Ministero dell'Università e della Ricerca

FIS

Ud'A Università degli Studi "G. d'Annunzio"

Dipartimento di Scienze

FIS2 Research Project

3D gEology-constrained seismic rupture dynamic models: a new interdisciplinary strategy For Earthquake forecastiNg and reSilience

Call: FIS2 – Italian Fund for Science, D.D. n. 23314 – 11.12.2024 – ERC sector: PE10 – Funding: 1.328.314 €

THE LOGO OF DEFENS

A **mountain range** at the top → the **geological and morphological setting** in which the project operates, mountainous environments and tectonic dynamics.

A red line on the right slope → an **active fault** → ongoing interaction between tectonic processes and landscape evolution.

In the upper right a drone → modern technologies for field studies, key for data collection.

DEFENS, stands out boldly at the center → the goal of the resilience and understanding natural phenomena.

The map of **Italy** in grey pixel-like dots → the **national scope** of the project and its **detailed territorial analysis**;

A **seismic waveform**, which transforms into a **geological hammer** → the **integrated methods** at the heart of the scientific project;

The **arc** enclosing the base of the logo evokes DEFENS's **comprehensive and protective vision** toward both the land and society.

Each element has been carefully designed to visually encapsulate the mission and core themes of DEFENS.

Why, despite decades of earthquake research, do we still struggle to link surface deformation, fault geometry at depth, and, mostly, rupture dynamics in a consistent way?

- we have excellent data, but they are often fragmented (even geographically);
- we have advanced models, but they are frequently weakly constrained by real geology;
- the connection between field observations, fault architecture, and rupture physics is still incomplete

DEFENS was born exactly in this gap:

- **between surface and depth;**
- **between observations and models;**
- **between single earthquakes and the seismic cycle.**

How major tectonic structures along the Apennines, with their geometric and structural complexities, govern the deformation and rupture propagation during major earthquakes?

Can we obtain geologically-constrained numerical models capable of forecasting future EQs nucleation areas, effectively mitigating seismic risk?

Can we engage the population in an easy and enjoyable way to achieve the dual objective of raising awareness about seismic risk and contributing to the development of geological knowledge?

Vision of the DEFENS project

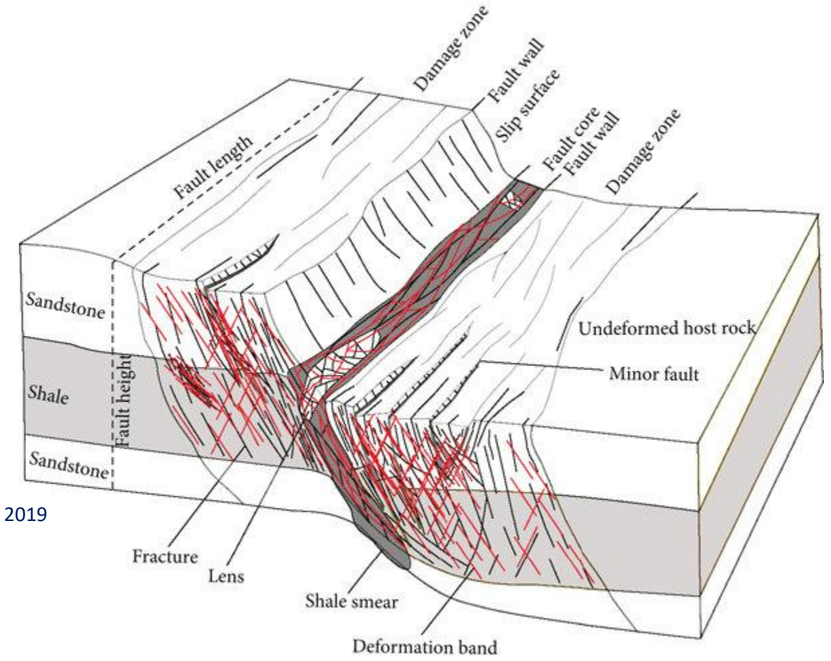
Structural geology as the backbone:
not an accessory, but a physical and geometrical constraint on everything else. Fault geometry, fault continuity and discontinuity, damage zones, kinematic relationships between fault segments, are not decorative inputs for models or interpretations, but physical constraints, that limit what is possible, and what is not.

Multi-scale:
a fracture observed at the outcrop scale, controls a fault, which controls a fault system, which controls the deformation of an orogen.

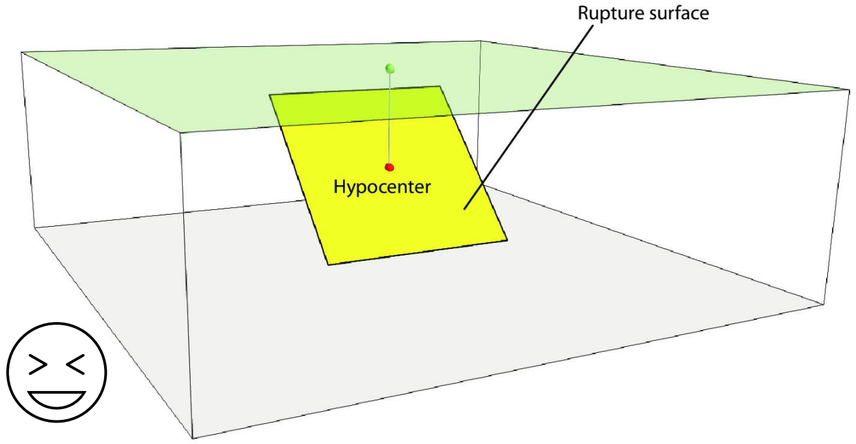
Multi-cycle:
the fault that ruptures today is the result of thousands to millions of years of growth, segmentation, linkage, inactivity and reactivation.

