New geochronologic and thermochronologic data from the Einstein Telescope candidate site of Sardinia (Italy)

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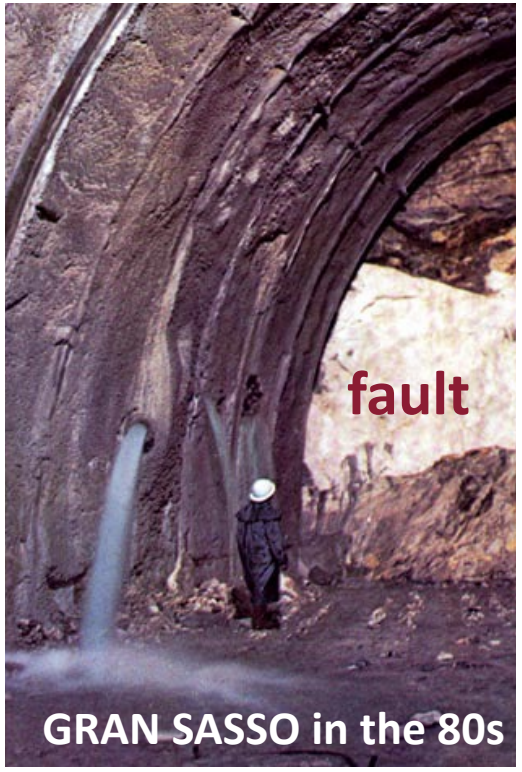
NEEDS

WHY GEOLOGY IN ET?

because geology helps predict construction site hazards and deals with both past geological processes and those still active in the area.



MOTIVATION

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Time
is essential
in recognizing costly
geological risks

Natural seismicity and seismic noise: the candidates

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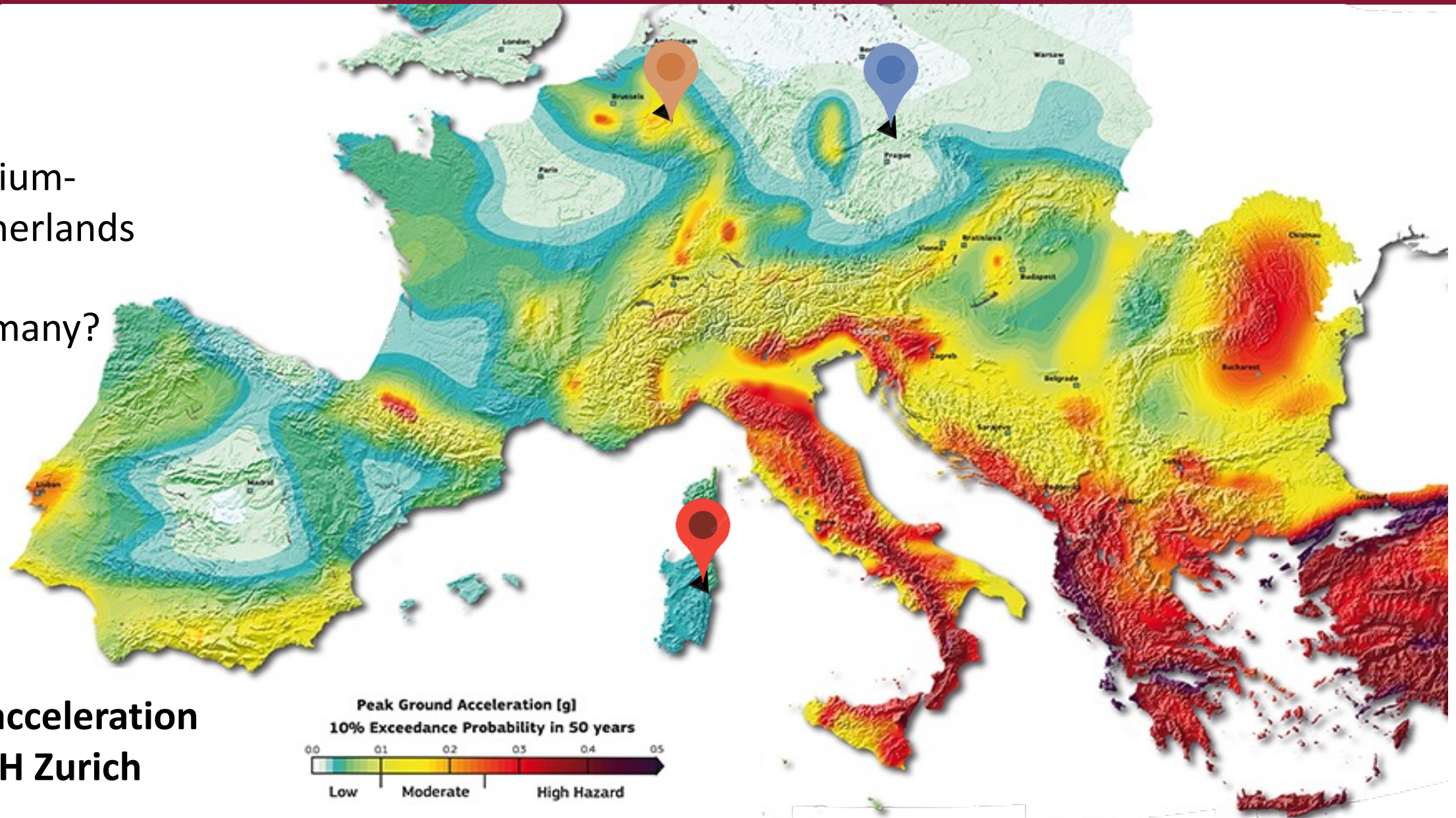
- Italy
- Belgium-Netherlands
- Germany?



Ground acceleration Map - ETH Zurich

Why candidate Sardinia?

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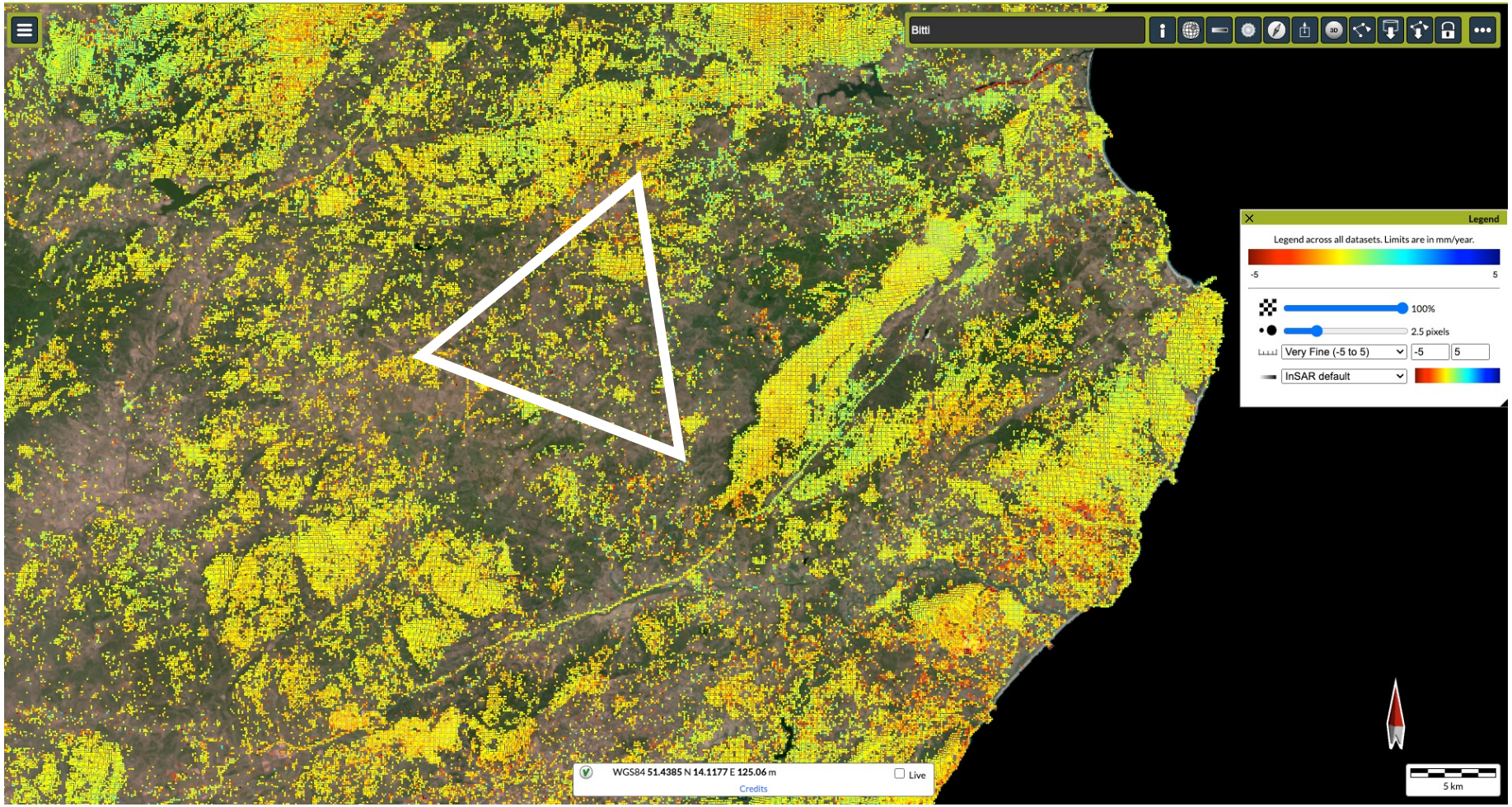
[InSar data available at the website https://egms.land.copernicus.eu/](https://egms.land.copernicus.eu/)

Very limited vertical movements

There are no significant gravitative or tectonic movements or extensive subsident or uplifting areas in Sardinia.



Why candidate Sardinia?

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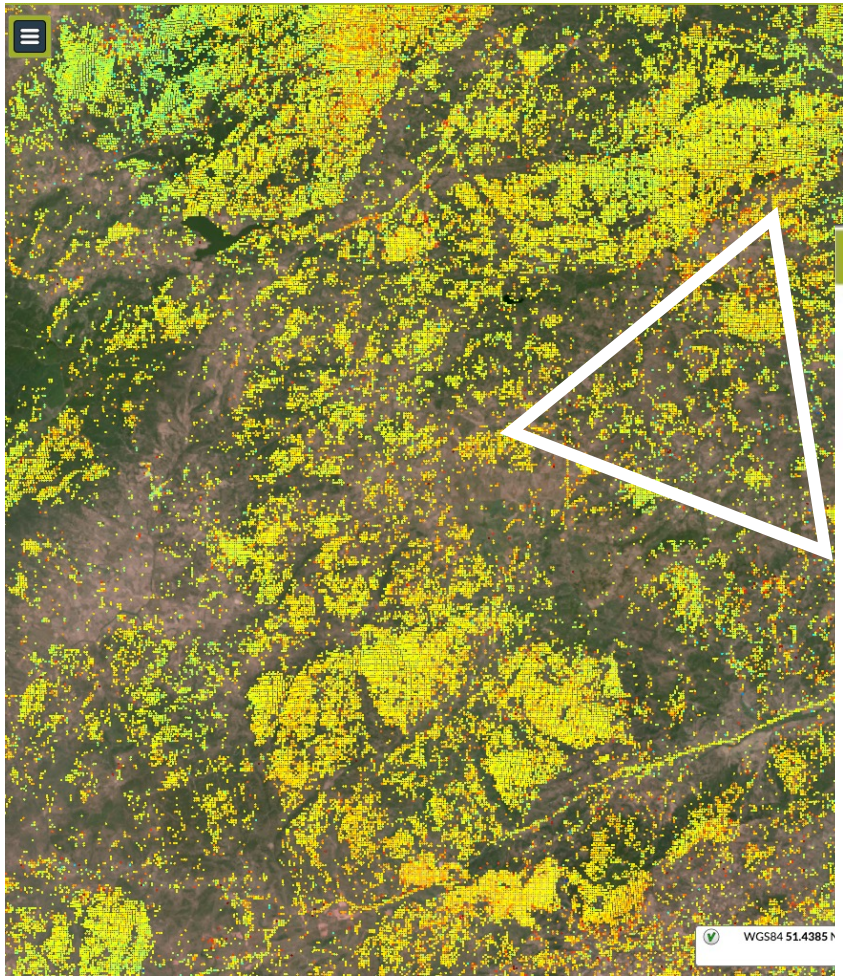

Why candidate Sardinia?

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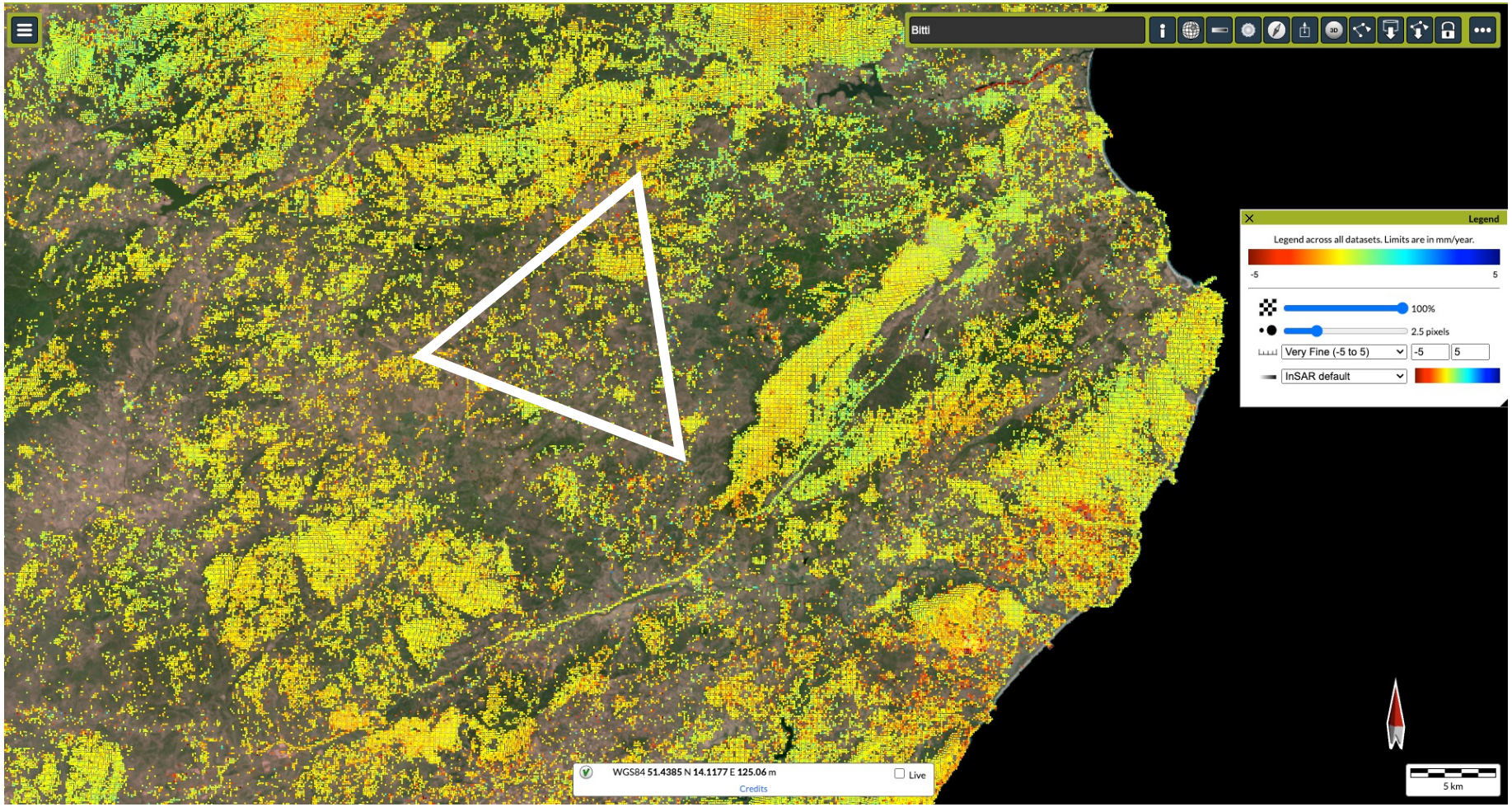

