IUGG IASPEI International Association of Seismology and Physics of the Earth's Interior

IUGG IAGA International Association of Geomagnetism and Aeronomy

31 August - 5 September 2025
Lisbon, Portugal

Geological, geophysical and petrophysical data integration for the geothermal energy potential assessment of the Romagna and Ferrara folds, Eastern Po-plain

Racine Basant[1], Valentina Cortassa[1], Magdala Tesauro[1,2], Gianluca Gola[3], Thomas Nanni[3], Antonio Galgaro[4], Pawel Slupski[4], Adele Manzella[3]

1 Dipartimento di Matematica, Informatica e Geoscienze, Universita di Trieste
2 Department of Earth Sciences, Utrecht University.
3 Istituto di Geoscienze e Georisorse, CNR.
4 Dipartimento di Geoscienze, Università di Padova.

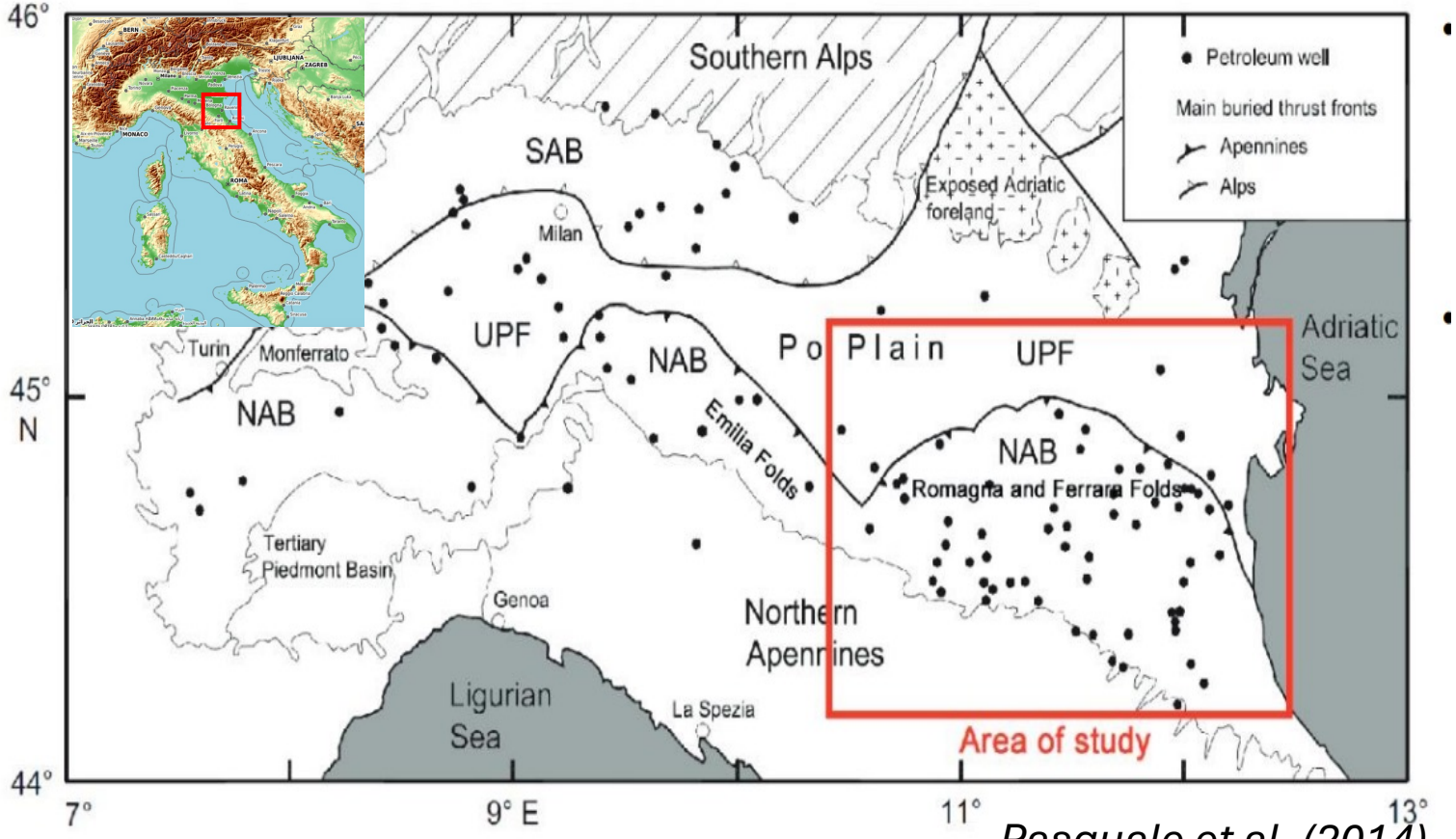
Finanziato dall'Unione europea NextGenerationEU
Ministero dell'Università e della Ricerca
Italiadomani PIANO NAZIONALE DI RIPRESA E RESILIENZA

Geothermal energy

- Tapping into the Earth's heat
  Contribute to achieving European Green Deal goal, which targets a 55 % reduction in CO_2 by 2030

- Critical to identify and properly characterize potentially exploitable geothermal areas

- InGEO: Innovation in geothermal resources and reserves potential assessment for the decarbonization of power/thermal sectors

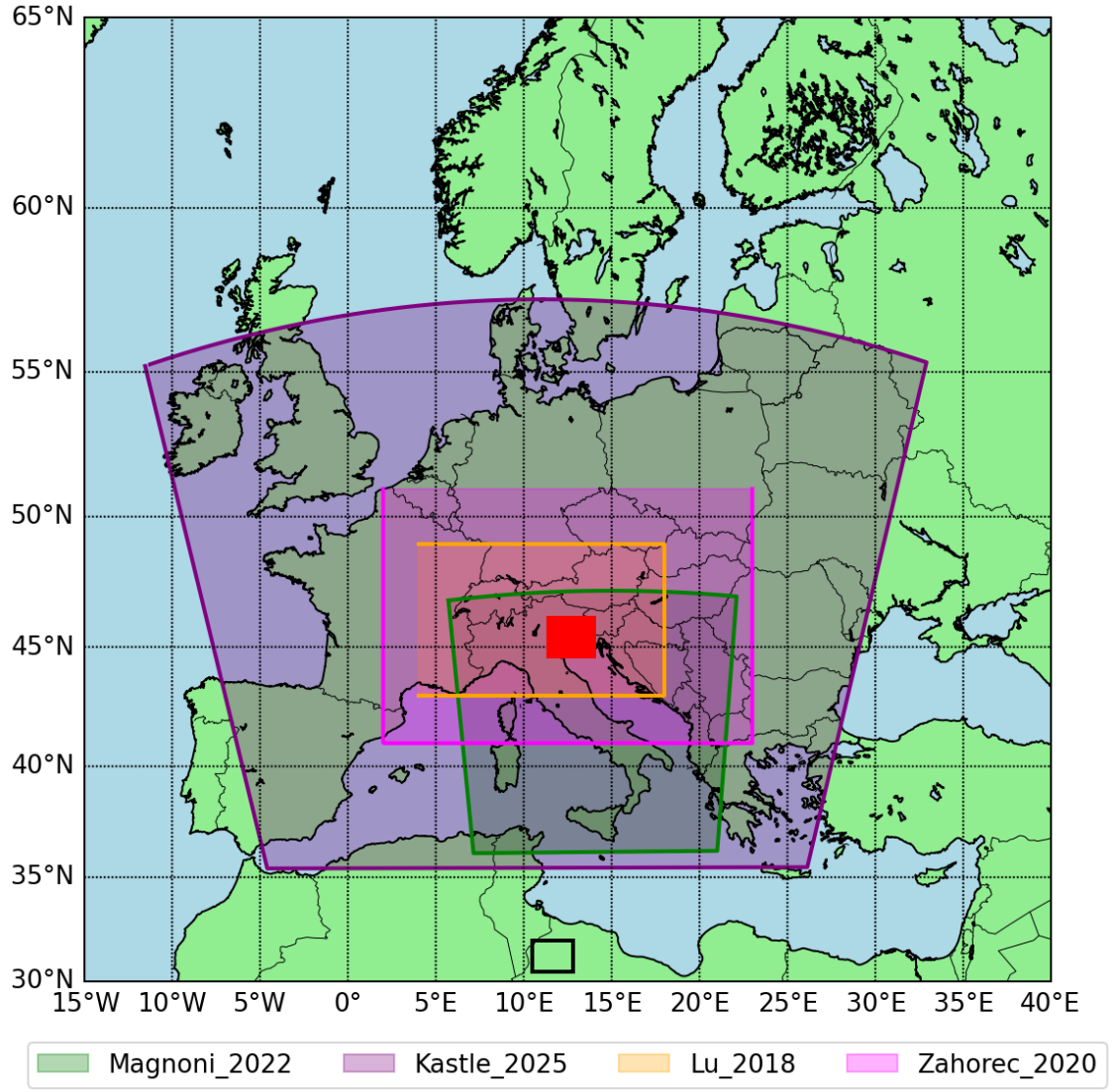


Pasquale et al. (2014)