True interdisciplinarity:
the geologist does geology, the seismologist does seismology, the modeler does modeling (each one presenting their own part)... that is multidisciplinarity, not interdisciplinarity.
What it really means is that the questions are shared, the data produced by one discipline constrain the work of the others.

DEFENS as a response to elegant but unrealistic models



Torabi et al 2019



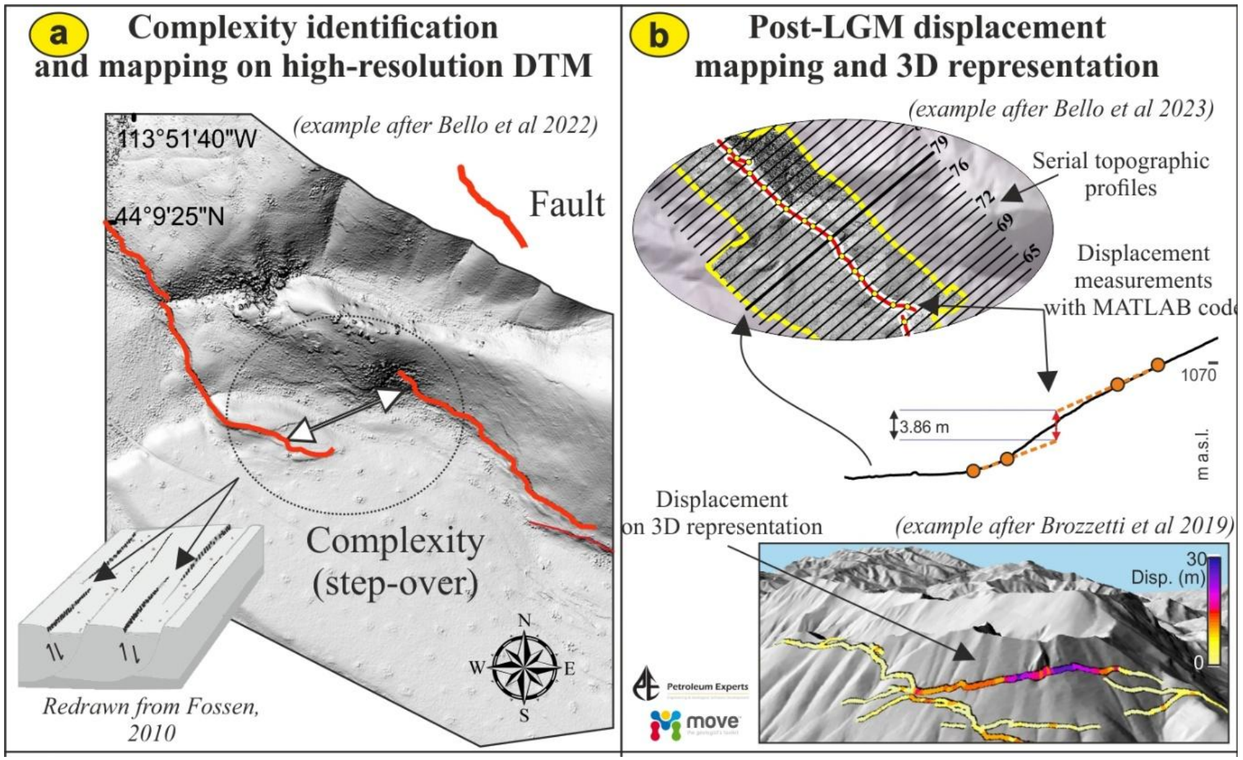
"What changes when real fault geometry enters models"

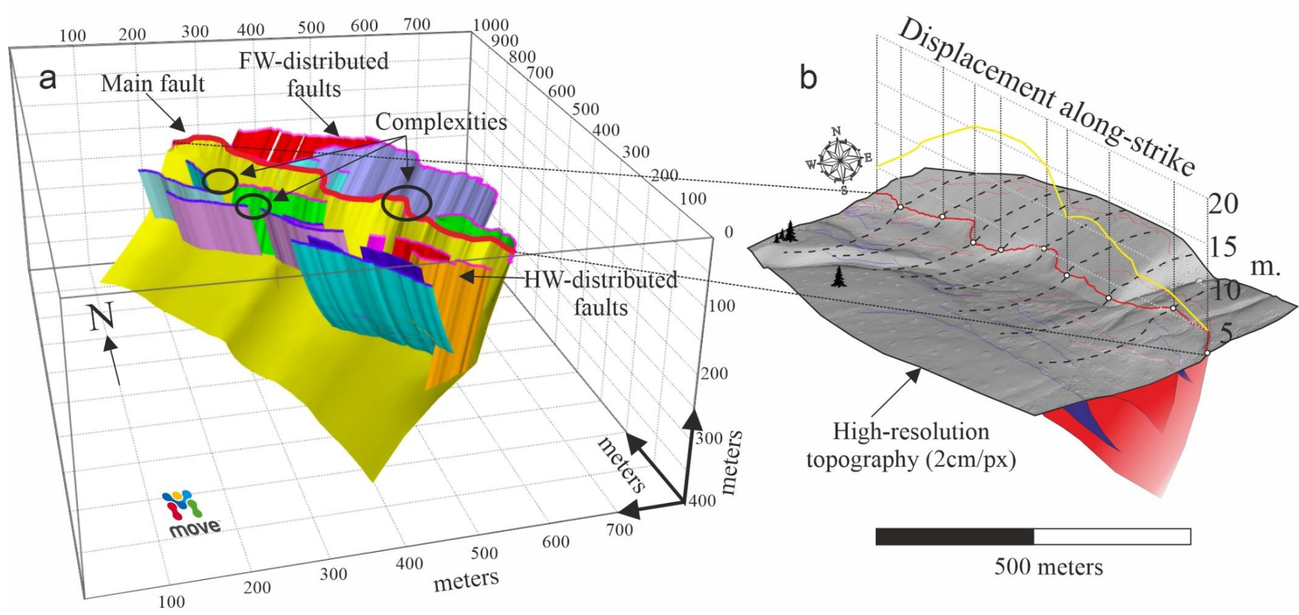
if a fault is curved, segmented, with step-overs, with real asperities, with synthetic and antithetic structures, then:

