Shallow geological models of Quaternary intermountain basins in Central Apennines

Pierfrancesco Burrato & Paola Vannoli

WP1.3 Geological and seismotectonic input data

SECURE

REGIONAL-SCALE EARTHQUAKE **GROUND MOTION PREDICTIONS** THROUGH PYHSICS-BASED AND EMPIRICAL APPROACHES: **A CASE STUDY CENTRAL ITALY**

Final Meeting SECURE Project (Pianeta Dinamico 2023-25), 11-12 March 2026, Roma

Central Apennines paleogeographic and tectonic overview

Area 1

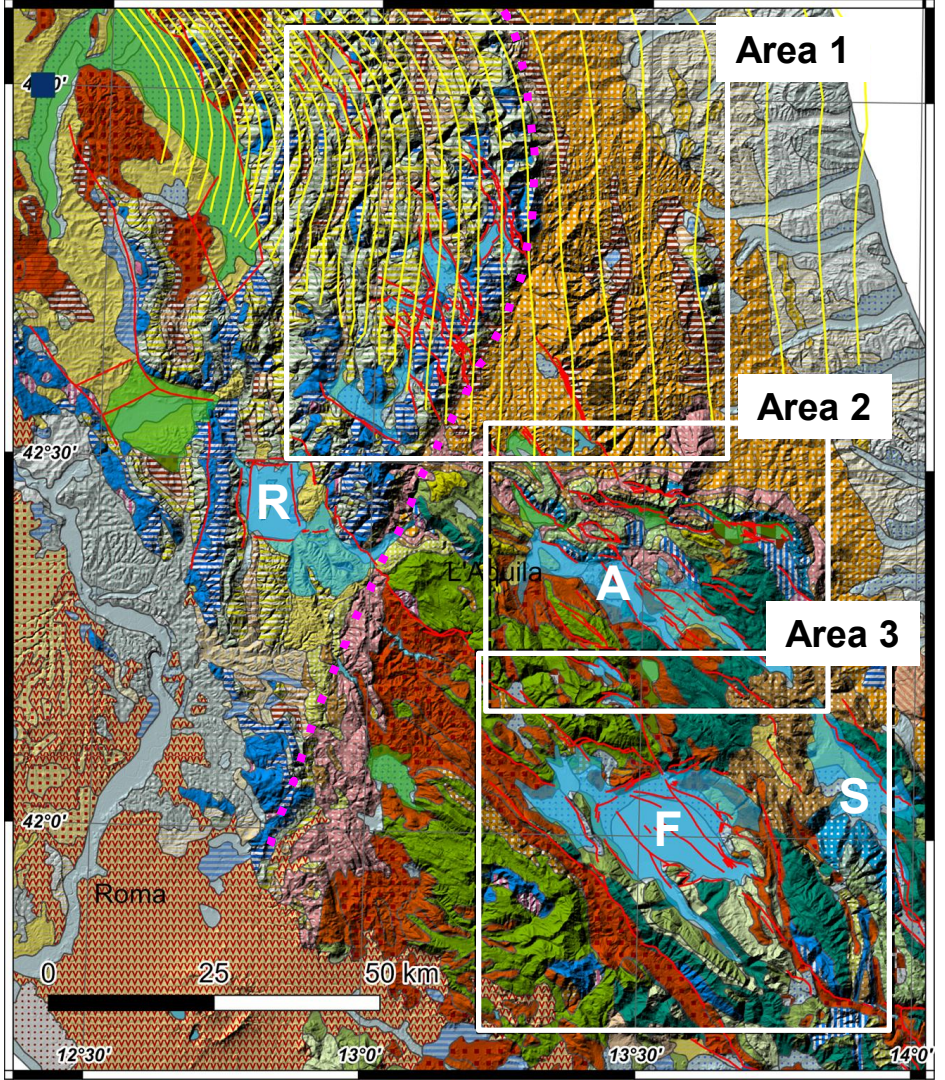
- W-dipping Adriatic monocline.
- Sibillini thrust front/Olevano-Antrodoco lateral ramp.
- Intermountain Q basins in the HW of Sibillini thrust.
- W-dipping normal fault systems antithetic to E-dipping low-angle Alto Tiberina Fault.

Area 2

- E-W trending Gran Sasso thrust salient.

Area 3

- Fucino and Sulmona largest Apennines intermountain basins



Central Apennines seismotectonic overview

Area 1

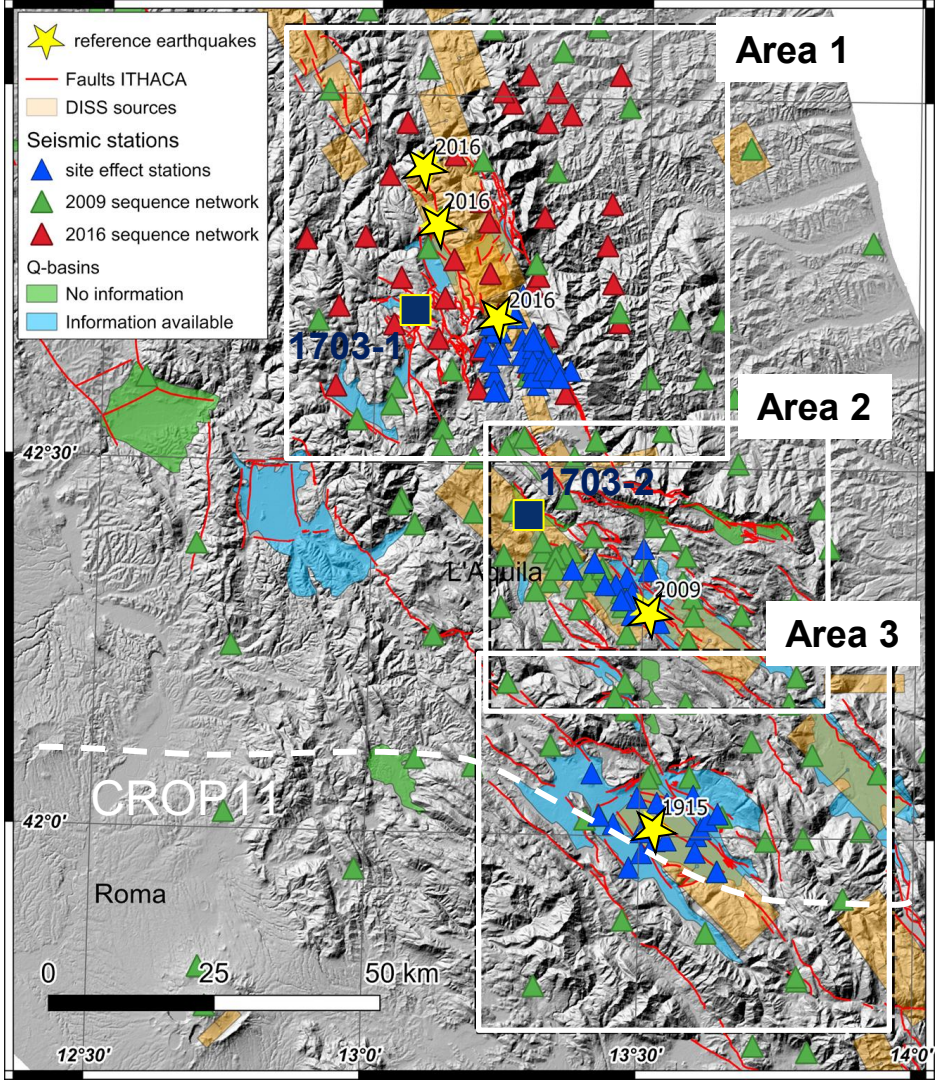
- 2016-2017 AVN eq sequence.
- 1997-1998 *Umbria-Marche* eq sequence.
- 1703 14 Jan Mw 6.9 *Valnerina* eq.
- RETRACE-3D Central Italy Geological Model.

Area 2

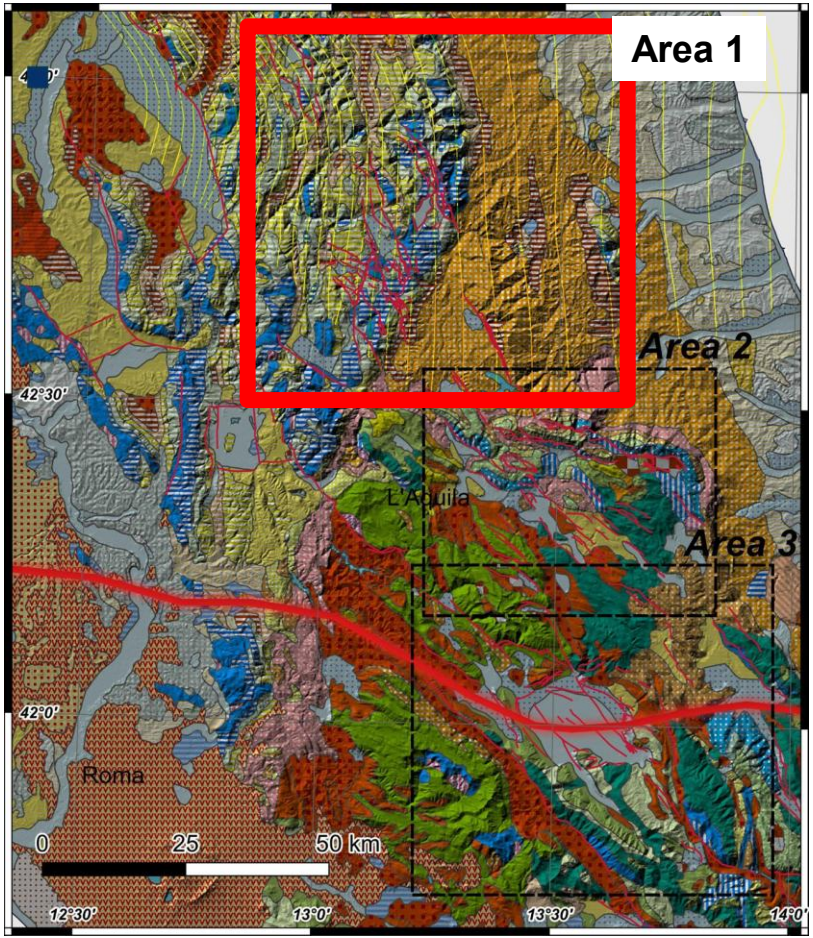
- 2009 *L'Aquila* Mw 6.3 earthquake.
- 1703 2 Feb Mw 6.7 *Aquilano* earthquake.

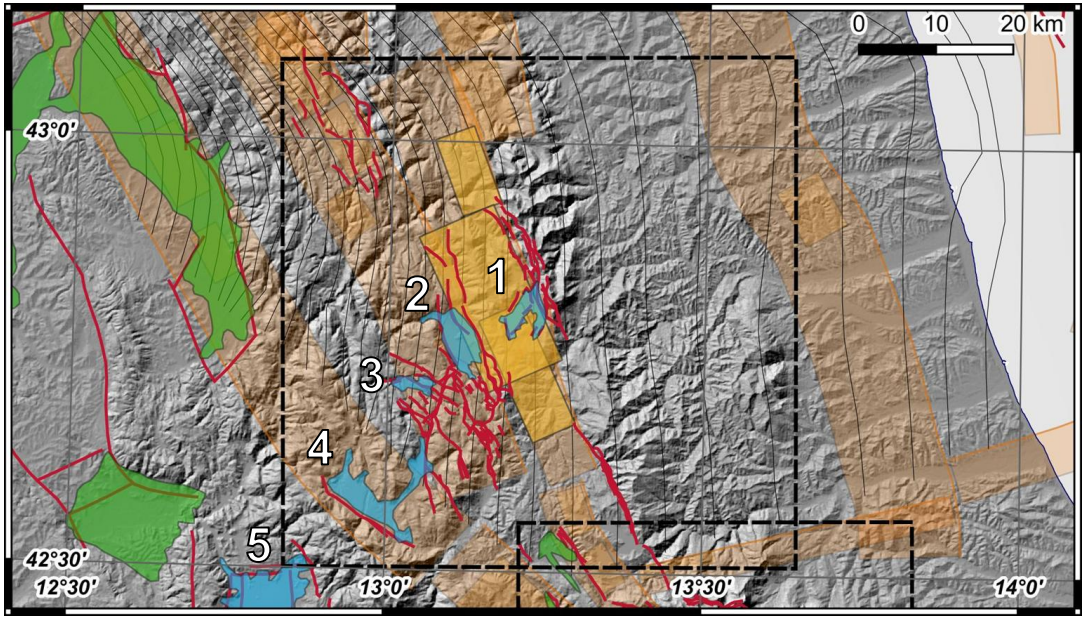
Area 3

- 1915 Mw 7.1 *Marsica* earthquake.
- Crossed by CROP11 line.