Geology + Petrophysics + Geophysics
Thermal Modelling

Geophysical data

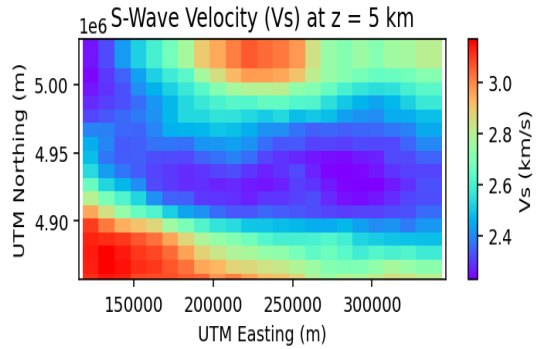
- Geophysical acquisition – image subsurface
- Data integration can reduce the uncertainties
- Existing geophysical data over RFF region
  - Seismic Tomography
  - Gravity
- Objective: Identify structural features amongst datasets for upper crustal region



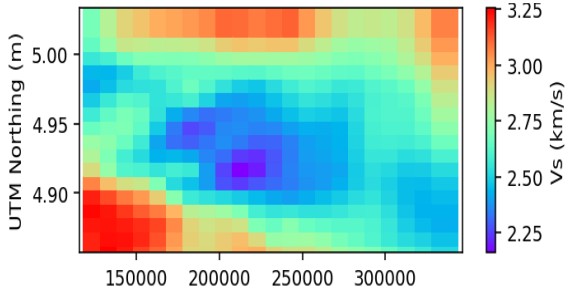
Data integration

1) Comparative analysis

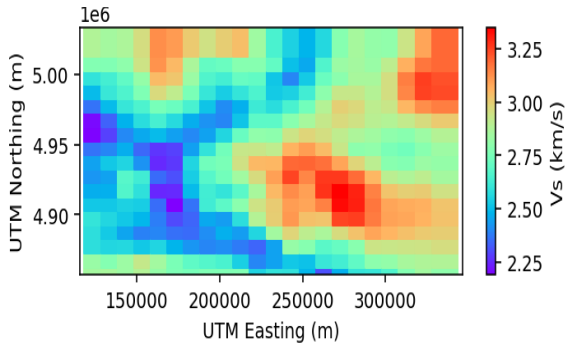
Lu (2018)



Kastle (2025)

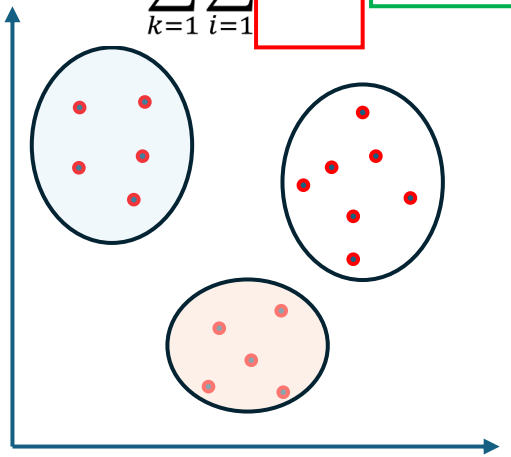


Magnoni (2022)



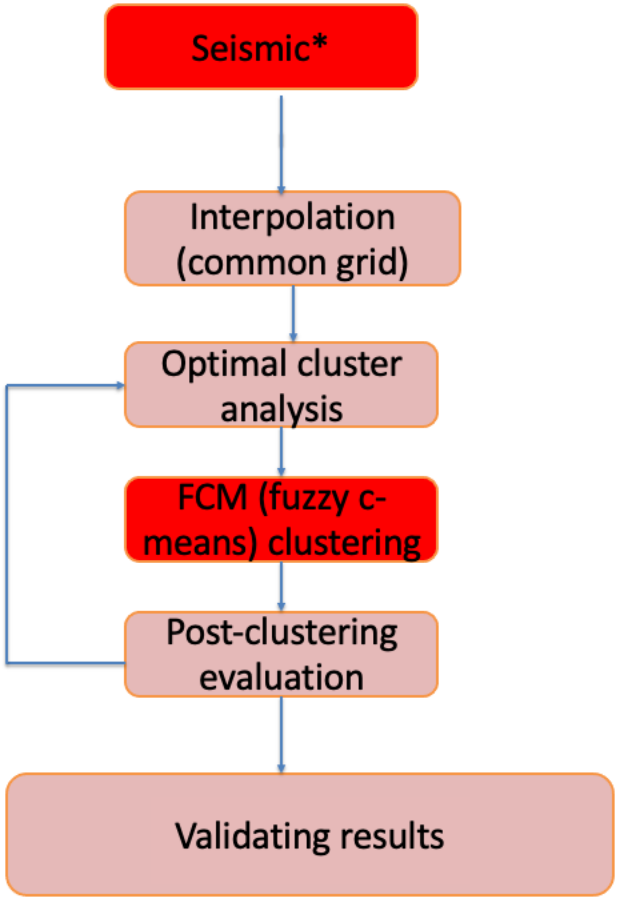
2) Quantitative analysis

$$J_m(U,v) = \sum_{k=1}^{N}\sum_{i=1}^{c}(u_{ik})^m \; \| y_k - v_i \|^2$$



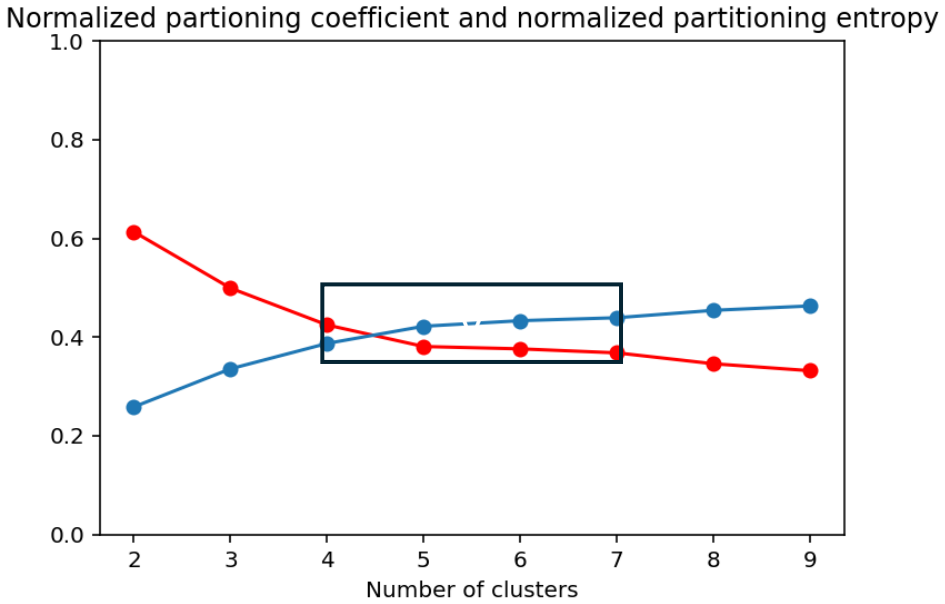
Clustering algorithms can be used to classify similarities amongst multidimensional datasets using distance measure. Soft clustering allows a datapoint to belong to different classes with varying degrees of membership.