rupture does not propagate as on a smooth surface, stress is not distributed uniformly, magnitude and rupture direction may change.

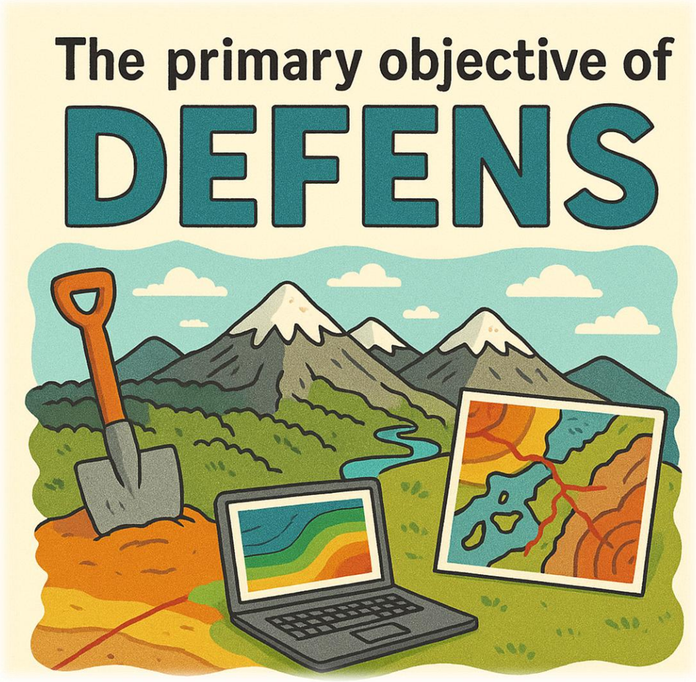
When fault geometry becomes realistic, rupture behavior stops being ideal.

A fault is not a surface. It is a volume with memory





The bottom line



The primary objective of DEFENS is to develop a worldwide first complete tool from field geology to numerical modeling of forthcoming earthquakes.

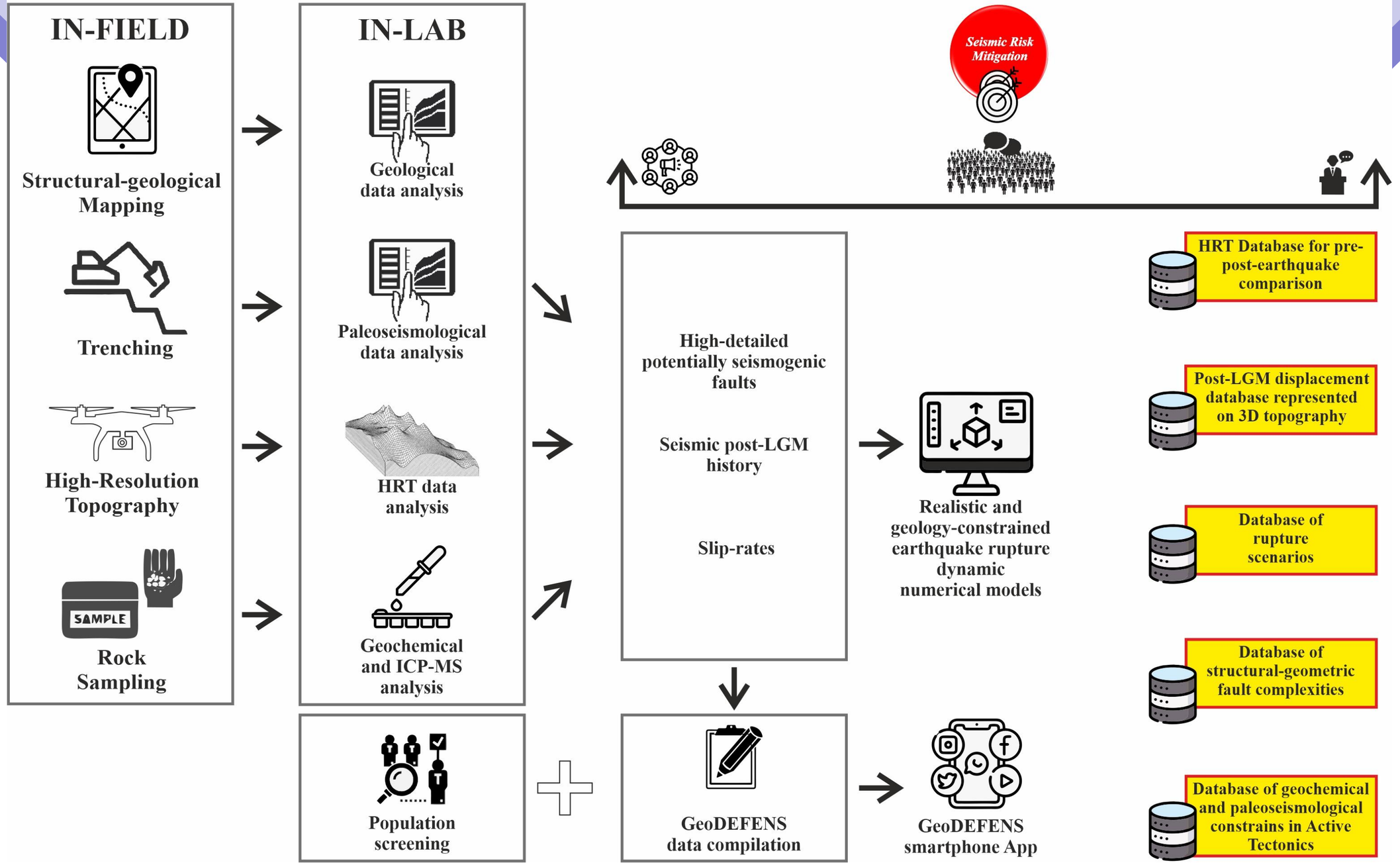
The national-scale models will be here first geologically constrained and replicate earthquake cycles for the time period since the last glacial maximum (~18/23 ky) to the present.

