

A consistent geological and geophysical model of the Eastern Po Plain (Italy) for the evaluation of geothermal energy

R. Basant¹, V. Cortassa¹, M. Tesauro^{1,2}, G. Gola³, T. Nanni^{4,3}, P. Slupski⁴, A. Galgaro⁴, A. Manzella³

¹ *Dipartimento di Matematica, Informatica e Geoscienze, Università di Trieste.*

² *Department of Earth Sciences, Utrecht University.*

³ *Istituto di Geoscienze e Georisorse, CNR.*

⁴ *Dipartimento di Geoscienze, Università di Padova.*

Proper assessment and integration of multi-parameter datasets is critical for the efficient and effective exploitation of geothermal energy resources. The InGEO project (Innovation in GEOthermal resources and reserves potential assessment for the decarbonization of power/thermal sectors) seeks to develop an innovative exploration workflow for combining multi-parameter datasets within the sector of the Northern Apennine buried - structures belonging to the Romagna and Ferrara Folds (RFF), Eastern Po Plain, Italy. Previous assessment of thermal data identified a thermal anomaly within this region attributable to deep fluid circulation within the deep-seated Mesozoic carbonate sequences (Pasquale et al., 2013; Pasquale et al., 2014).

This study develops a consistent geological and geophysical model of the Eastern Po Plain region (Italy). For the model, we first characterized the shallow geological features (< 16 km), by analyzing data from over 200 seismic surveys from the VIDEPI database (www.videpi.com), 700 deep (>1500 m) boreholes (CNR database, www.geothopica.igg.cnr.it) and 160 borehole logs (sonic and lithological logs) (Livani et al., 2023). We developed a 3D geological model comprising of eight horizons ranging in age from the Quaternary to the Permian and depicted the thickness variation of these units, by identifying primary lithological unconformities through seismic reflection interpretations constrained by well stratigraphy.

Next, we classified deeper structural features (16 – 50 km), by applying machine learning algorithms (K-means and Fuzzy c-means) to reconstructed, spatially coincident seismic tomography models (Brazus et al. 2025; Kästle et al., 2025; Lu et al., 2018; Magnoni et al., 2022; Magrini et al., 2022) and new density models inverted using the first pan-Alpine surface-gravity database (Zahorec et al., 2021) shown in Figure 1. We use the seismic tomography datasets as a priori constraints in the inversion to assess uncertainties. The unsupervised classification resulted in the 3D characterization of four classes interpreted as 1) sediments to basement 2) upper crust 3) lower crust and 4) the mantle. We validated the range in geophysical parameters of the four classes with thermo-physical measurements on rocks obtained as part of the InGEO project (Slupski et al., 2025), high temperature and pressure laboratory data on rocks (Burke and Fountain, 1990; Christensen and

Mooney, 1995) compiled from the literature and sonic logs (Livani et al., 2023). Furthermore, we highlighted the spatial consistency and overlap of the 3D geological horizons with Cluster 1 'sediments to basement'.

The consistent geological/geophysical model will be the main input for a thermal model of the region and the implementation of an open-source and web-based GIS tool that will assess the deep geothermal resource potential for both hydrothermal resources and closed-loop heat exchange. Lastly, the workflow of InGEO project will be used as a decision support system for developing geothermal projects in Italy.