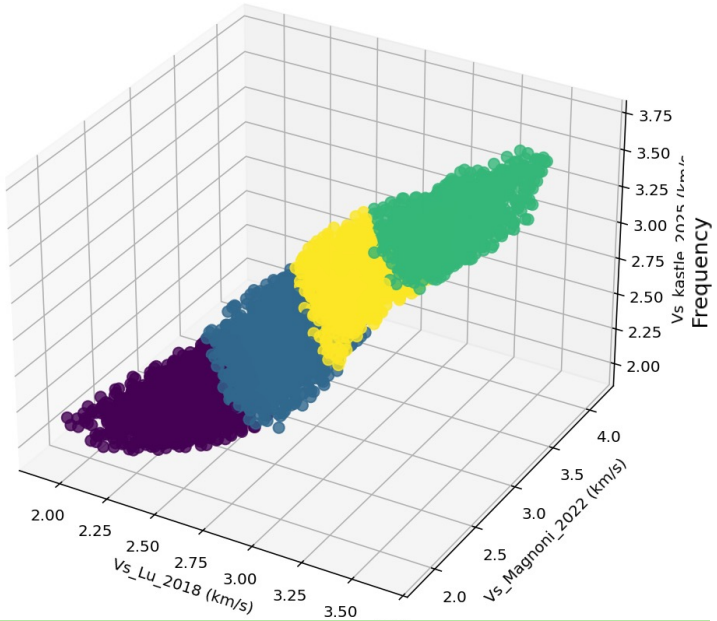
3)Proposed approach

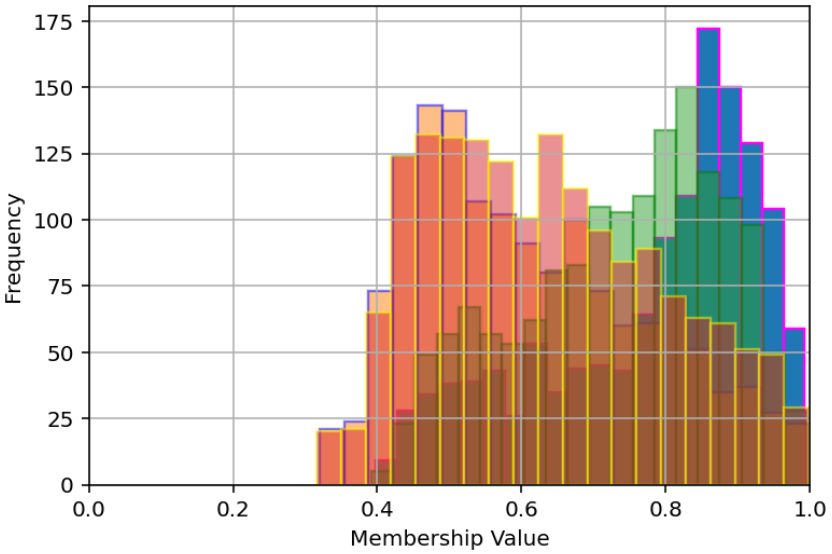


Clustering evaluation

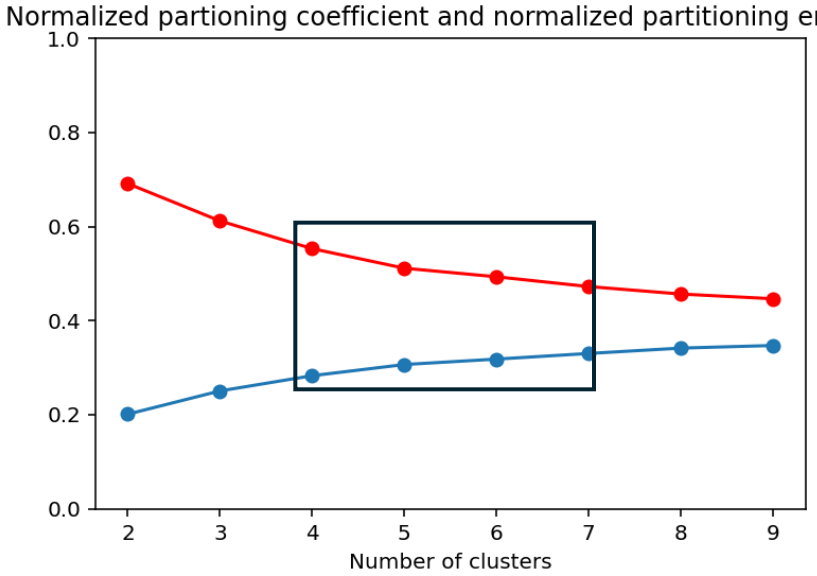
Vs

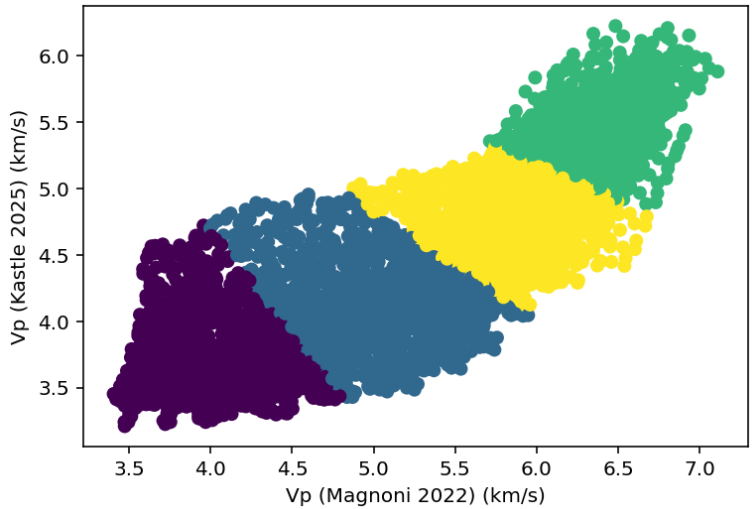


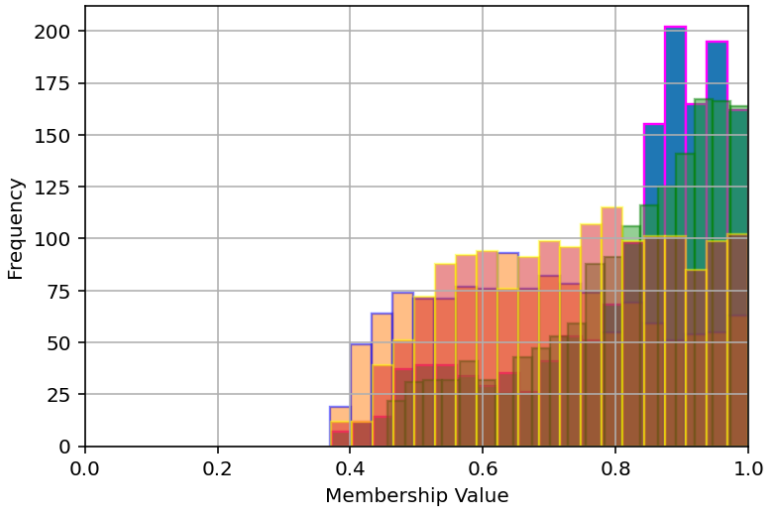




Vp

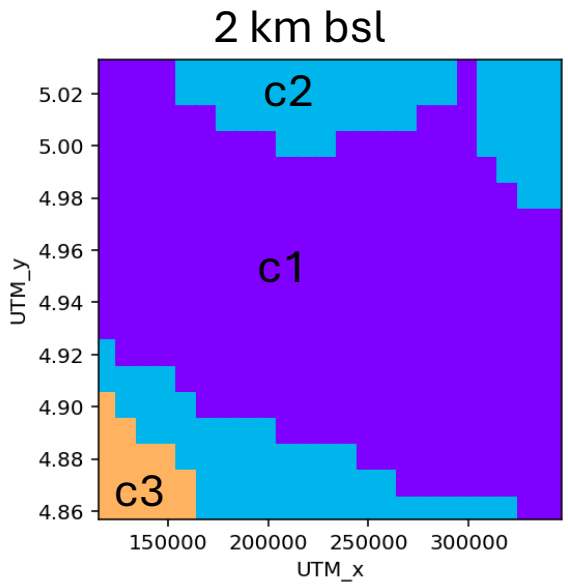


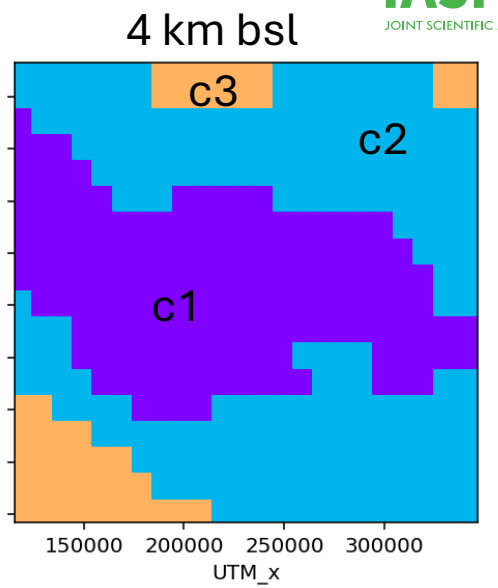


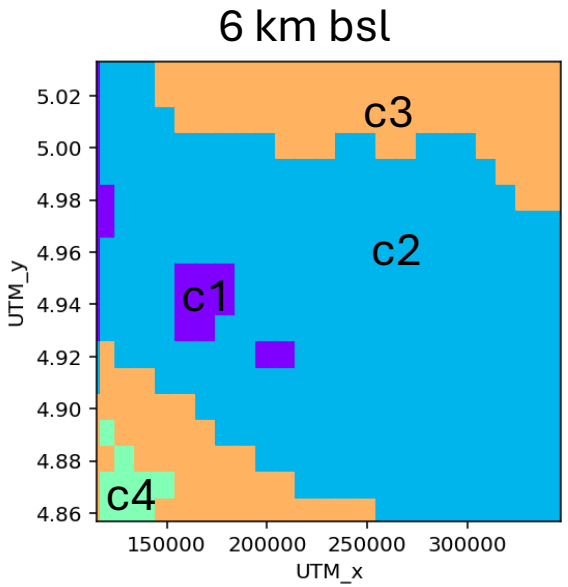