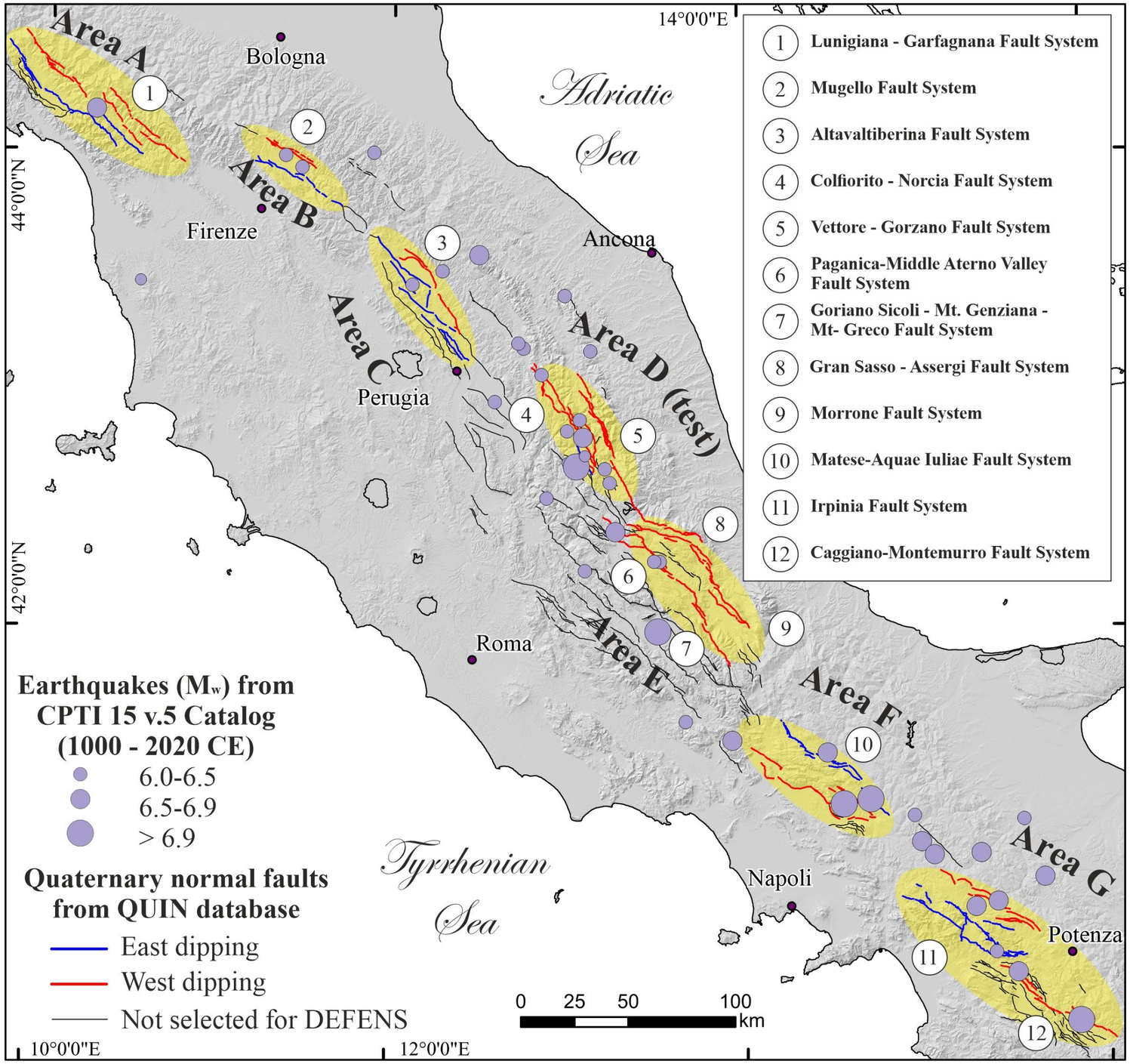
Data input from detailed fault segmentation, extensive fieldwork for structural-geological, geochemical, and paleoseismological constrained information on past earthquakes, will help forecast the character and preferred epicentral zones of future events.

DEFENS does not add complexity for the sake of complexity, but because the Earth is complex, and ignoring this leads to elegant but fragile models.