Area #1 - available data for Quaternary basins

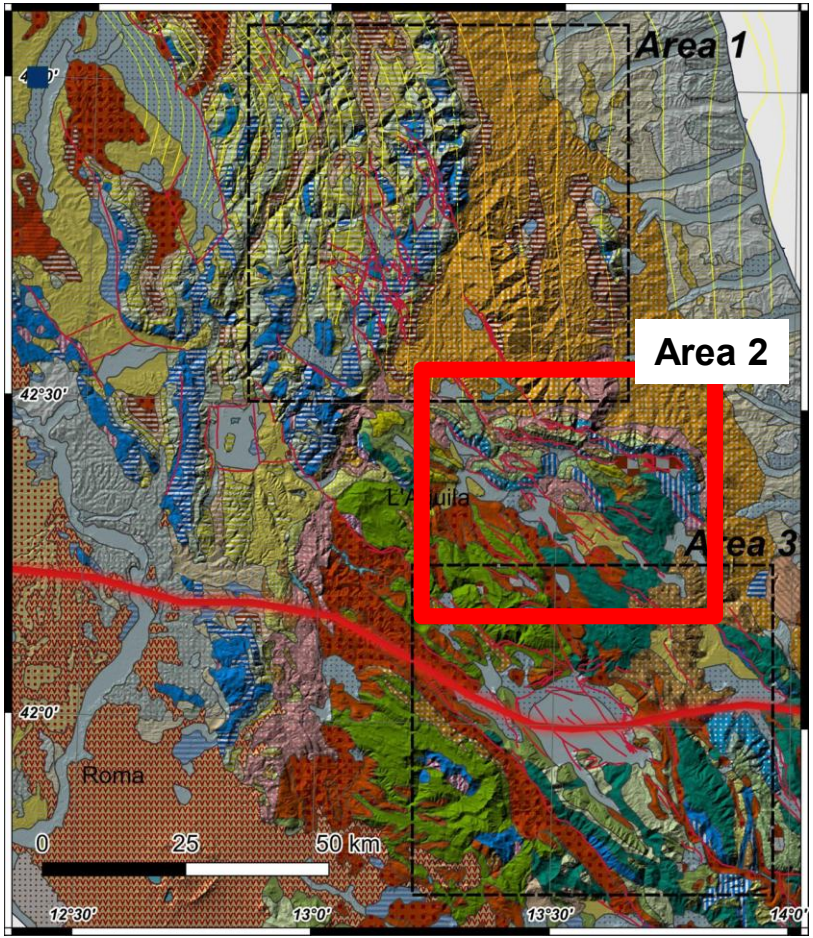


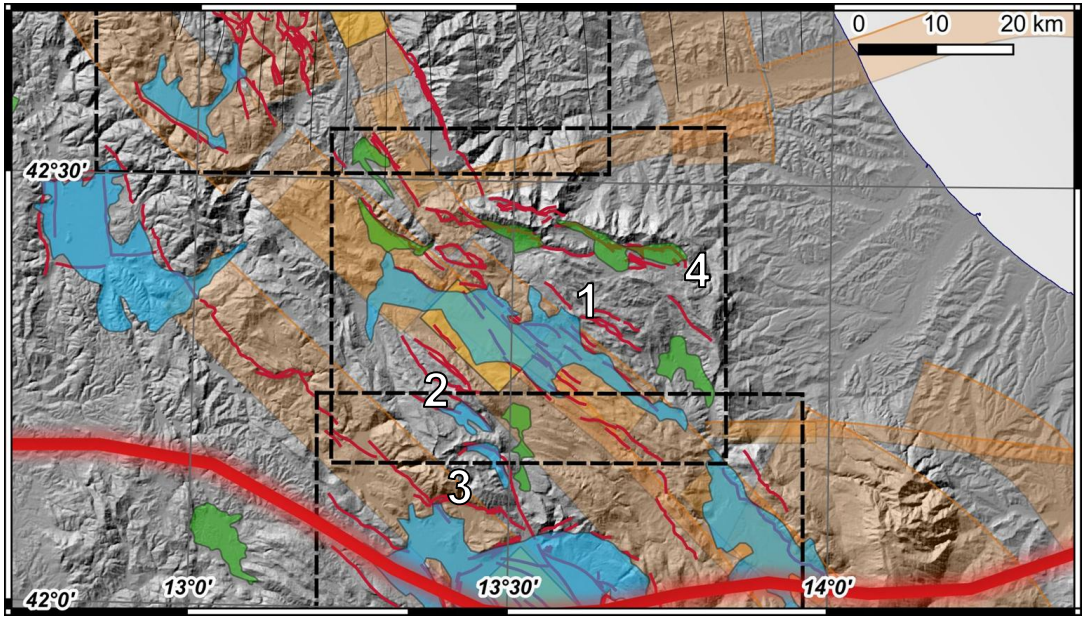


Quaternary basins with available subsurface studies

1- **Castelluccio**
2- **Norcia**
3- Cascia
4- Leonessa
5- Rieti

Area #2 - available data for Quaternary basins





Quaternary basins with available subsurface studies

1- **Middle Aterno Valley**

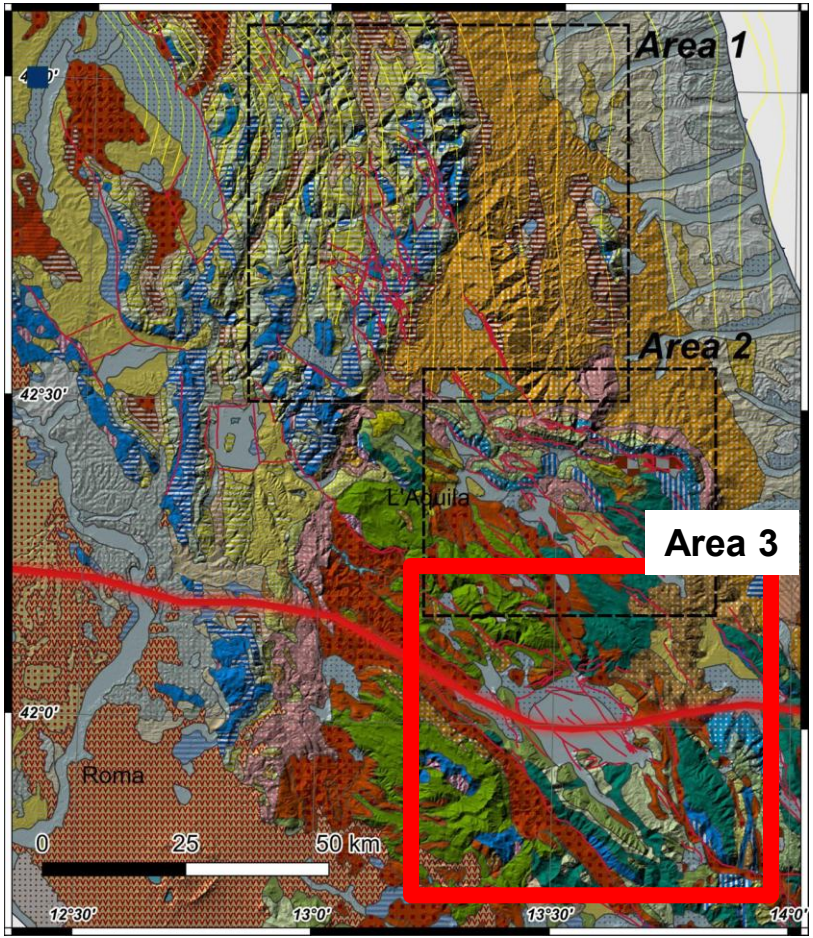
2- Campo Felice

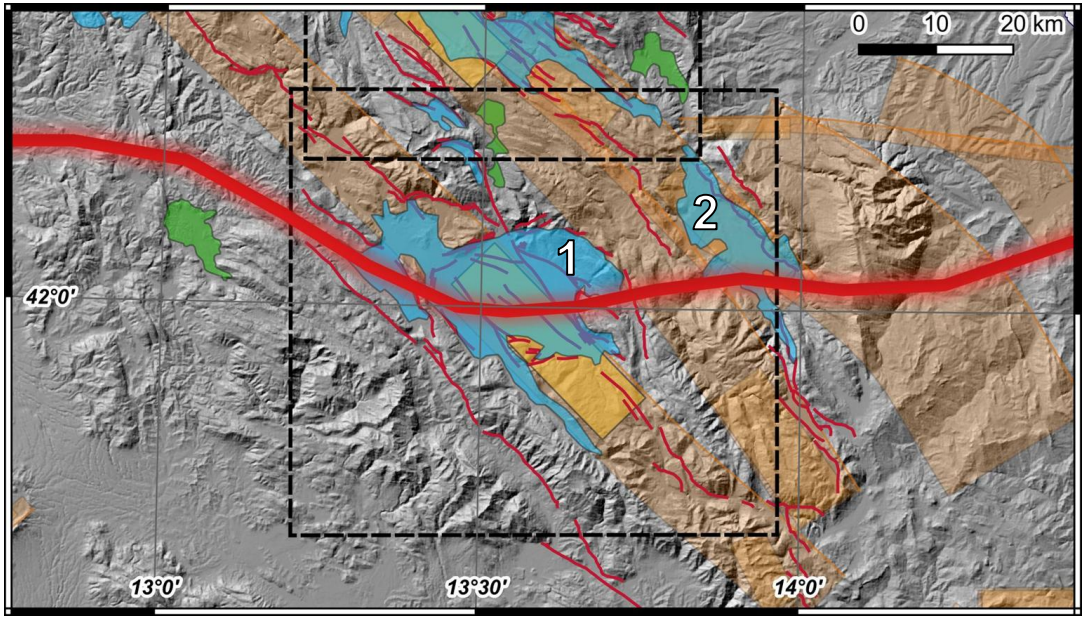
3- Piani di Pezza

Main Quaternary basin w/o subsurface studies

4- Campo Imperatore

Area #3 - available data for Quaternary basins





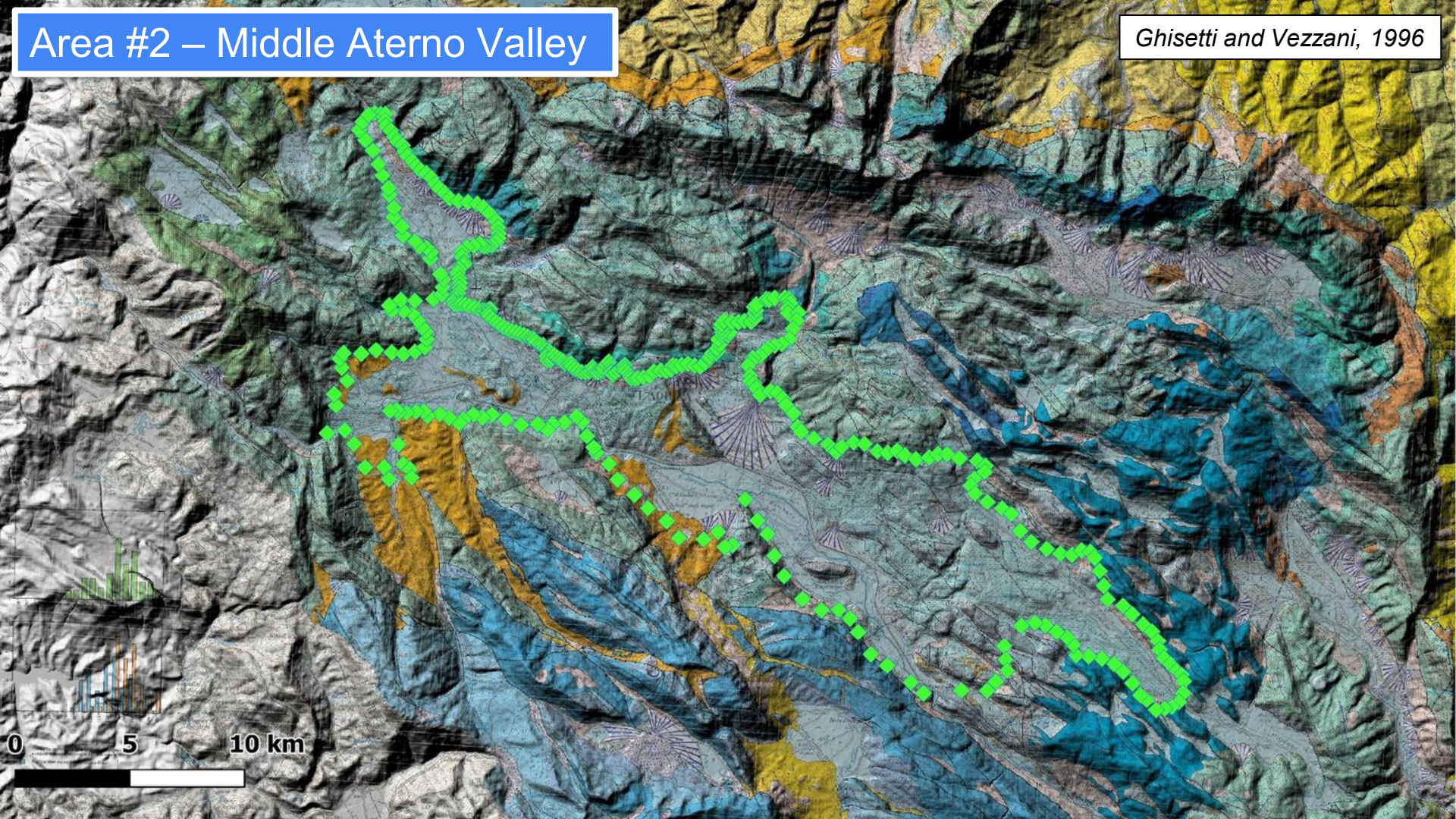
Quaternary basins with available subsurface studies