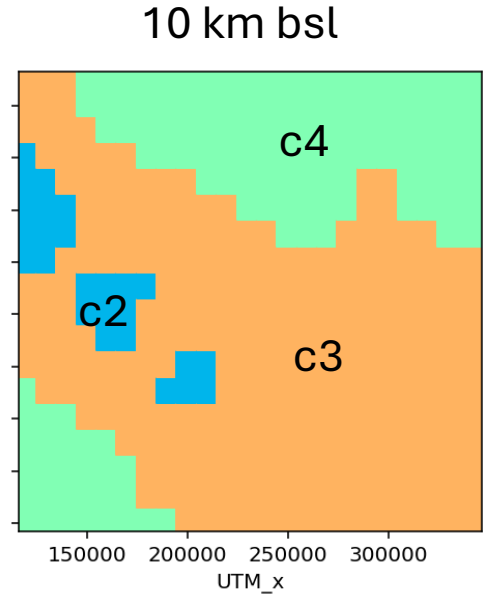
Cluster Model (Vs)

Cluster	Vs (km/s) (Lu_2018)	Vs (km/s) (Magnoni 2022)	Vs (km/s) (Kastle 2025)
c1	2.34	2.32	2.23
c2	2.69	2.72	2.58
c3	2.98	3.14	2.96
c4	3.27	3.35	3.28



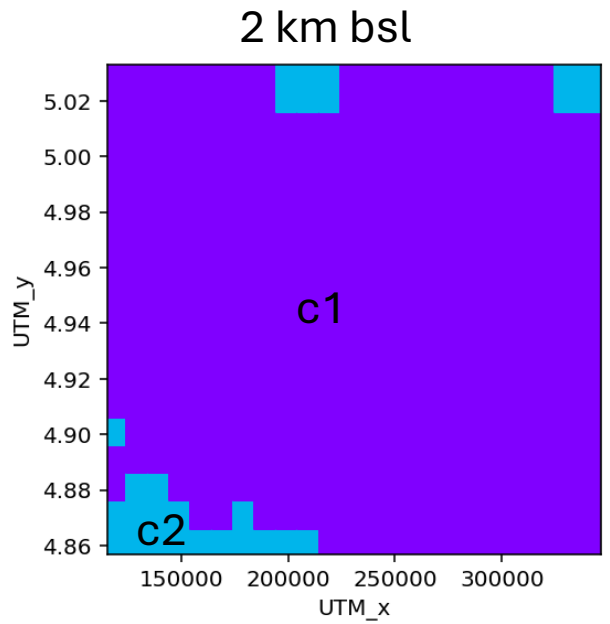


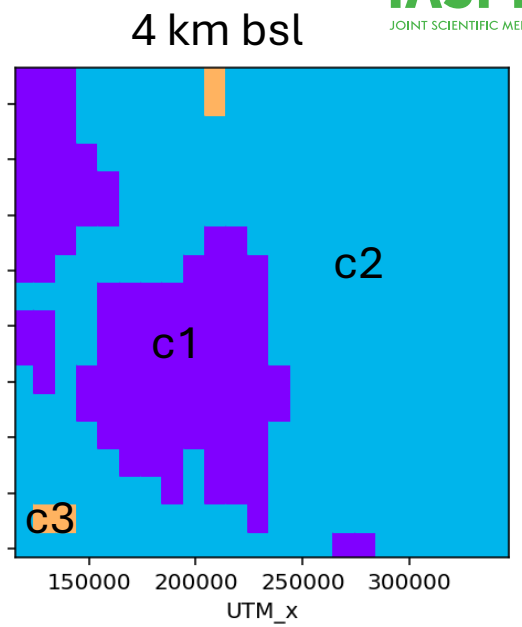


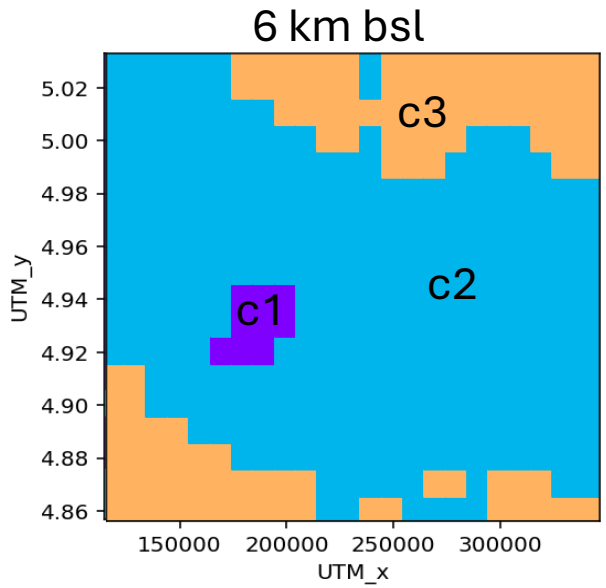


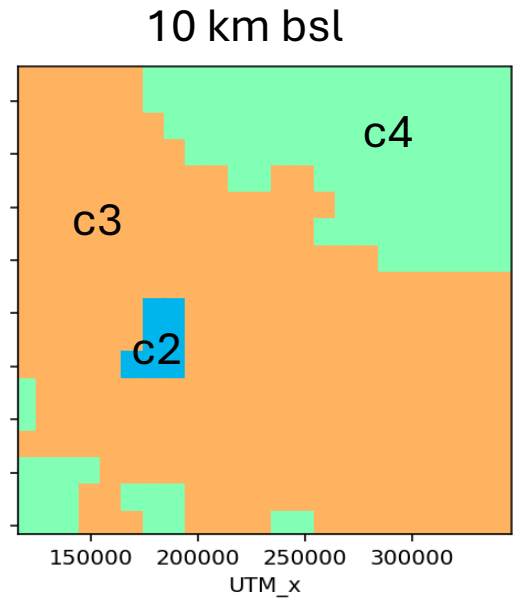
Cluster Model (Vp)