Let’s compare with the Belgian-Dutch site

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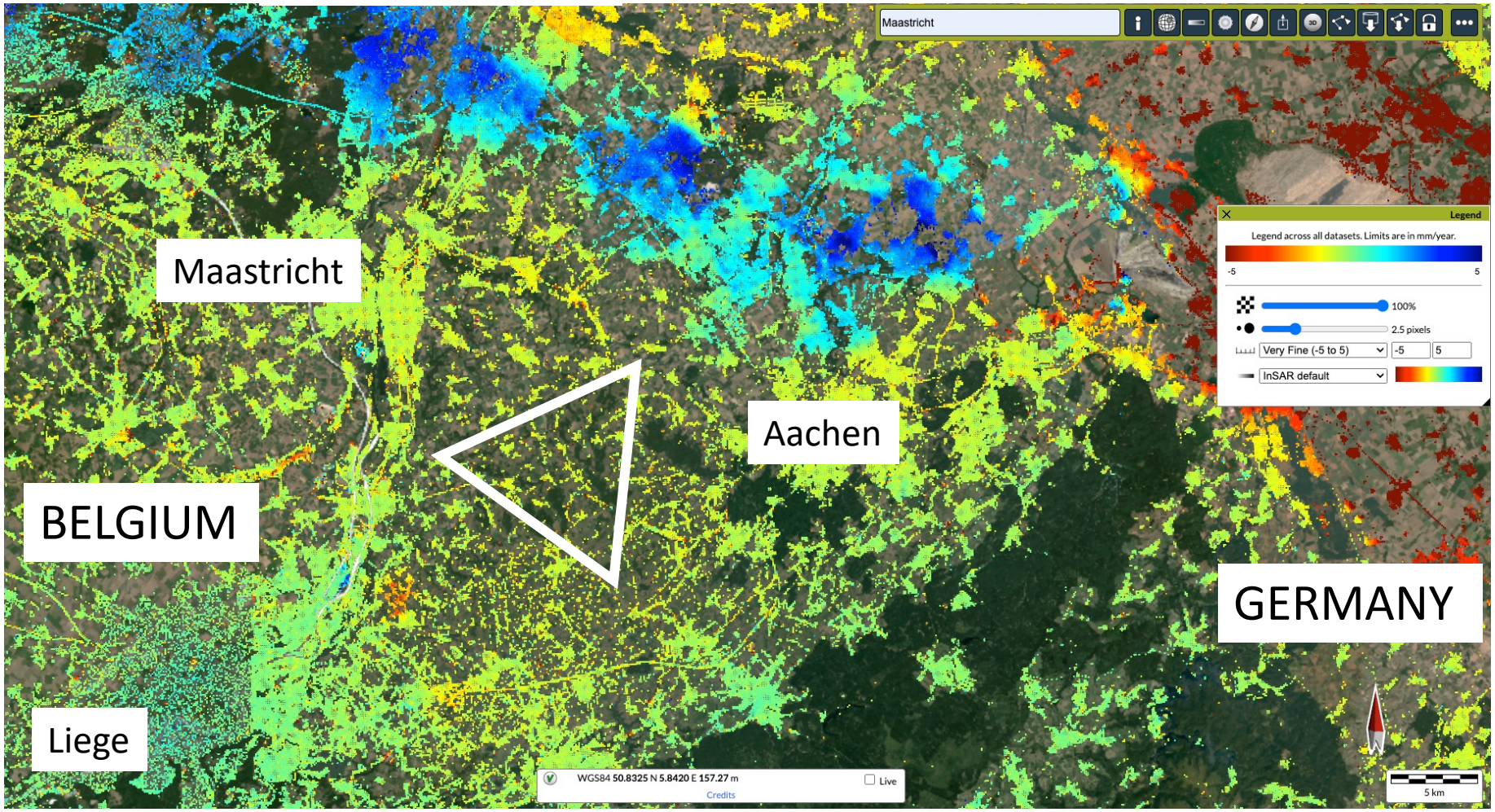
[Dati satellitari InSar disponibili sul sito https://egms.land.copernicus.eu/](https://egms.land.copernicus.eu/)

More pronounced vertical differential movements of natural origin.

In the region, there are evident uplift and subsidence movements linked to the compaction of sediments from the Rhine River and its tributaries and to the tectonics affecting the entire Rhine trench between France and Germany. The surrounding area is densely populated.



Let’s compare with the German ET candidate (?) site

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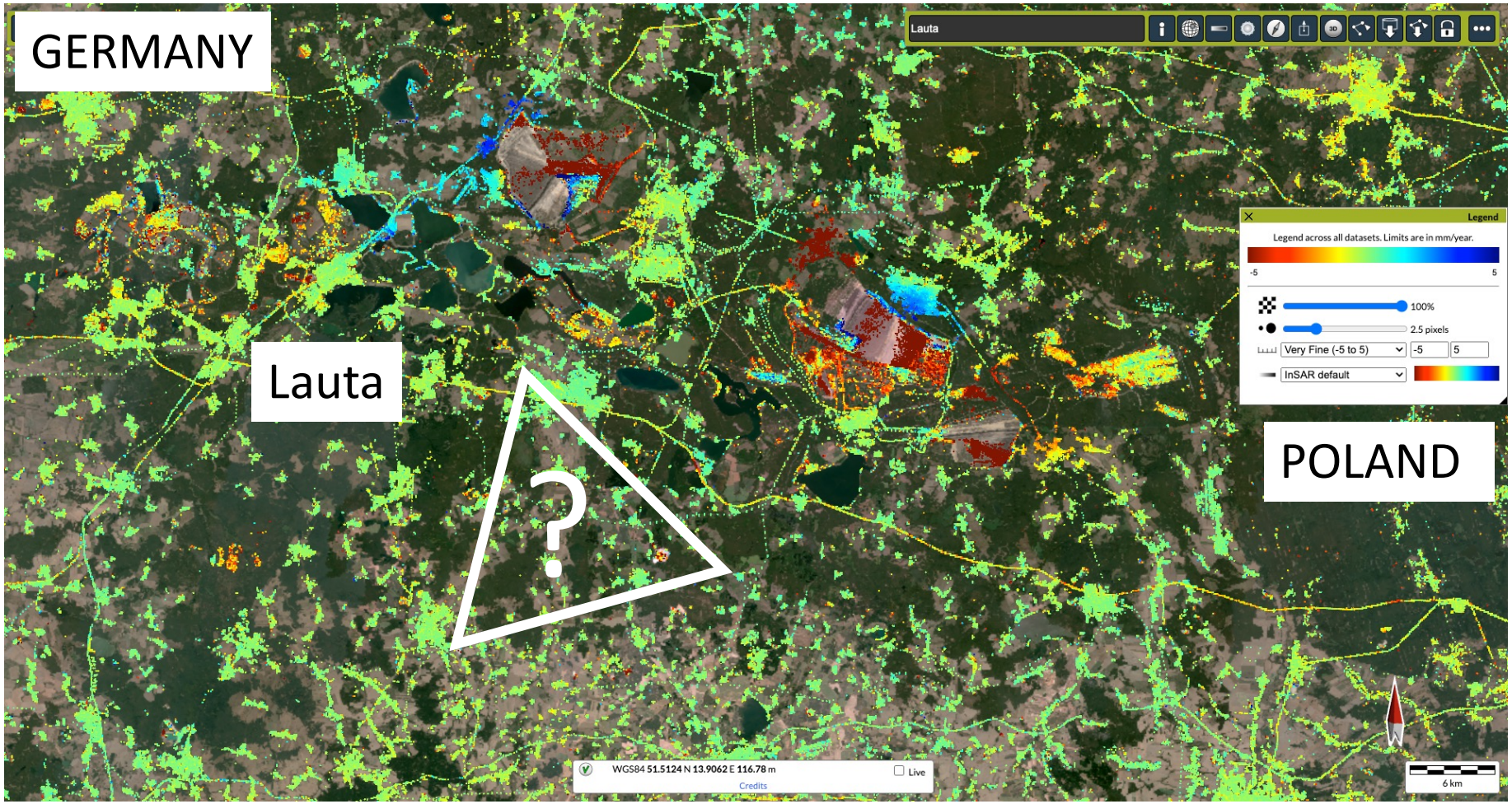
InSar data available at the website https://egms.land.copernicus.eu/

More pronounced vertical movements of anthropic origin.

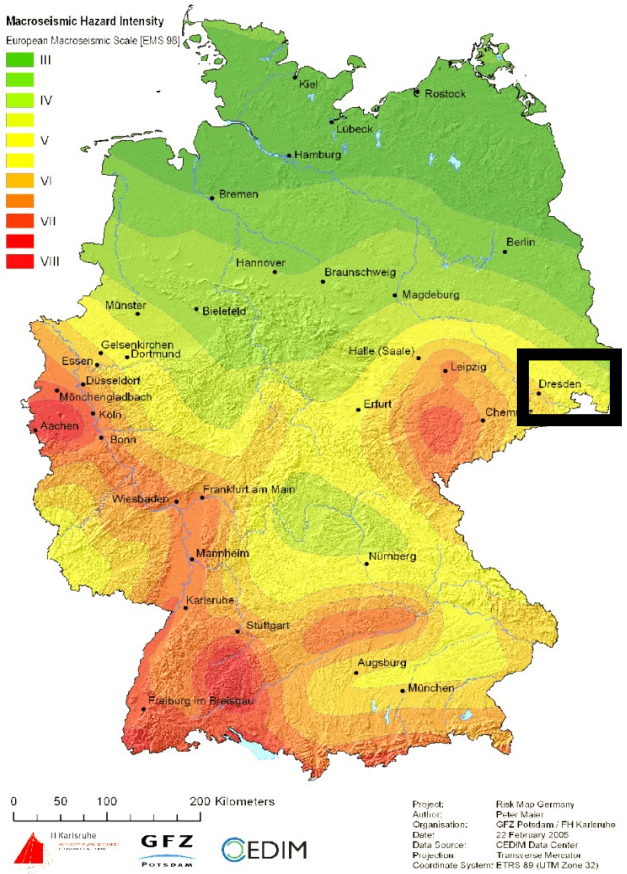
Despite the low seismicity and low population density, in Lusatia there are **evident uplift and subsidence movements linked to mining activities in the mining district**.

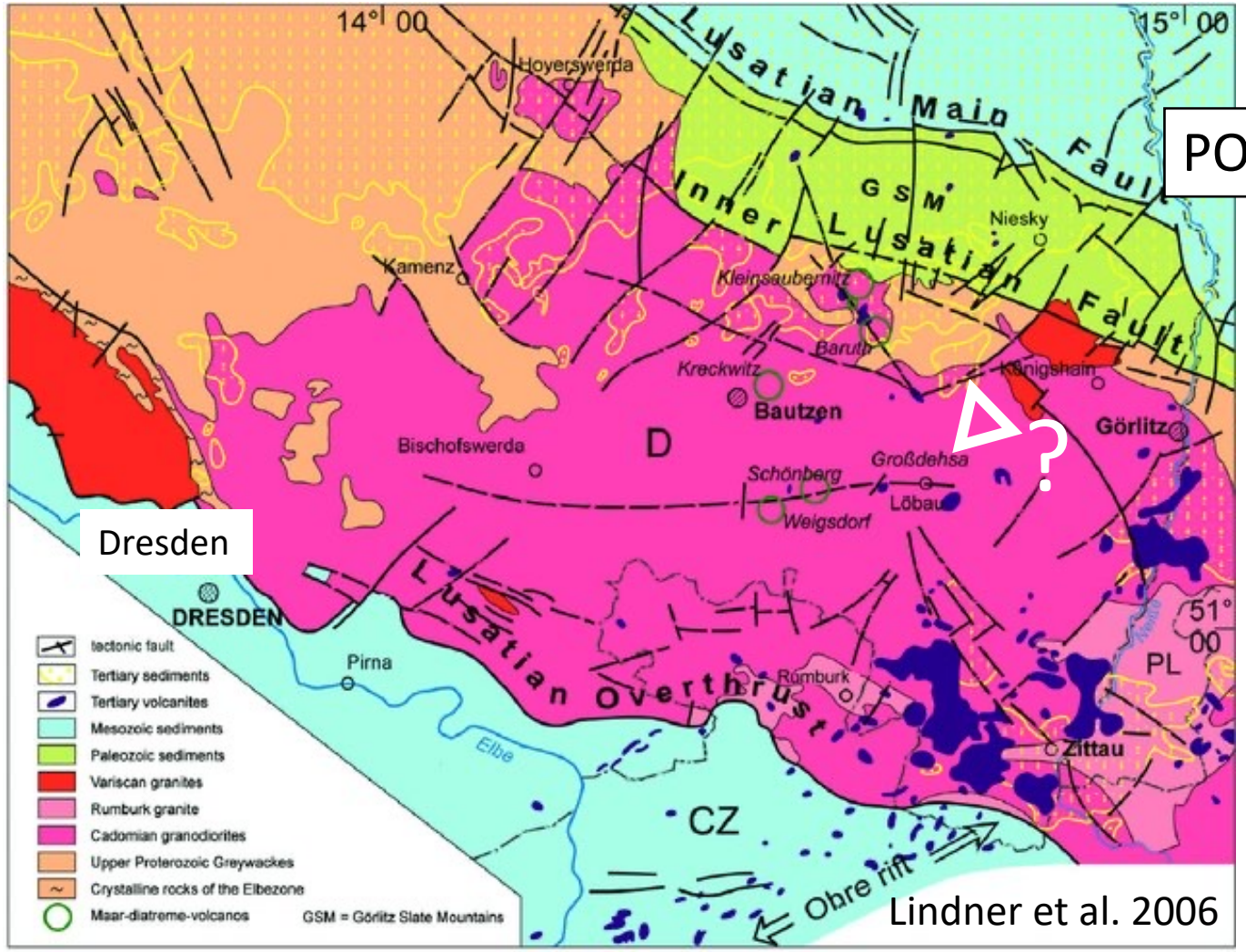
We don't know exactly where the Germans want to position their triangle.



Görlitz

Geological comparison: the ET german site





POLAND

Ancient crystalline rocks.

Granite intersected by some ancient faults with mineralizations of copper, gold, and other economically valuable minerals.