1- **Fucino Basin**

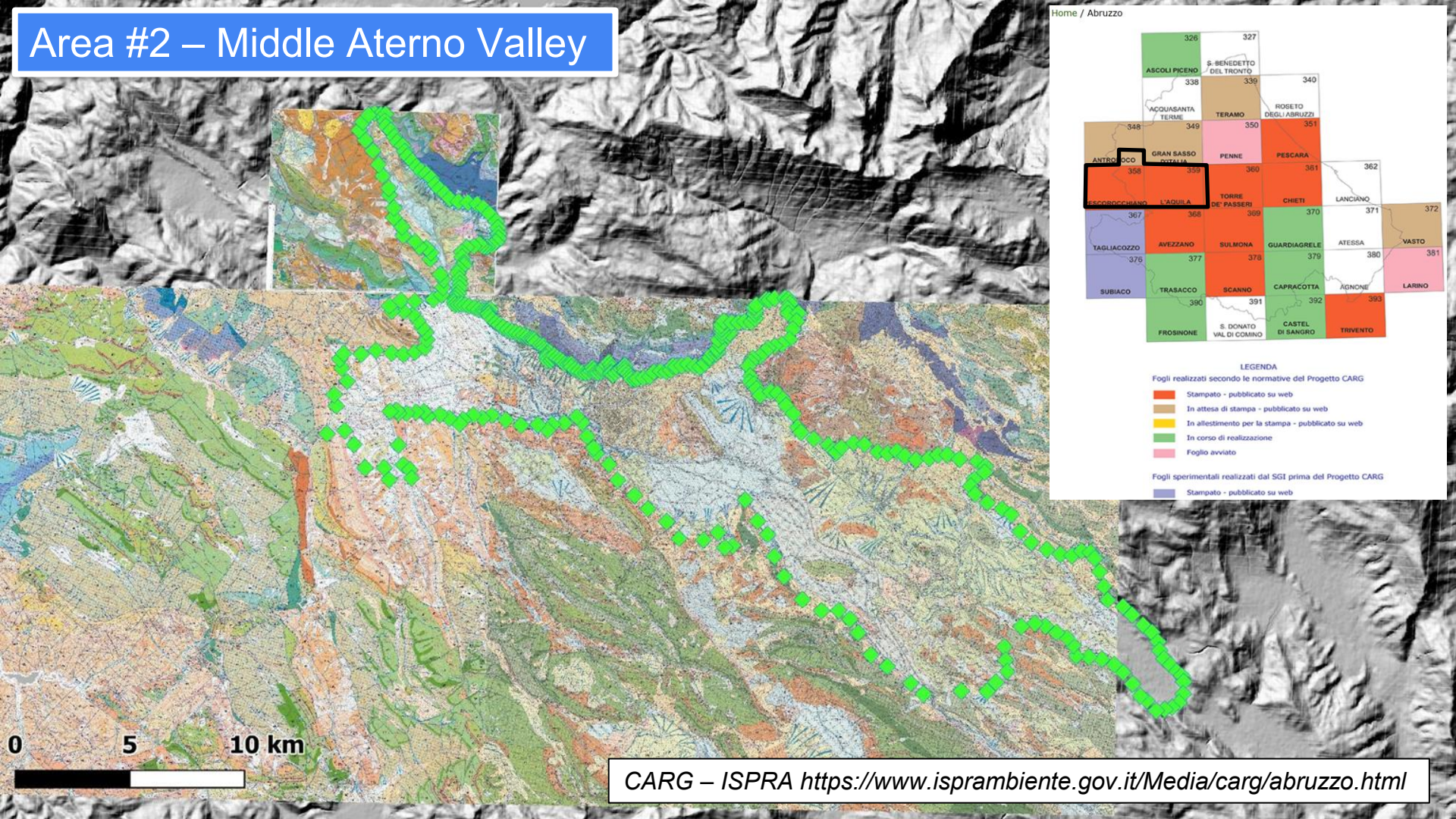
2- Sulmona Basin

Area #2 – Middle Aterno Valley

Ghisetti and Vezzani, 1996



Area #2 – Middle Aterno Valley

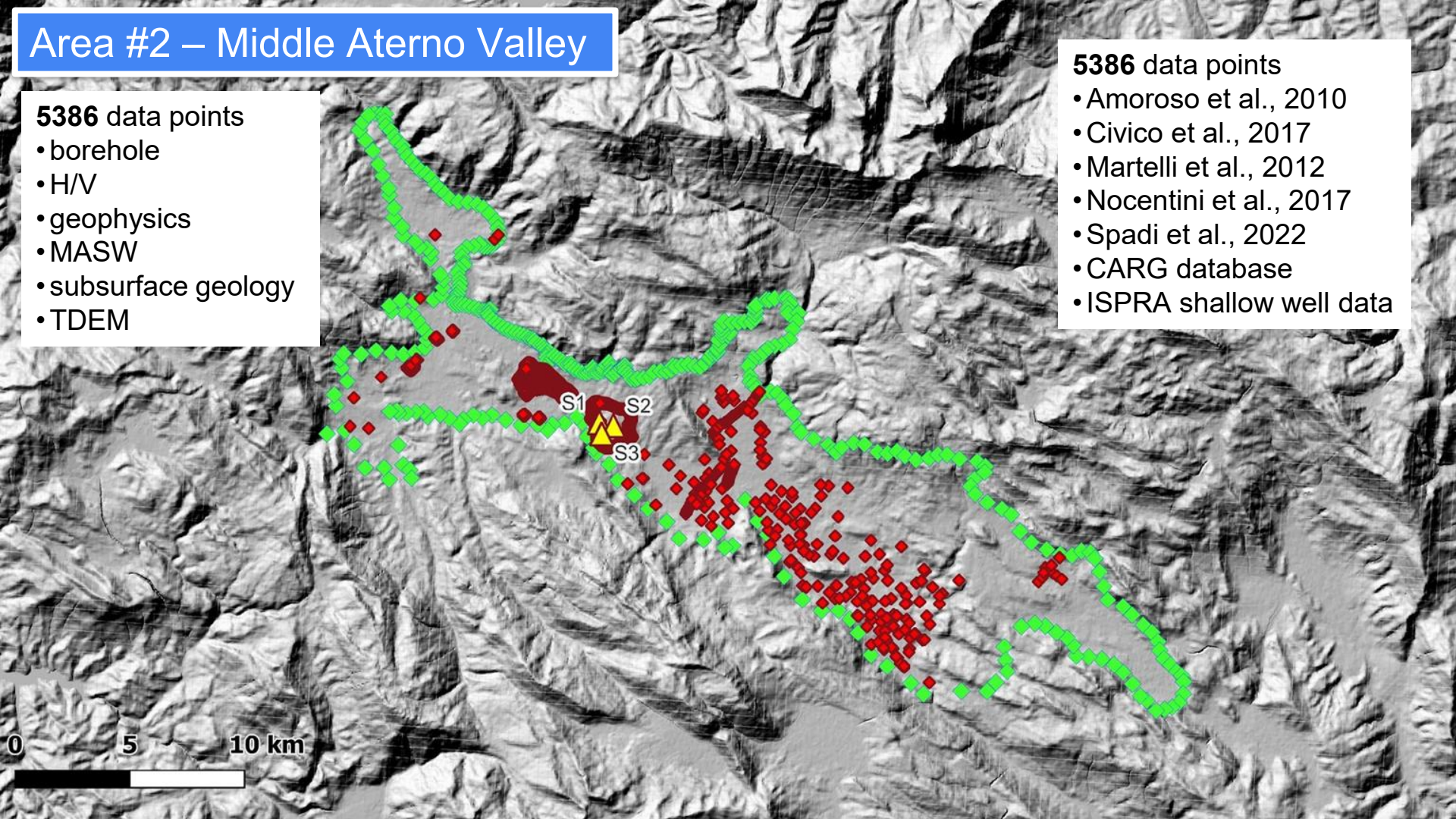


CARG – ISPRA https://www.isprambiente.gov.it/Media/carg/abruzzo.html

Area #2 – Middle Aterno Valley

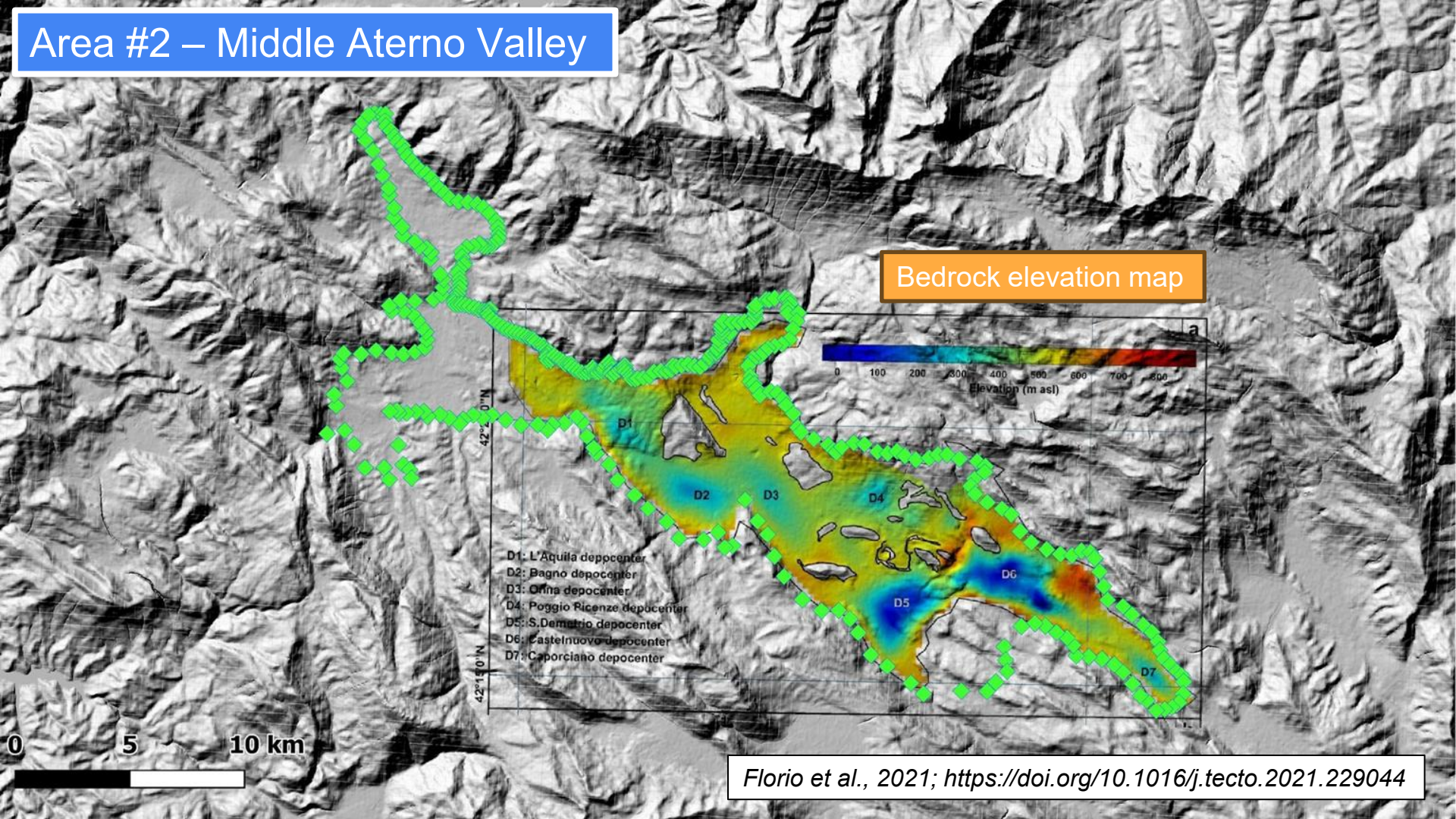
5386 data points
- borehole
- H/V
- geophysics
- MASW
- subsurface geology
- TDEM