Cluster	Vp (km/s) (Magnoni 2022)	Vp (km/s) (Kastle 2025)
c1	4.01	3.69
c2	5.03	4.12
c3	5.88	4.78
c4	6.39	5.42



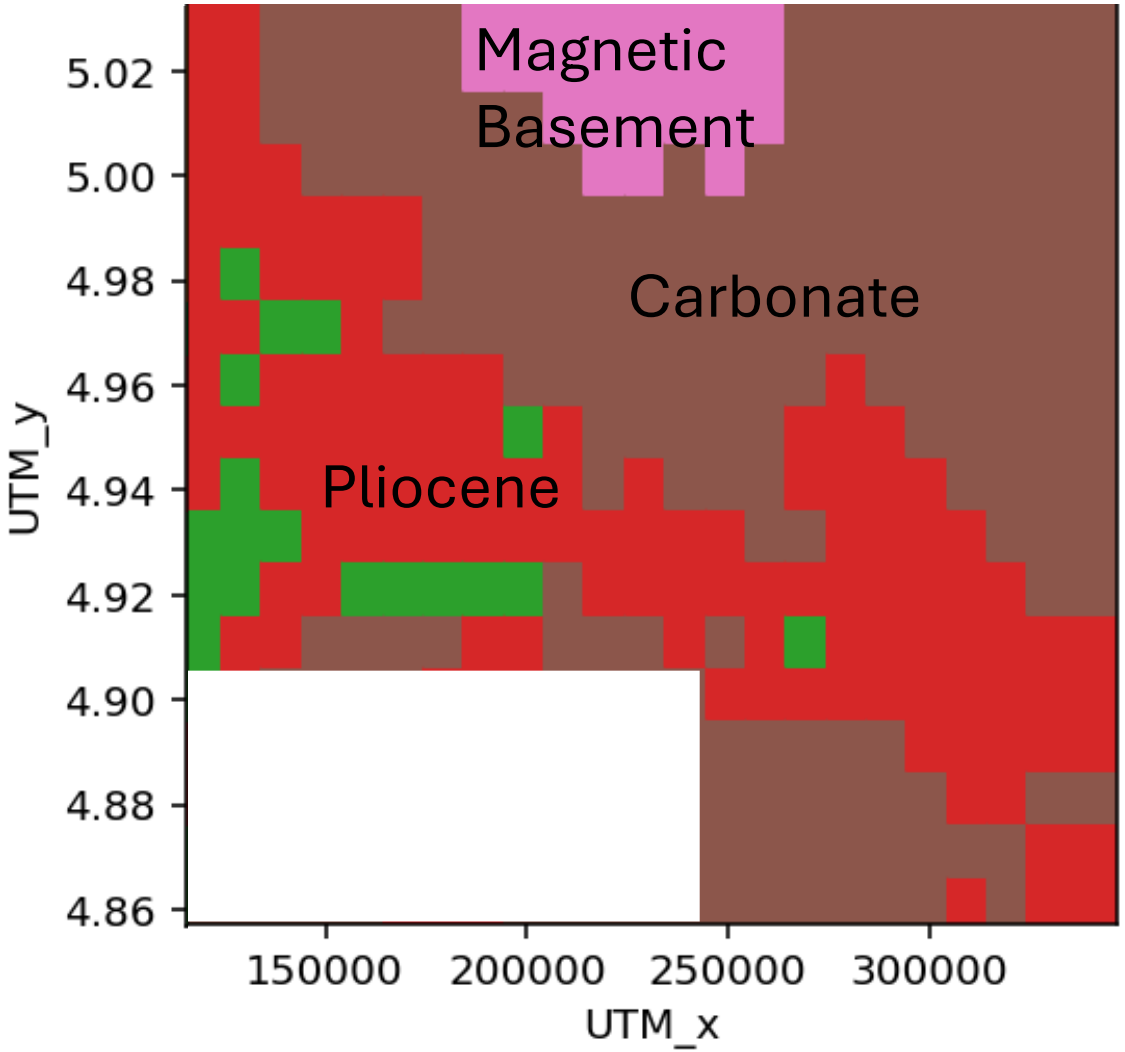




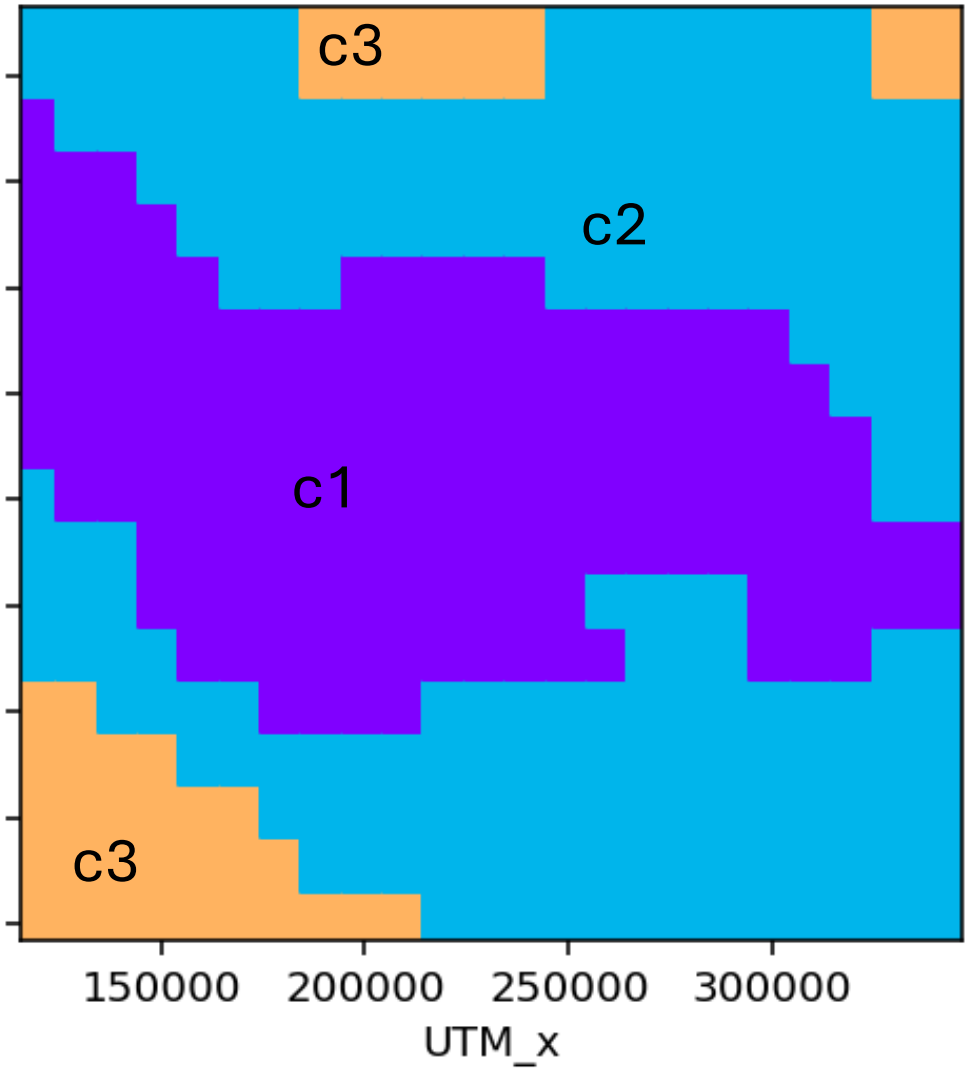


Validating Cluster Model (Geological Model)