Geological comparison: the ET Italian candidate

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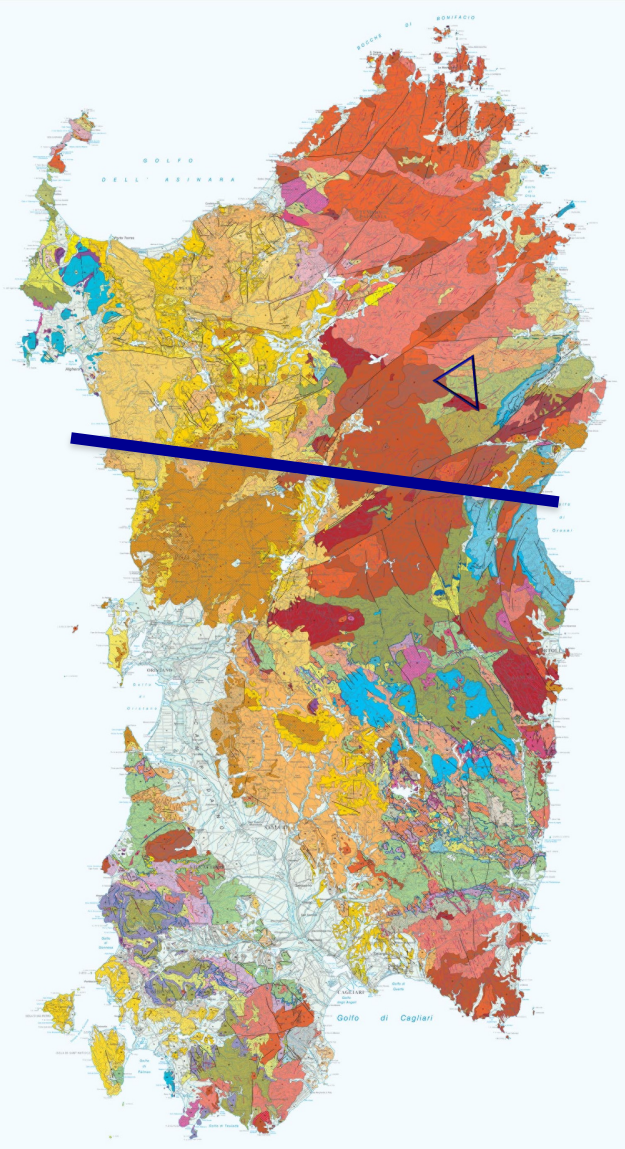
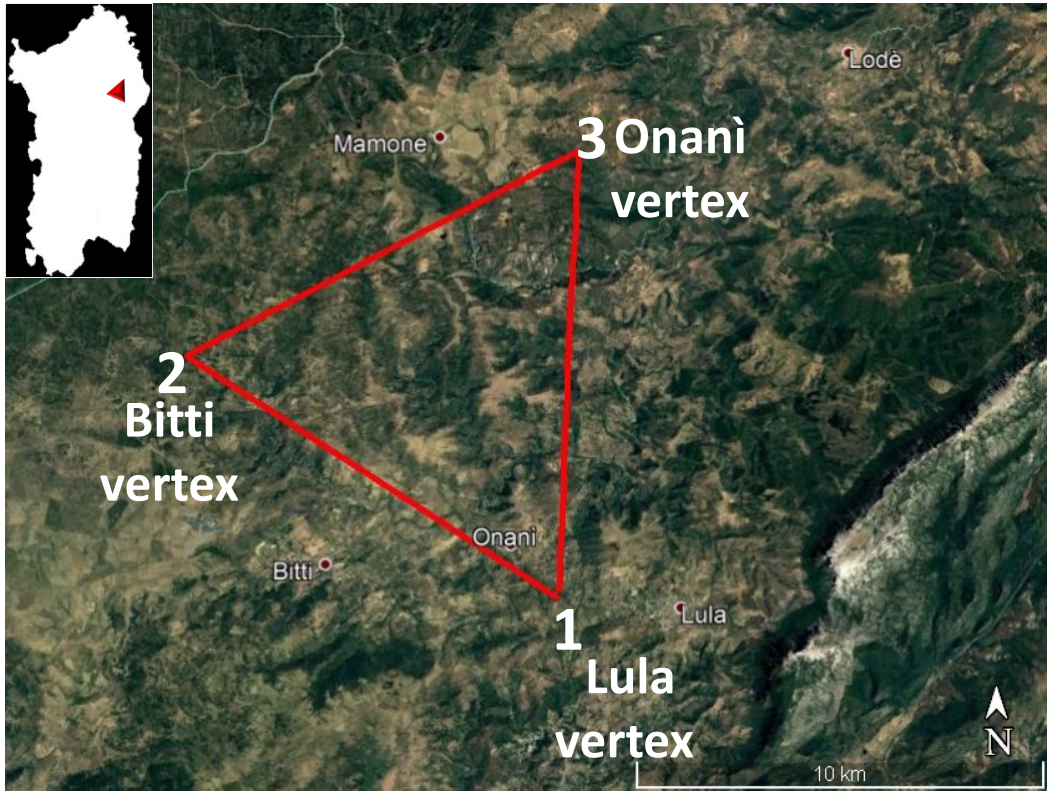
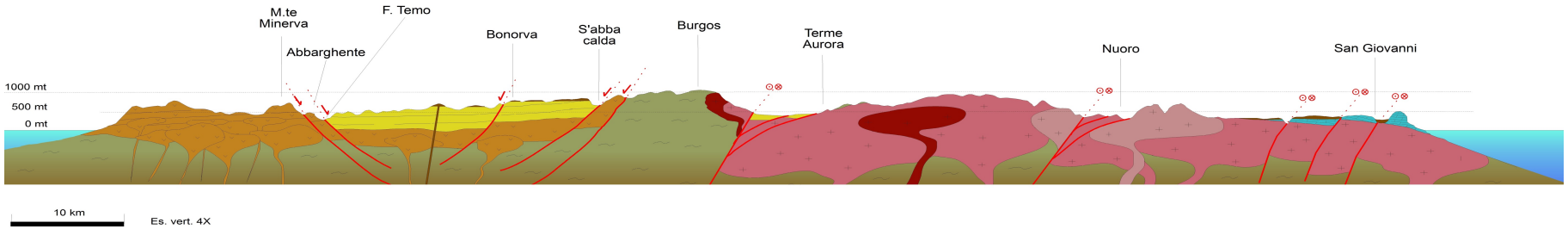


Sardinia is rich in granites (red), derived from the solidification of magma over 300 million years ago, and even older metamorphic rocks (green). There are regional faults that resulted from the movements the island underwent during the Mesozoic (blue) and Miocene (orange) periods.

In the last few million years, the island has been essentially tectonically quiet.





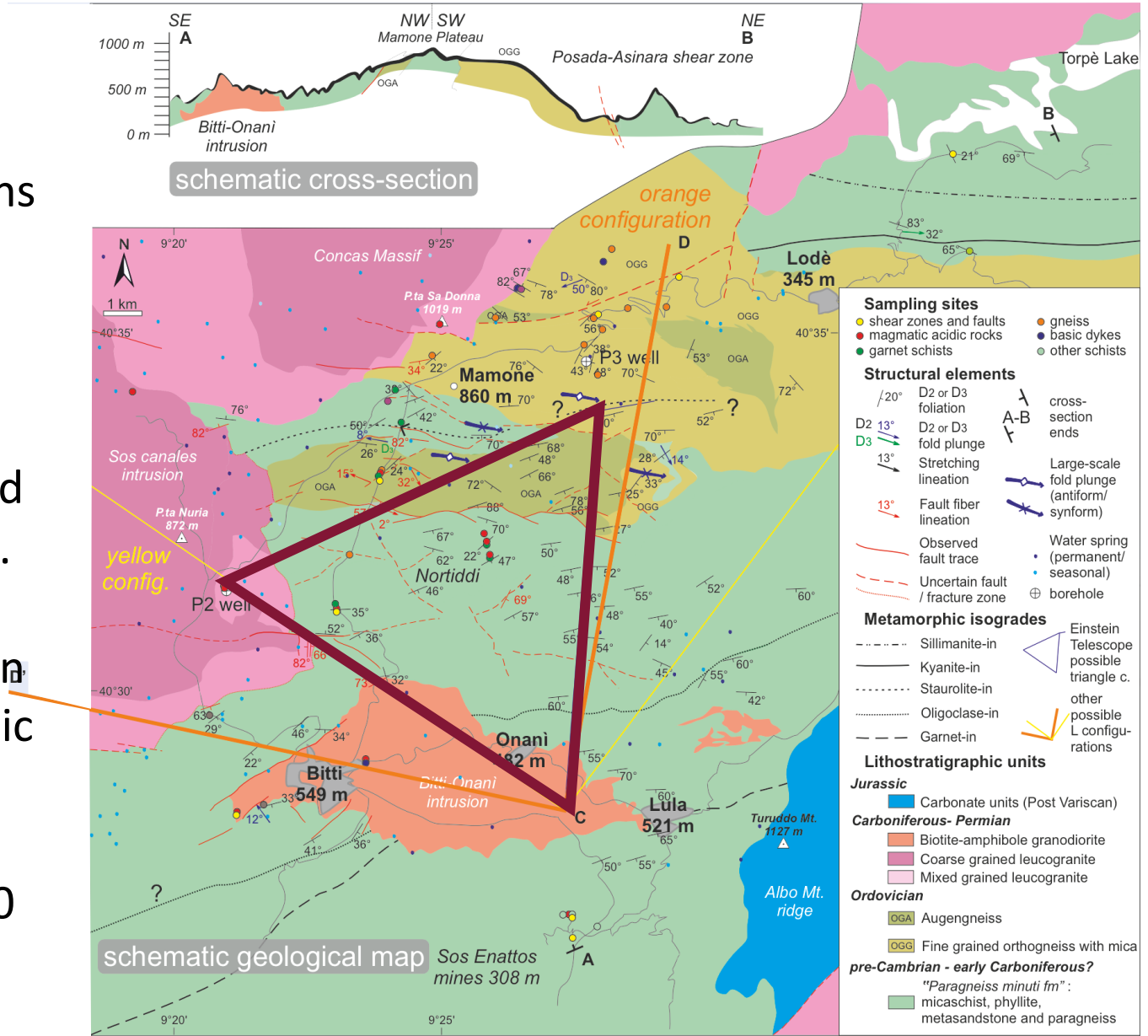
2023 geological structural map

The analysis of new data has allowed to:

- Compare previous interpretations
- Utilize satellite data
- Add new data on brittle structures (faults)

Faults are of limited extensions and intersect previous ductile contacts.

Faults are associated, in orientation and composition, with late orogenic intrusive bodies, allowing us to attribute their activity to a geological past between about 320 and 300 million years ago.



Geological comparison: the Belgian-Dutch site

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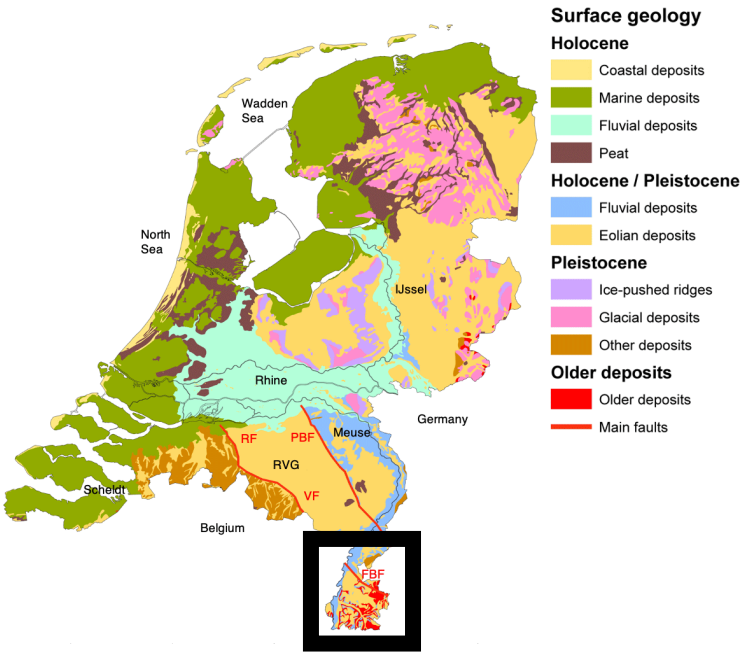
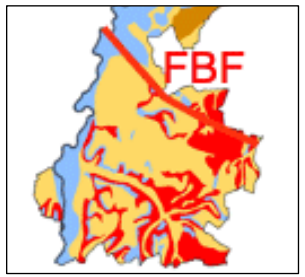
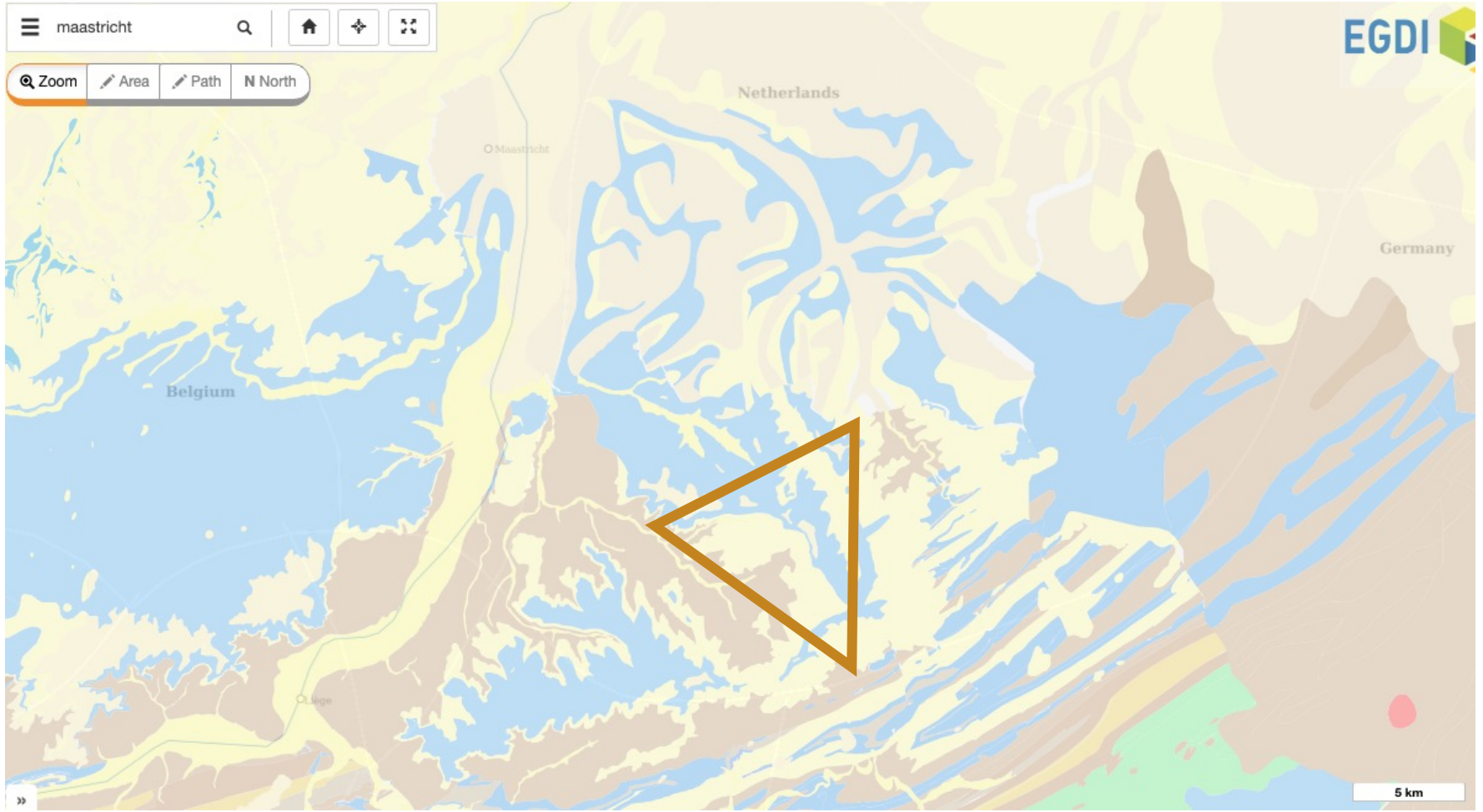
Sedimentary rocks and recent sediments