DEFENS researchers team skills

Structural geology - Seismotectonics - Paleoseismology - Geochemistry - Modelling - Web managing - Psychology

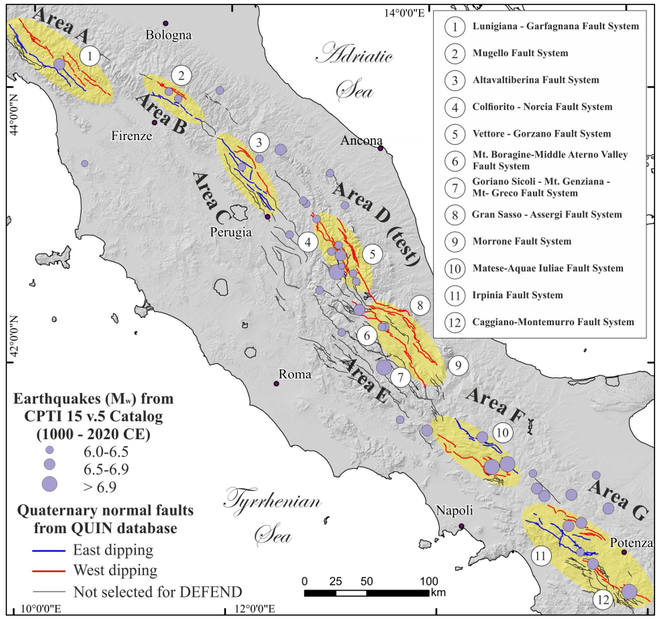




STUDY AREAS

DEFENS builds on the QUIN databases (Lavecchia et al 2022, 2023a, b), aggregating ~7500 structural-geological data points and fault traces across the Apennines.

The 12 FSs within DEFENS are present in the QUIN database and span ~600 km in peninsular Italy, distributed across seven test areas (A-G).



12 of the highest seismic potential normal FSs of Italy are in the 7 DEFENS' Test areas:

Area A: E- and W-dip **Lunigiana and Garfagnana** normal FS with an along-strike length of ~90 km. Historically, it experienced the 1920 Garfagnana and Lunigiana EQ M6.5, the most devastating historic Tuscan EQ.

B: the 40 km-long **Mugello** normal FS. Historically, it saw two Mugello EQs (1542, M6.0 and 1919, M6.2), with proximity to Florence making it a critical study area.

C: normal-to-normal oblique faults from the **Altotiberina system**, spanning ~80 km along-strike. Historically, the northern portion had two EQs with M>6 (1352, M6.3 and 1389, M6.0). The central and southern parts had no ≥M6 events, but moderate EQs (e.g., 1917, M5.7) were highly destructive because surficial.

D (Control Area): **Colfiorito-Norcia** (~75 km) and **Vettore-Gorzano** (~70 km) normal FSs. Besides the recent Seismic Sequence (2016, Mw6.6), this area experienced numerous historical EQs >M6, including the 1279 M6.2, 1328 M6.4, 1730 6.0, 1599 M6, 1639 M6.2, and 1703 M6.7.

E: 4 FSs - **Paganica-Middle Aterno Valley**, **Goriano Sicoli-Mt. Greco**, **Gran Sasso-Assergi-Bussi**, and **Morrone**. The first two FSs, aligned, measure ~90 km along-strike, while the Gran Sasso-Assergi-Bussi and Morrone alignment is ~85 km. This area experienced the L'Aquila EQ in 2009 Mw6.1, preceded by the 1451 M6.5 and 1703 M6.7 EQs, as well as one of the shocks of the 1349 sequence M6.8.

F: the **Matese-Aquae Iuliae FS** with two conjugate fault alignments bordering a central horst (~60 km each). The area hosts high M EQs, including a 1349 M6.8 sequence shock and the 1456, 1688, and 1805 EQs (M7.2, 7.1, and 6.9).

G: normal faults from the **Irpinia** and **Caggiano-Montemurro FSs**, featuring synthetic-antithetic conjugate FSs each ~60 km-long. The area experienced the Irpinia 1980 EQ (Mw6.9), activating both the E- and W-dip normal faults of the Irpinia FS. The northern portion had the 1561 M6.3 and 1694 M6.7 shocks, while the southern portion released the 1561 M6.7 and 1857 M7.1.

Active collaborations

Prof. Ramon Arrowsmith
Prof. Chelsea P. Scott
Arizona State University
Geomorphology of fault zones, paleoseismology, HRT

Dr. Paolo Galli
Department of Civil Protection
Paleseismology

Prof. Daniil Moraitis
University of Sharjah
Geochemistry of fault zones

Dr. Edoardo Peronace
Dr. Biagio Giaccio
National Research Council
Paleseismology and Quaternary Geology

Dr. Vasiliki Mouslopoulou
Institute of Geodynamics - National Observatory of Athens, Greece
Active tectonics and REE analysis

Dr. Stefano Pucci
National Institute of Geophysics and Volcanology (INGV)
Earthquake Geology and HRT

Prof. Piero del Boccio
Dr. Maria Concetta Cufaro
Center for Advanced Studies and Technology
ICP-MS techniques

Prof. Jean-Jacques Bahain
Prof. Pierre Voinchet
Muséum national d'Histoire naturelle, Paris
ESR and U-series dating methods - Quaternary Geochronology