5386 data points
- Amoroso et al., 2010
- Civico et al., 2017
- Martelli et al., 2012
- Nocentini et al., 2017
- Spadi et al., 2022
- CARG database
- ISPRA shallow well data



Area #2 – Middle Aterno Valley

Bedrock elevation map



Florio et al., 2021; https://doi.org/10.1016/j.tecto.2021.229044

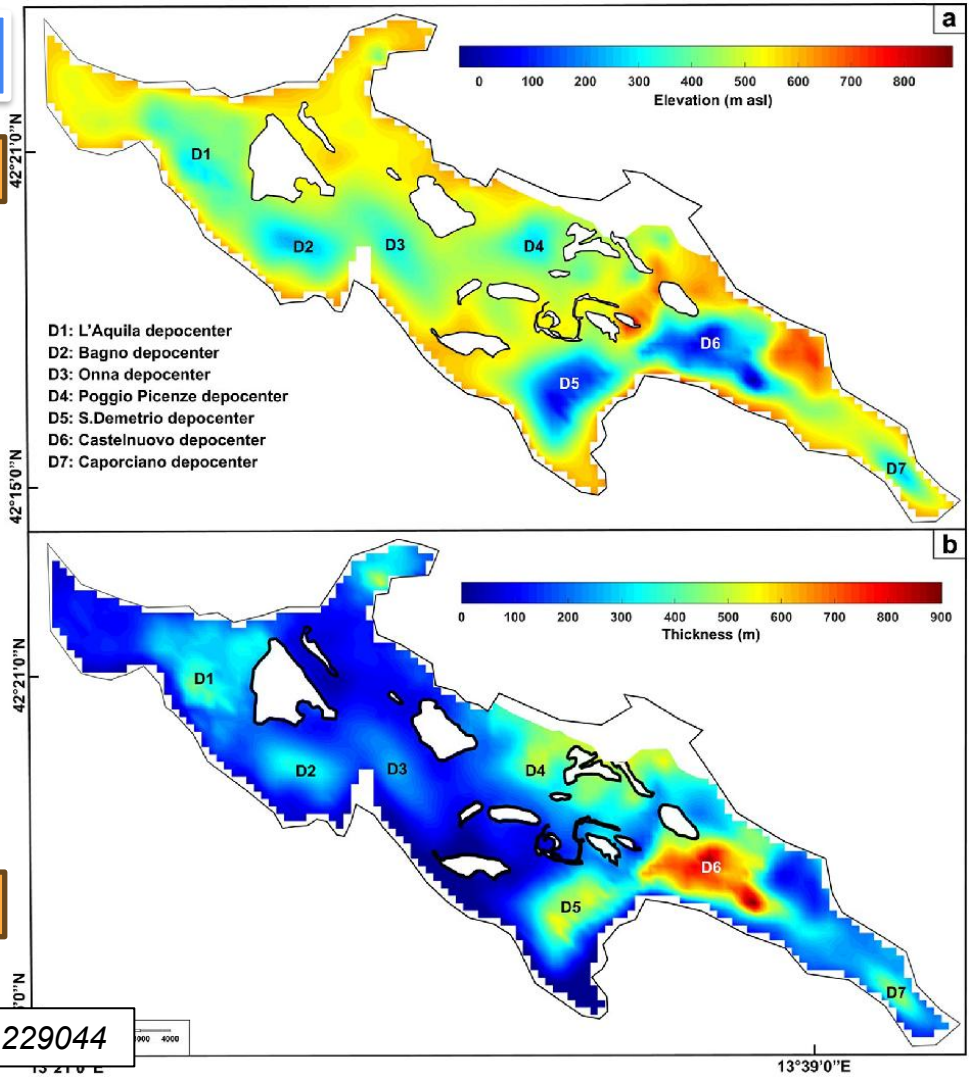
Area #2 – Middle Aterno Valley

Bedrock elevation map

Key observations

1. Numerous depocenters with variable thickness
2. «Islands» of outcropping bedrock
3. Outcropping flysh deposits: depocenter
4. Bedrock morphology controlled by tectonics and karstic features