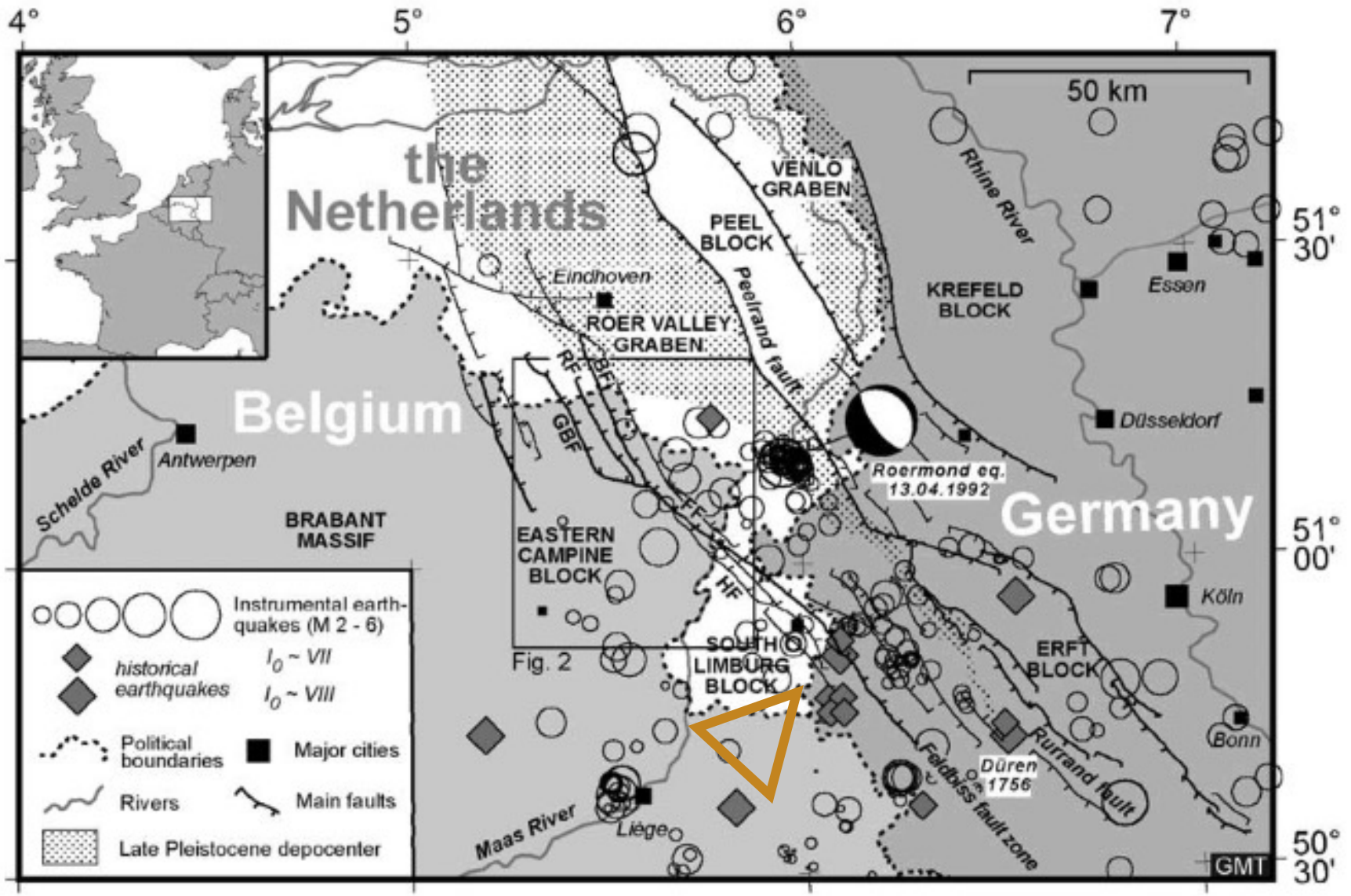
https://www.europe-geology.eu/data-and-services/map-viewer/

Geological comparison: the Belgian-Dutch site

Active tectonics

Seismic activity recorded throughout the area with magnitudes similar to those affecting the Alps and the Apennines.

Vanneste et al. 2001
Journal of Seismology



Geological comparison: the Belgian-Dutch site

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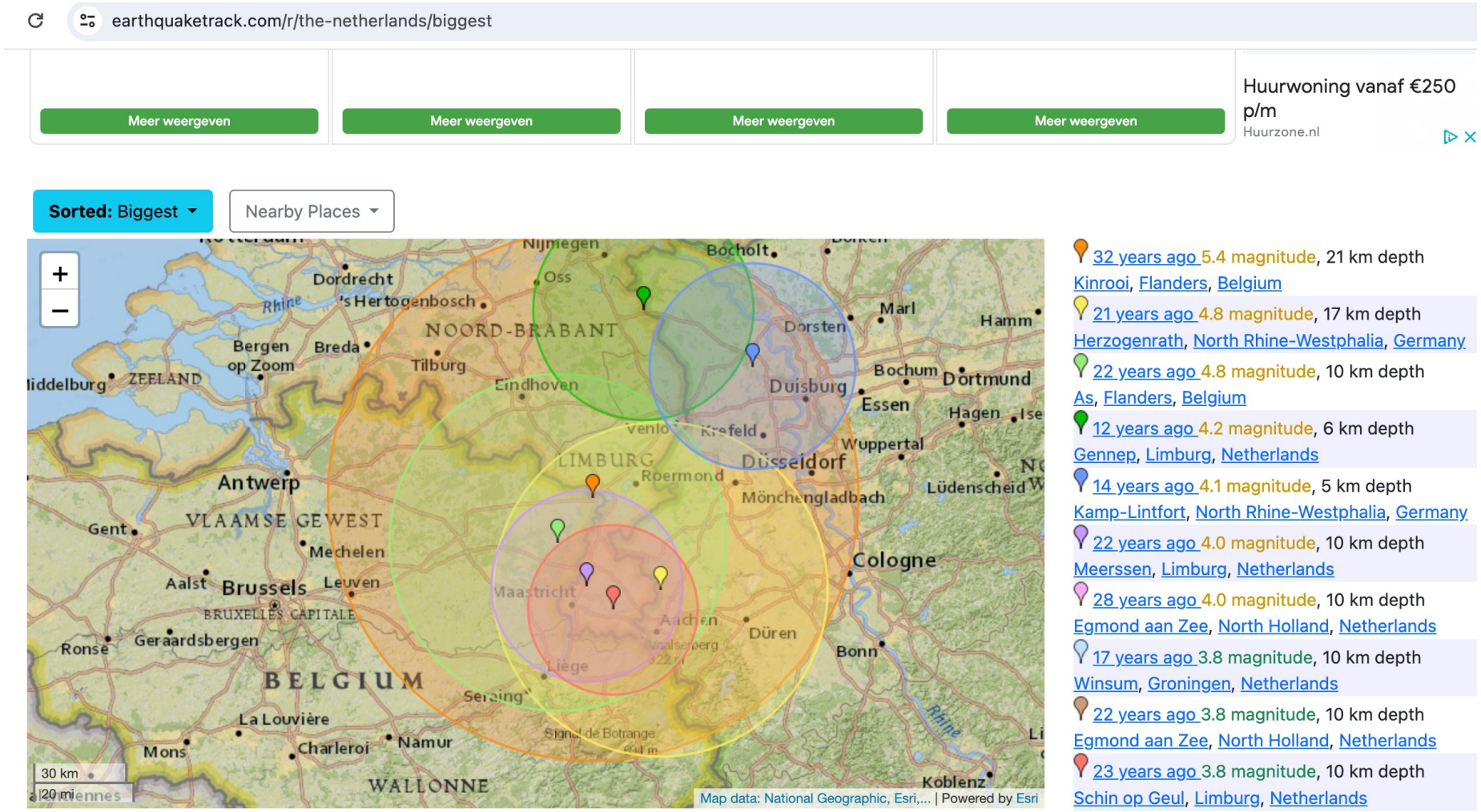

The «seismicity» of Sardinia

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According to INGV

since 1985

The area around Lula (ray 50 km)

has experienced only 6 earthquakes with magnitude ≤ 3.2

Data e Ora (Italia)	Magnitudo	Zona	Profondità	Latitudine	Longitudine
2024-05-03 09:55:03	ML 1.3	2 km E Ottana (NU)	10	40.23	9.07
2023-04-24 09:15:58	ML 1.5	4 km SE Ottana (NU)	1	40.21	9.07
2023-04-04 09:26:50	ML 1.7	4 km SE Ottana (NU)	1	40.20	9.06
2022-07-27 11:12:24	ML 1.8	3 km NW Sarule (NU)	1	40.25	9.14
2022-07-08 08:25:54	ML 1.2	4 km S Ottana (NU)	1	40.20	9.06
2022-06-13 08:54:37	ML 0.8	3 km SE Ottana (NU)	1	40.22	9.07
2022-06-09 09:41:01	ML 1.5	4 km SE Ottana (NU)	1	40.21	9.07
2022-05-30 09:14:11	ML 0.9	4 km SE Ottana (NU)	1	40.21	9.06
2021-10-18 09:43:48	ML 1.3	3 km SE Ottana (NU)	1	40.21	9.07
2021-09-15 10:45:42	ML 1.7	3 km W Orani (NU)	1	40.25	9.14
2021-09-02 10:40:25	ML 1.5	3 km SW Oniferi (NU)	1	40.26	9.14
2021-08-30 09:17:18	ML 1.5	4 km SE Ottana (NU)	1	40.20	9.07
2021-07-23 09:37:56	ML 1.6	2 km N Loculi (NU)	1	40.43	9.60
2021-07-22 09:35:22	ML 1.6	3 km W Orani (NU)	1	40.25	9.14
2015-10-20 09:08:11	Md 2.5	5 km E Telti (OT)	9	40.89	9.41
2011-07-20 10:12:17	Md 2.2	2 km NW Orotelli (NU)	11	40.32	9.11
2007-03-15 12:10:50	ML 1.0	2 km W Oniferi (NU)	5	40.27	9.15
2007-01-21 12:10:31	ML 2.3	Costa Sarda Nuorese (Nuoro)	1	40.67	9.88
2006-02-03 12:39:07	ML 1.8	2 km E Sarule (NU)	5	40.23	9.19
2000-04-27 03:15:41	Md 3.2	Costa Sarda nord orientale (Olbia)	10	40.70	9.82

BUILDING UP AN ET METHOD

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And yet we got to derisk

Objective and Approach

Objective

Characterize the structure of the candidate site to host ET in Sardinia in 4D to predict lithologies and the distribution of faults associated with preferred fluid circulation pathways.

Approach

Multidisciplinary geological investigation (structural, geomorphological, **geochronological**, and geophysical analyses including satellite deformation studies).

From needs to objectives

The contract is responsable for

- Geophysical campaign
- New drillings and site characterizations
- Engineering design

The academia will continue with studies on:

- Geochronological constraints capable of tracing the stages of structural evolution in the area.
- Follow up with the contractor

4D

TIME

BUILDING UP AN ET METHOD

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The perspective of a replicable method

NEW DATA AND COLLABORATIONS

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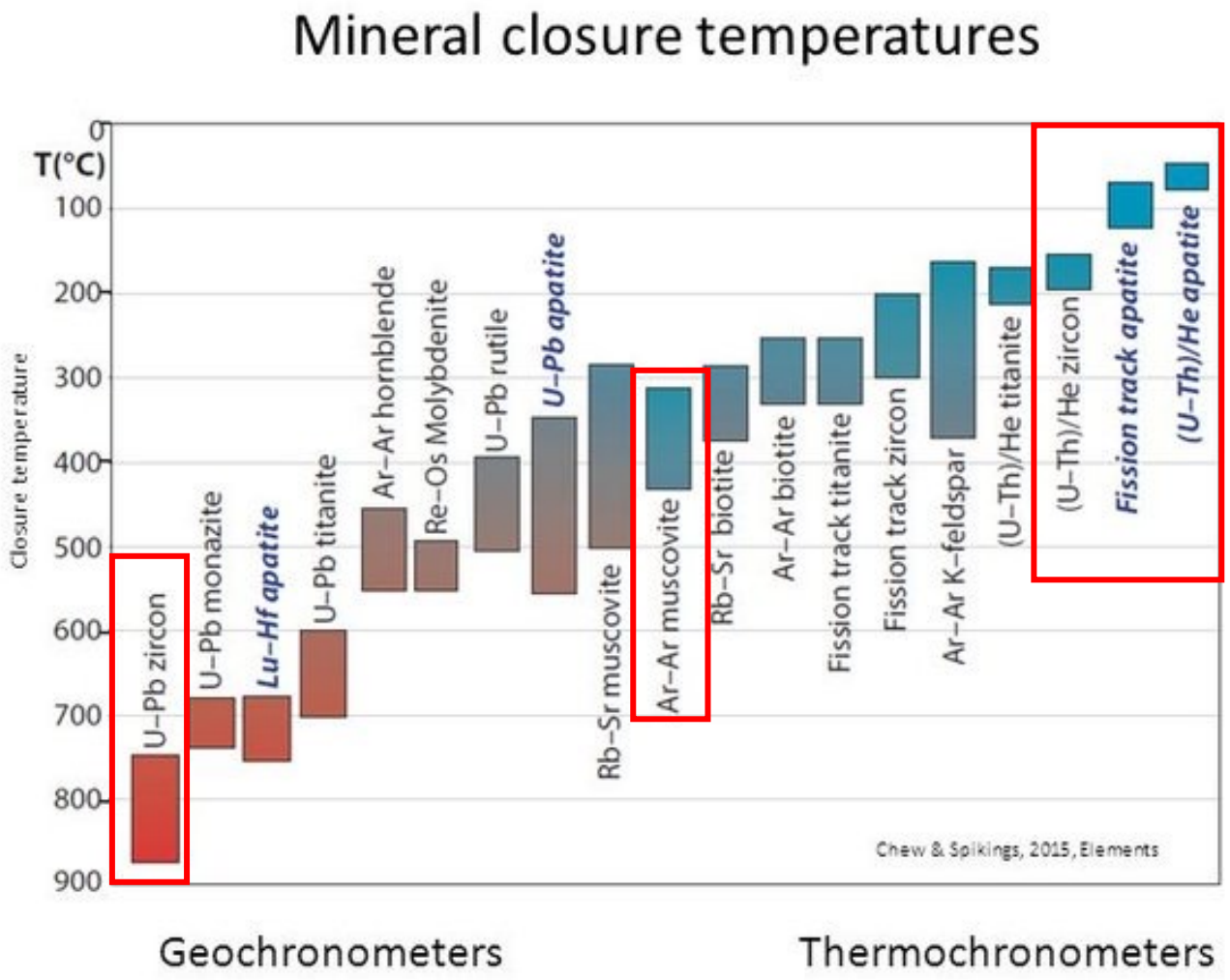
GEOCRONOLOGY FOR THE FOURTH DIMENSION:

- **U-(Th)-Pb (Zircone, Monazite) (7-12 samples) FRANCE**
- Raman Spectroscopy (20 samples) SPAIN
- Mica Ar–Ar geochronology (5-7 samples) CNR PISA
- **Low temperature thermocronometry (20 samples) UNI PAVIA**
- K–Ar illite dating (8 samples) CSIRO AUSTRALIA

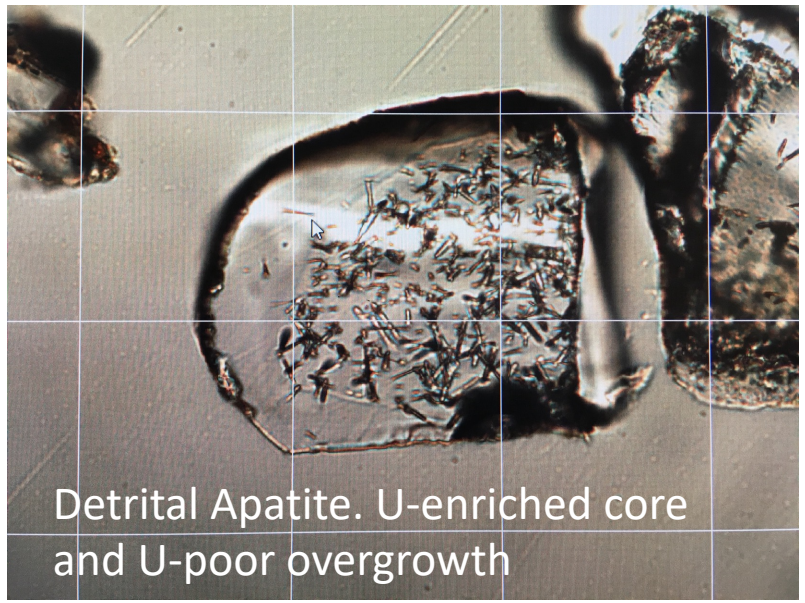
GEOCRONOLOGY

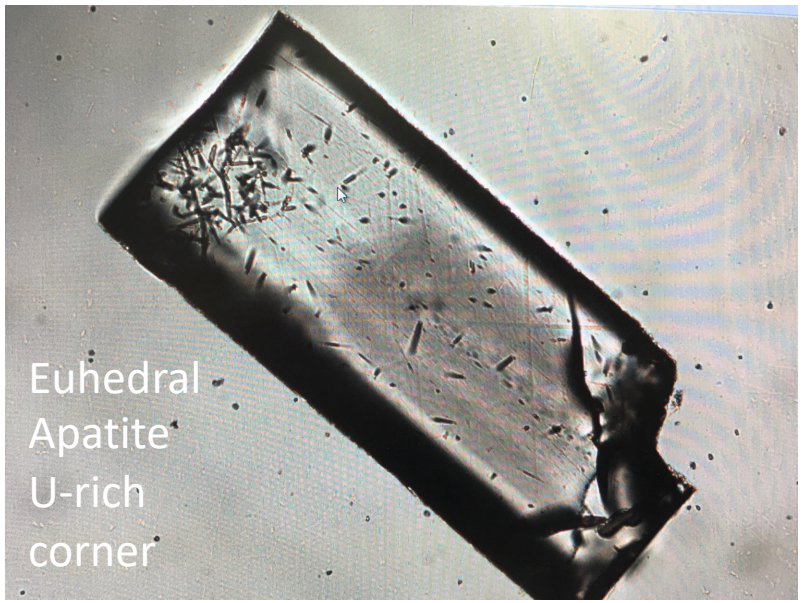


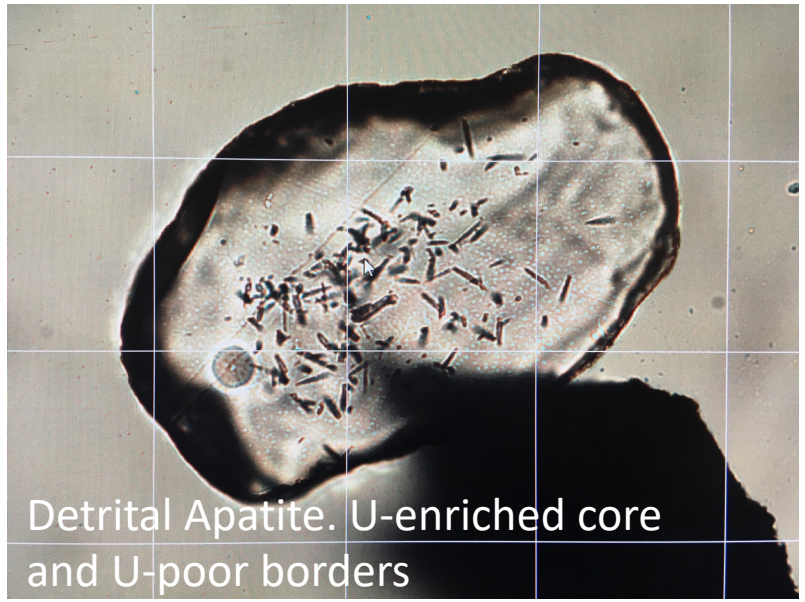
These techniques allow for a temporal and thermal scanning of deformations and …

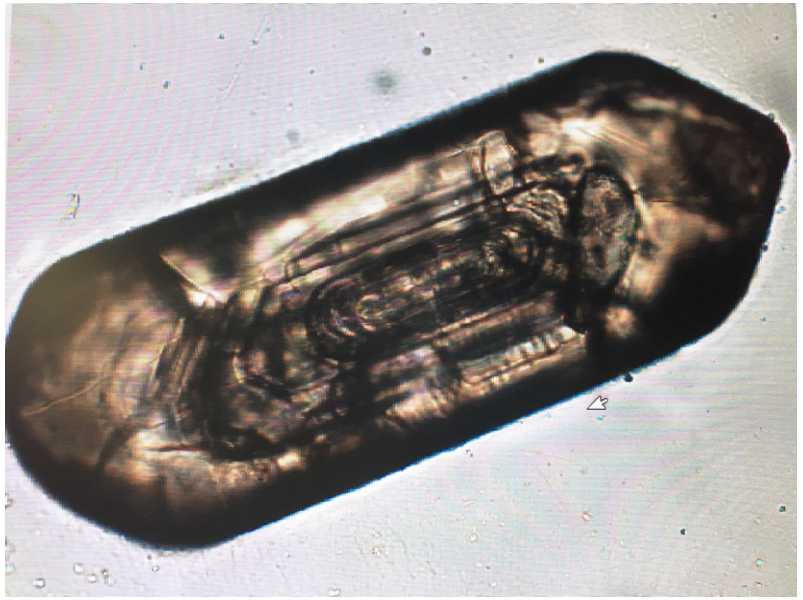
provide the time/temperature constraints of some geological processes related to seismic risks.

GEOCRONOLOGY: target minerals

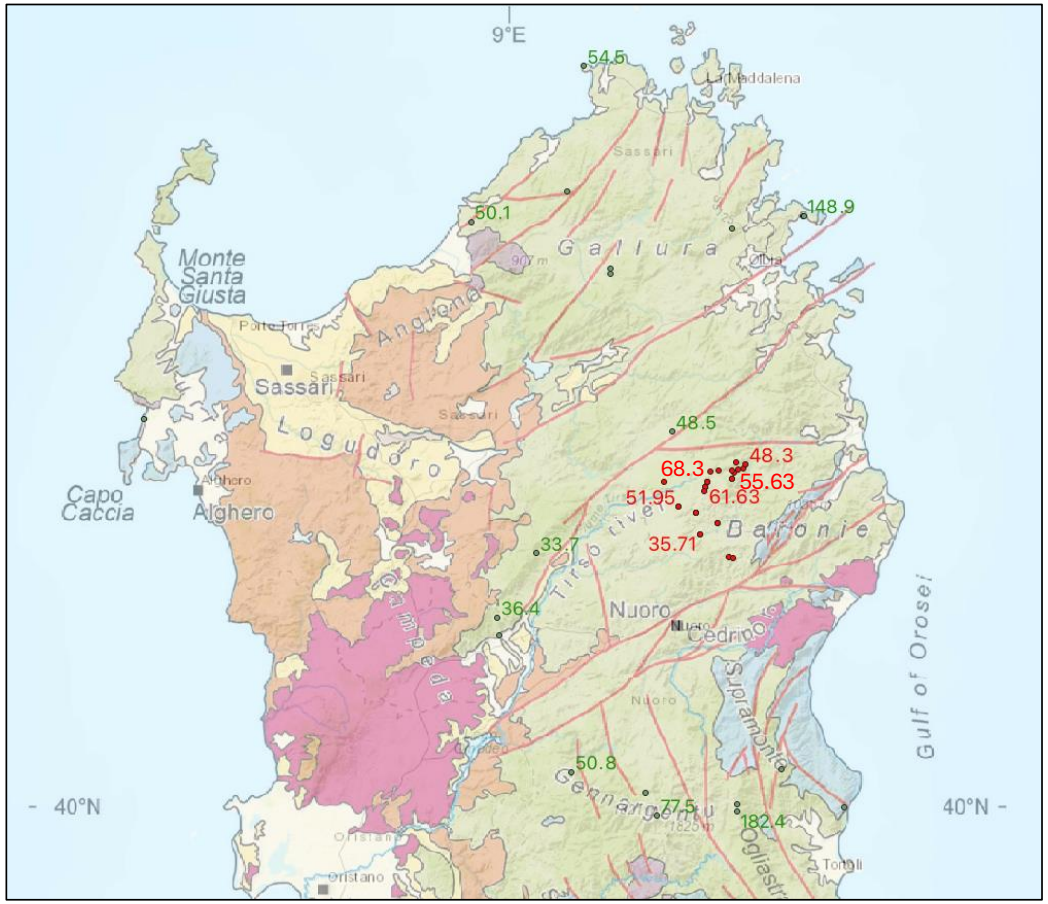


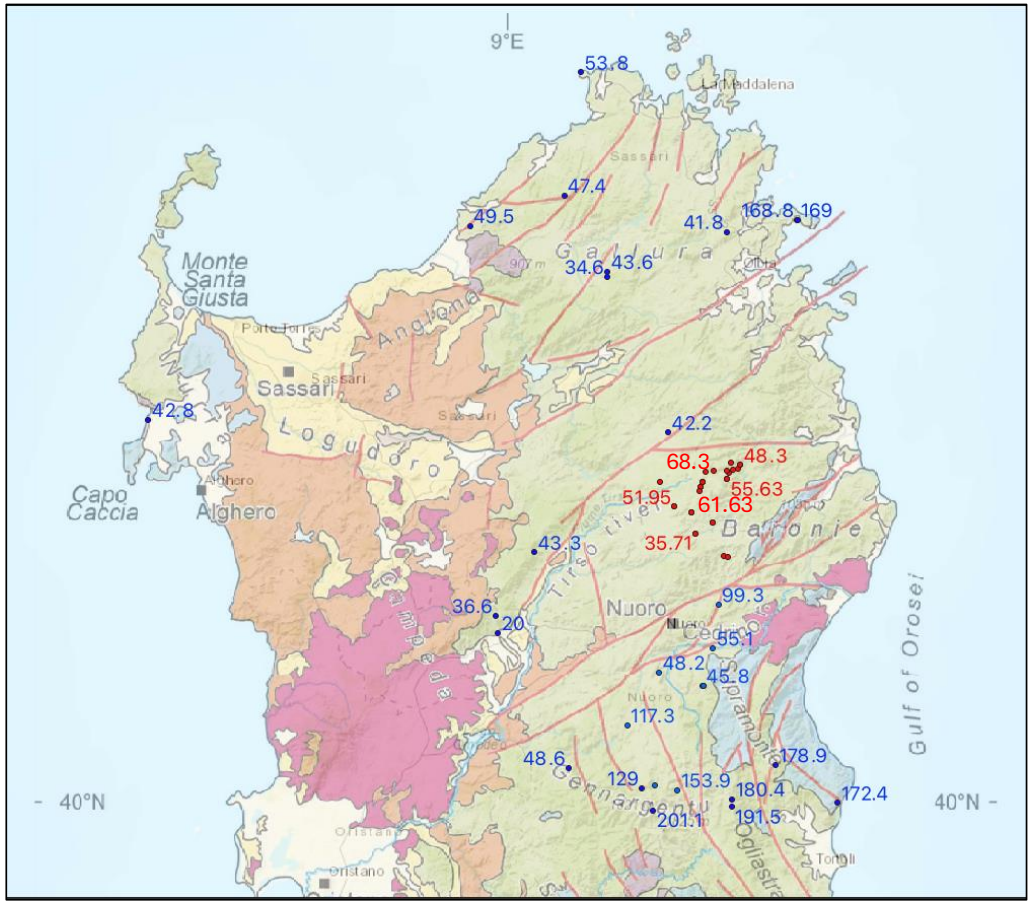




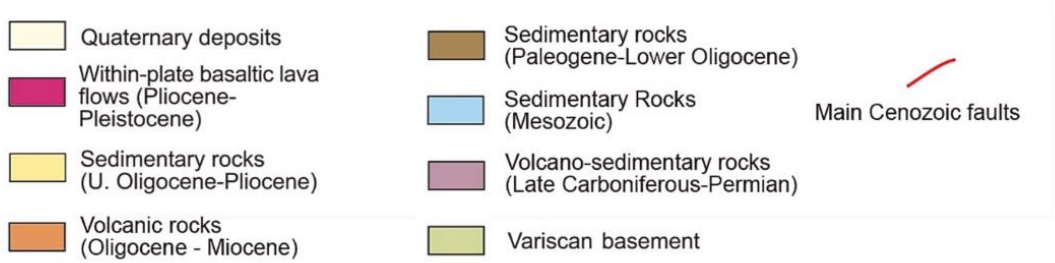


Looking for a replicable method:





- AHe by Malusá et al 2016
- AHe this work



- AFT by Malusá et al 2016; Zattin et al 2008

Looking for a replicable method:

