DEFENS

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

«Gabriele d'Annunzio» University
Chieti – Pescara
Department of Sciences

Dipartimento di Scienze

DEFENS PROJECT KICK-OFF Meeting
27th January 2026

Recruited Research Team Self-Introduction

DEFENS TEAM

FIS

Ministero dell'Università e della Ricerca

DEFENS Team

Carlo Andrenacci

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Maria Grazia Perna

Post–Doc Researcher

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Edoardo Sanità

Post–Doc Researcher

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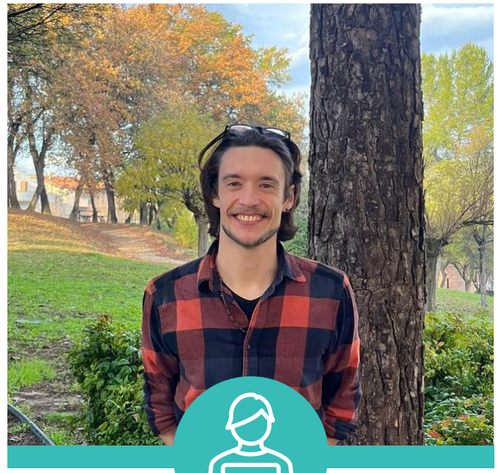

Michael Guy Marshall

Ph.D. student

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Scholarship Fellow

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

CARLO ANDRENACCI – Ph.D.

Now

Post-Doc Researcher
University "G. d'Annunzio" of Chieti – Pescara
Department of Sciences

2024 -2025

Research fellow
Istituto Nazionale di Geofisica e Vulcanologia

2020-2024

Ph.D.
Earthquake and Environmental Hazards
"G. d'Annunzio" University of Chieti – Pescara

2017-2019

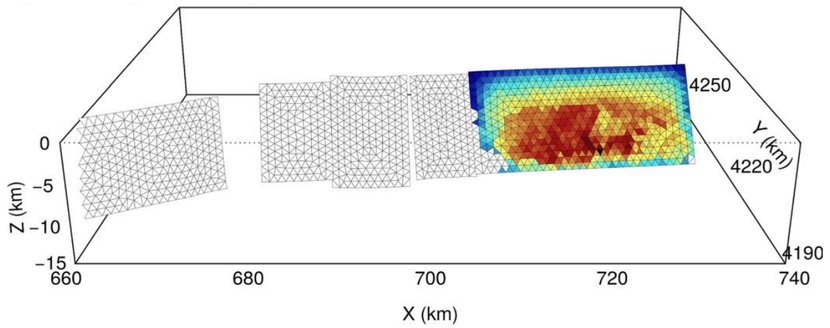
Master degree
Geological Sciences and Technologies
"G. d'Annunzio" University

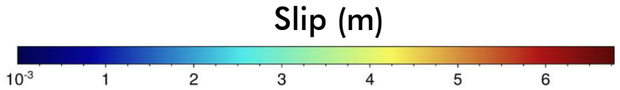
"My research interests include kinematic and deformation analysis of earthquake-related geological processes in active seismotectonic regions. My multidisciplinary approach includes structural geology, 3D numerical modeling, data analysis, and computer science applied to the study of active seismotectonic areas"

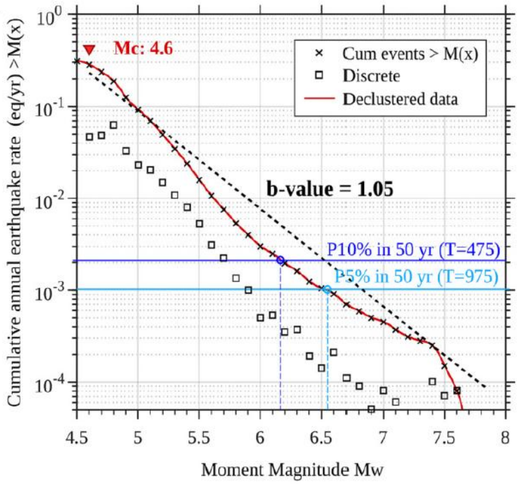
ROLE IN DEFENS

Post–Doc Researcher in Structural Geology and Numerical Modeling

Herrero-Barbero et al., 2023







Modeling the seismogenic sources

Identify and model the potentially seismogenic sources of extensional fault systems through the use of numerical modeling software.

Replication of the seismic cycle

Seismic simulators are capable of replicating rheological conditions and tectonic stresses in order to reproduce dynamic seismic cycles and coseismic ruptures over very long time periods.

Analysis of the role of earthquake gates

It is important to analyze the role of structural complexities of fault systems and their three-dimensional geometries in order to understand the actual seismic potential of seismogenic sources.

Interpretation and validation of models

The simulation results will be compared with seismological, historical, and paleoseismological data to validate the models that best represent reality and to provide more accurate tools for assessing seismic hazard in our country.

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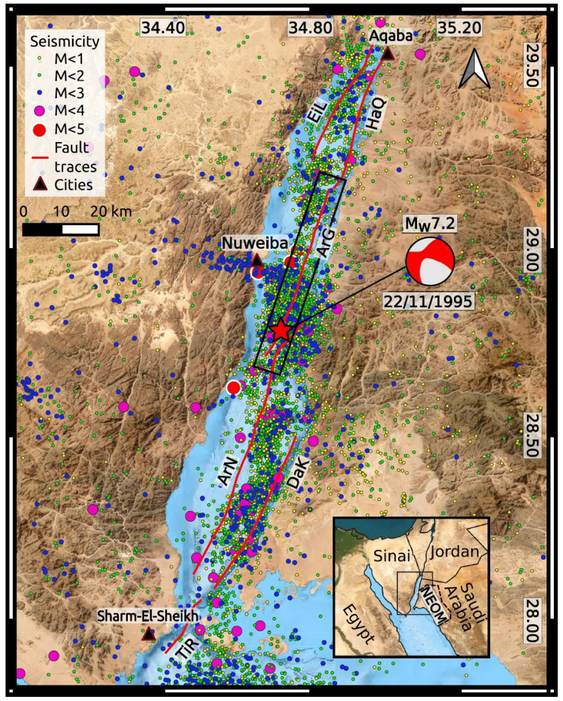
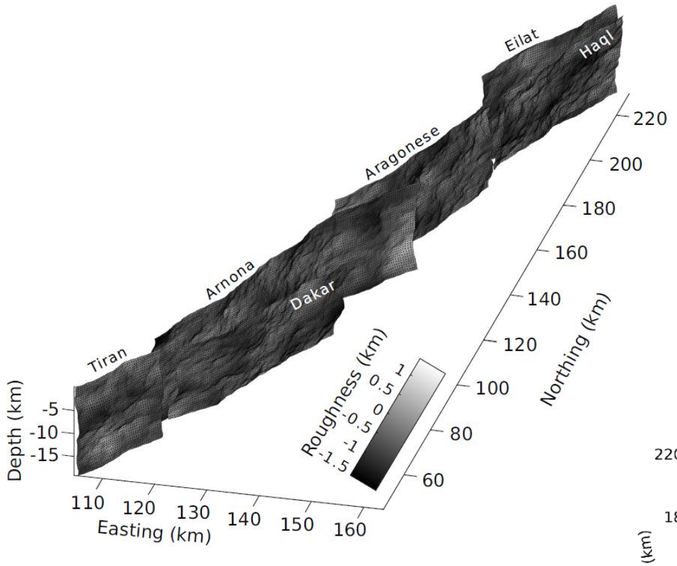
ONGOING ACTIVITIES