Sediment thickness map

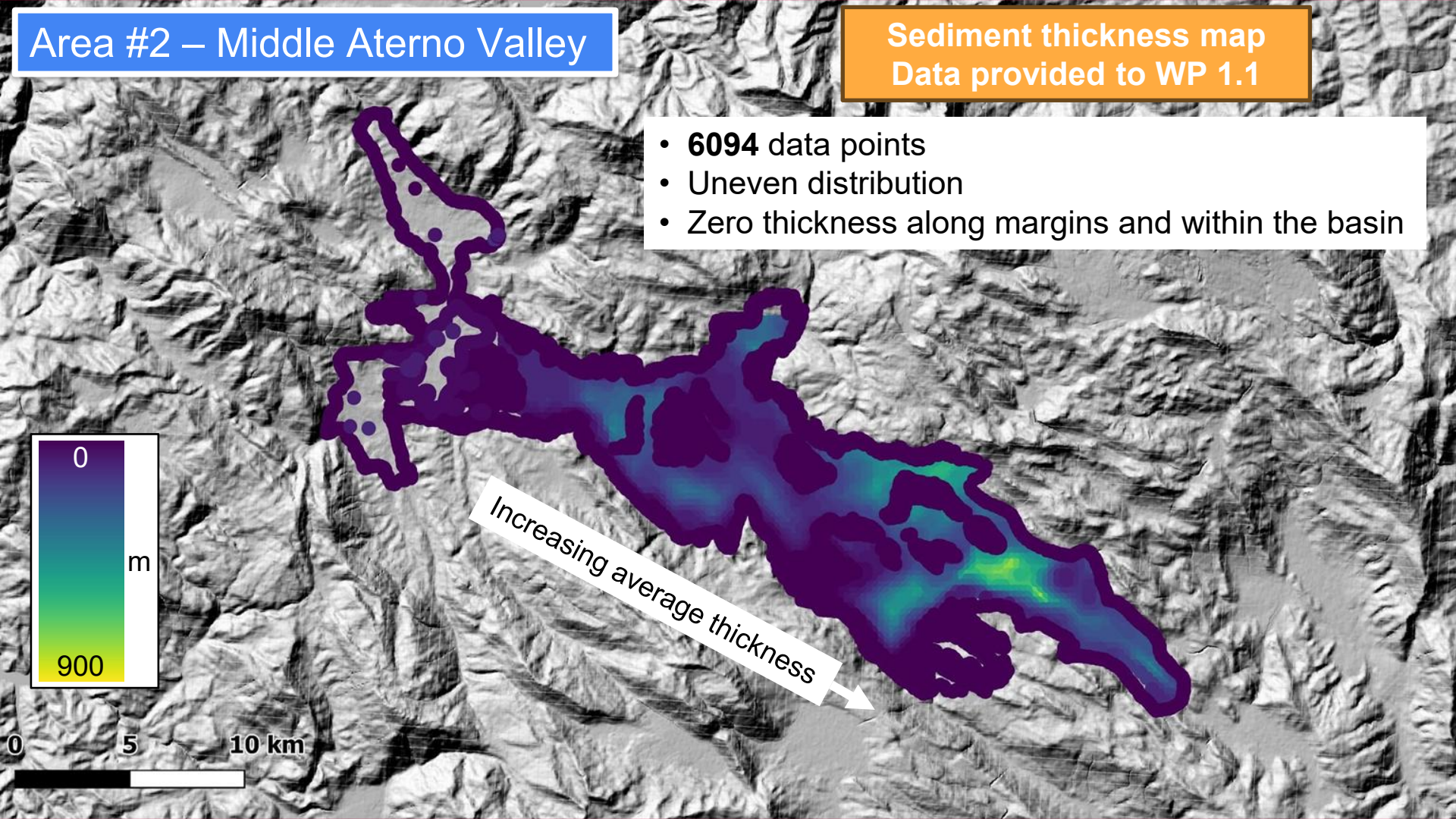


Florio et al., 2021; https://doi.org/10.1016/j.tecto.2021.229044

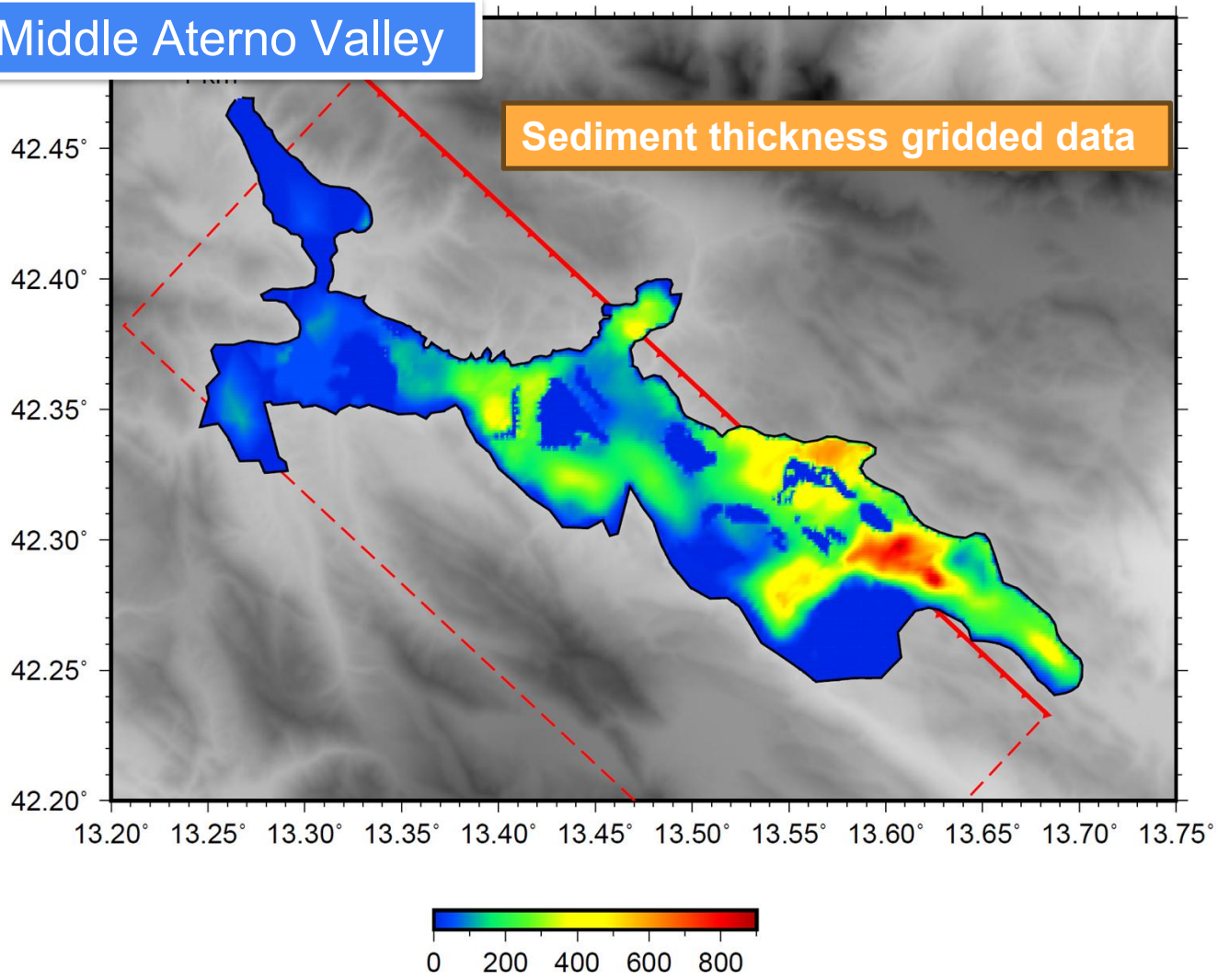
Area #2 – Middle Aterno Valley

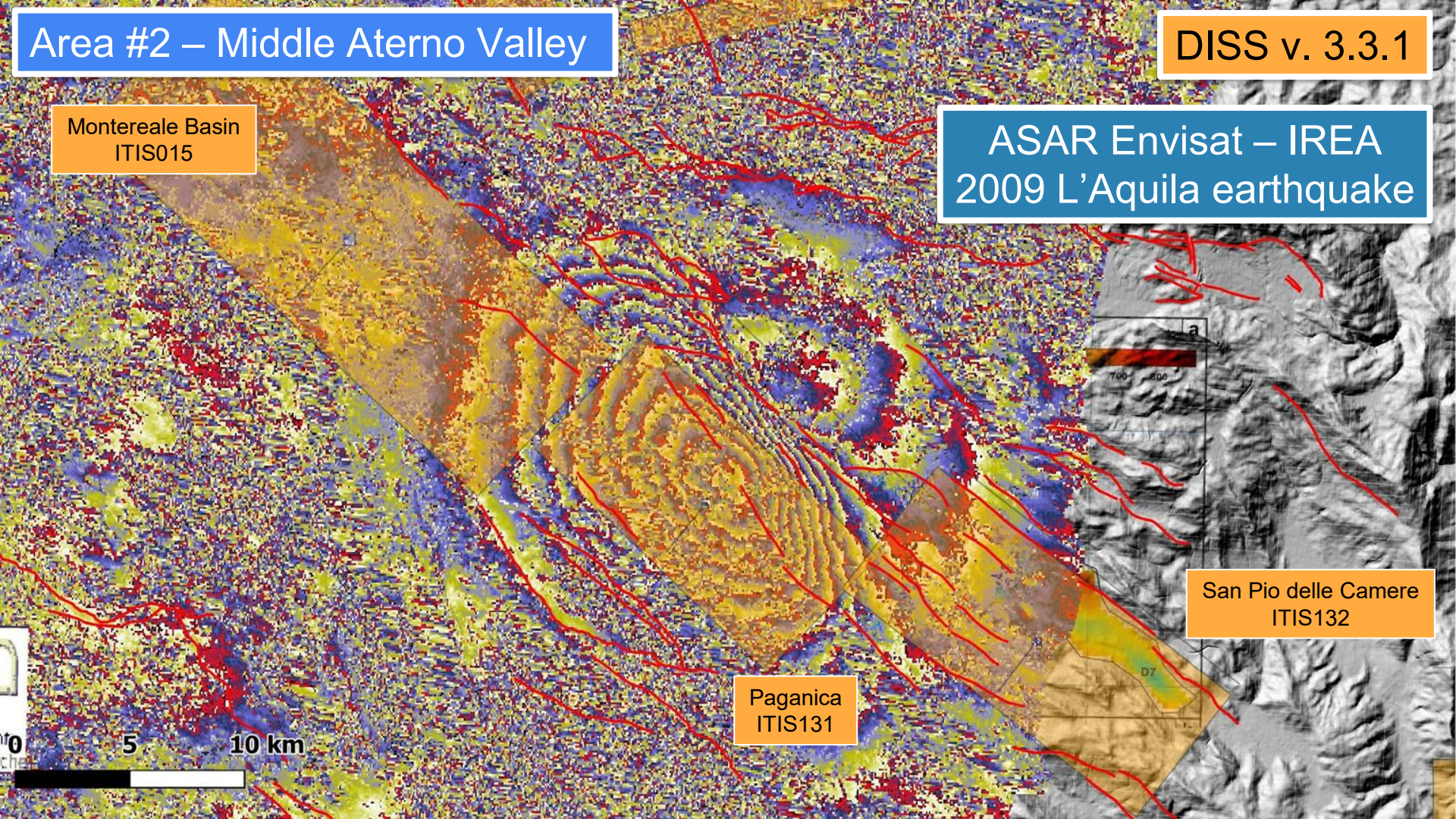
Sediment thickness map
Data provided to WP 1.1

- **6094** data points
- Uneven distribution
- Zero thickness along margins and within the basin



Area #2 – Middle Aterno Valley

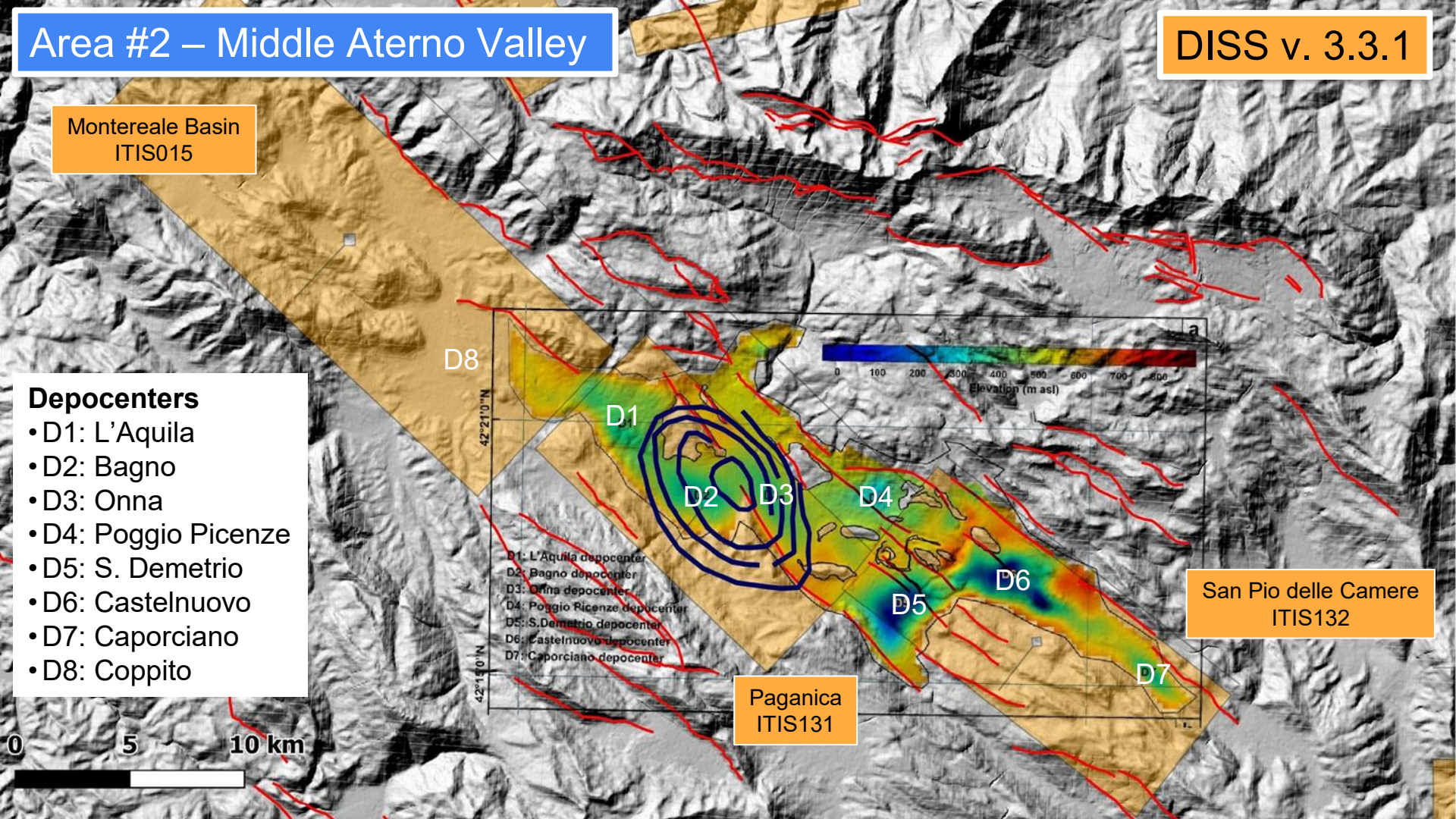



Area #2 – Middle Aterno Valley
DISS v. 3.3.1
Montereale Basin
ITIS015
ASAR Envisat – IREA
2009 L'Aquila earthquake
San Pio delle Camere
ITIS132
Paganica
ITIS131
5
10 km

Area #2 – Middle Aterno Valley

DISS v. 3.3.1

Montereale Basin
ITIS015



Depocenters

- D1: L'Aquila
- D2: Bagno
- D3: Onna
- D4: Poggio Picenze
- D5: S. Demetrio
- D6: Castelnuovo
- D7: Caporciano
- D8: Coppito

San Pio delle Camere
ITIS132

Paganica
ITIS131

0 5 10 km

Area #2 – Middle Aterno Valley - **SUMMARY**

Age of the basin: 3.0 to 3.2 Ma

The continental sedimentation within the intermontane basin began in the late Pliocene (late Piacenzian) to early Pleistocene (Gelasian/Calabrian), a recent analysis of a long sediment core recovered from the Paganica-San Demetrio-Castelnuovo sub-basin constrains the onset of the oldest lacustrine sedimentation to approximately 3.0 to 3.2 Ma.

Maximum depth of the Quaternary infill: 550-700 m (max SE sector)

The thickness of the Plio-Quaternary continental infill is highly variable, but it reaches significant maximum depths. The greatest thicknesses are recorded in the southern and eastern sectors, where **3D gravity modeling** and **deep boreholes** estimate maximum depths exceeding 550 m and reaching over 700 m in the Castelnuovo depocenter. In the nearby San Demetrio area, multiple **geophysical methods** (TDEM, ambient noise, deep ERT) infer a maximum basement depth ranging from 450 m to approximately 600 m. Furthermore, beneath L'Aquila downtown, the sedimentary fill also reaches a maximum thickness of about 600 m.

Area #2 – Middle Aterno Valley - **SUMMARY**

Multiple depocenters (up to 8 depocenters of variable thickness)

The buried architecture of the basin is highly complex and structured by a network of Quaternary normal faults that created structural and topographic highs (thresholds) separating several distinct deep basins. Geophysical surveys and deep boreholes have identified several principal depocenters:

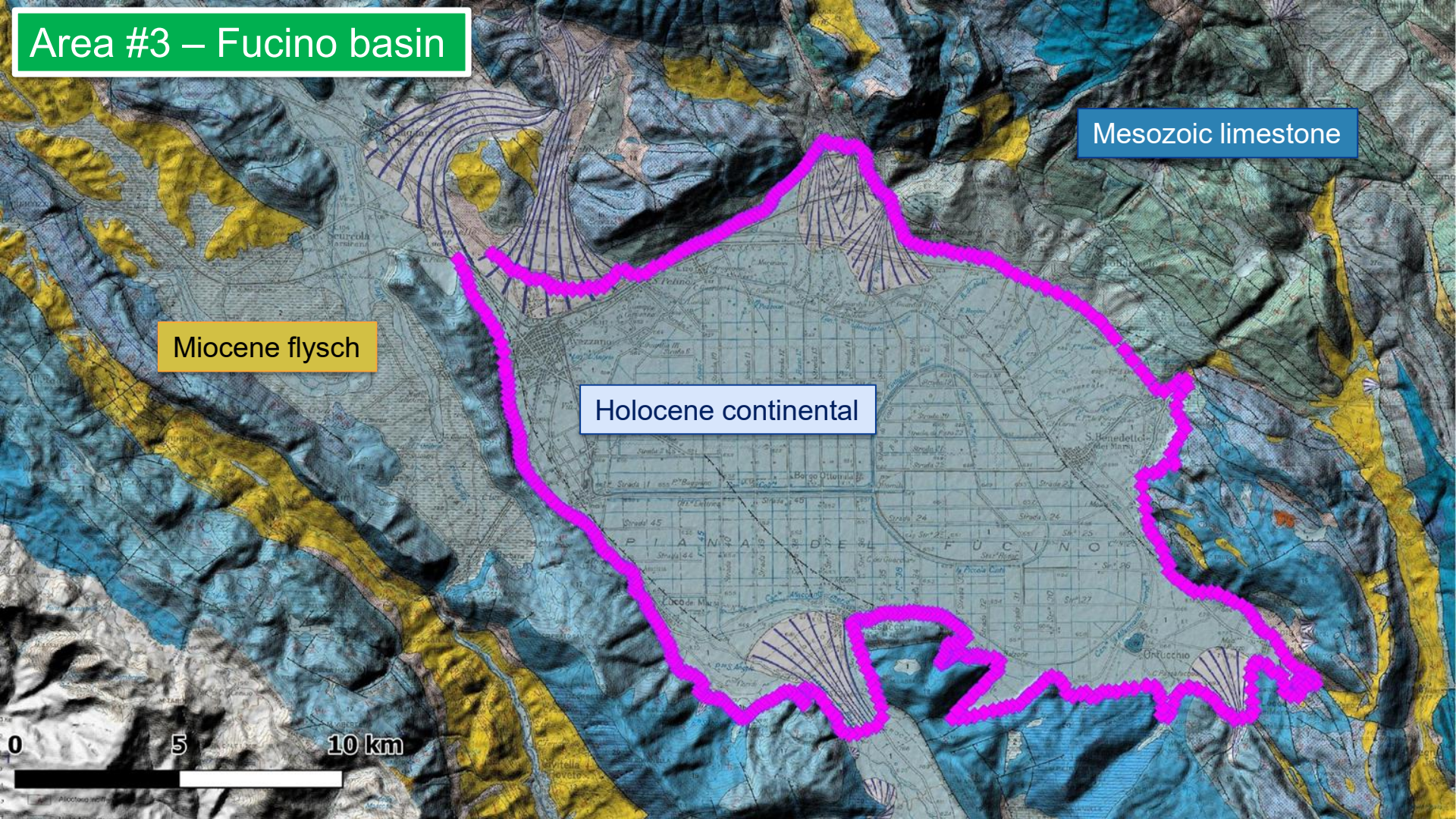
1. L'Aquila (~600 m deep).
2. Bagno (~220-250 m deep).
3. Paganica-Onna (~300 m deep).
4. Poggio Picenze (~500 m deep).
5. San Demetrio (450–600 m deep).
6. Castelnuovo (>700 m deep).
7. Caporciano (up to 480 m deep).
8. Coppito (up to 50 m deep)