4 km bsl

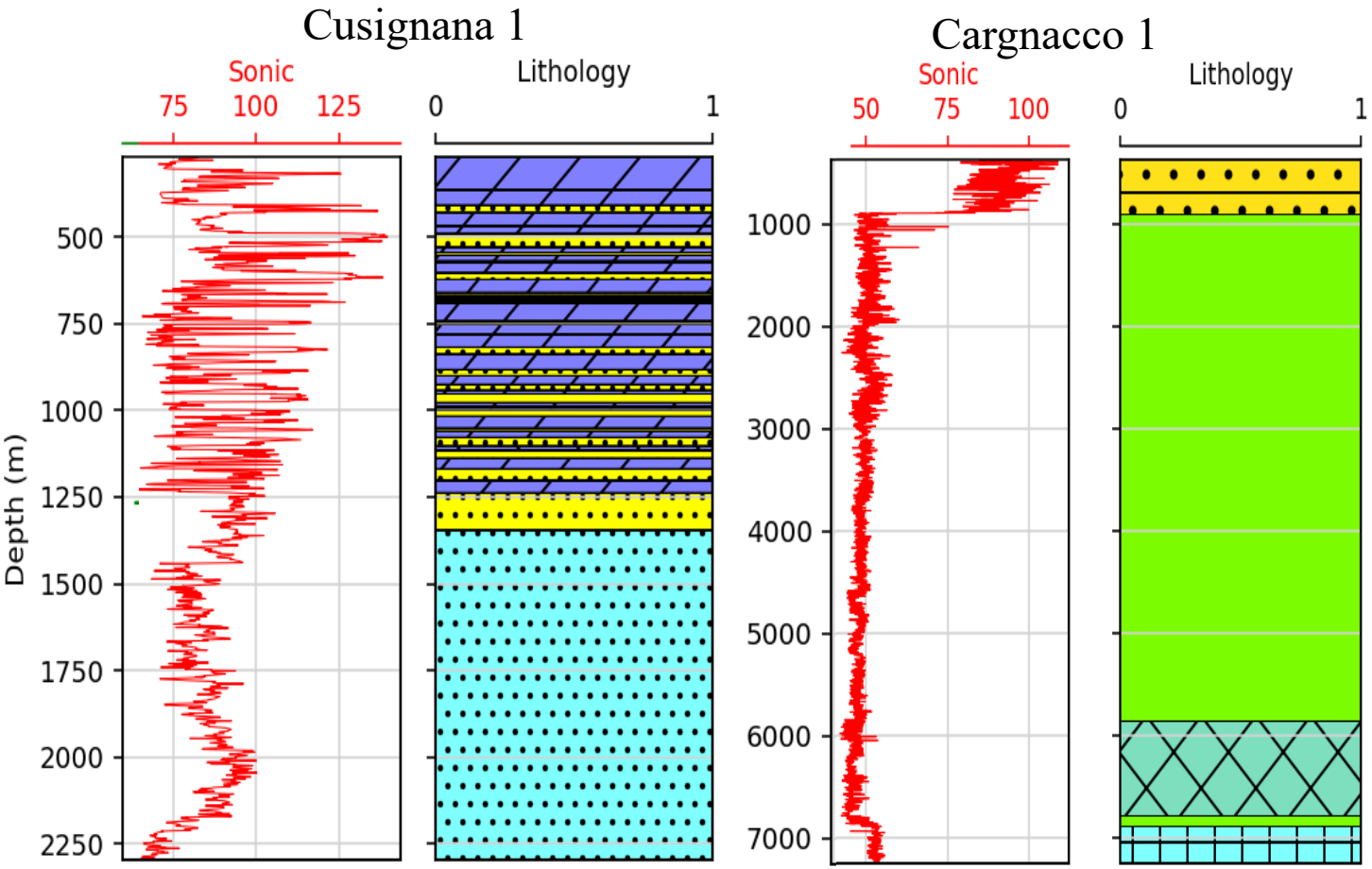


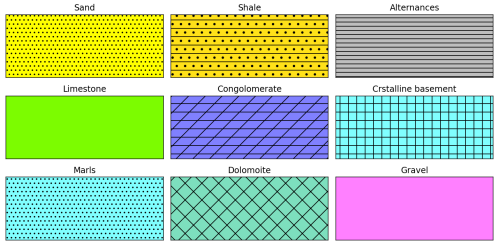
Livani et al. (2023)



Vs cluster model

Validating Cluster Model (Well logs)





	This study	Montone and Mariucci (2020)
UNIT	vel. (km/sec)	vel. (km/sec)
Q	2.3 ± 0.3	2.2 ± 0.1
PL	2.9 ± 0.5	3.4 ± 0.6
MIO-PL	3.7 ± 0.8	4.0 ± 0.5
FMA		4.0 ± 0.3
EO-MIO		4.8 ± 0.5
C-EO	5.5 ± 0.9	5.8 ± 0.3
J-C		5.9 ± 0.4
J		6.3 ± 0.4
TR		6.3 ± 0.3
V		4.9 ± 0.2

Cluster	Vs (km/s) (Lu_2018)	Vs (km/s) (Magnoni 2022)	Vs (km/s) (Kastle 2025)
c1	2.34	2.32	2.23
c2	2.69	2.72	2.58
c3	2.98	3.14	2.96
c4	3.27	3.35	3.28