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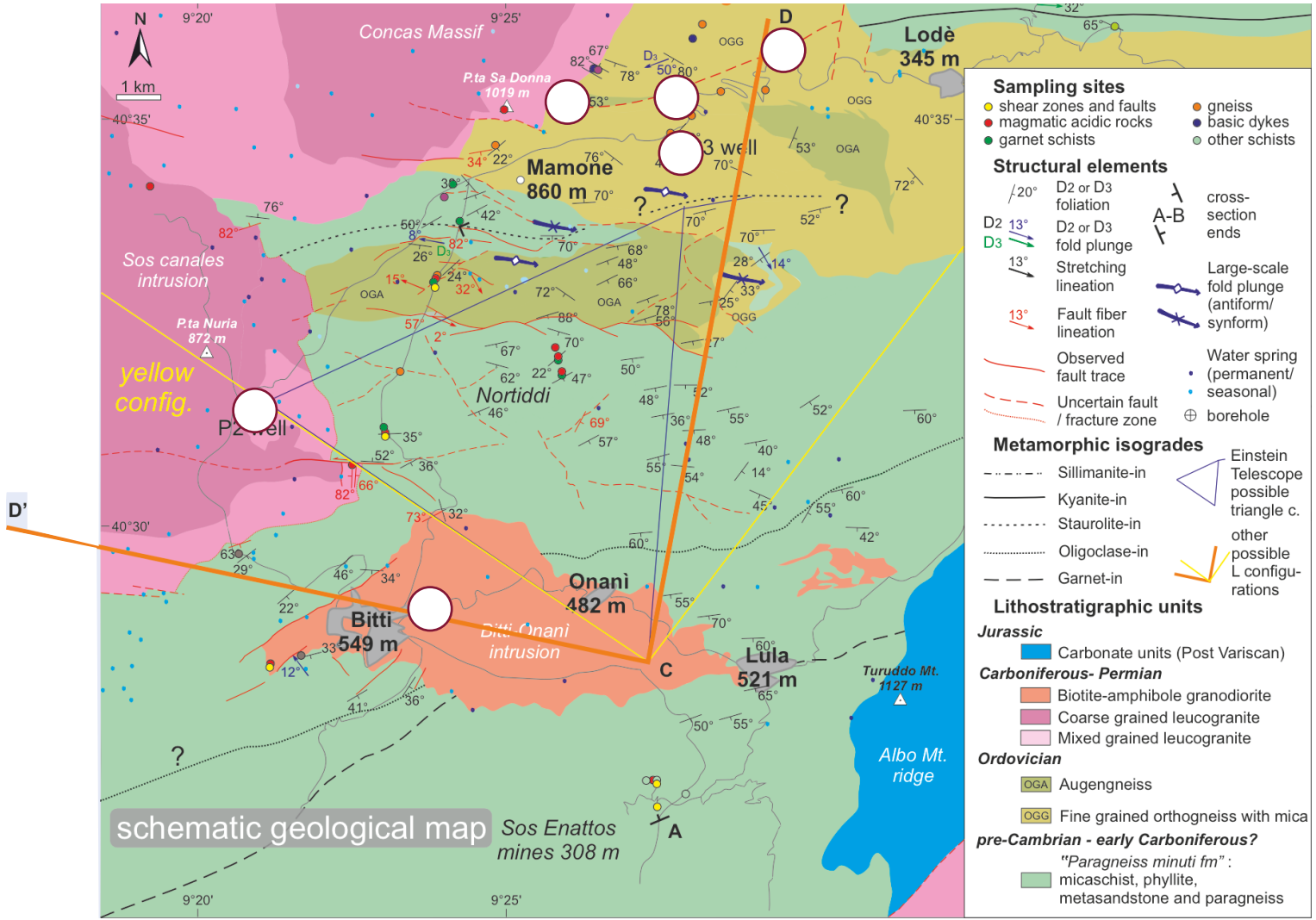
WHEN DID OUR ROCKS COOL DOWN?



Looking for a replicable method:

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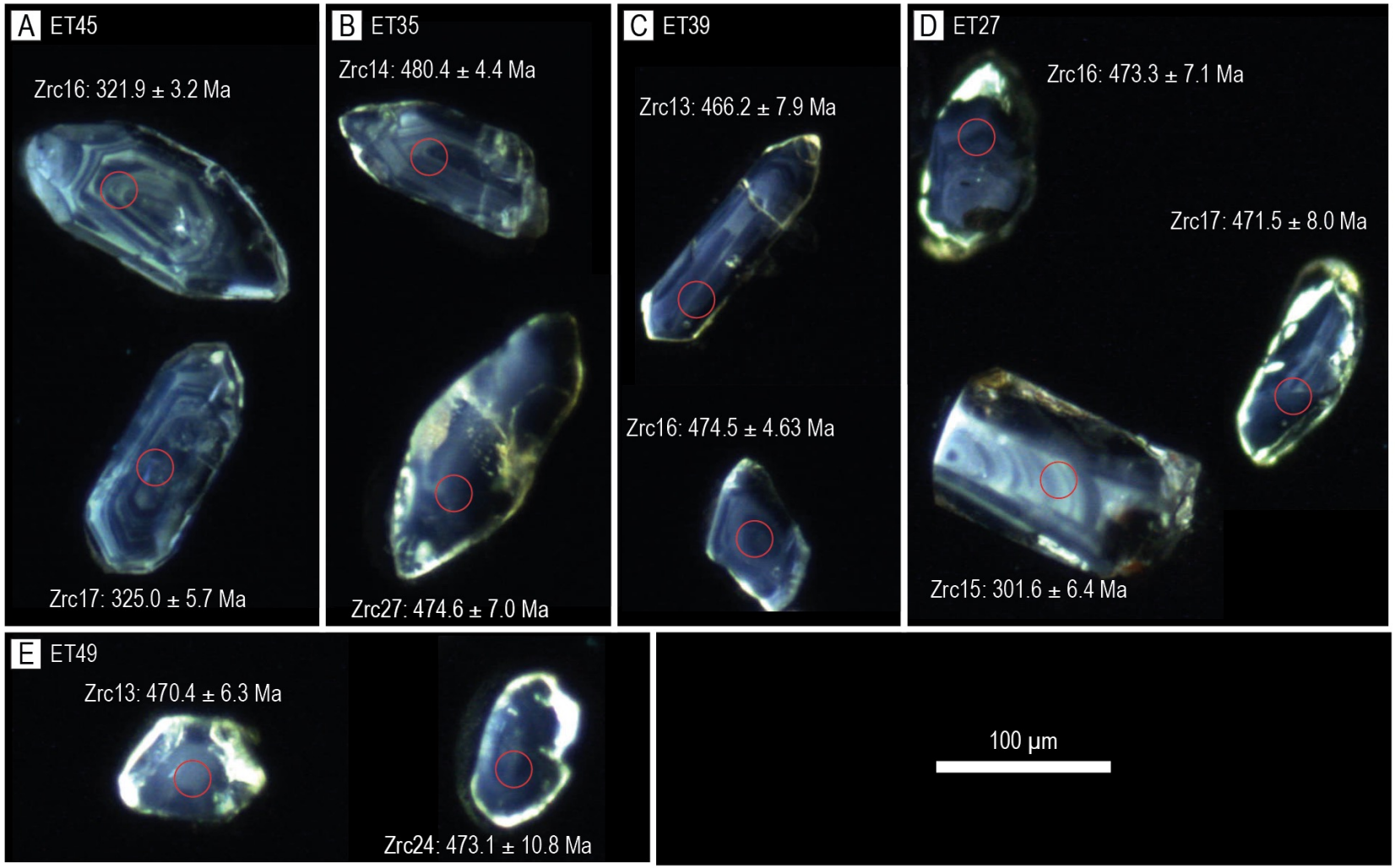
WHEN DID OUR ROCKS COOL DOWN?

We utilized a dating technique called U-Pb on zircon crystals from five samples. This allowed us to obtain the first estimate of the age of magmatism associated with the Bitti intrusion, dating back approximately 321 million years. But there's more: the metamorphic rocks of the plateau have even older ages, with zircons dating to around 480-468 million years ago.

These preliminary results have provided us with an initial insight into the age of the previously undated magmatic rocks of Bitti.



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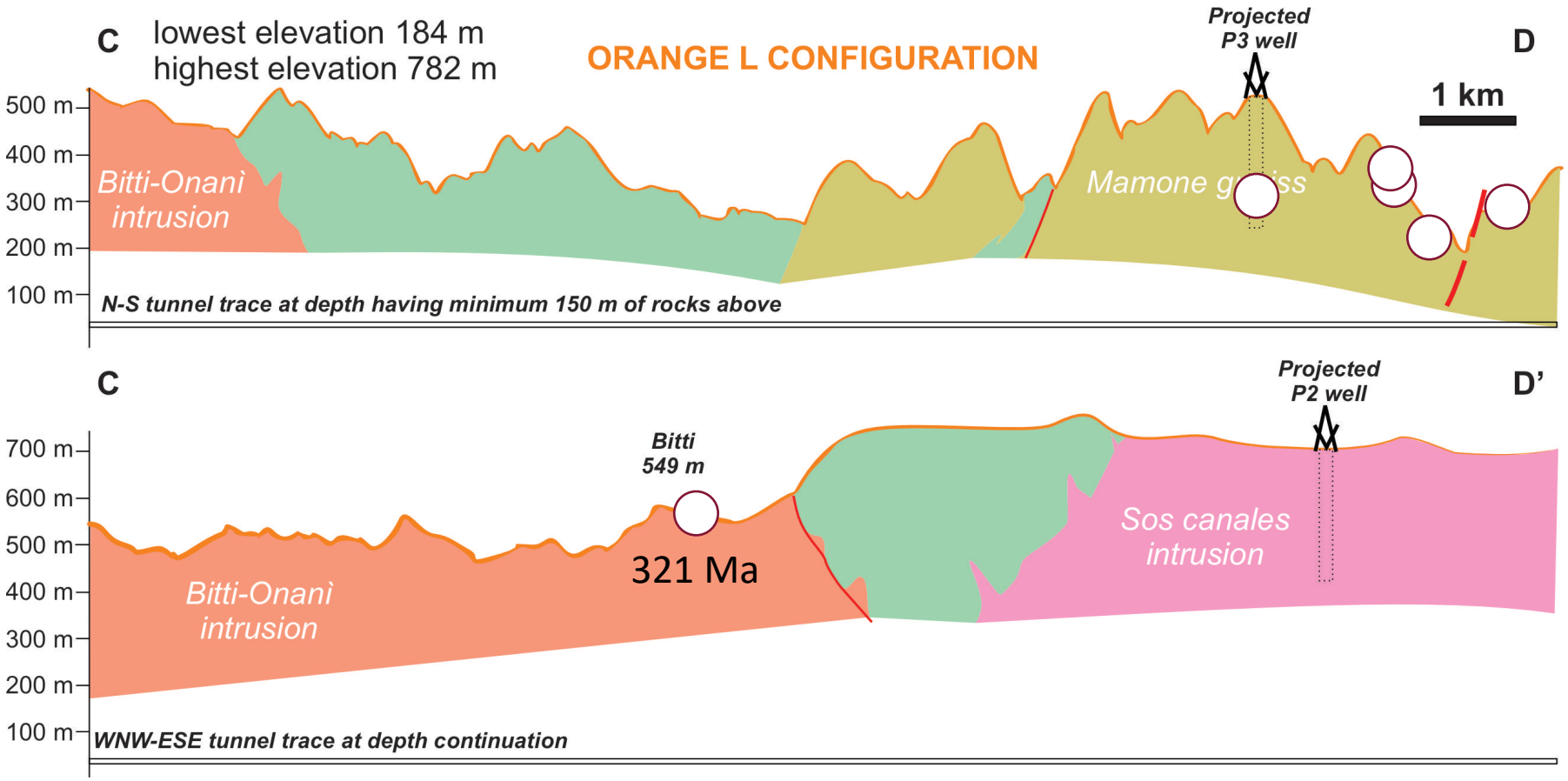
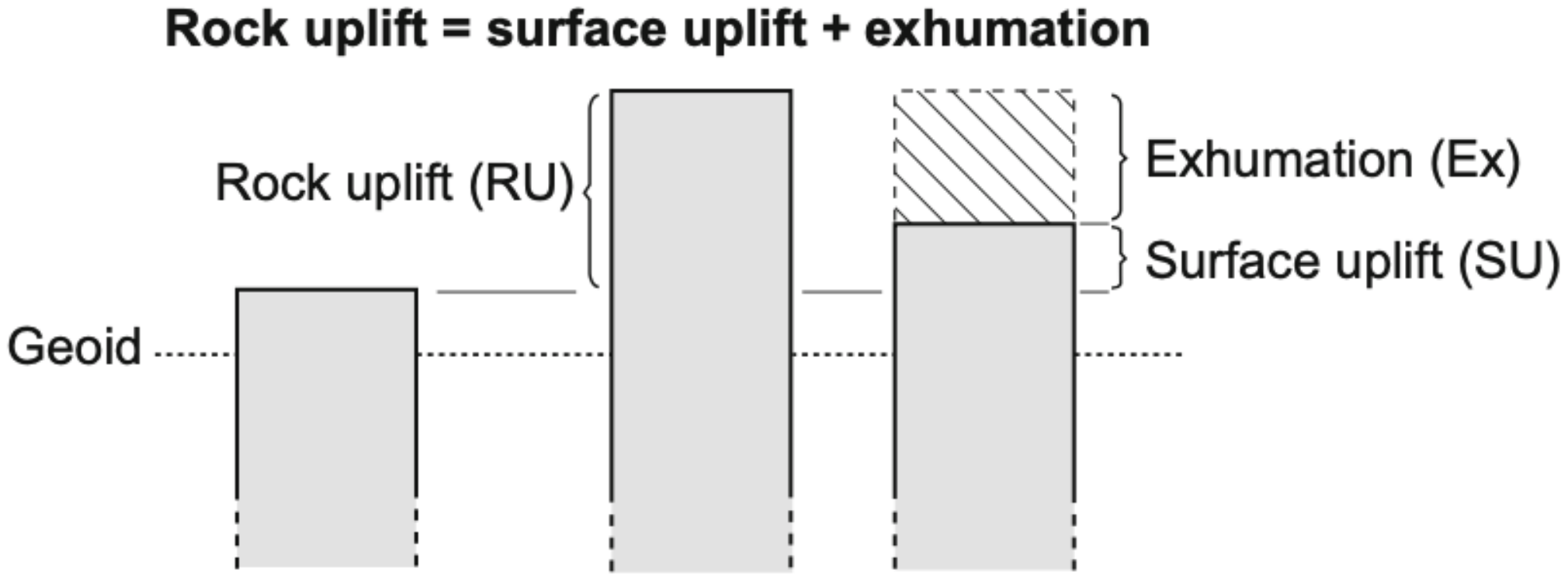


WHY DO ROCKS EXHUME?