MCQ Sim

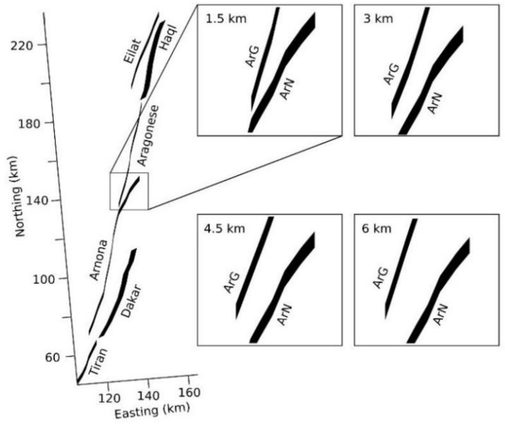
Source Model

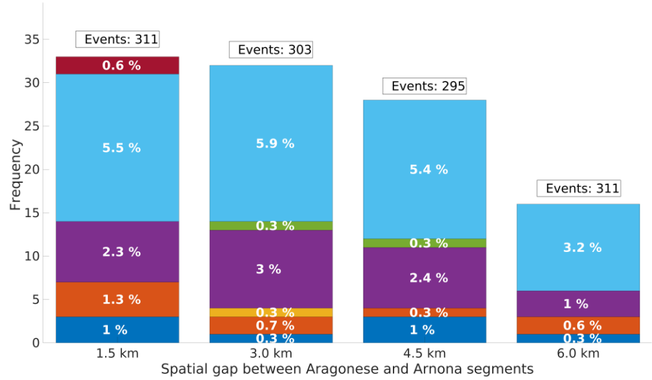




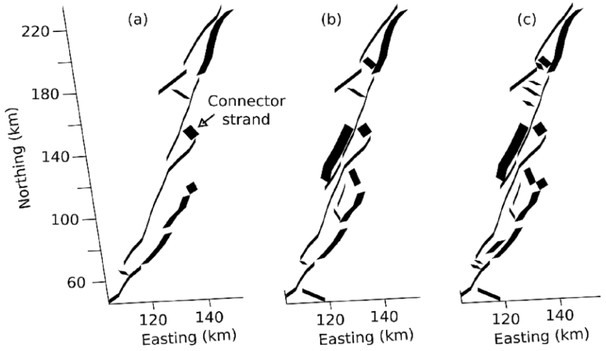
Aspitis et al., 2025

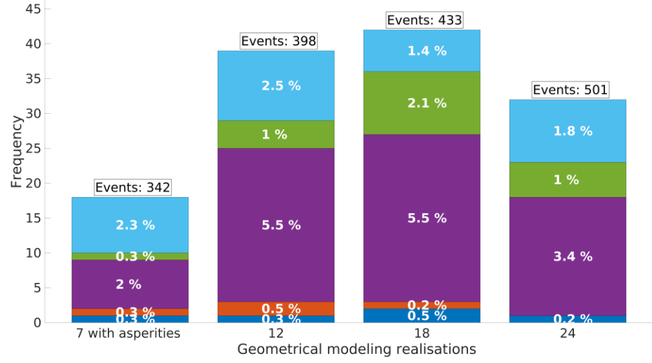
Effect of fault gaps





Effect of fault segmentation

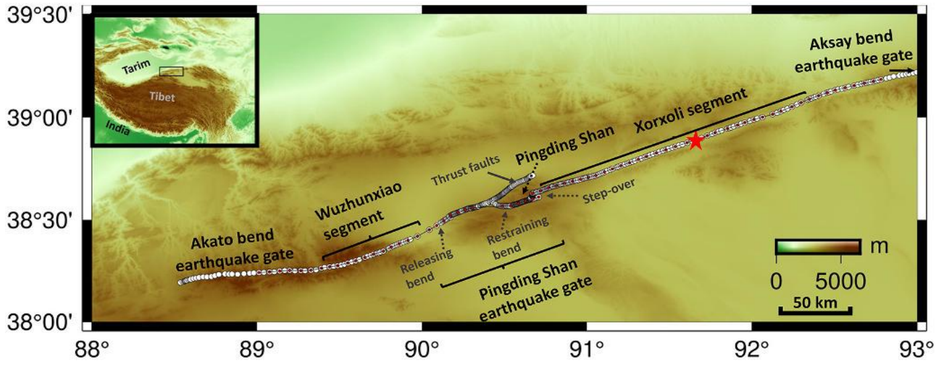


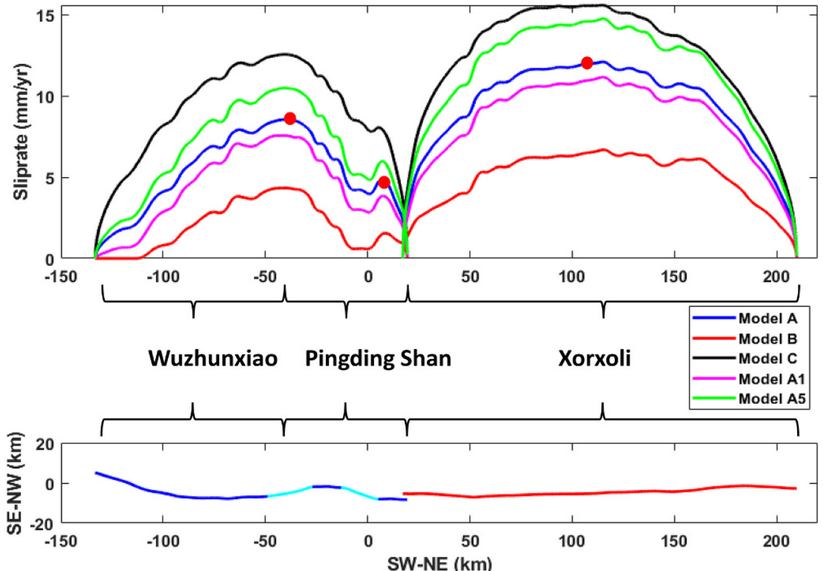


ONGOING ACTIVITIES

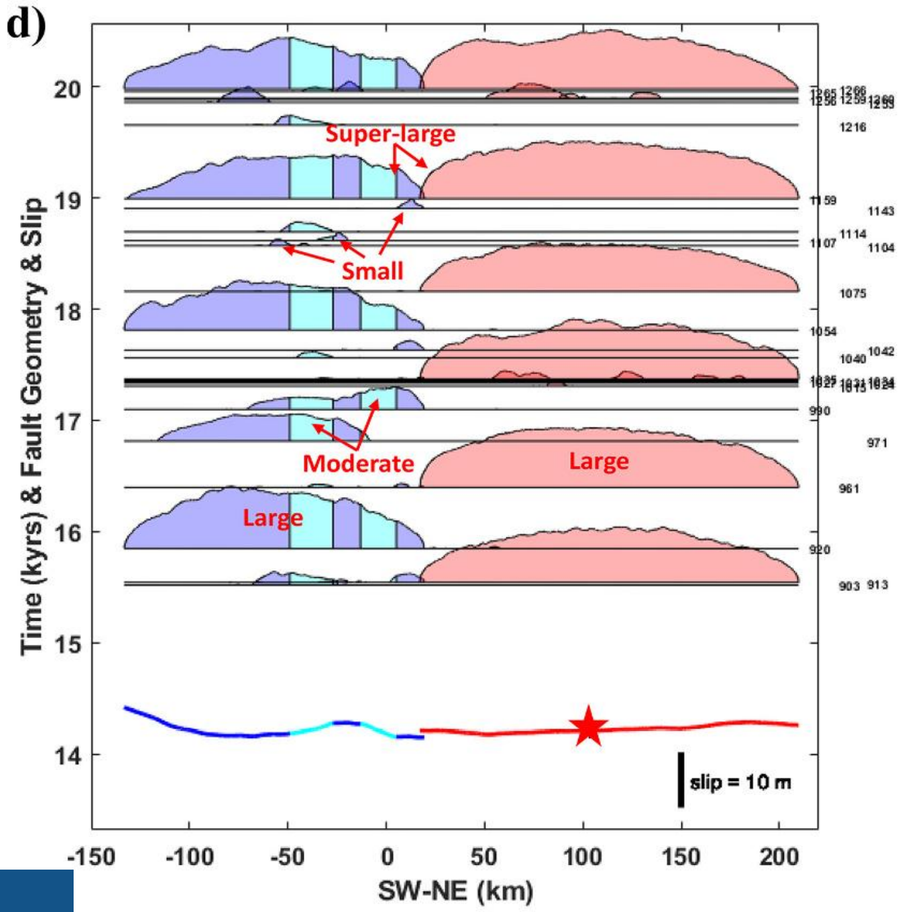
EQDyna

Source Model





Multicycle dynamic model



Liu et al., 2021

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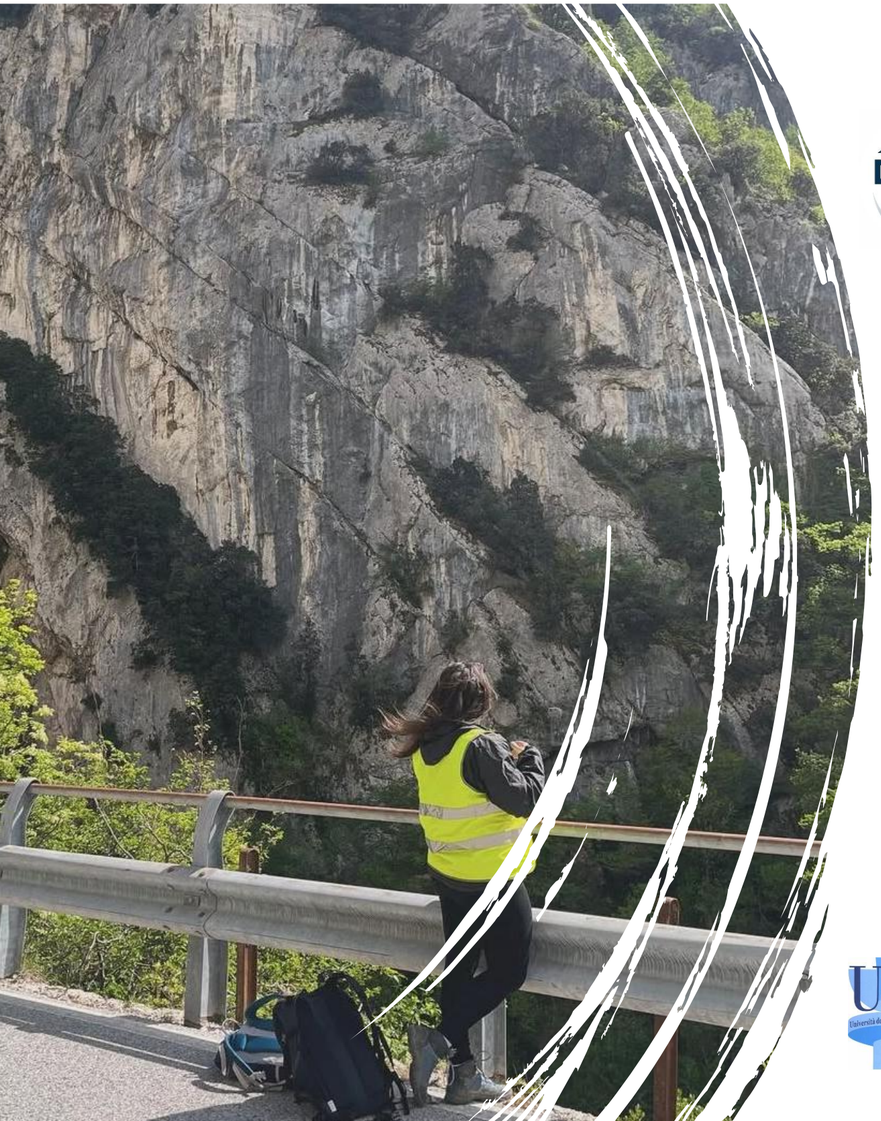
MARIA GRAZIA PERNA – Ph.D.



Now

Post-Doc Researcher
University "G. d'Annunzio" of Chieti – Pescara
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2024 -2025

Post-Doc fellow
Ore Geology
University of Padova
Department of Geosciences

2020-2024

Ph.D.
Earthquake and Environmental Hazards
"G. d'Annunzio" University of Chieti – Pescara

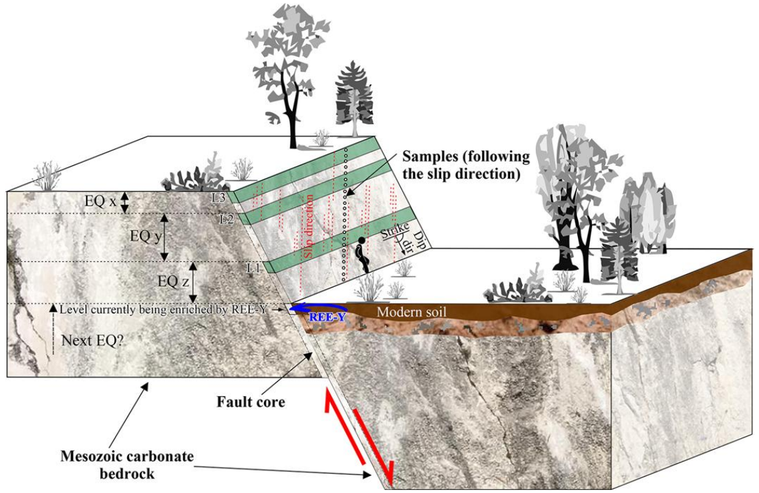
2017-2019

Master degree
Geological Sciences and Technologies
"G. d'Annunzio" University

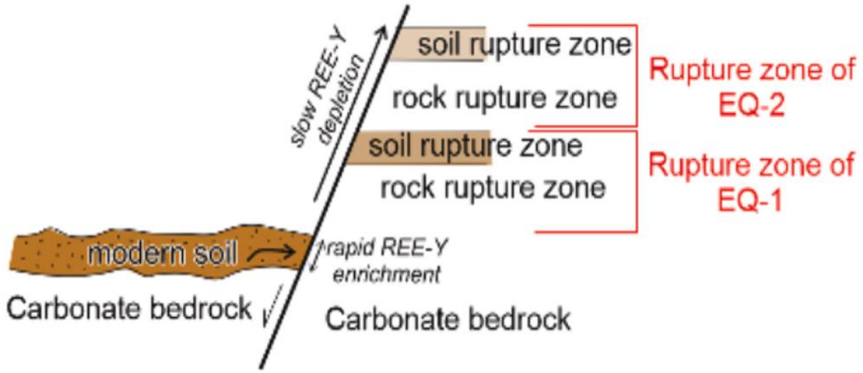
Maria Grazia focuses on alkaline and peralkaline environments integrating mineralogical, petrographic and geochemical analysis. I mainly investigate mineralogy and geochemistry of complex phases enriched in Rare Earth Elements. I also focus on the behavior of Rare Earth Elements in active tectonic settings