Area #2 – Middle Aterno Valley - **SUMMARY**

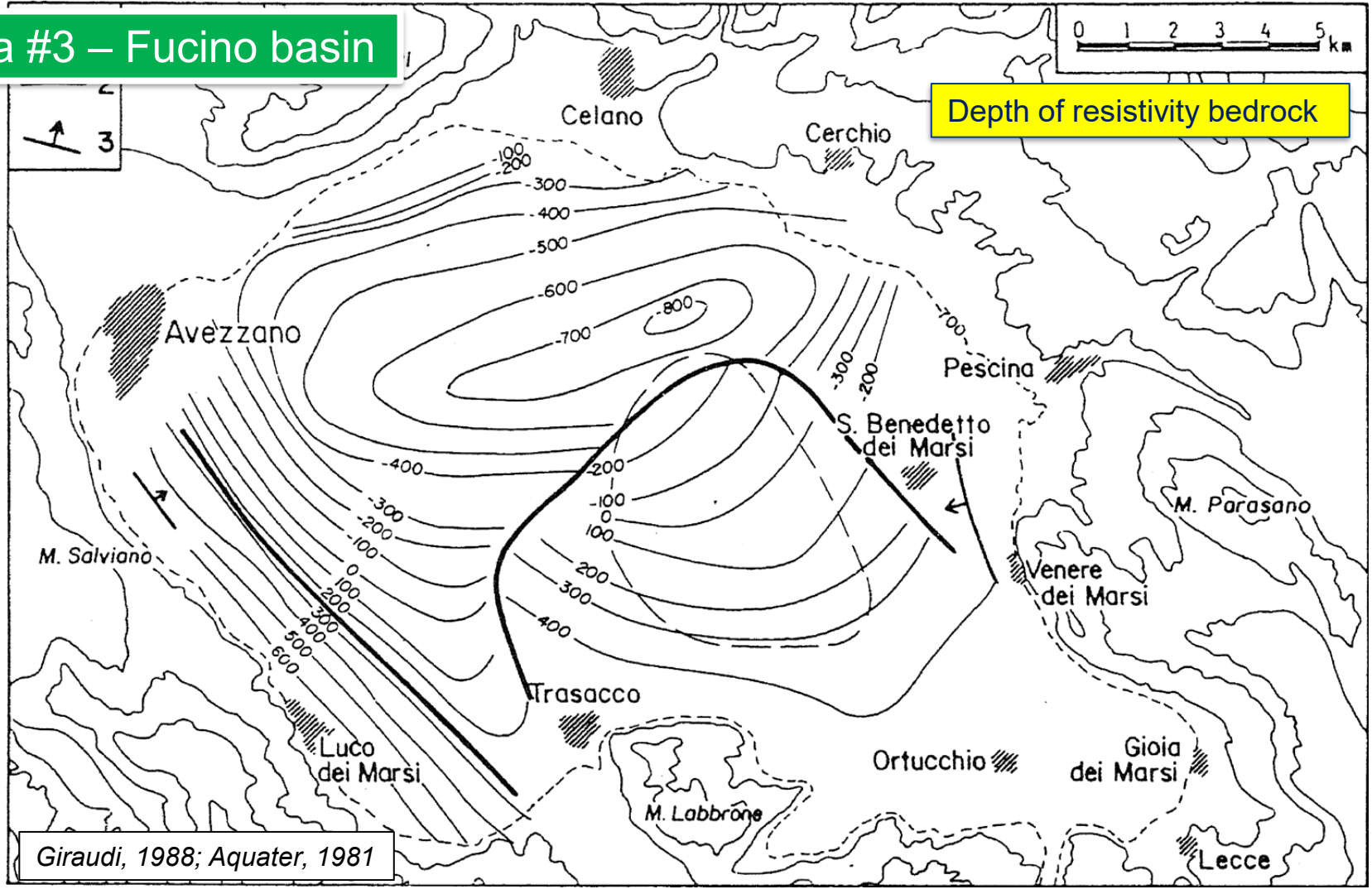
Stratigraphic heterogeneity due to variable environments

The stratigraphic sequence contains deposits spanning a wide variety of environments—lacustrine, fluvial, alluvial fan, and slope—often exhibiting lateral heteropic (interfingering) relationships.

1. **Lacustrine**: represented primarily by the early stages of basin filling, and include laminated, whitish calcareous silts and organic-rich clays, which accumulated in deep to low-energy lake environments.
2. **Fluvial and deltaic**: the early lake was partially filled by a prograding Gilbert-type deltaic system, evidenced by sandy bottomsets, steeply dipping gravel foresets and sub-horizontal braided river topsets. Later stages are characterized by meandering river systems with floodplains and swampy areas, as well as braided or wandering river systems.
3. **Alluvial Fan**: the basin margins host well-stratified, cross-bedded conglomerates and gravels representing alluvial fans that fed sediment into the main valley transversely.
4. **Slope**: the mountain fronts and fault escarpments are flanked by heterometric, angular calcareous breccias and megabreccias. These were deposited by slope-derived debris flows and rock avalanches.


Area #3 – Fucino basin
Mesozoic limestone
Miocene flysch
Holocene continental
0
5
10 km

Area #3 – Fucino basin



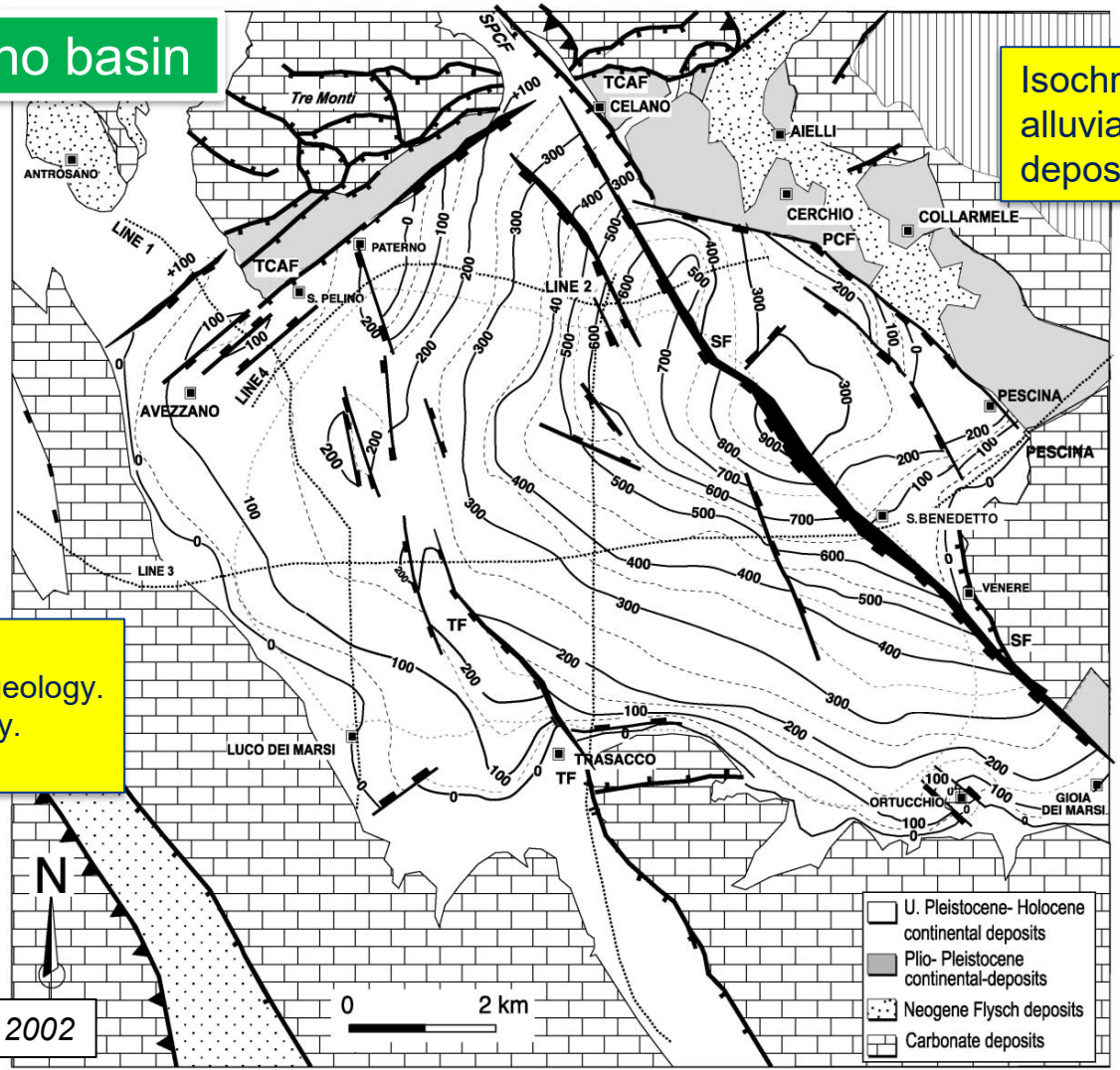
Giraudi, 1988; Aquater, 1981

Area #3 – Fucino basin

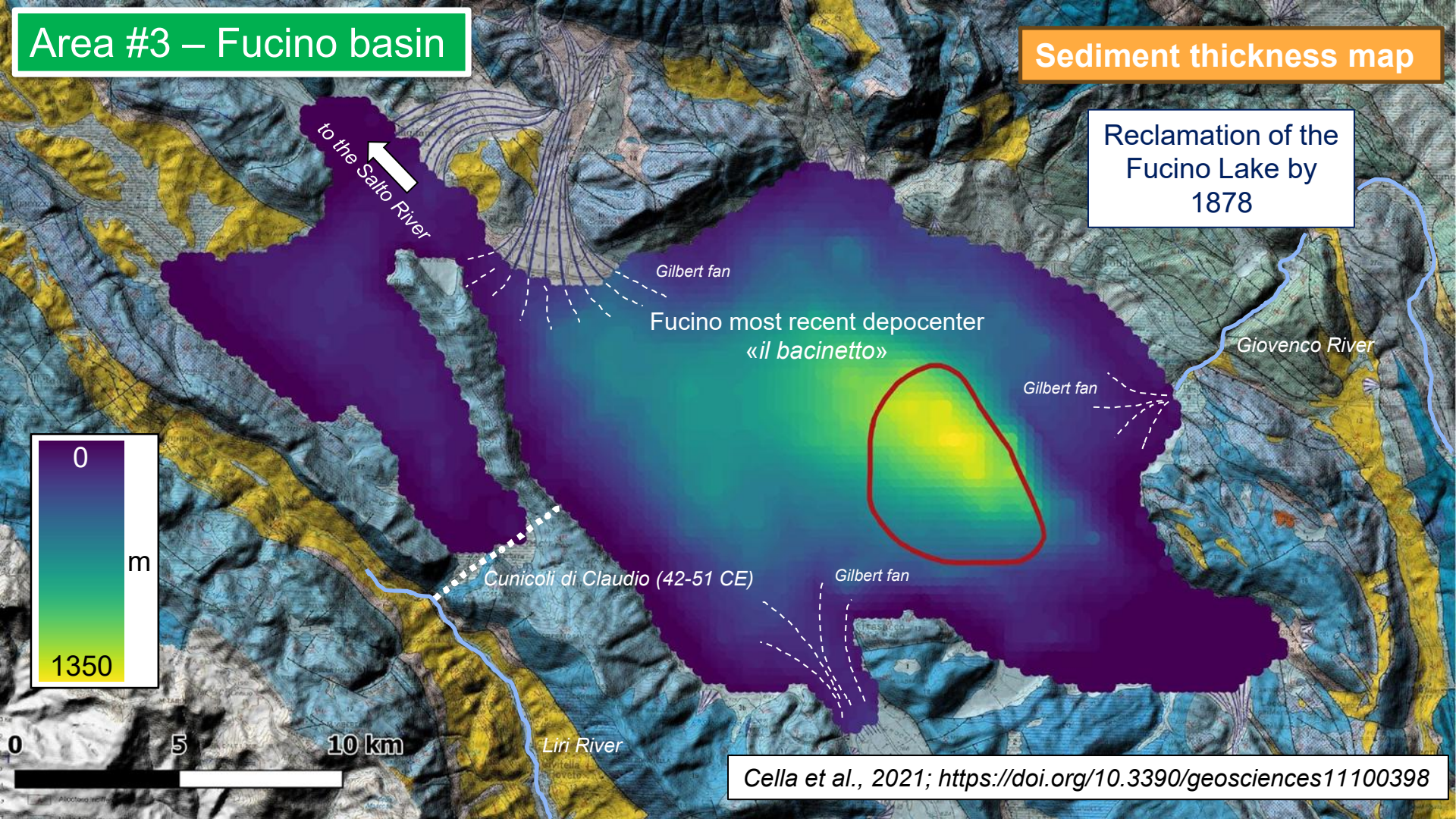
Isochron of the base of alluvial and lacustrine deposits

From:

- Mapping of surface geology.
- Borehole Stratigraphy.
- Seismic Reflection.