EXUMATION IMPLIES ROCK REMOVAL

AGE / EXHUMATION RELATIONSHIP

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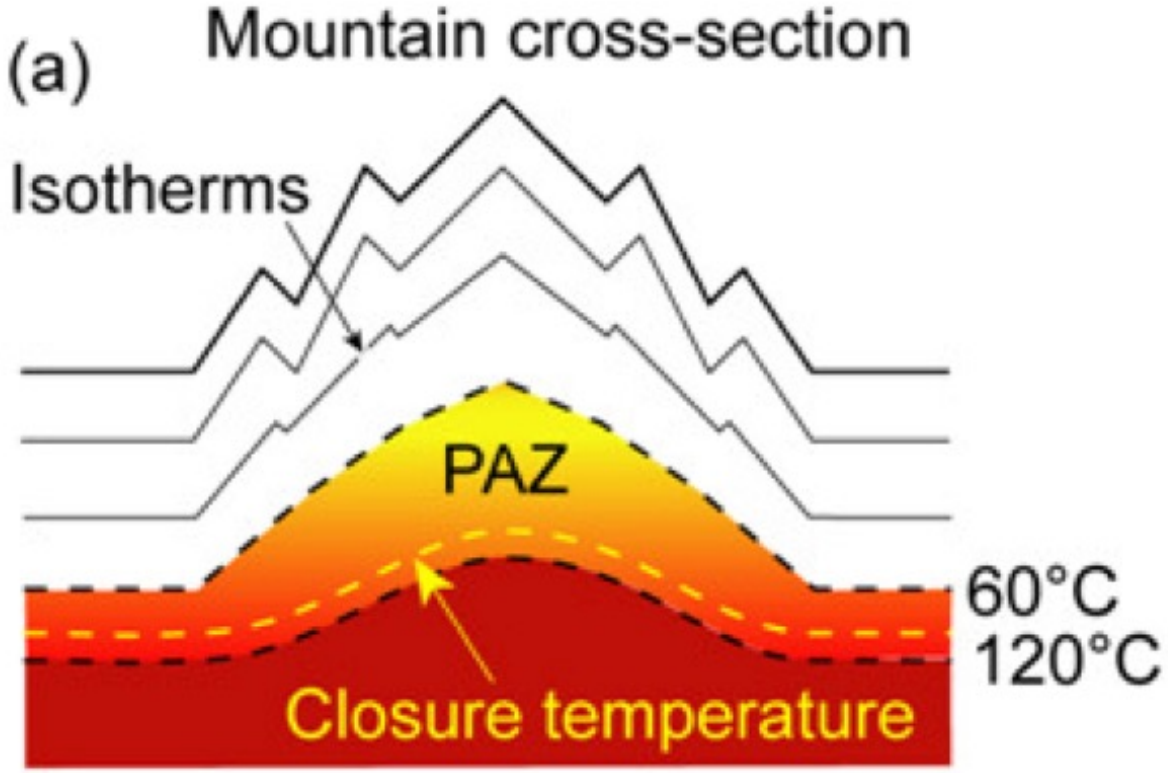
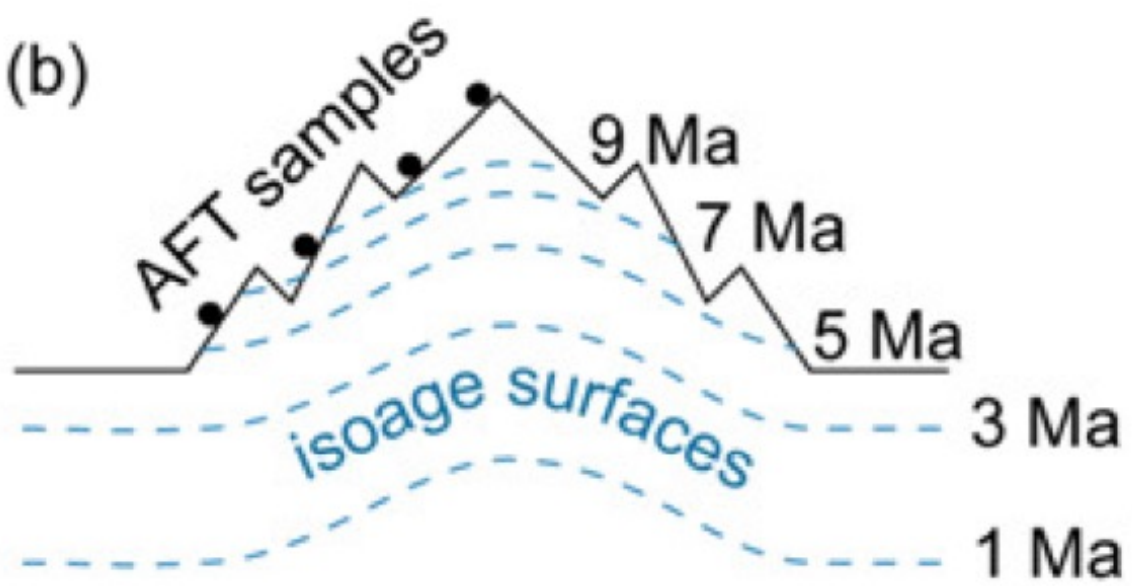
i s o t h e r m e s → i s o a g e





Looking for a replicable method:

WHEN DID OUR ROCKS COOL DOWN?

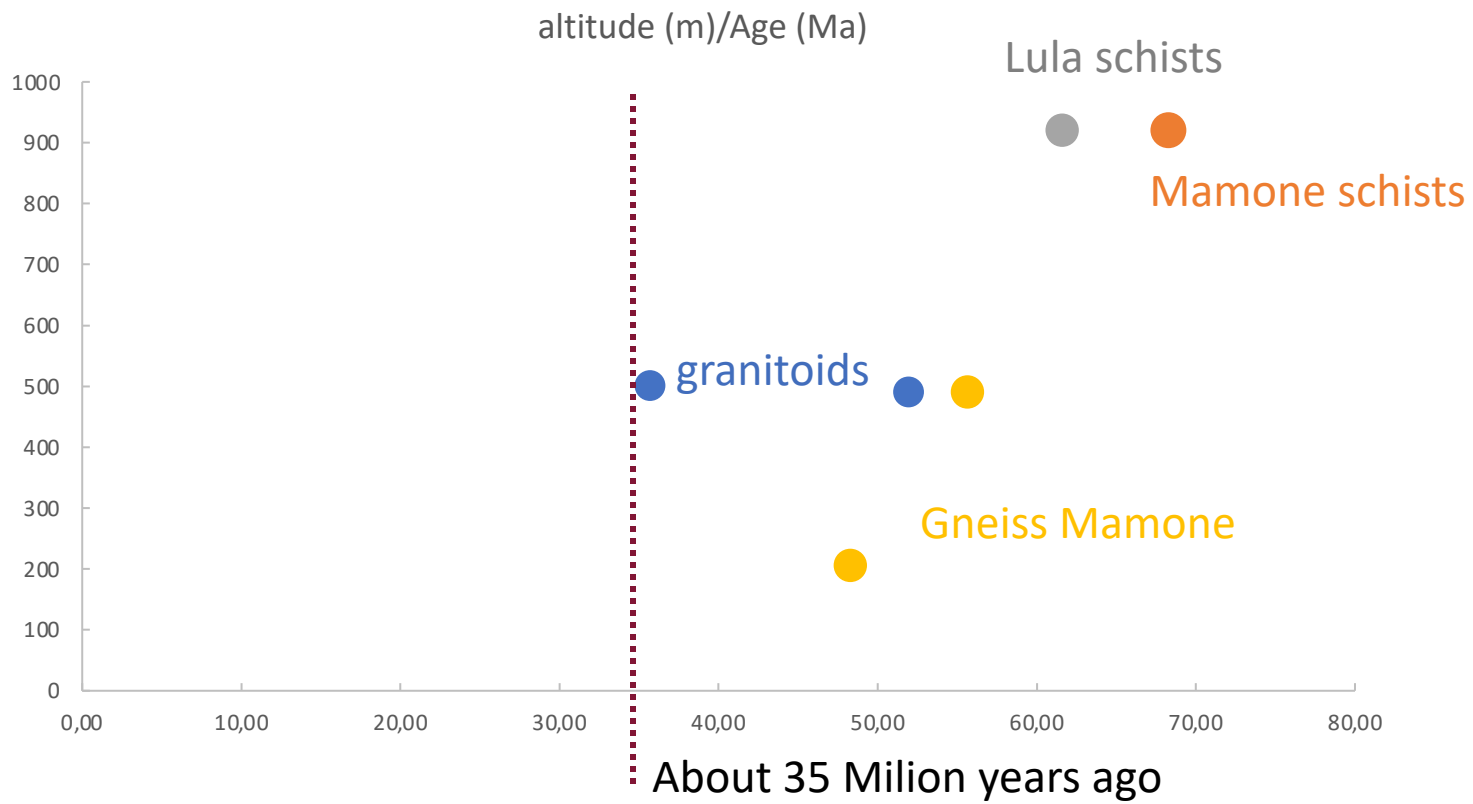
Together with
UNI PAVIA

Scottish Universities Environmental Research Centre

The available cooling ages suggest the removal of approximately 2 km of rock from the plateau over the last 35 million years.

A preliminary estimate of exhumation/erosion rates, since the Paleocene-Eocene time, shows **very low values** (maximum 0.06 mm/year) compared to tectonically active regions in the world characterized by values up to two to four orders of magnitude higher.

In summary, the geochronological analysis underscores the **stability of the region's rocks**, highlighting the limited impact of erosion and recent tectonic activity on its topography.



WHAT ABOUT THE AGE OF FAULTS?

FAULTS INTERSECTED BY VEINS

The fault rocks are intersected by large veins.

These **veins** are typical of **ancient hydrothermal circulation** that mineralized the areas traversed by **mineralizing fluids in the past**.

These quartz-rich vein areas can be several tens of meters thick.

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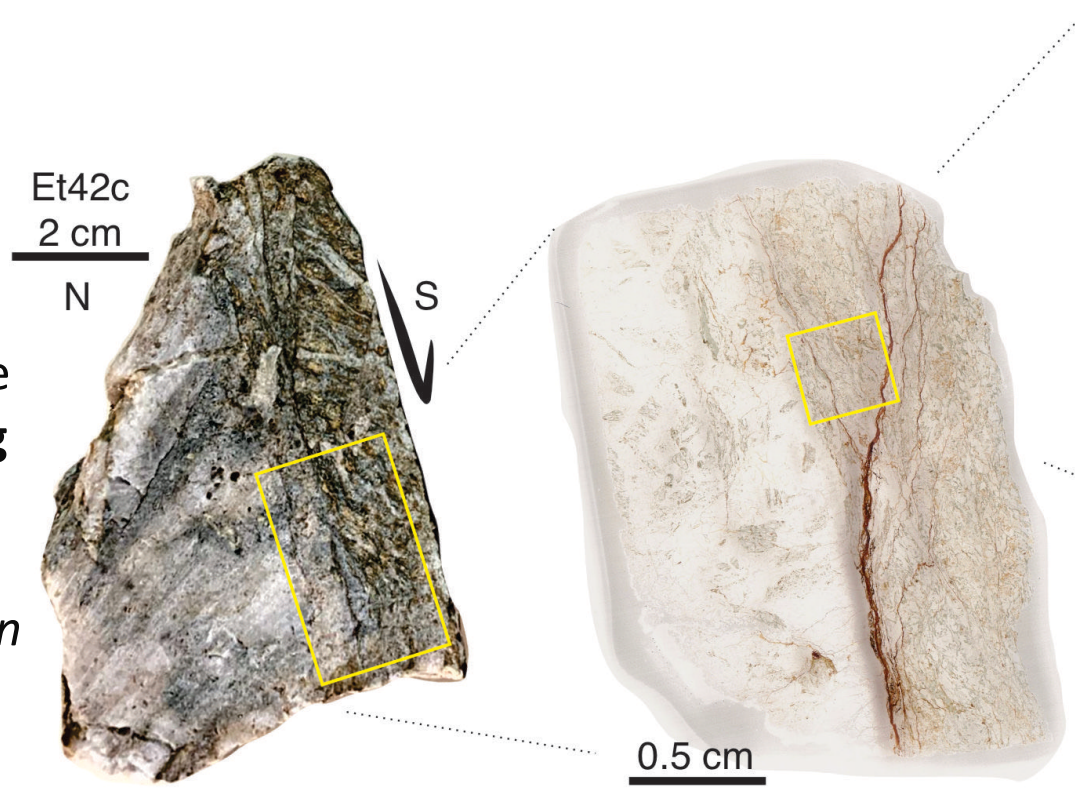

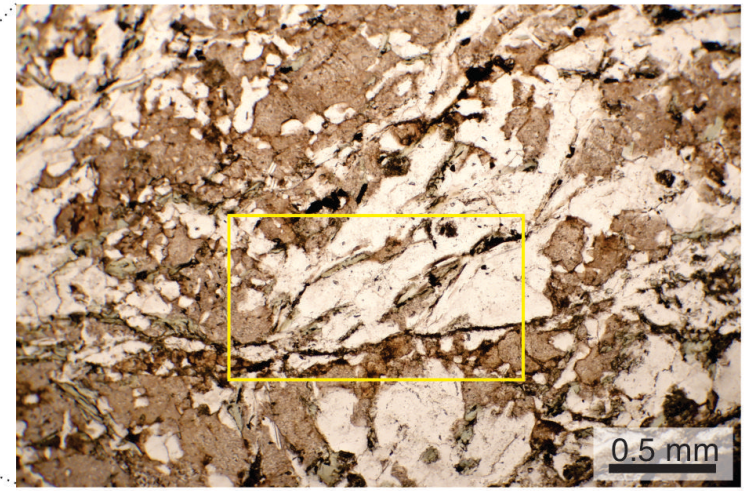

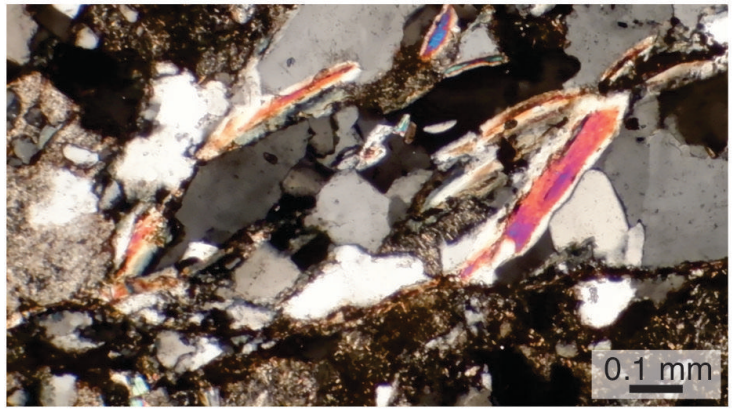

FAULTS INTERSECTED BY VEINS

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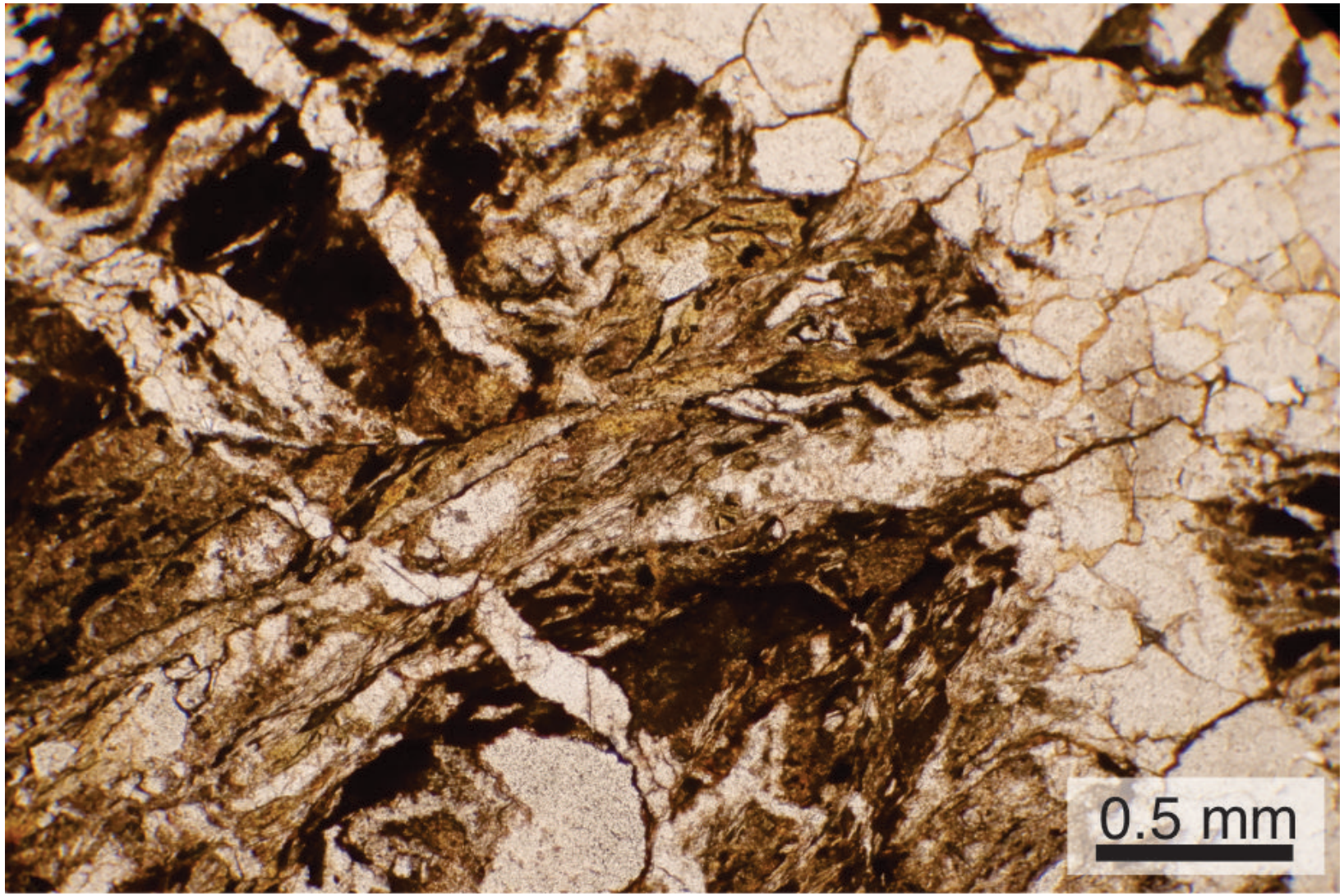
Brittle ductile structures at the microscale



