully asscoaited with a minor structure imaged at the footwall of GuF*

3. FLUID-RELATED APPROACH : Fluid inclusion data reveal a compartmentalized fault system, deep meteoric fluid circulation and the role of major and minor faults in controlling fluid ascent (Figure 4).



Fluid 1: Th 60-75 °c, salinities 1-2% wt. NaCl eq.
Fluid 2: Th up to 150 °c, salinities up to 5% wt NaCl eq.

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***Figure 4**. Deep meteoric fluids circulate to depths of 3–4 km, interact with Triassic evaporites, and subsequently migrate upward along major and minor fault zones, likely triggered by seismic activity, precipitating calcite within the fractured footwall of the GuF.*

CONCLUSIONS

- Low-magnitude earthquakes (M_L < 4.5) can cause damage, especially in vulnerable urban areas.
- These events are associated with faults not exposed at the surface, but imaged in seismic reflection profiles → they should be properly identified and included in seismic hazard assessments.
- Integrating seismological, geophysical, structural, and geochemical data, this study links short-term seismic processes with long-term fault evolution and highlights the seismogenic potential of minor faults not exposed at the surface, with direct implications for seismic hazard assessment in the Apennines

Photos taken by Antonucci et al., 2023

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