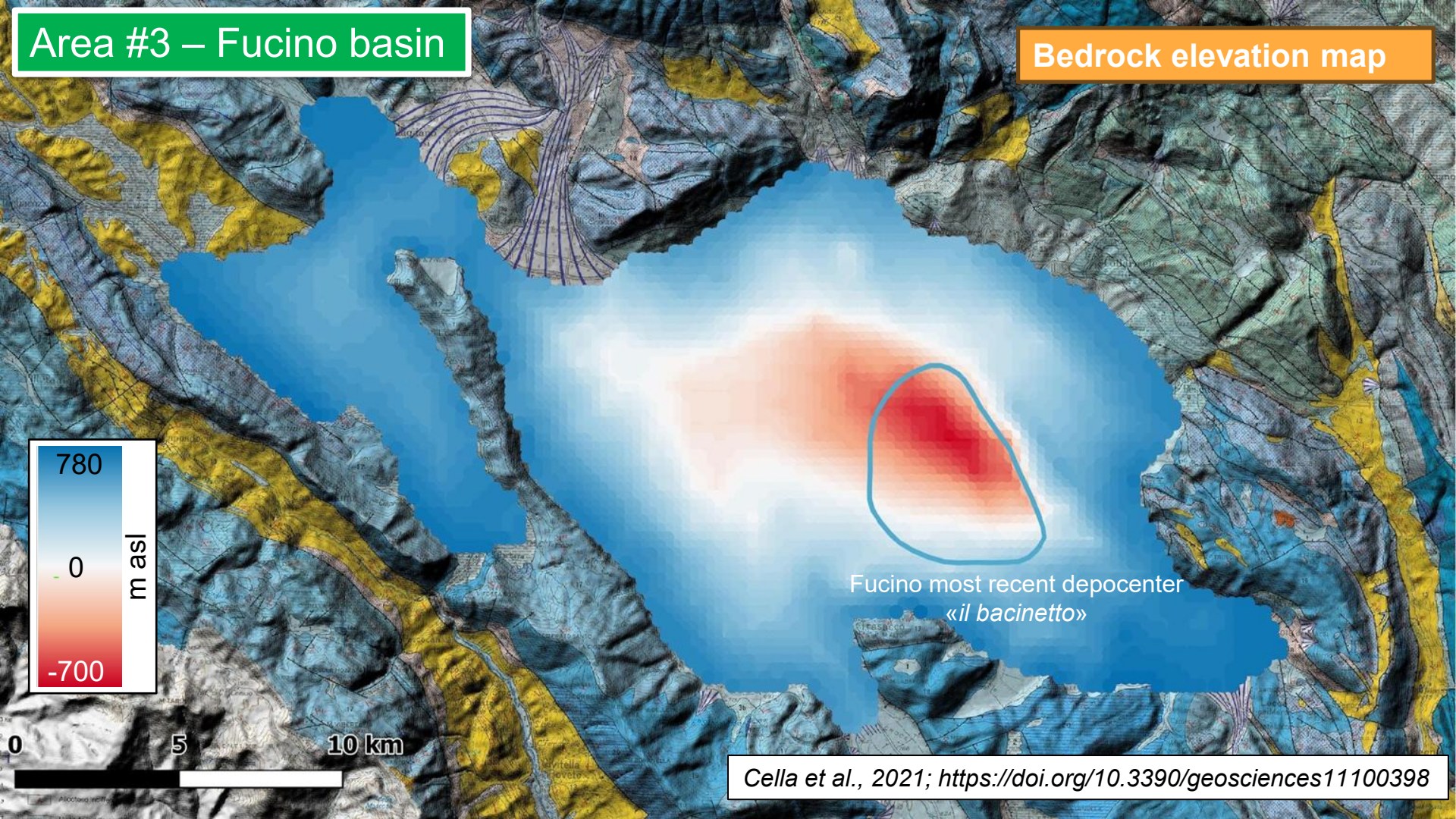


Cavinato et al., 2002


Area #3 – Fucino basin
Sediment thickness map
Reclamation of the Fucino Lake by 1878
to the Salto River
Gilbert fan
Fucino most recent depocenter
«il bacinetto»
Giovenco River
Gilbert fan
Cunicoli di Claudio (42-51 CE)
Gilbert fan
Liri River
0
m
1350
0
5
10 km
Cella et al., 2021; https://doi.org/10.3390/geosciences11100398

Area #3 – Fucino basin

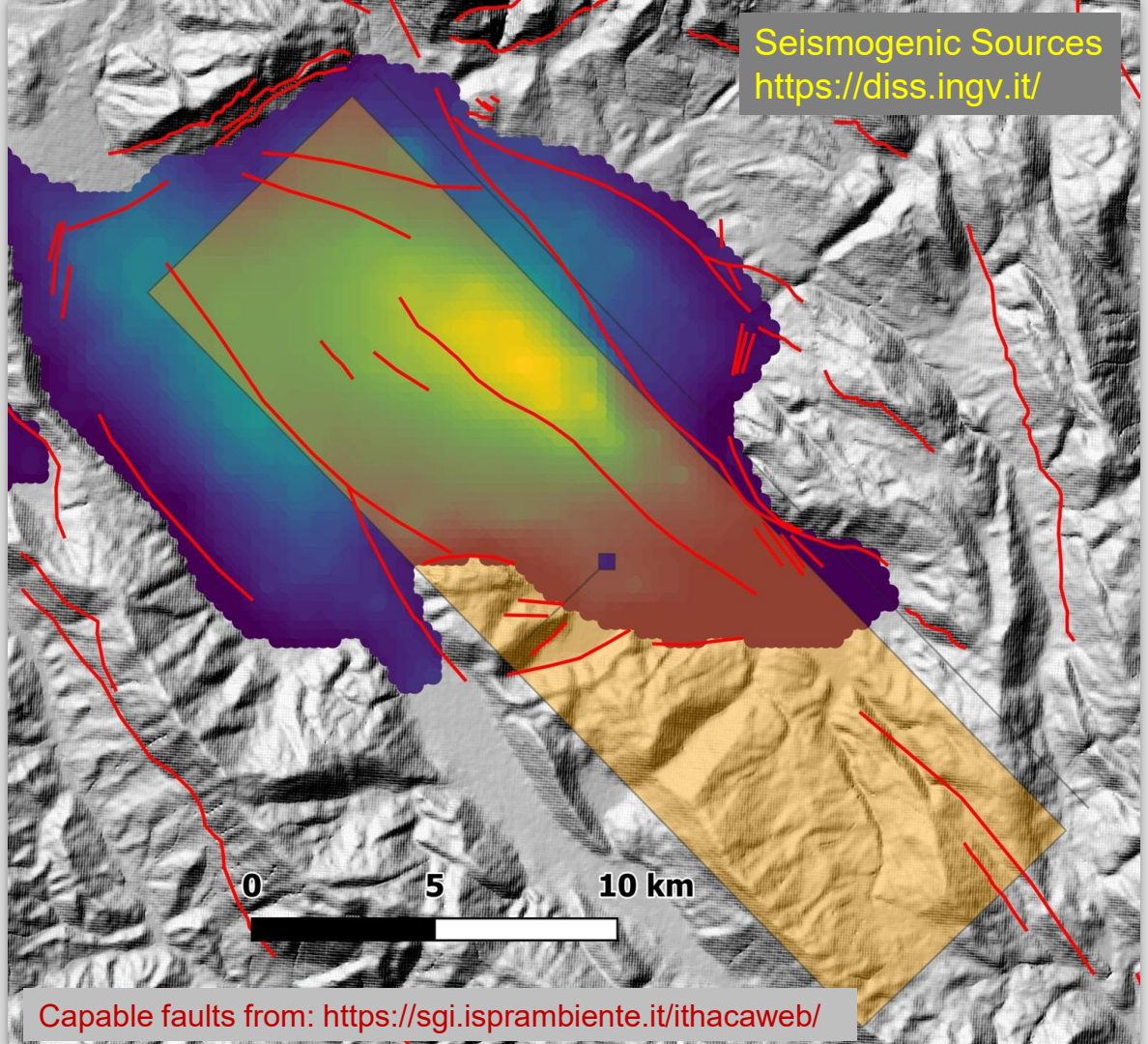
Bedrock elevation map



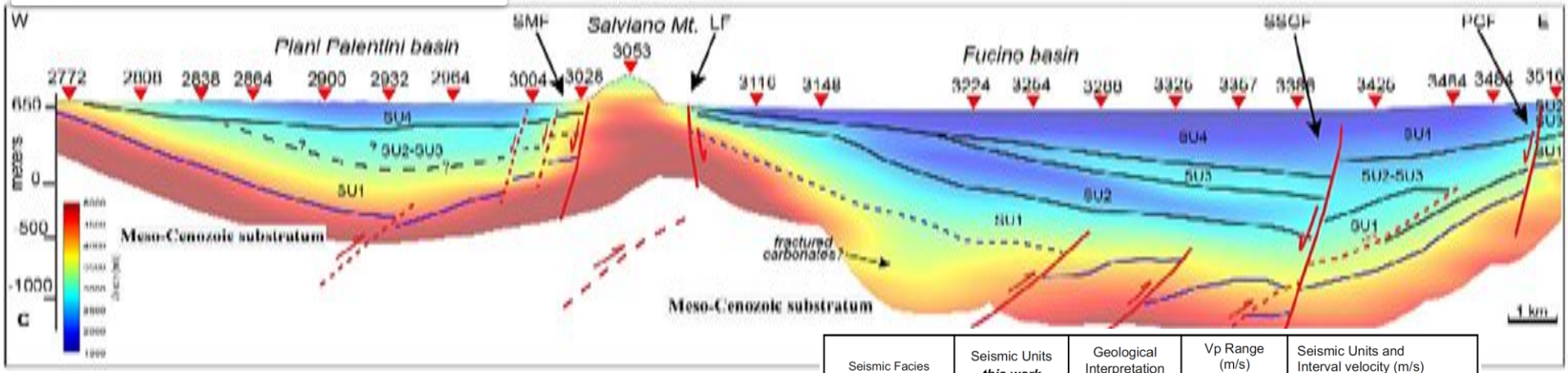
Cella et al., 2021; https://doi.org/10.3390/geosciences11100398

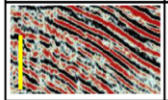
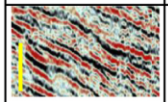
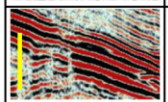
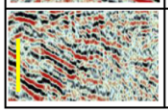
Area #3 – Fucino basin

Relationships between the Fucino basin geometry and the Mw 7.1, 1915 Seismogenic Source