ROLE IN DEFENS

Post–Doc Researcher in Geochemistry and Petrology



Bello et al., 2023



Moraetis et al., 2023

Quantify soil–fault contribution to REE–Y enrichment

Measure and model the quantitative contribution of surrounding soils to REE–Y enrichment on carbonate fault scarps, investigating how soil pH, mineralogy, and organic matter influence REE–Y speciation, fixation, and mobility at the soil–carbonate interface.

Evaluate REE–Y levels as proxies for seismic cycles

Characterize successive enrichment/depletion levels along fault scarps to determine their reliability for reconstructing past seismic activity and calibrating temporal enrichment/depletion patterns.

Experimental data and thermodynamic modeling

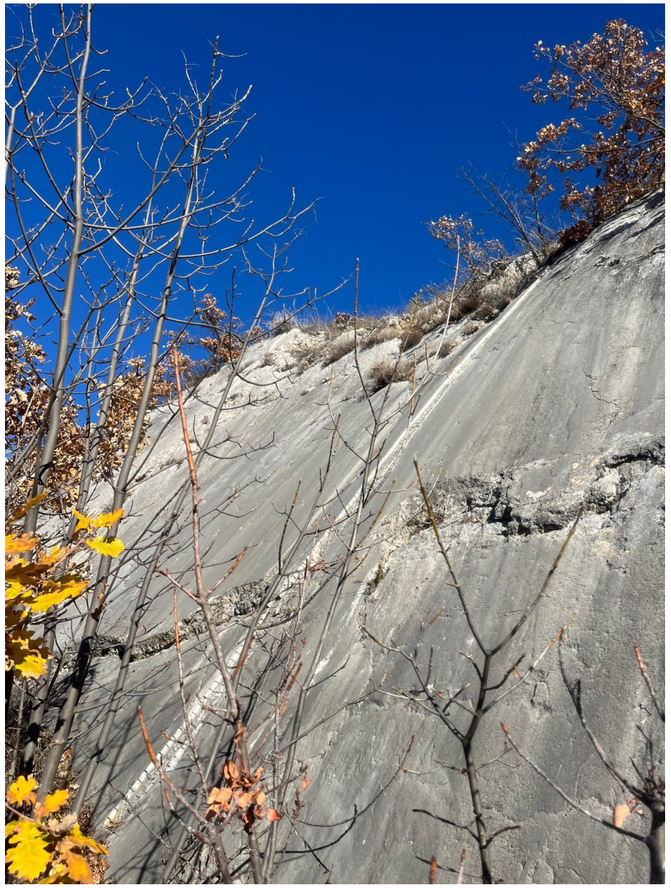
Combine laboratory experiments with thermodynamic simulations to improve the understanding and predictive modeling of REE–Y mobility during seismic cycles.

Geochemical database development

Development of a comprehensive geochemical database integrating paleoseismological data, ^{36}Cl exposure ages, tephra geochemical analyses, radiocarbon dating, and $^{40}Ar/^{39}Ar$ chronologies for seismic history reconstruction.

ONGOING ACTIVITES

Sampling strategy



ONGOING ACTIVITES

Sample preparation for ICP-MS analysis

FROM → **THROUGH** → **TO**

Washing of the sample with 5 mL H_2O_2 (130 vol.)