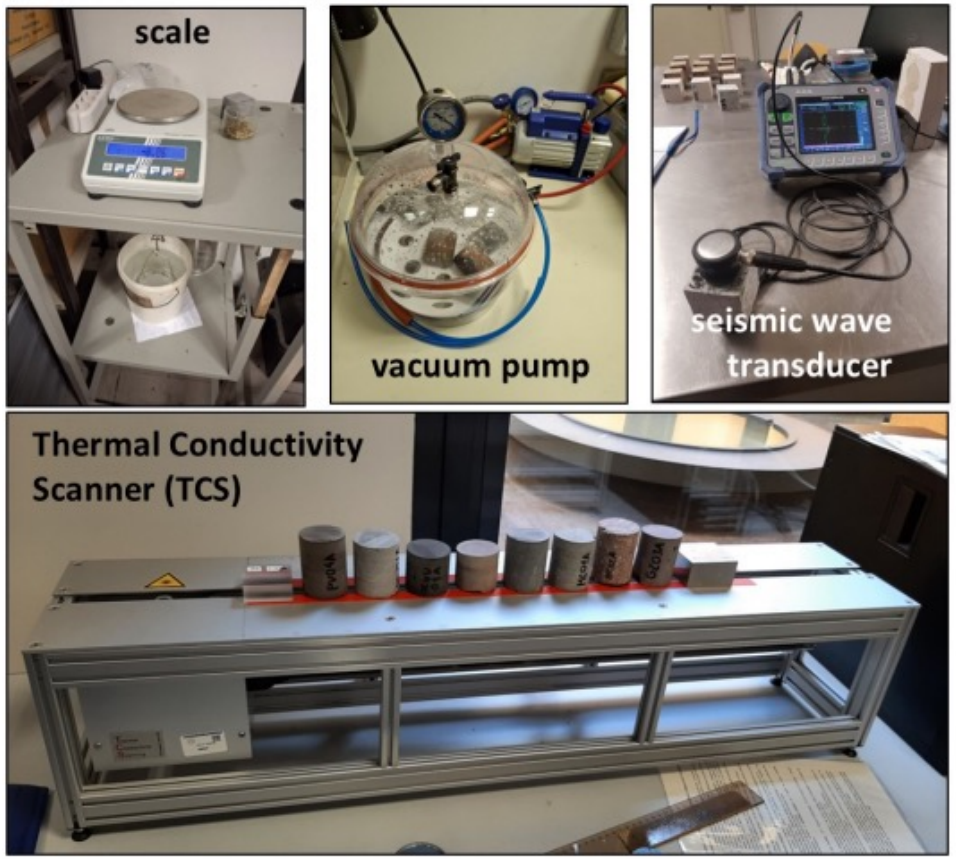
V = 1,000,000 / Δt

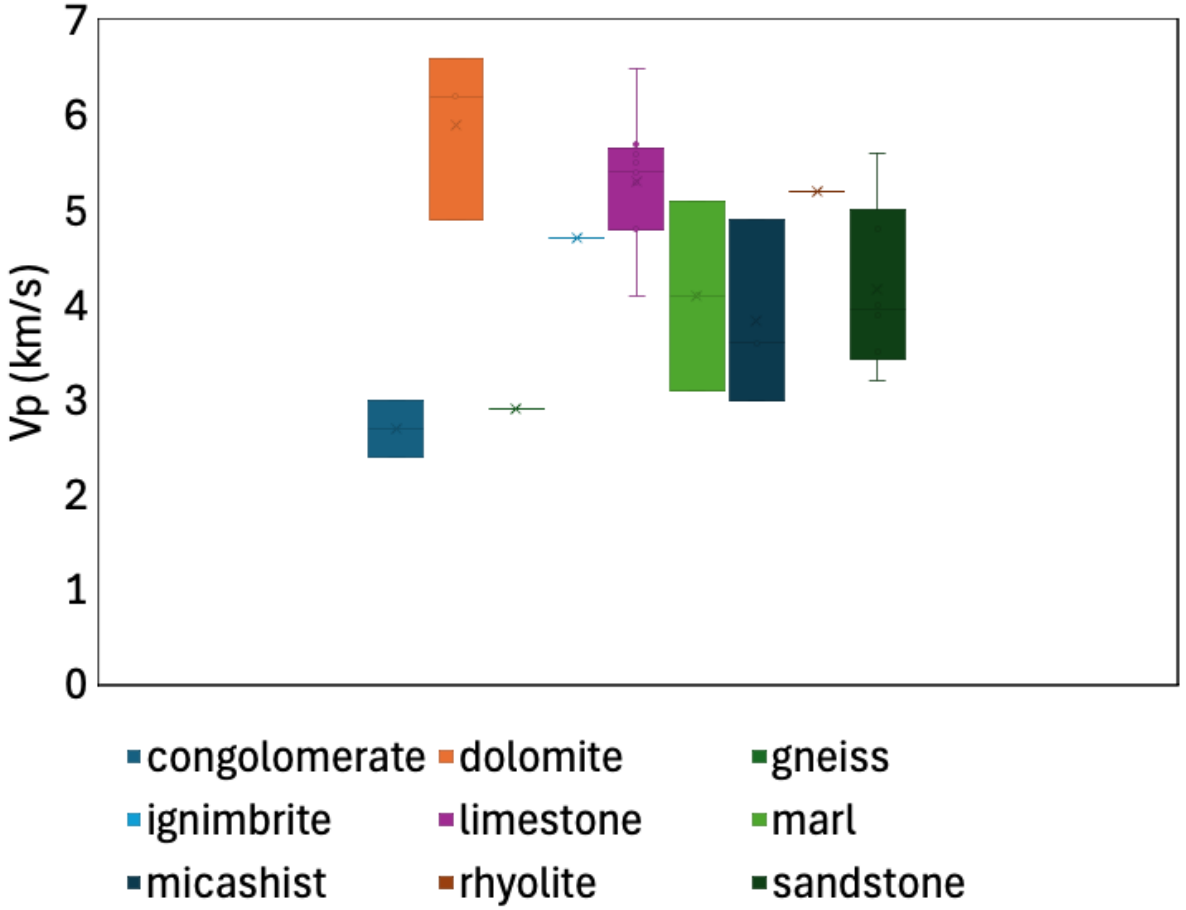
Benetatos et al. (2023)

Q, Quaternary; PL, Pliocene; MIO-PL, Miocene-Pliocene; FMA, Marnoso Arenacea Formation; EO-MIO, Eocene-Miocene; C-EO, Cretacic-Eocene; J-C, Jurassic-Cretacic; J, Jurassic; TR, Triassic; V, Verrucano

Validating Cluster Model (Petrophysical data)

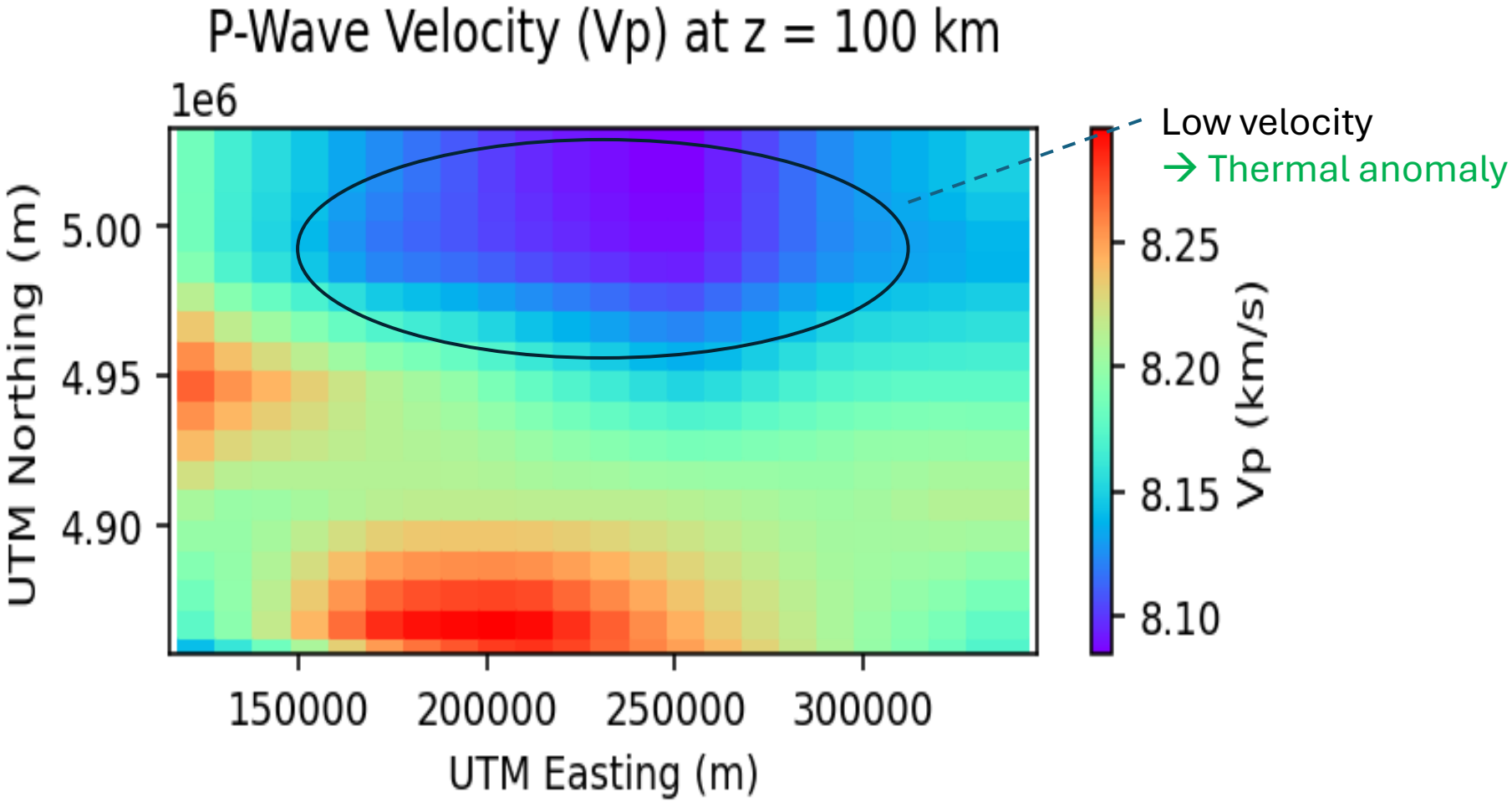
Sulpski et al (2025)





Field campaign collecting rock samples representative of the Northern Apennines Triassic carbonate platform and underlying basement rocks. Petrophysical measurements on 44 samples of varying lithologies