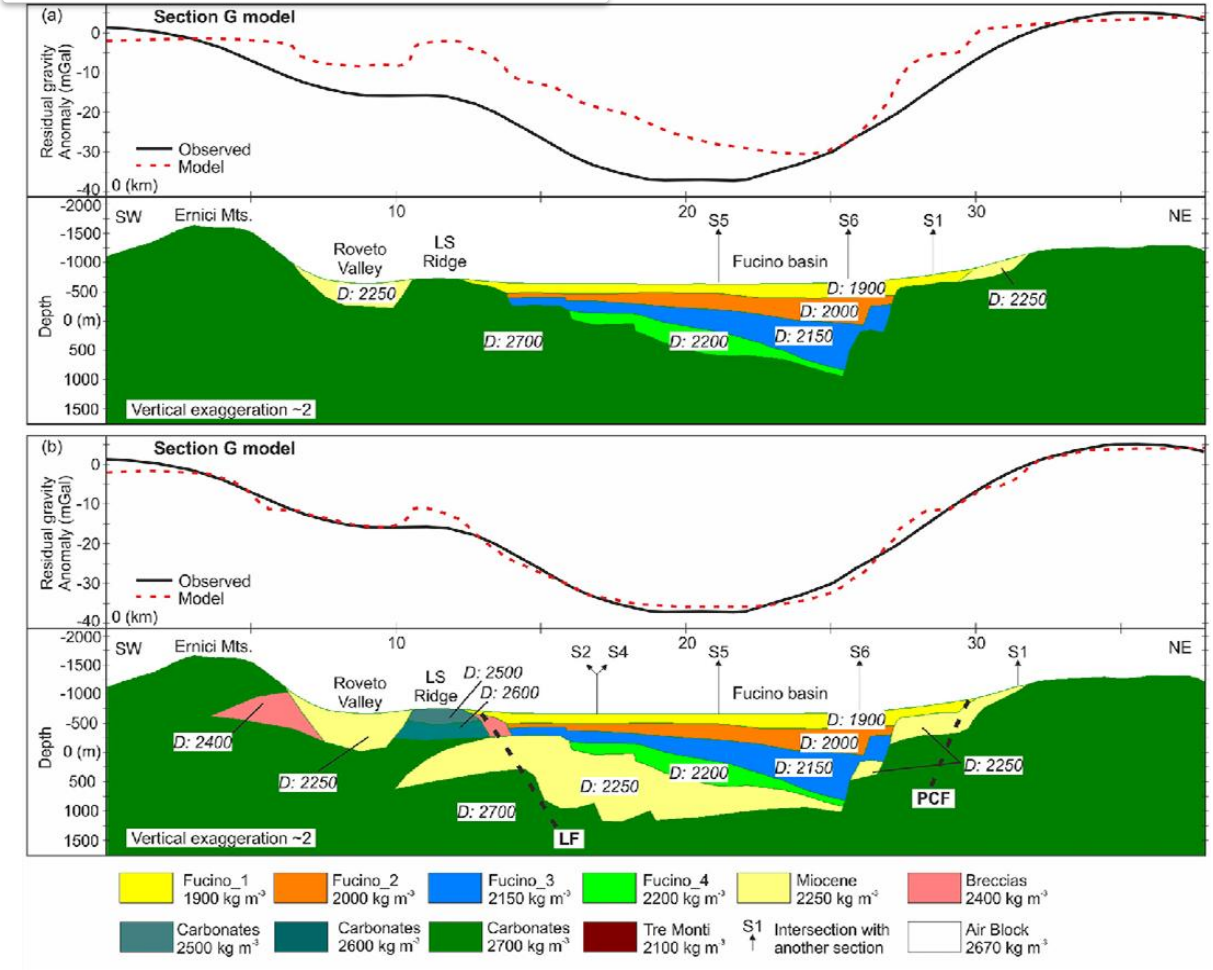
Area #3 – Fucino basin

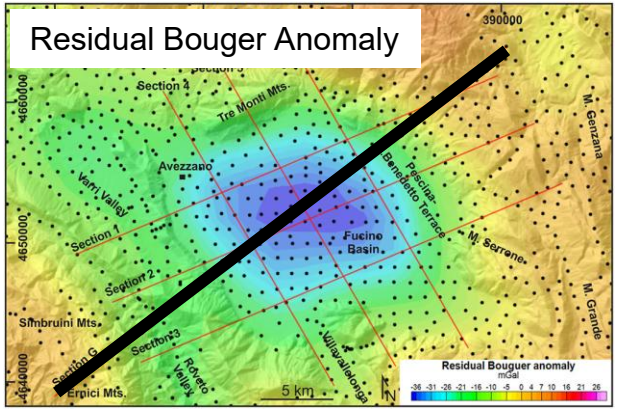


Seismic Facies	Seismic Units *-this work-*	Geological Interpretation	Vp Range (m/s) *-this work-*	Seismic Units and Interval velocity (m/s) *Patruno and Scisciani, 2021*
	**SU4**	Alluvial and lacustrine deposits (Plio-Pleistocene)	1400-2400	Yellow (1400) Orange (1800)
	**SU3**	Thrust-top deposits (upper Messinian)	2400-2900	Blue (2250)
	**SU2**		2000-2500	
	**SU1**	Flysch deposits (lower Messinian)	2900-4000	Green (2500)
	**Meso-Cenozoic bedrock**	Meso-Cenozoic bedrock	4000-5000	Pre-Pliocene Apennine units (2750)

Caielli et al., 2023
https://doi.org/10.1016/j.tecto.2023.230043

Area #3 – Fucino basin





- Deep structure of the Fucino basin
- Miocene flysch depocenter (?)

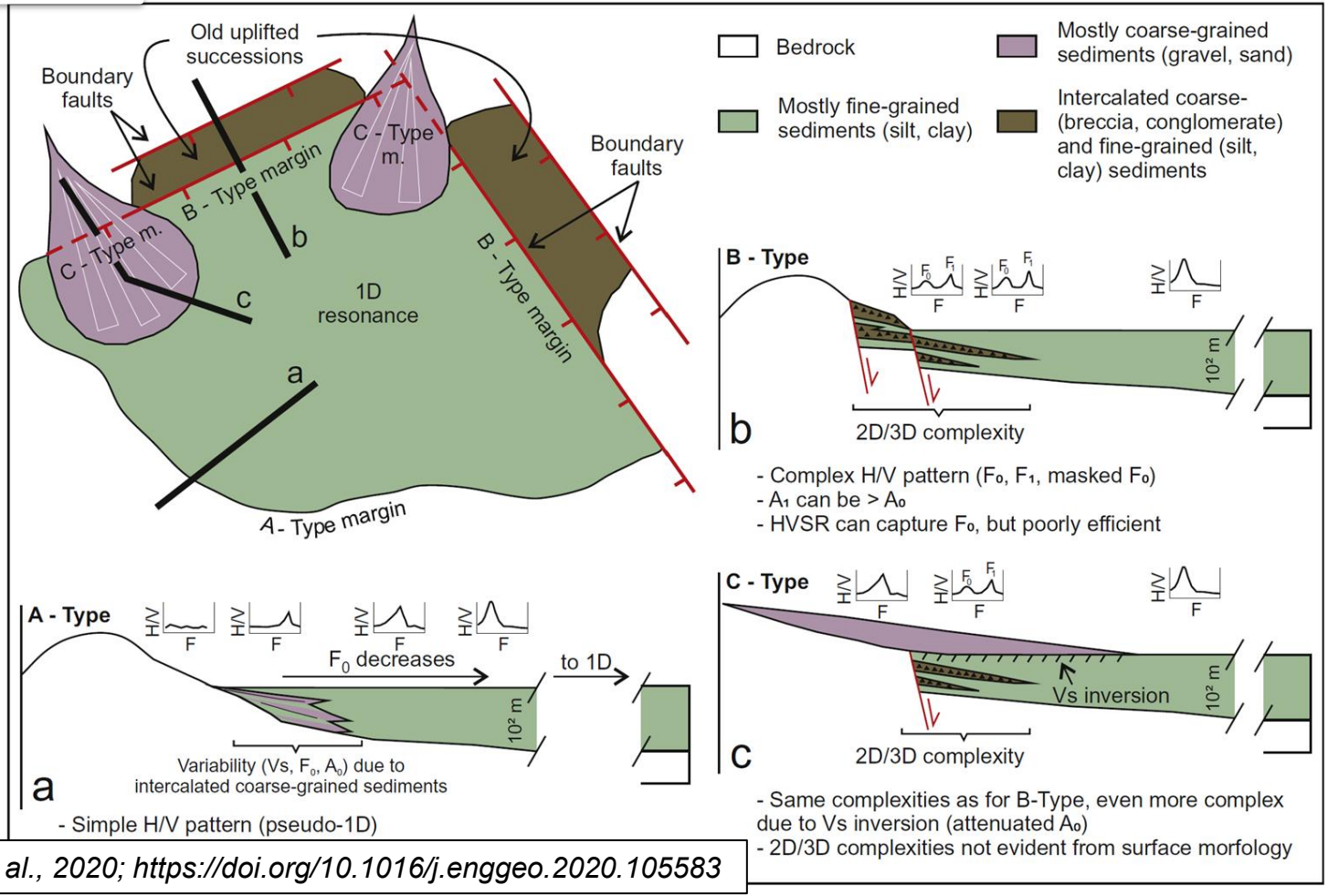
Mancinelli et al., 2021
https://doi.org/10.1016/j.tecto.2021.229144

Florio et al., 2022
https://doi.org/10.1016/j.tecto.2022.229540

Area #3 – Fucino basin

Key observations

1. Presence of subsurface geological complexities associated with velocity inversions (along the basin margins)



Di Naccio et al., 2020; https://doi.org/10.1016/j.enggeo.2020.105583

Area #3 – Fucino basin - **SUMMARY**

Age of the basin: last 2 Ma

The basin exhibits a complex, multi-phase history, and the age of its oldest fill depends on the tectonic phase being considered:

1. **Syn-orogenic marine phase** (Late Miocene) with Messinian siliciclastic flysch deposits directly overlying the Meso-Cenozoic carbonate bedrock.
2. **Post-orogenic continental phase** (Late Pliocene to Pleistocene) spanning approximately the last 2 million years and registering the opening of the extensional basin.

Maximum depth of the Quaternary infill: 1000-1750 m

Estimates for the maximum depth of the Plio-Quaternary infill vary slightly depending on the geophysical methods and models used, ranging between **900/1000** m up to **1750** m (well data, gravity methods and high-resolution seismic reflection).

Depocenters: two controlled by orthogonal faults

The Fucino basin is characterized by multiple depocenters, defining it as a **dual-polarity half-graben**, with the older northern depocenter controlled by the Tre Monti Fault, and the more recent eastern one in the hanging-wall of the San Benedetto Fault (1915 earthquake).

Area #3 – Fucino basin - **SUMMARY**

Stratigraphic heterogeneity

The Quaternary stratigraphy of the Fucino basin is highly heterogeneous, featuring a complex interfingering of deposits from multiple environments:

1. **Lacustrine**: the central domain of the basin is heavily dominated by fine-grained open and marginal lake sediments, primarily alternating silts, clays, mudstones, and peat layers.
2. **Fluvial and deltaic**: present predominantly along the basin margins, these consist of cross-stratified sands, gravels, and channel deposits that prograded into the shallow lake environment.
3. **Alluvial Fan**: thick, coarse-grained alluvial fan deposits (such as the Valle Majelama and Celano fans) prograded significantly into the lacustrine basin from the surrounding steep reliefs during Pleistocene cold climatic conditions. These include stream-flow deposits and gravelly foreset beds typical of Gilbert-type fan deltas.
4. **Slope** (Gravity-driven): located at the base of the carbonate mountain fronts and active normal fault scarps, these deposits consist of massive or coarsely stratified calcareous breccias, debris flows, and colluvial-eluvial deposits formed by gravitational processes along the steep basin edges.

Takeaways

1. Central Apennines Quaternary basins are characterized by a complex tectonic and structural evolution, being generated and evolved through multiple distinct tectonic phases and non-tectonic processes.
2. During the compressional tectonic phase, these basins formed as thrust top or shallow foredeep basins and hosted the main depocenters of flysch deposits (flysch is interlayered between the limestone bedrock and the Plio-Quaternary continental infilling).
3. As a consequence, they are characterized by complex geometrical and stratigraphic characteristics.
4. The bedrock morphology is often controlled by karstic phenomena.
5. Due to their thickness, deep boreholes reaching the bedrock are often lacking and their deep geometry and sedimentary infilling is inferred heavily relying on indirect geophysical methods.
6. Along their margins, the alluvial or lacustrine infilling interfingers with coarse, often cemented, alluvial fan or slope deposits that may have mechanical characteristics similar to the limestone bedrock.

Bibliography

- 43 references explicitly dealing with basin geometry and tectonic history.
- 10 basins with available geological and geophysical studies.

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GRAZIE PER L'ATTENZIONE!