FAULT CONTACTS with IMPERMEABLE GOUGE

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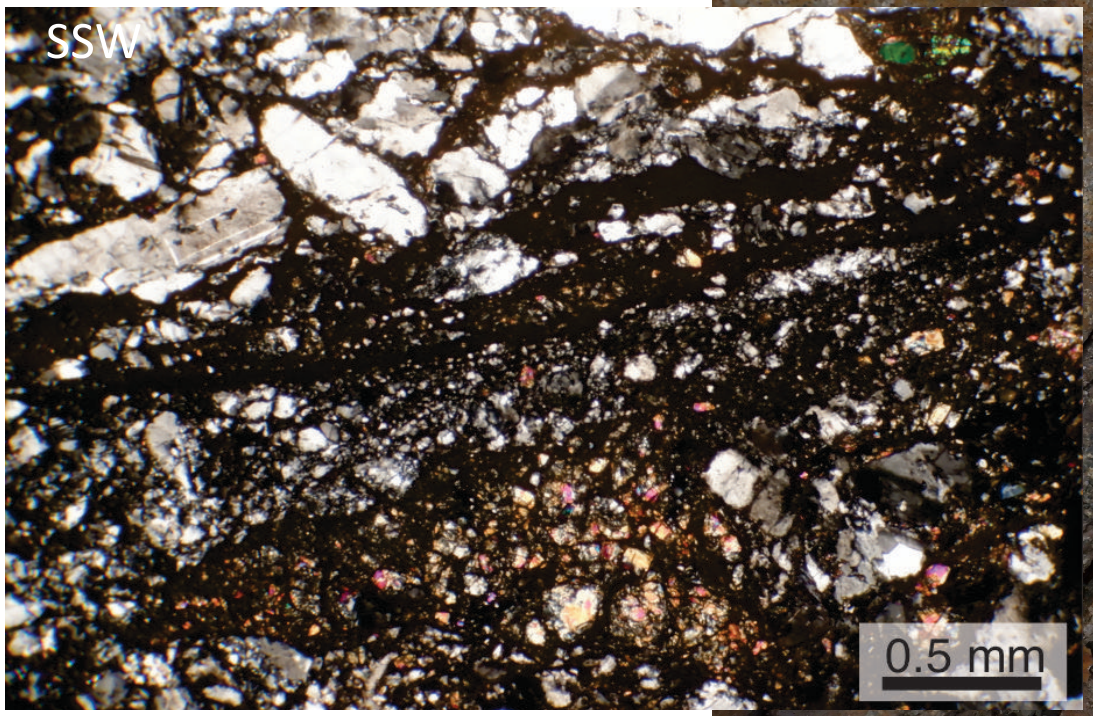
Fault gouge within the granodiorite of Bitti



FAULT CONTACTS with IMPERMEABLE GOUGE

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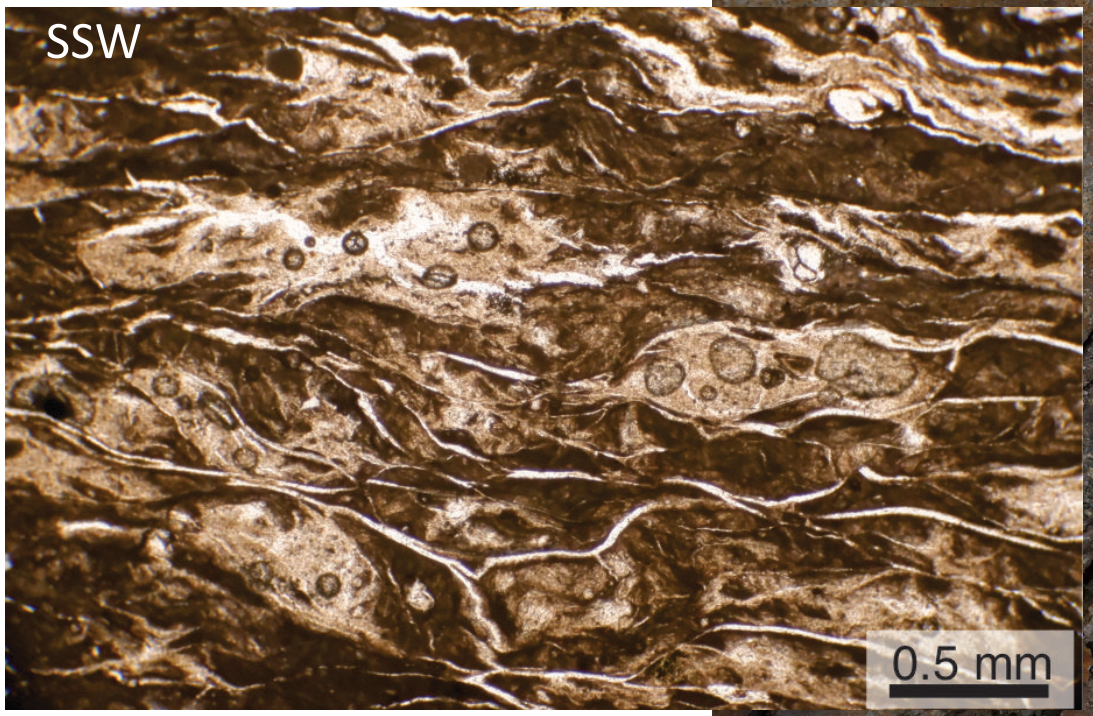
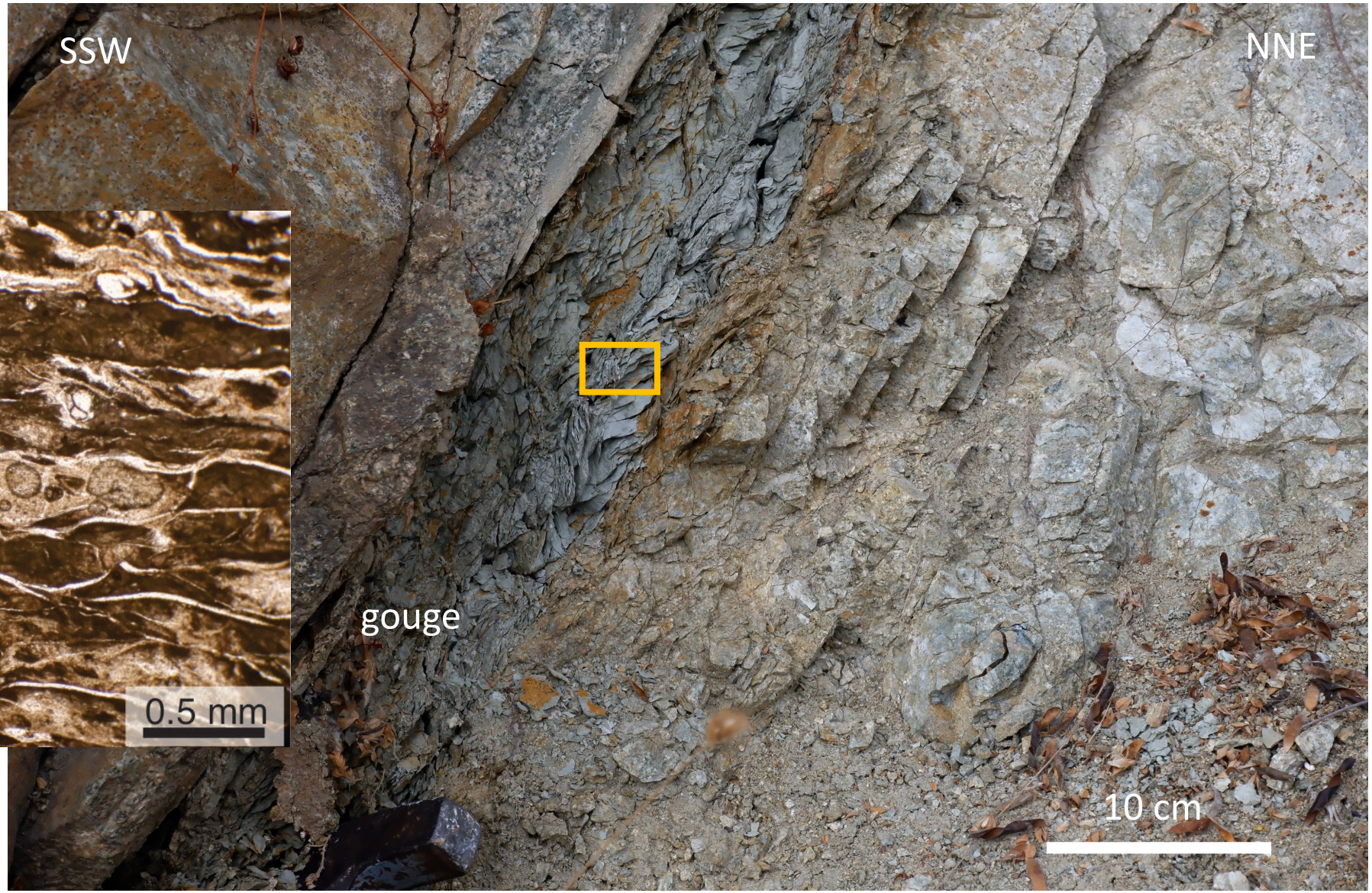
Fault gouge within the granodiorite of Bitti





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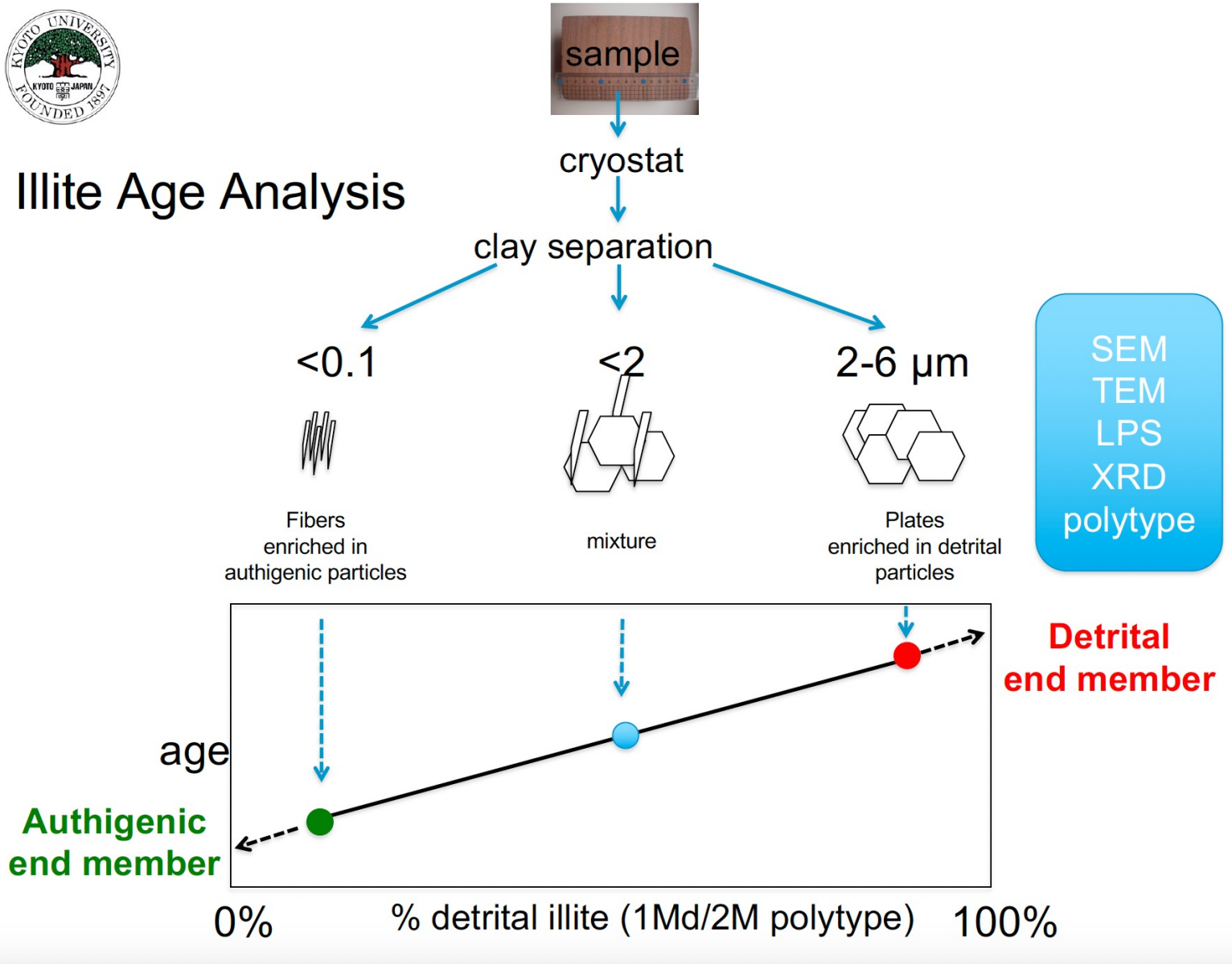
Dating the illite contained in fault debris allows us to obtain ages of the most recent fault activity in the area from faults that have already shown post-Variscan evidence.

DERISKING: In areas affected by polyphasic tectonics, we could potentially exclude recent coseismic reactivation at the site.

Nine samples of fault debris have been sent to Australia for dating using the K-Ar method.

RESULTS APPROACHING!

Fault gouge dating



EXPECTED RESULTS (2024-2025)

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Insights on the reduction of the potential risk of the candidate site from Italy for ET

- Fault dating
- Completion of rock cooling dating
- Estimation of tectonic stability/erosion
- … a new dataset is coming from the contractor’s exploration!

DANK U WEL

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Researchers involved

PhD Chiara Amadori researcher and lecturer in Basin Analysis and manages the mineral separation laboratory at the University of Pavia (IT). She contributes to clarifying the thermochronological evolution of the candidate site.

Prof. LEONARDO CASINI supervisor of the geological characterization of ET and teacher of Geology.
He is an expert in granitoids petrology and Variscan tectonics.

PhD GIOVANNI LUCA CARDELLO researcher and lecturer in Geological Surveying at the University of Sassari. In the TETI committee for candidacy, he conducts multidisciplinary structural studies on the candidate site.