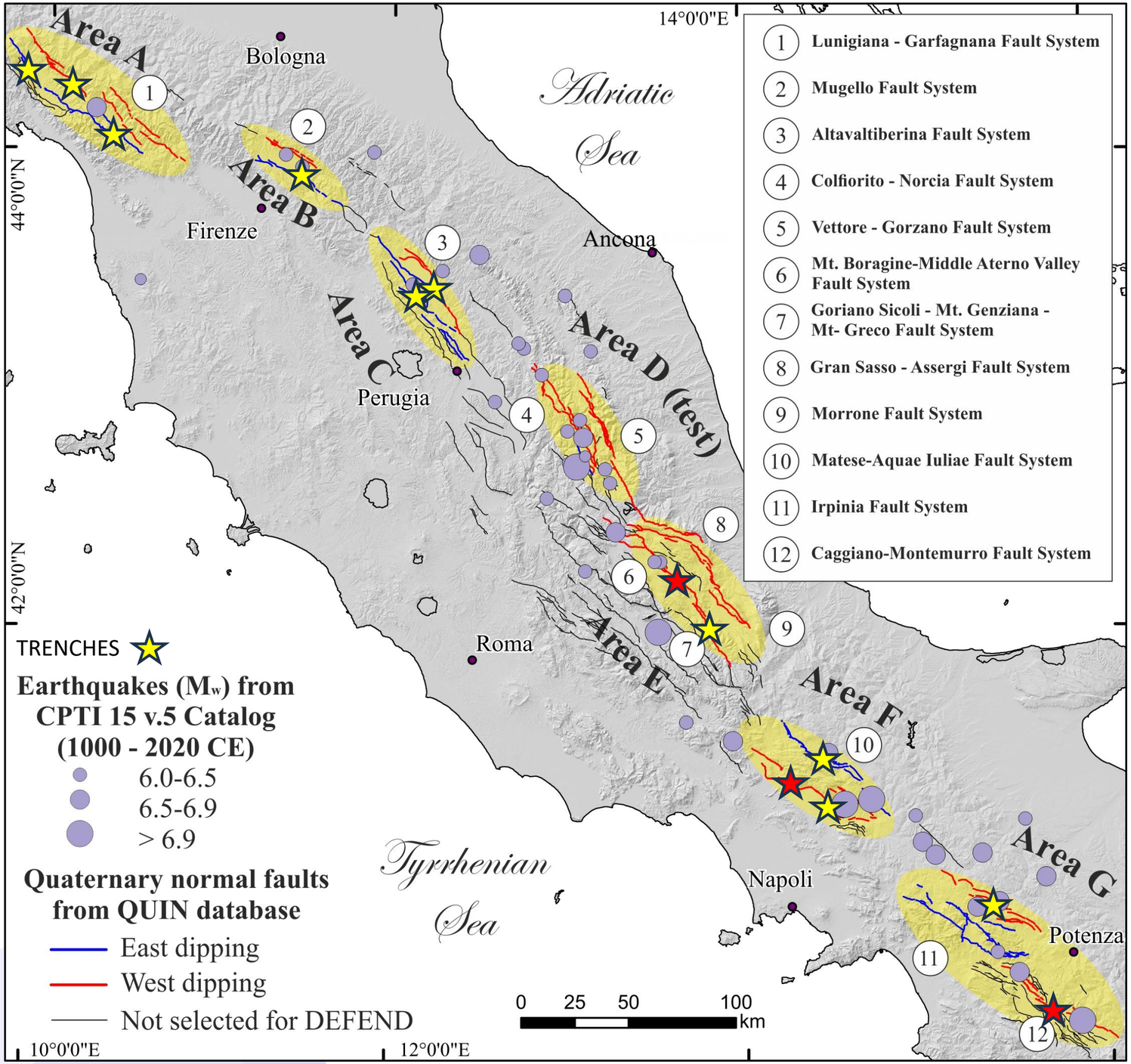
Trenching in DEFENS

14 trenches will be excavated

ERT surveys will precede trench placement where necessary.

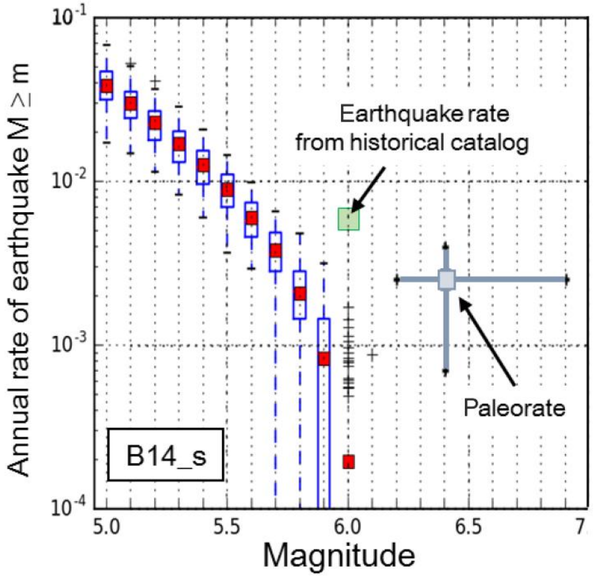
Where possible, we'll gather samples for radiocarbon analysis an accredited lab.