Mechanical removal of ~2 mm of surface patina

Collection of ≥ 0.03 g of material

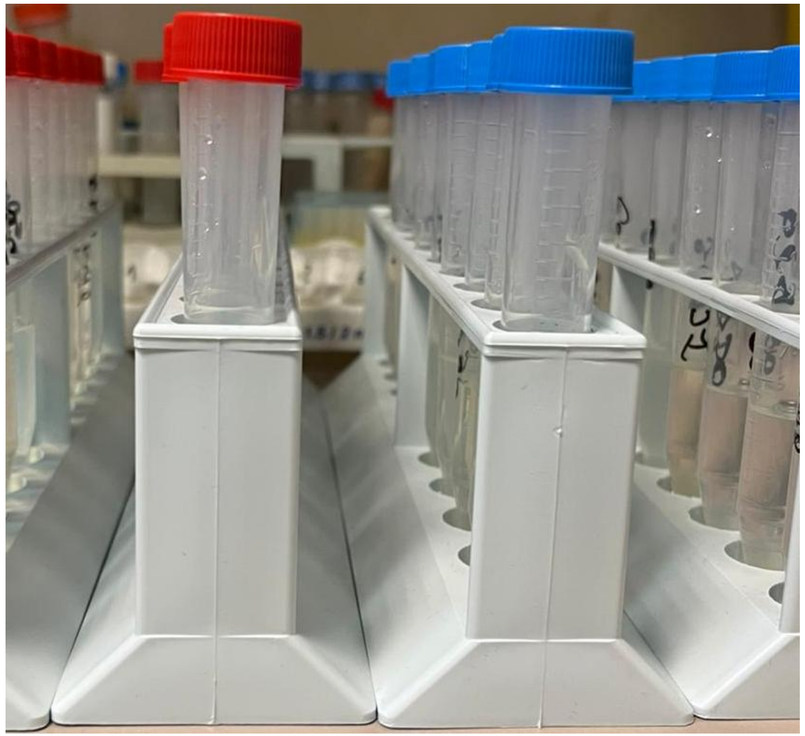
Second washing with 5 mL H_2O_2 (130 vol.)

Drying at 80 °C until complete dryness

Digestion with 10 mL HCl 2 N

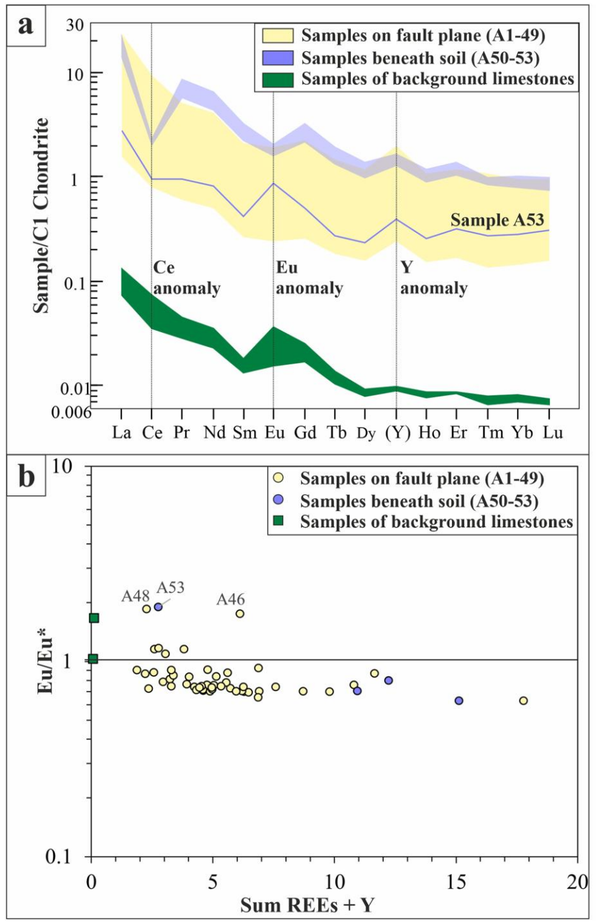
Drying at 105 °C until complete dryness

Second digestion with HNO_3 diluted 1:10 with distilled H_2O



ONGOING ACTIVITES

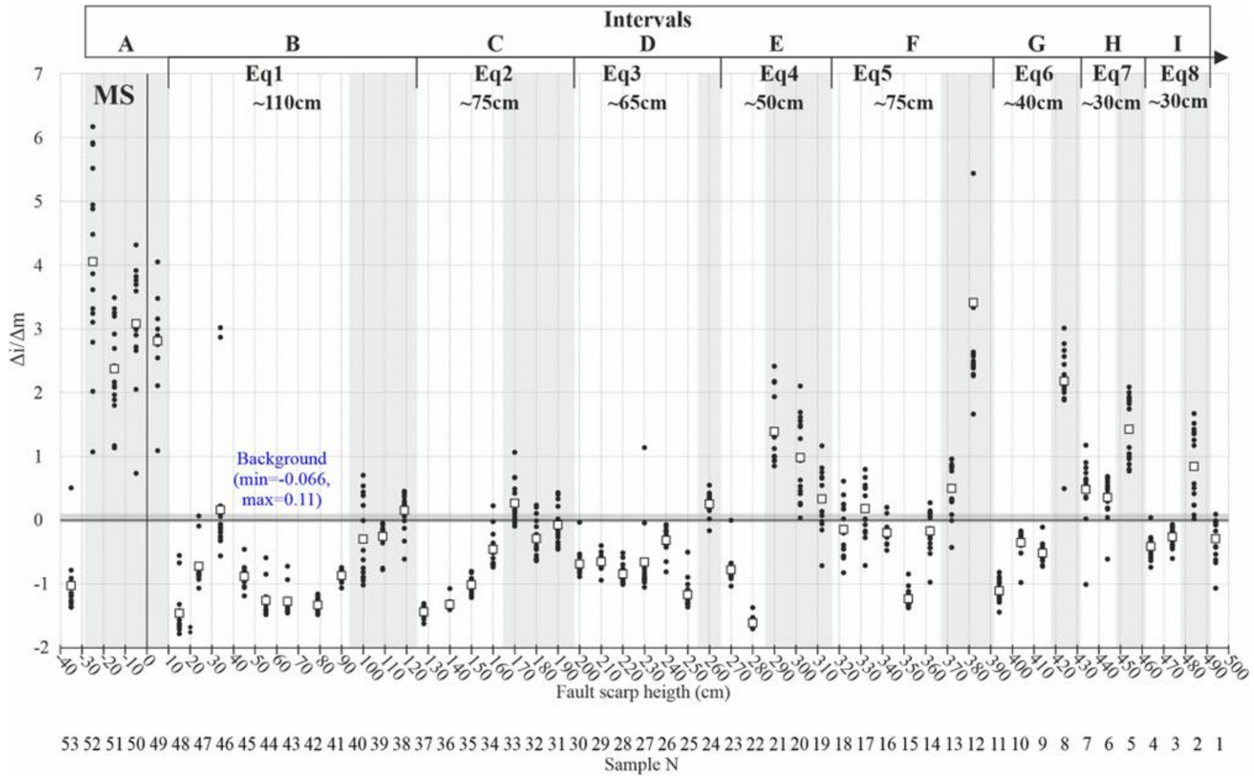
ICP-MS analysis results



(a) Pattern of Rare Earth Elements (REE) + Y (REE + Y) for the LIM bedrock and fault carbonates samples.
(b) Total REE + Y (ΣREE + Y) compared to the Eu/Eu* ratios of the samples analyzed.

Bello et al., 2025

Variability of rare earth elements + Y (REE-Y) content in our limestone sample cores along the fault scarp height (cm).