More on data integration

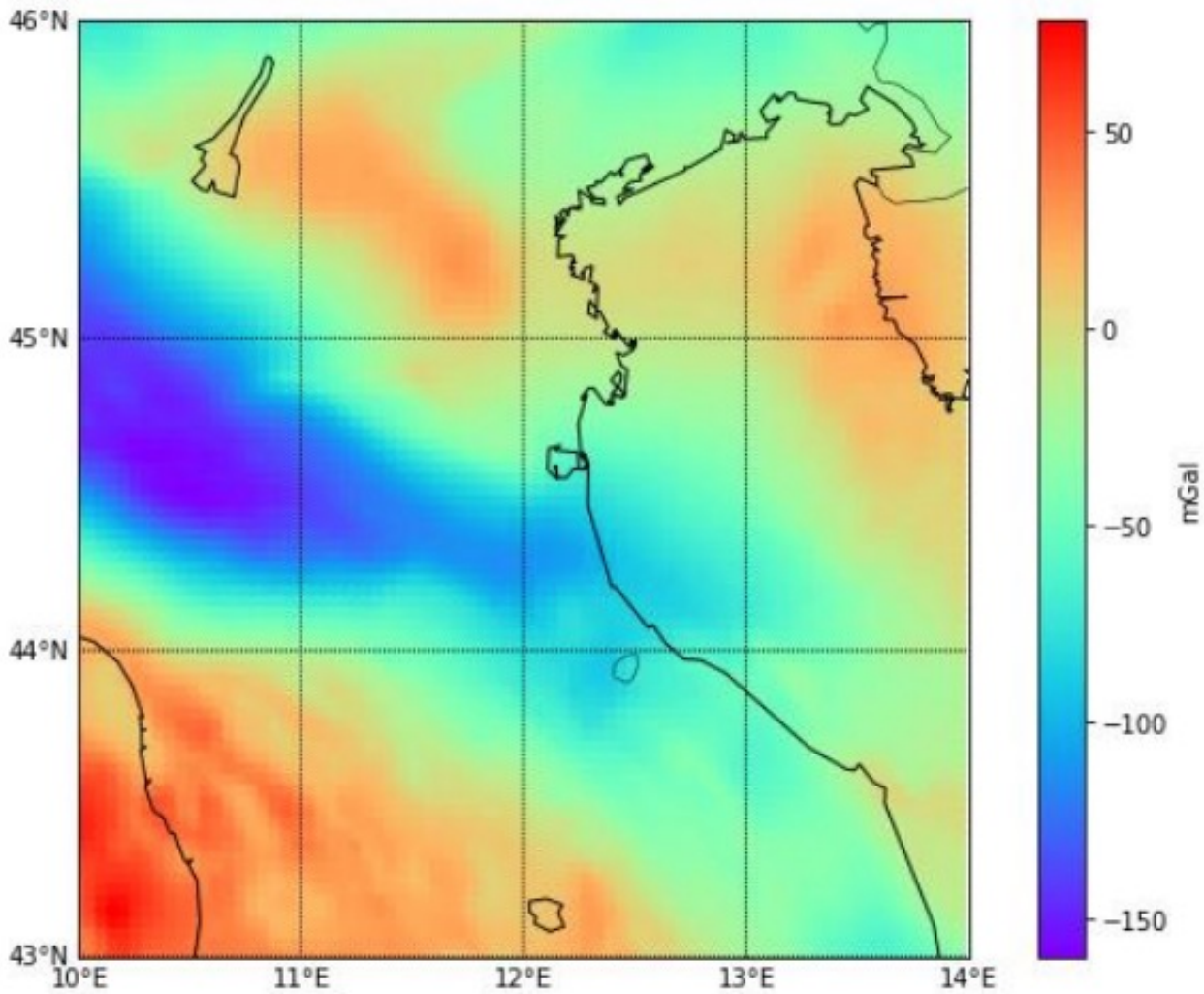


Rappisi et al. (2025)

More on data integration

Gravity Modelling

- Complete Bouguer Anomaly (CBA) map (Zahorec et al. 2021)
- Land and Marine acquisitions
  - 4 km
- 3D inversion using seismic constraints



Zahorec et al. (2021)

Conclusions and Outlook

- 3D Structural constraint of upper crustal features.
- Integration of geological and petrological data to validate model
- Uncertainty analysis
- Results will contribute to implement a consistent geological/geophysical model to characterize geothermal reservoir of the region
- Ultimately, workflow developed is transferable and can be applied to future geothermal prospects

Acknowledgements

InGEO is a PRIN 2022 PNRR Project and has received funding from the European Union, Next Generation EU

Thank you for your attention!

InGEO
https://www.ingeo.cnr.it/en/

Racine Basant, Valentina Cortassa, Magdala Tesauro, Gianluca Gola, Thomas Nanni, Antonio Galgaro, Pawel Slupski, Adele Manzella

Racineabigail.basant@units.it

Finanziato dall'Unione europea NextGenerationEU
Ministero dell'Università e della Ricerca
Italiadomani PIANO NAZIONALE DI RIPRESA E RESILIENZA

References

1. Livani, M., Petracchini, L., Benetatos, C., Marzano, F., Billi, A., Carminati, E., Doglioni, C., Petricca, P., Maffucci, R., Codegone, G. and Rocca, V., 2023. Subsurface geological and geophysical data from the Po Plain and the northern Adriatic Sea (north Italy). *Earth System Science Data Discussions*, *2023*, pp.1-41.
2. Lu Y., et al., 2018. High-resolution surface wave tomography of the European crust and uppermost mantle from ambient seismic noise. Geophys. J. Int., 214, 1136–1150, https://doi.org/10.1093/gji/ggy188. Magnoni F., et al., 2023. Adjoint tomography of the Italian lithosphere. COMMUNICATIONS EARTH & ENVIRONMENT| (2022) 3:69. https://doi.org/10.1038/s43247-022-00397-7.
3. Kästle, E.D., Paffrath, M., El-Sharkawy, A. and AlpArray and Swath-D working groups, 2025. Alpine Crust and Mantle Structure From 3D Monte Carlo Surface-and Body-Wave Tomography. *Journal of Geophysical Research: Solid Earth*, *130*(2), p.e2024JB030101.
4. Magnoni, F., Casarotti, E., Komatitsch, D., Di Stefano, R., Ciaccio, M.G., Tape, C., Melini, D., Michelini, A., Piersanti, A. and Tromp, J., 2022. Adjoint tomography of the Italian lithosphere. *Communications Earth & Environment*, *3*(1), p.69.
5. Rappisi, F., Lo Bue, R., Vanderbeek, B. P., Confal, J. M., Erman, C., Baccheschi, P., Faccenda, M. (2025). 3-D mantle flow and structure of the Mediterranean from combined P-wave and splitting intensity anisotropic tomography. *Journal of Geophysical Research: Solid Earth*, *130*(6), e2024JB030883.
6. Zahorec P. et al., 2021. The first pan-Alpine surface-gravity database, a modern compilation that crosses frontiers. Earth Syst. Sci. Data, 13, 2165–2209, https://doi.org/10.5194/essd-13-2165-2021.
7. Montone, P. and Mariucci, M.T., 2020. Constraints on the structure of the shallow crust in central Italy from geophysical log data. *Scientific reports*, *10*(1), p.3834.
8. Pasquale, V., Verdoya, M. and Chiozzi, P., 2014. Heat flow and geothermal resources in northern Italy. *Renewable and Sustainable Energy Reviews*, *36*, pp.277-285.
9. Benetatos, C., 2023. Preliminary statistical analysis of borehole and geological data from the Po plain. *Geoingegneria Ambientale e Mineraria*, *169*, pp.47-56.
10. Cortassa V., Tesauro M., Gola G., Nanni T, Galgaro A. and Manzella A.; 2025. Integrated geological modelling for assessing geothermal potential in the Romagna and Ferrara Folds (Italy). Gruppo Nazionale per la Geofisica della Terra Solida (43° National Conference GNGTS), Bologna, 11-14 February 2025 (Abstract).