BETA
RADIOCARBON DATING
Consistent accuracy
Delivered on time
Beta Analytic



Data integration - modeling and interpretation

Model validation

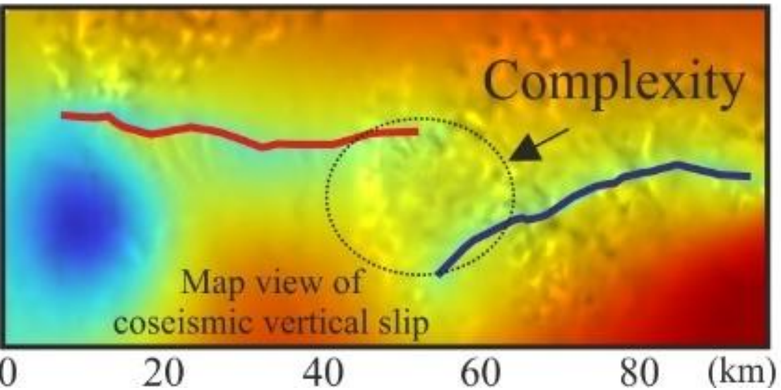


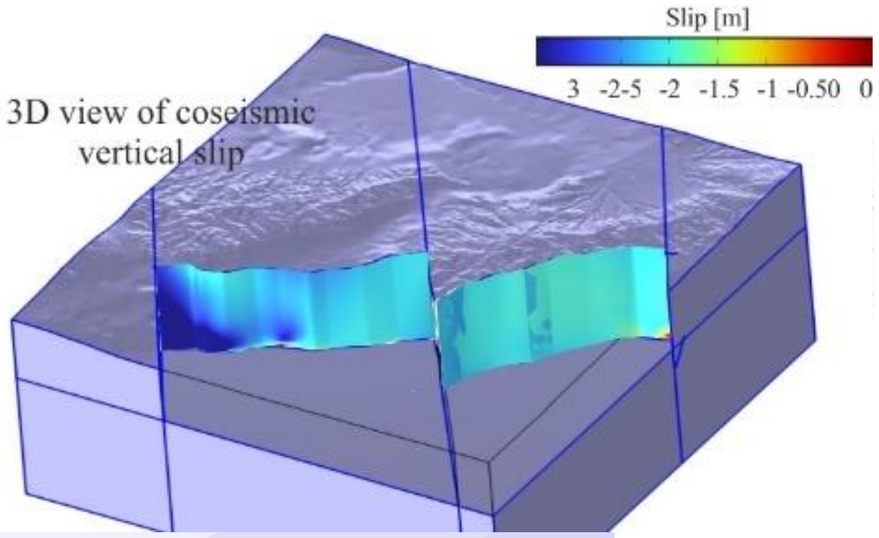
Comparison of simulation results (annual cumulative earthquake rate) with rates obtained from structural, geochemical, and paleoseismological data.

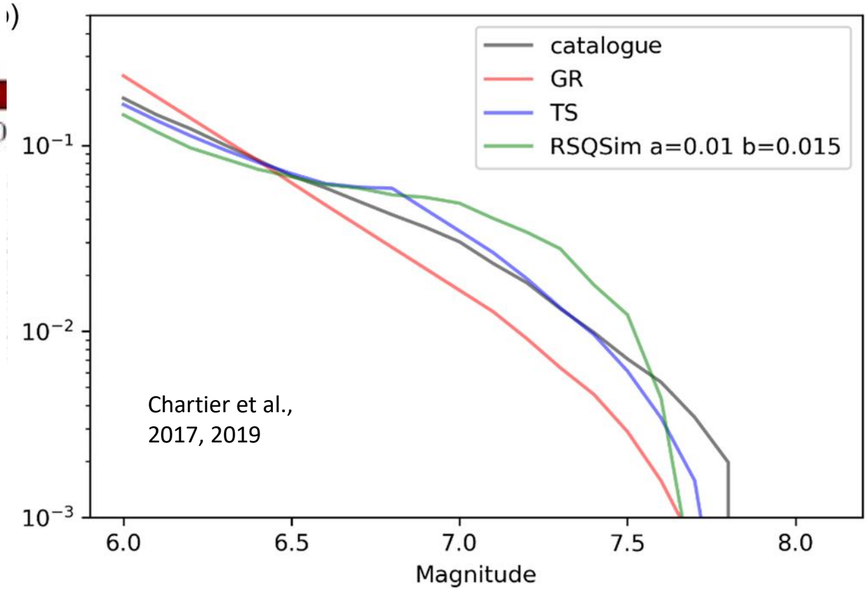
Comparison also with eq catalogs for eq rate

Analysis of the role of "earthquake gates"

We want to evaluate the role of fault complexities as earthquake gates for determining seismic potential of sources.







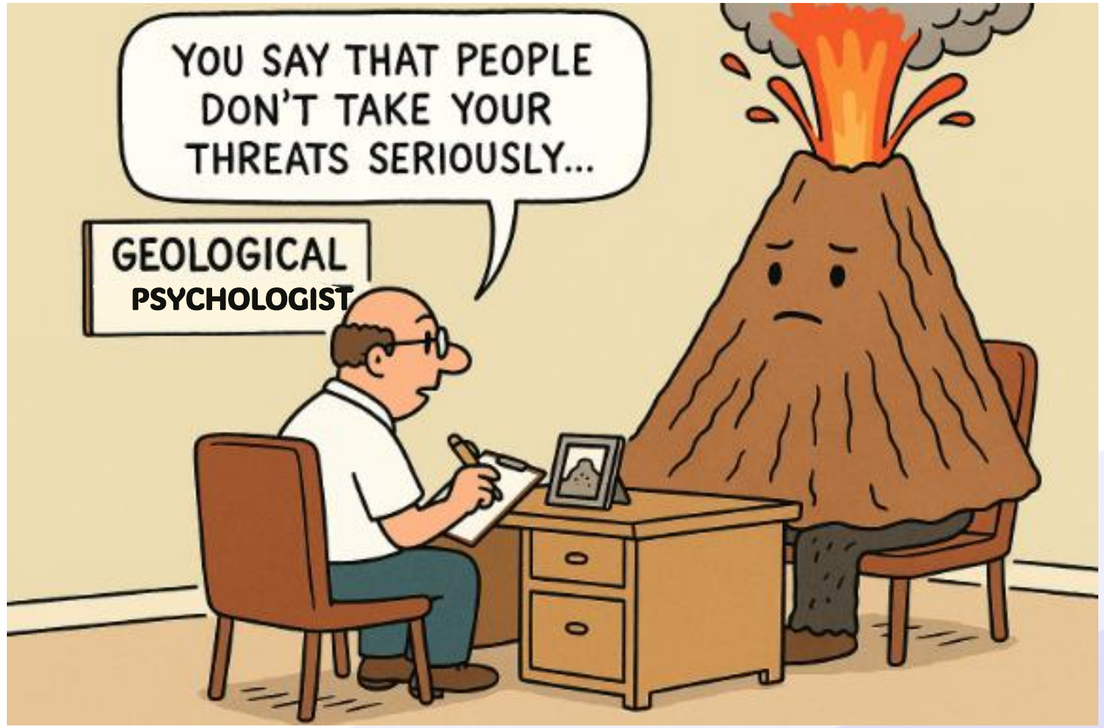
Psychological study for the GeoDEFENS App