Bello et al., 2025

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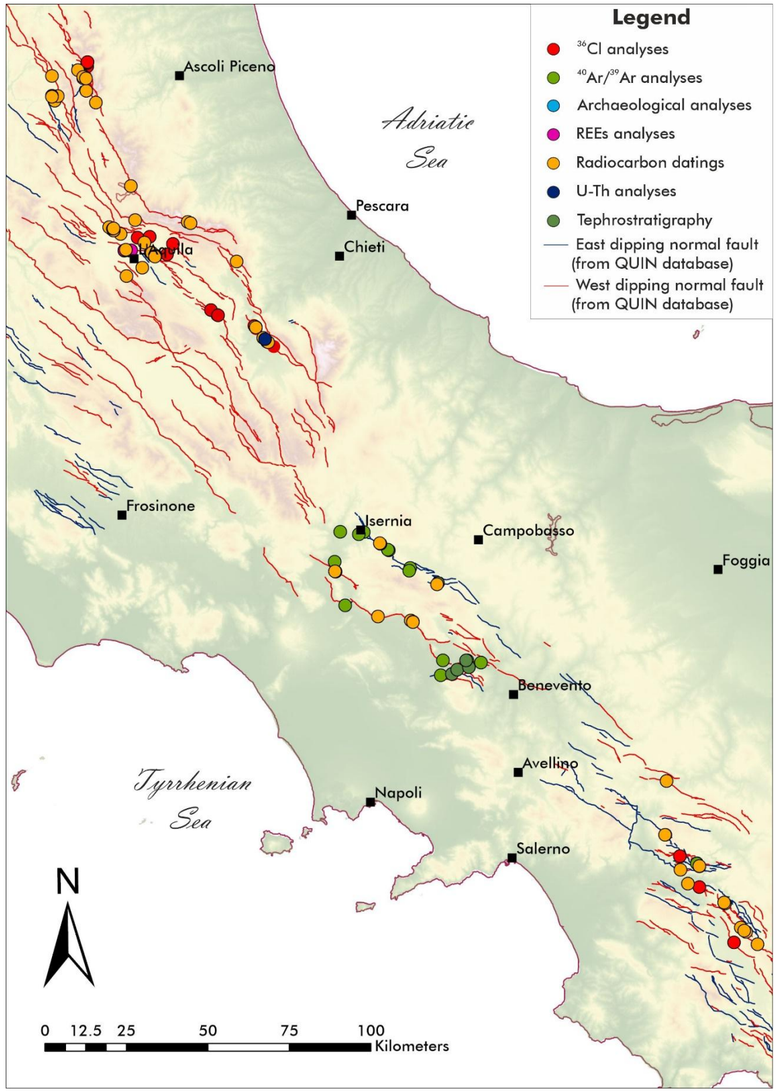
ONGOING ACTIVITES

Geochemical – paleoseismological database construction



DataID	19	20
Latitude	41.3403	41.33660
Longitude	14.4106	14.41842
AreaID	10	10
Area	Matese - Aquae Iulie	Matese - Aquae Iulie
Main Fault (QUIN)	Ailano - Sant'Angelo di Alife	Ailano - Sant'Angelo di Alife
Fault System (QUIN)	Aquae - Iulie - Piedimonte Matese	Aquae - Iulie - Piedimonte Matese
Fault segment	San Potito	San Potito
Type of analysis	Radiocarbon datings	Radiocarbon datings
Trench / Sampling site	San Potito	San Potito
Stratigraphic Unit	Buried Paleosol	Colluvium
Sample ID	S249-A	S227
Material	Charred material	Organic Sediment
Radiocarbon age (years B.P.)	38800 ± 380 BP	3000 ± 30 BP
2σ calibrated age ranges	43301 - 42209 BP	3253 - 3075 BP (89.4%) - 3326 - 3297 BP (6.0%)

DataID	85	95
Latitude	42.103677	42.124117
Longitude	13.918334	13.886263
AreaID	9	9
Area	Morrone - Porrara	Morrone - Porrara
Main Fault	Mt. Morrone	Mt. Morrone
Fault segment	Popoli-Roccacasale-Pacentro	
Site		Roccacasale
Analysis Type	^{36}Cl	U - Th
Sample ID	RC6	M4G/1
n(^{36}Cl)/n(^{35}Cl) (*10^{-12})	1.25 ± 0.06	
n(^{35}Cl)/n(^{37}Cl)	6.28 ± 0.13	
Atoms $^{36}Cl_{corr}$/gr (×10^{5})	11 ± 0.62	
Cl (ppm)	33.23 ± 1.51	
CaO (%)	46310	
Exposure age (ky)	First model (with RC7) 41.5 ± 3.5 - Second model (without RC7) 44.7 ± 2.8	
Deposition age (ky)	Second model 2.0 ± 1.1	
^{238}U (ppb)		154.95 ± 0.16
^{232}Th (ppb)		0.1216 ± 0.0020
Δ^{234}U measured		21.6 ± 1.4
[^{230}Th/^{238}U] activity		0.903 ± 0.0018
^{230}Th/^{232}Th atomic (*10^{-6})		18969 ± 315
Age (ka) uncorrected		230.3 ± 2.0
Age (ka) corrected		230.3 ± 2.0
Δ234U corrected		41.5 ± 2.6
ReferenceID	10	12
Main Authour	Puliti	Vignaroli
Journal	Tectonics	Tectonophysics
Year	2024	2022

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EDOARDO SANITA' – Ph.D.

Now

Post-Doc Researcher
University "G. d'Annunzio" of Chieti – Pescara
Department of Sciences

2023-2025

Post-Doc fellow
Structural Geology, Tectonics, and Metamorphism
University of Pisa
Department of Earth Sciences

2019-2022

PhD in Structural Geology and Tectonics
University of Firenze
Department of Earth Sciences

2016-2019

Master degree
Geological Sciences and Technology
University of Pisa

"My research interests focus on the kinematic and deformation analysis of geological processes across different crustal levels in active seismotectonic regions and fossil systems (e.g., the Alps, the Apennines, and the Makran) responsible for mountain building events. My multidisciplinary approach includes structural geology, field mapping, micro- and nano-analytical techniques, and thermodynamic modelling"

ROLE IN DEFENS

Post–Doc Researcher in Structural Geology and Tectonics

Fieldwork

Field mapping and structural analysis of main fault systems targeted by DEFENS.

High-Resolution Topography

High-Resolution Topography, photogrammetry-derived DEM and Lidar acquisition through Airborne, and topographic profile analysis.

Textural analysis of fault rocks

High-resolution microtextural analysis of fault rocks through Electron Back-Scattered Diffraction (EBSD) techniques for elucidating the aseismic-seismic transition during crustal deformation.

Database Development

Development and implementation of geological databases with structural-geometrical and topographic data got through DEFENS.

ONGOING ACTIVITES

Field activities management

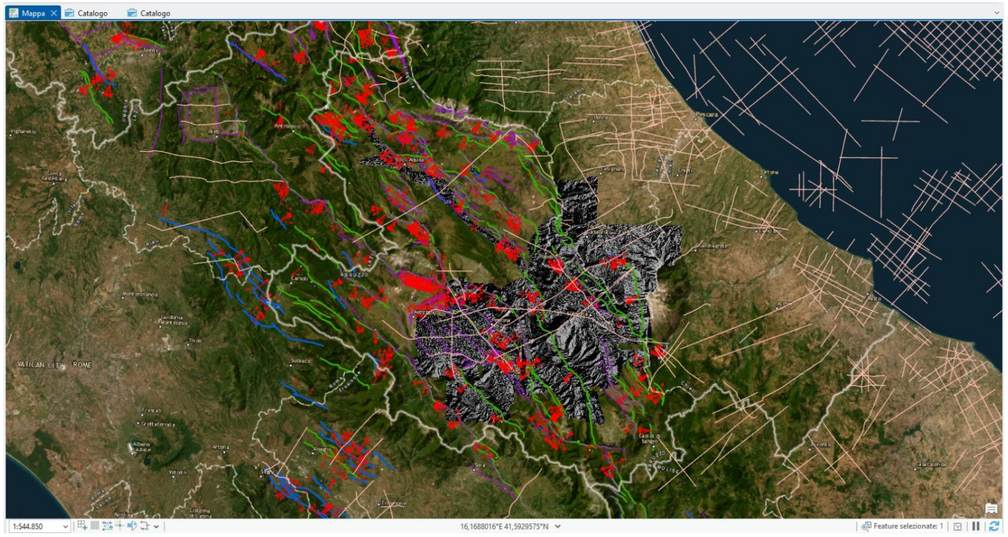
Bibliographic review for:

- Campaigns planning
- Trenches planning
- LIDAR acquisition by AirBorne

Structural mapping and sample collection

- Classic fieldwork
- Structural data collection
- Sample collection for EBSD analysis

Structural and topographic data storage in a GIS database



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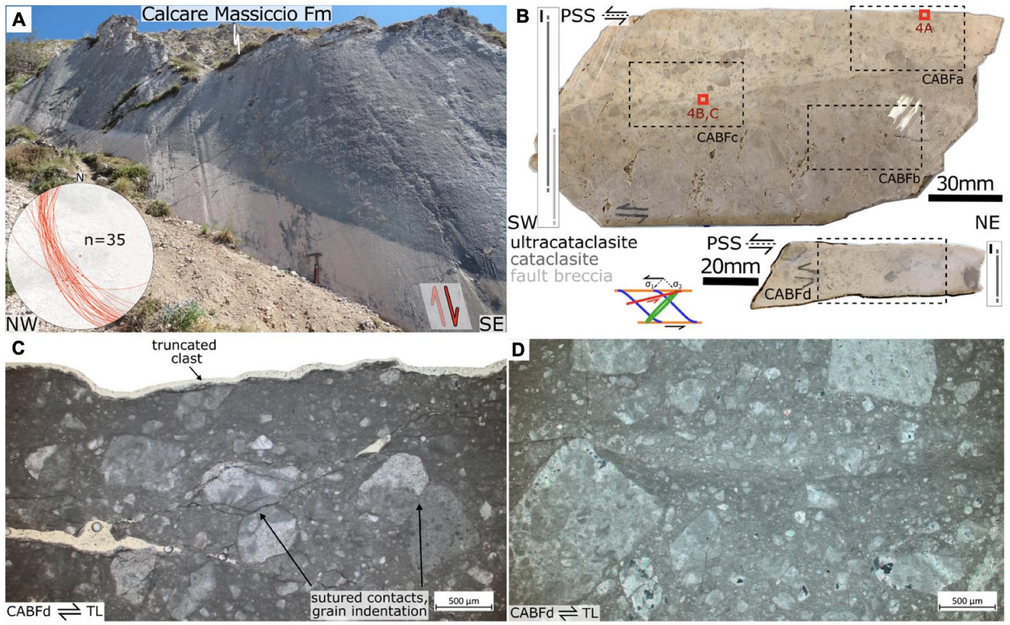
ONGOING ACTIVITES

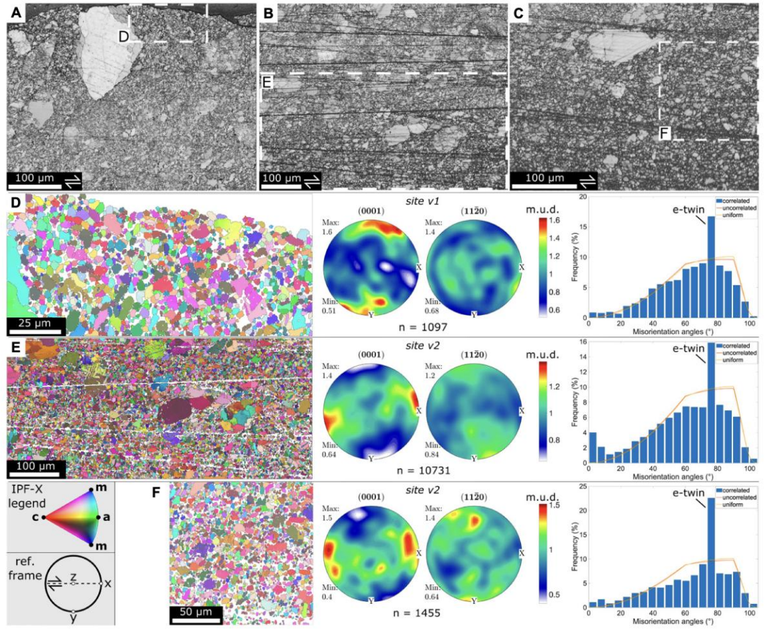
EBSD analysis

Example from **Mt. Vettore Fault**

Investigate microscale mechanisms controlling deformation along active fault system



Del Sole et al., 2024



Del Sole et al., 2024

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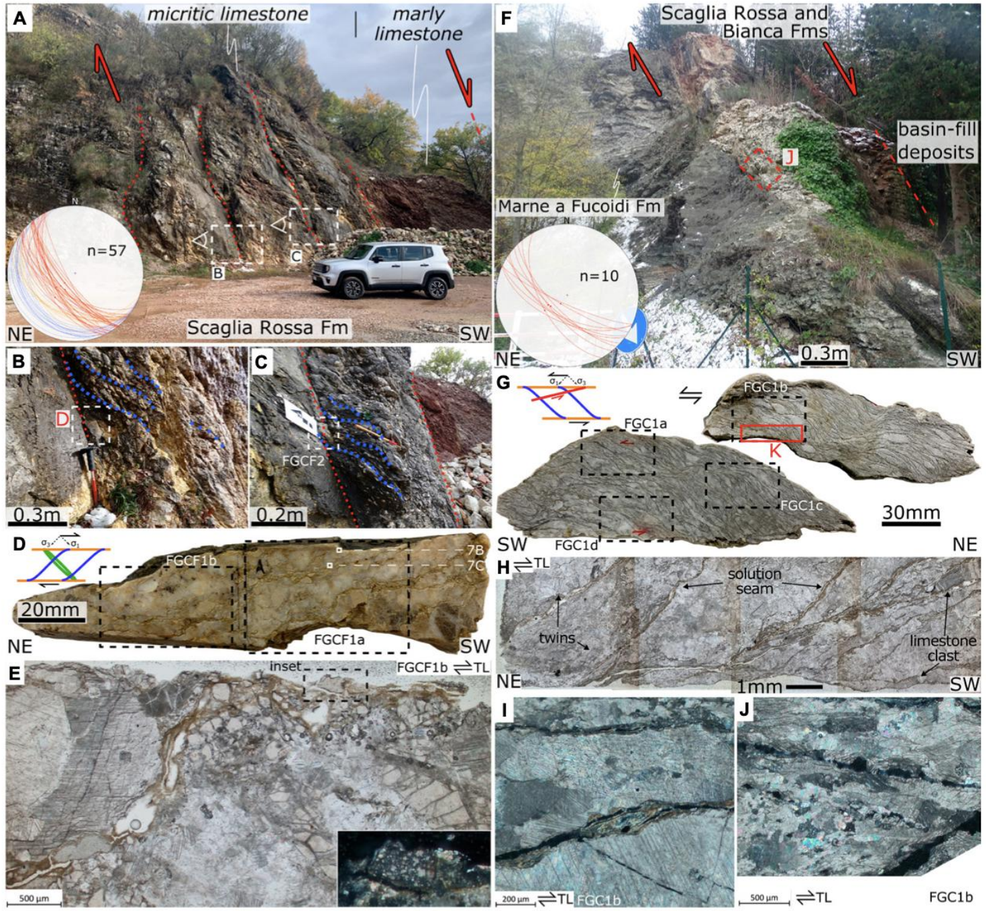
ONGOING ACTIVITES

EBSD analysis

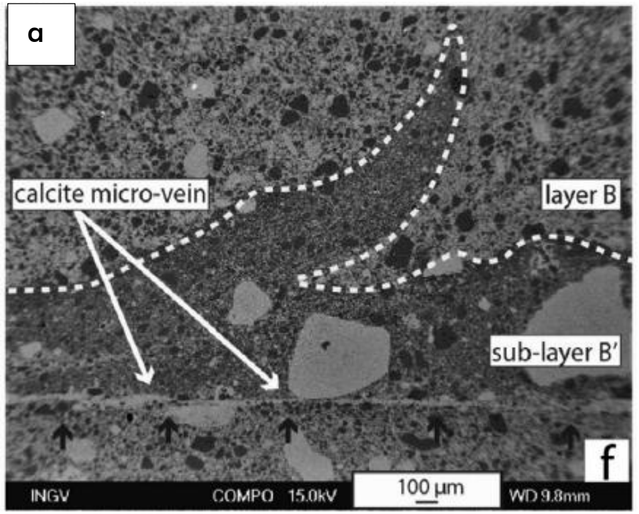


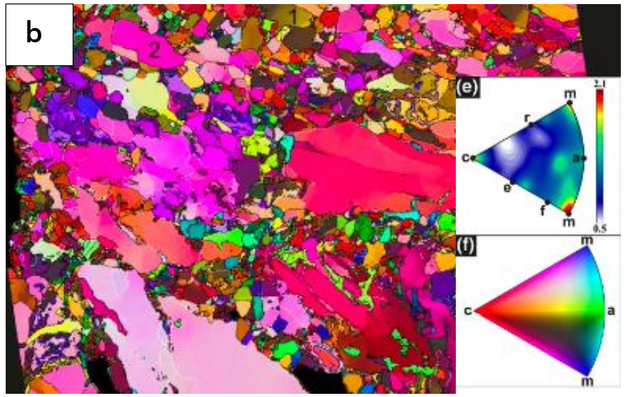
Del Sole et al., 2024

Example from **Gubbio Fault**

Investigate microscale mechanisms controlling deformation along active fault system

Different deformation mechanisms may coexist simultaneously in different domains of a fault. Understanding which mechanisms promote or inhibit future ruptures and fault propagation in space and time is fundamental