Psychological screening with tests:

Initial population screening, involving psychological tests, will probe citizen preferences on geological knowledge and seismic risk. This is crucial for optimizing the GeoDEFENS App's launch impact through effective messaging strategies. The screening will be conducted via social media and online platforms, exploring nuanced aspects of individuals' perceptions of seismic risks and geological knowledge, accounting for gender, age, and education.

GeoDEFENS App data compilation:

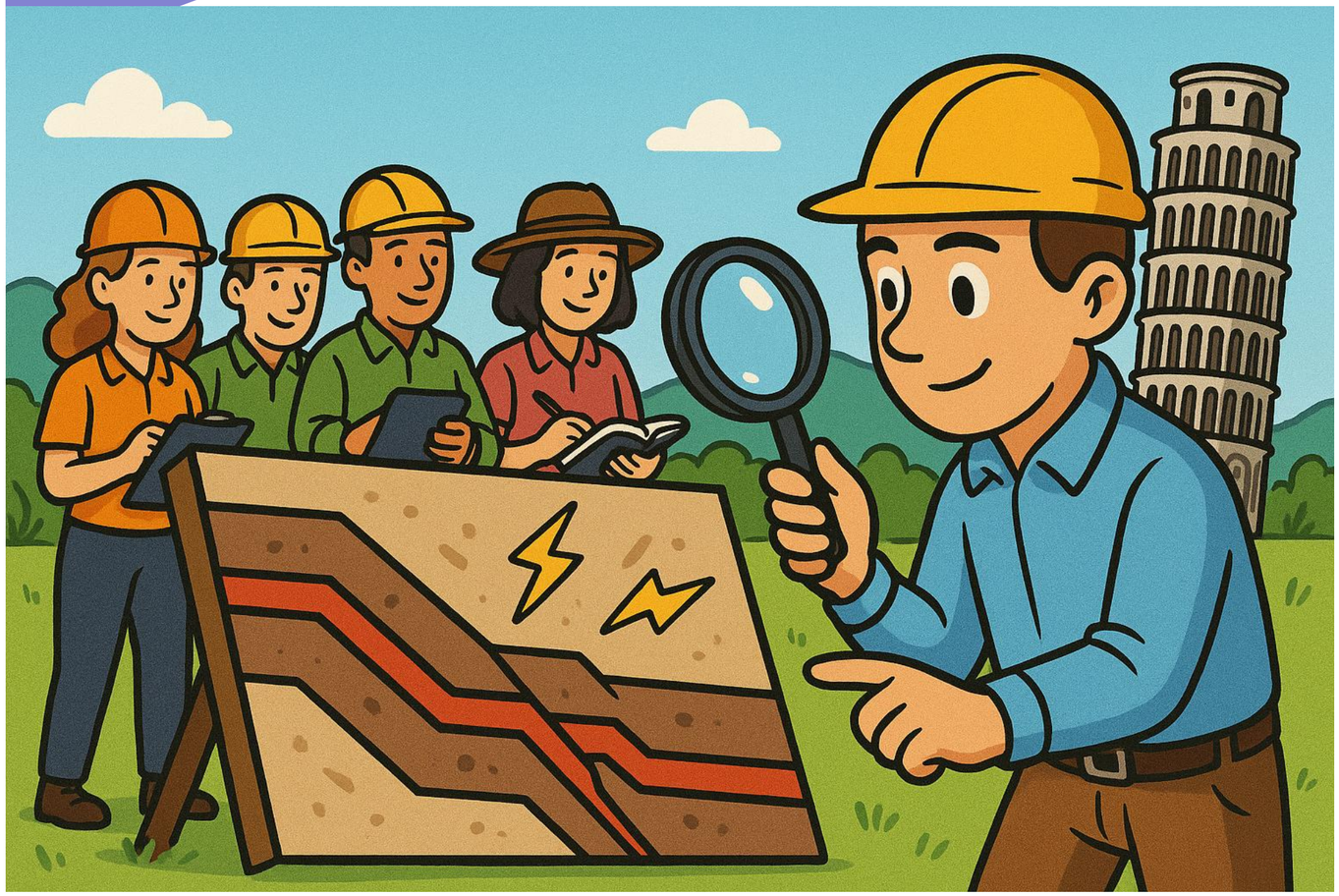
Technical-informative sheets compilation (on Excel) for the GeoDEFENS App by incorporating information on EQs and faults gathered during the project. The compilation will follow the guidelines set forth by the study on appropriate language defined in the psychological study.



GeoDEFENS App and DEFENS website (work in progress...)

Futura

Impact



Innovative fault and earthquake modeling

Improved seismic safety and awareness

Reduced earthquake-related losses

Eco-friendly, environmentally low-impact research

If DEFENS succeeds, it will not be because of a single good idea, but because of continuous interaction between people.

Simone

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