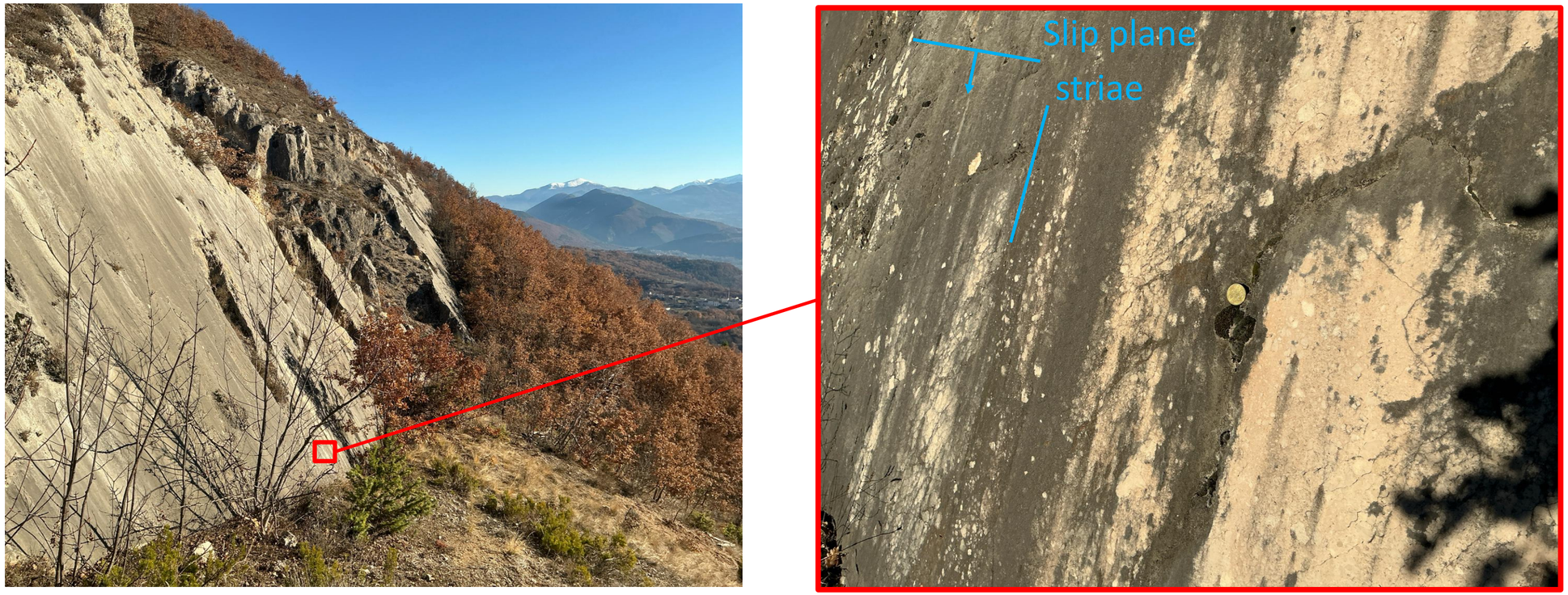
Ohl et al., 2019

ONGOING ACTIVITES

EBSD analysis

Samples from **Roccapreturo Fault System** (Middle Aterno Valley, Central Apeninnes)

Investigate microscale mechanisms controlling deformation along active fault system



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MICHAEL GUY MARSHALL – M.Sc.

Now

Ph.D. Student in Structural Geology
Geosciences
"G. d'Annunzio" University of Chieti – Pescara

2022-2025

Geology Master Student
RaMES
Alma Mater Studiorum - University of Bologna

ERASMUS
"NTNU" in Trondheim, Norway

Internship abroad with "Metamorphic A.S."
Norway

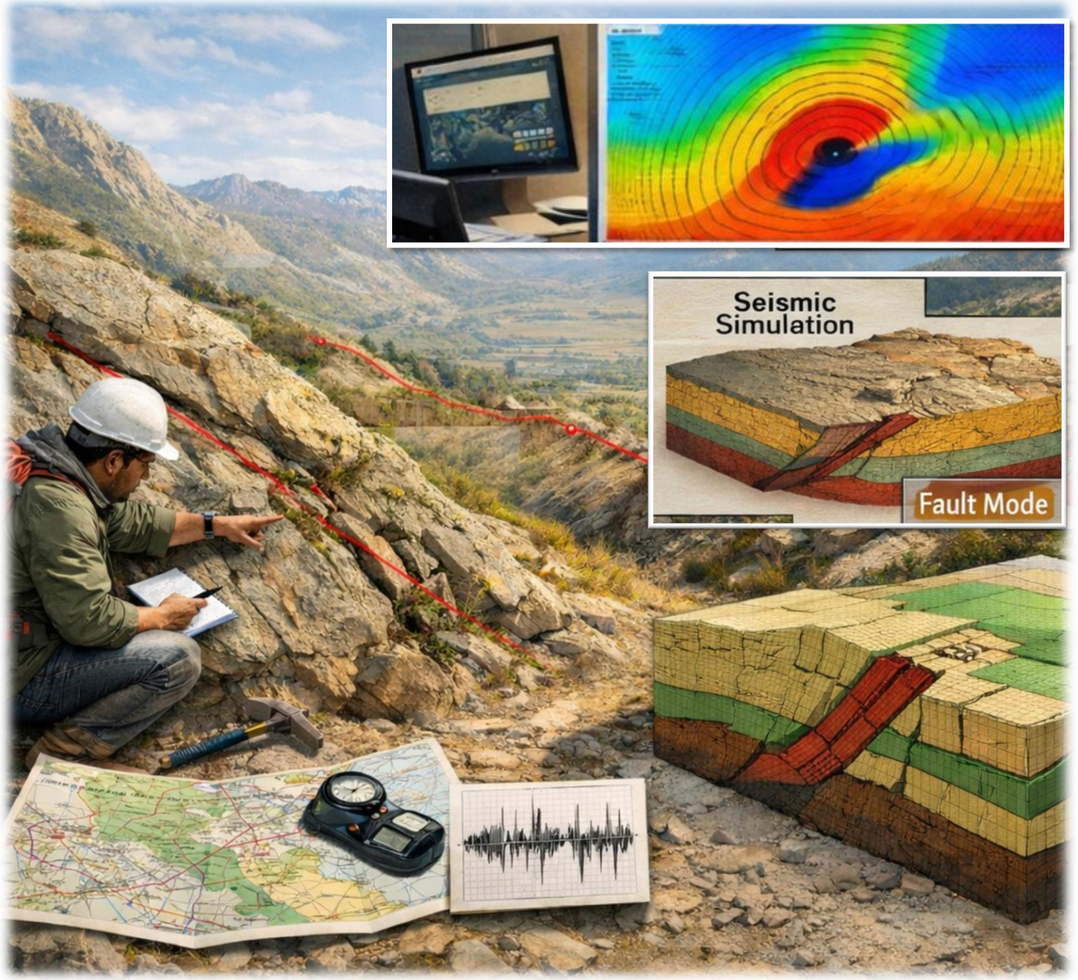
2018-2021

Bachelor degree
Geological Sciences
Alma Mater Studiorum - University of Bologna

"Geologically constrained 3D modeling of subsurface geometries is my personal passion and was the backbone for my thesis. Incorporating these with physically backed dynamic models will be the basis for my PhD project. I hope to learn these state-of-the-art parameter collecting strategies from my team and apply them accordingly"

ROLE IN DEFENS

Structural Geology Ph.D. Student



Collect structural field data

Collecting data in the field is the first step. Data is intended as both classic «compass and hammer» structural data and high-resolution LIDAR imaging. The data will be meticulously treated with the highest standards.

Develop 3D models

The field data will be used alongside a thorough state of the art literature study session as input to the modeling phases. An important milestone will be the development of high-resolution topographic 3D models of selected areas along the Apennines.

4D Dynamic rupture models

Once a strong backbone has been achieved, the time dimension can be added to fault models, obtaining an archive of time constrained seismic events. These will be used to check the model's reliability and (if determined reliable) even forecast future seismic events.

Disseminate scientific knowledge

The publishing of relevant scientific articles in these three years will be impactful and will aim to spread evidence backed scientific knowledge about the seismic hazards looming below the Apennines.

ONGOING ACTIVITES

Currently working on… getting settled in.

I have just started working alongside the team with:

- Catching up as fast as I can (completed ArcGis Pro Course)
- Reading literature about the project's study areas
- Selecting (undisclosed) area of interest.
- Learning the team's methods and goals.
- Studying dynamic rupture simulation software.
- Verifying possible machine learning applications.
- Understanding university policies, politics, practices, forms, website, etc…

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CAMILLO DE NOVELLIS

Now

Scolarship fellow
University "G. d'Annunzio" of Chieti –Pescara
Department of Sciences

2021-2026

Master degree
Geological Sciences and Technologies
"G. d'Annunzio" University

2017-2021

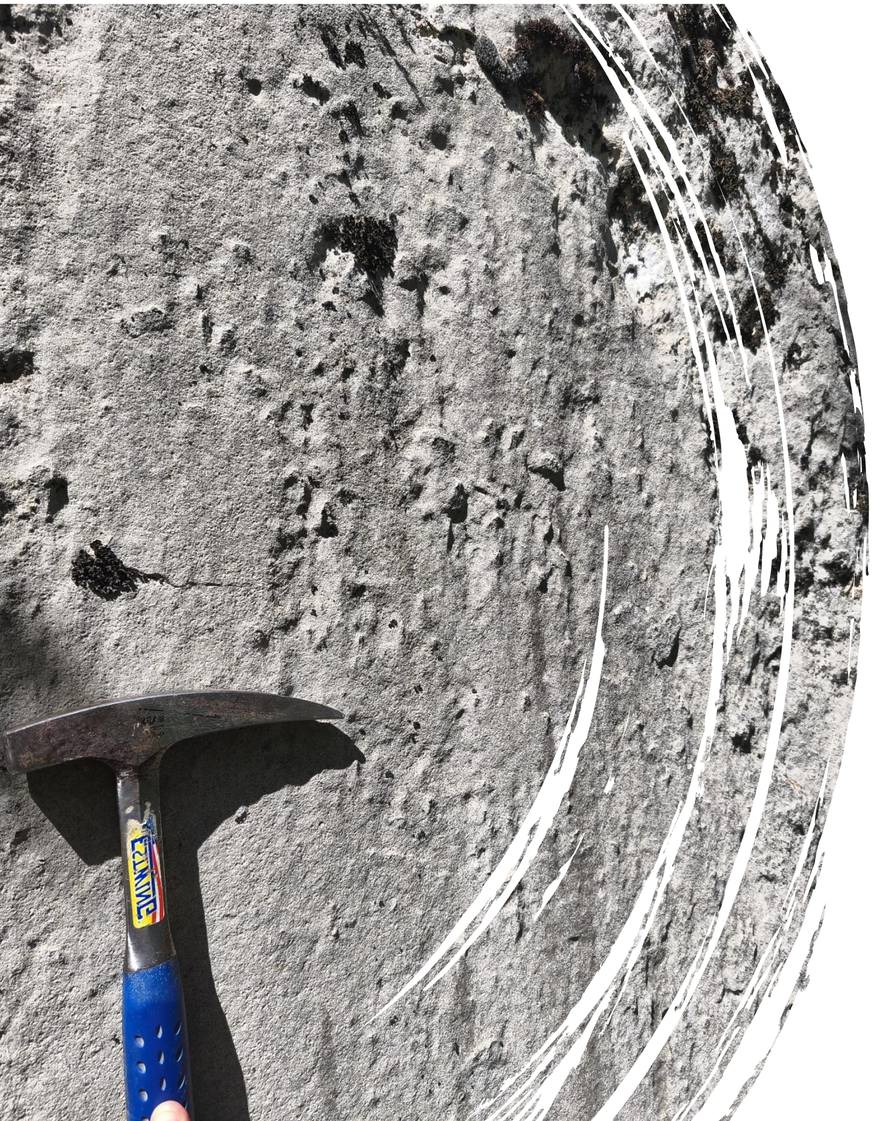
Bachelor degree
Geological Sciences
"G. d'Annunzio" University

"Geological and structural mapping of fault systems to understand their kinematic evolution and deformation history.

Identification, characterization, and spatial analysis of fault geometries, slip indicators, and structural relationships, in order to constrain the mechanisms of fault activity."

ROLE IN DEFENS

Scolarship Fellow



Geological survey

Structural field survey activity for a systematic and georeferenced collection of geological and structural-geological data necessary to characterize the long-term surface deformation.

Geological-structural data management

Development of conceptual and thematic structural-geological maps and datasets.

Structural analysis

Analysis and integration of acquired structural data to identify the main deformation patterns and the geometric and kinematic relationships between structures.

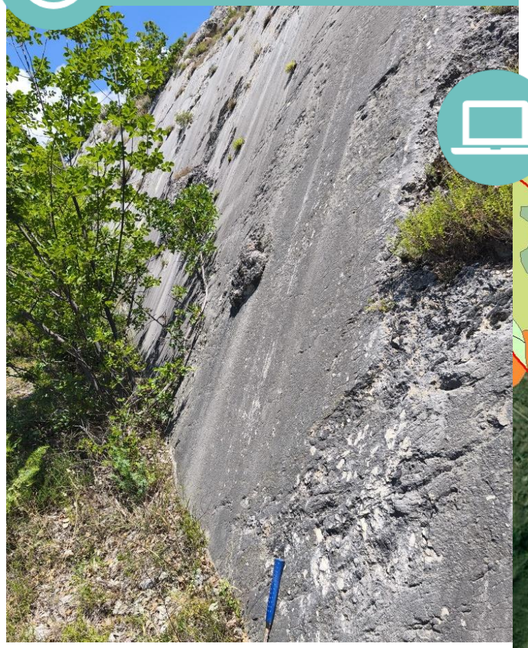
Interpretation

Interpretation of the results within the regional structural and geodynamic framework, to support the evolutionary reconstruction of the study area.

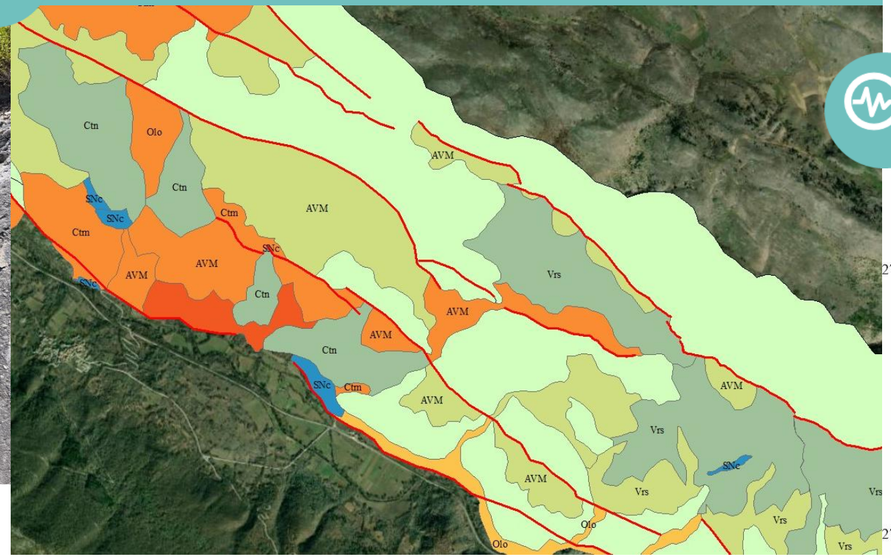
**DEFENS – 3D gEology-constrained seismic rupture dynamic models:
a new interdisciplinary strategy For Earthquake forecastiNg and reSilience**

ONGOING TO ACTIVITIES

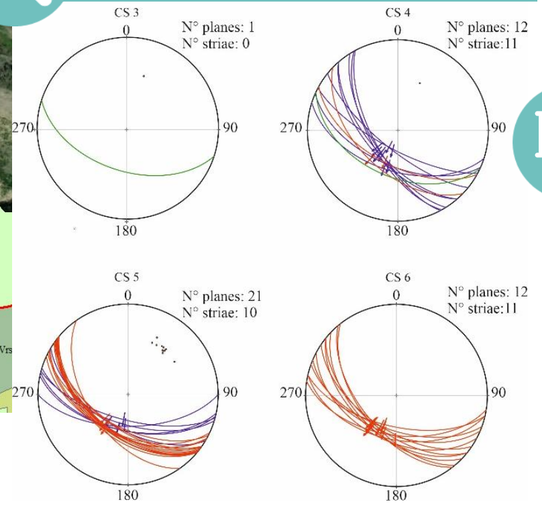
Geological survey



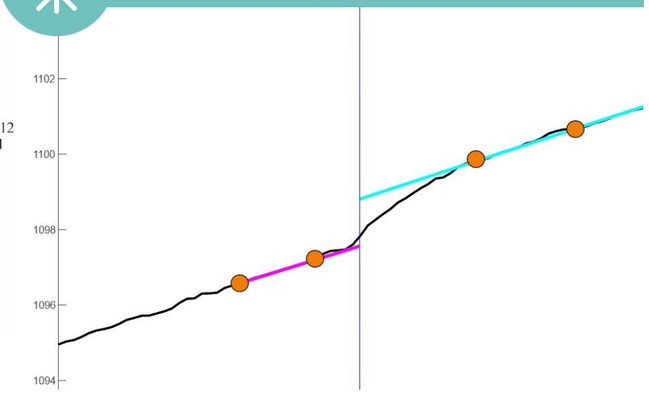
Geological – structural data management



Structural analysis



Interpretation



All this will be in my upcoming master's thesis!

AND NOW, LET'S GO TO WORK

DEFENS TEAM