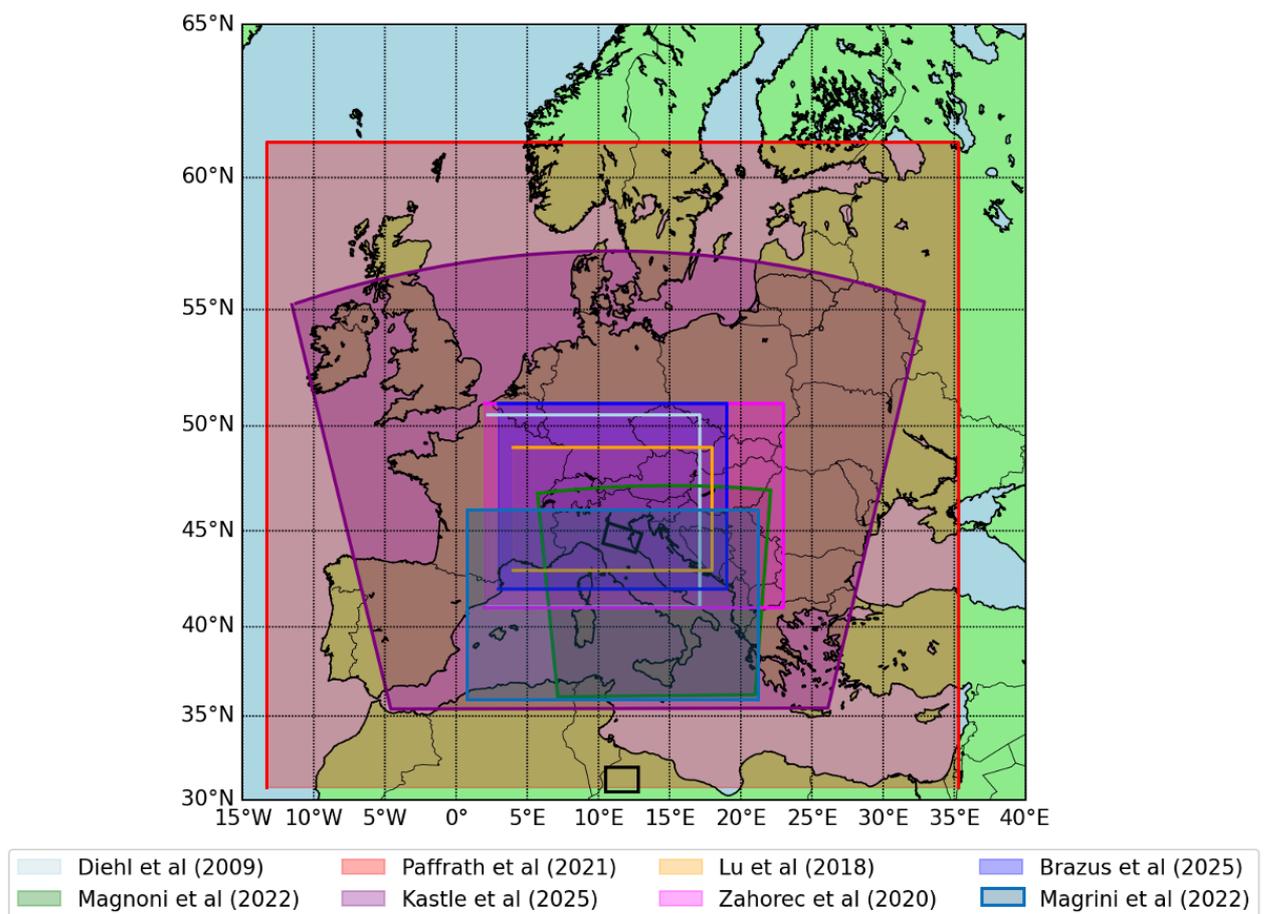


Figure 1: Spatial overlap of geophysical datasets.

Acknowledgments

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

References

Braszus, B., Rietbrock, A., Haberland, C., 2025: A 3D velocity model for the European Alps: New insights into the crustal structure. *Journal of Geophysical Research: Solid Earth*, 130(10), p.e2025JB031877, <https://doi.org/10.1029/2025JB031877>.

Burke, M.M., Fountain, D.M., 1990: Seismic properties of rocks from an exposure of extended continental crust—new laboratory measurements from the Ivrea Zone. *Tectonophysics*, 182(1-2), 119-146, [https://doi.org/10.1016/0040-1951\(90\)90346-A](https://doi.org/10.1016/0040-1951(90)90346-A).

Christensen, N.I., Mooney, W.D., 1995: Seismic velocity structure and composition of the continental crust: A global view. *Journal of Geophysical Research: Solid Earth*, 100(B6), 9761-9788, <https://doi.org/10.1029/95JB00259>.

Kästle, E.D., Paffrath, M., El-Sharkawy, A., 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, <https://doi.org/10.1029/2024JB030101>.

Livani M. et al., 2023: Subsurface geological and geophysical data from the Po Plain and the northern Adriatic Sea (north Italy). *Earth Syst. Sci. Data*, 15, 4261–4293, <https://doi.org/10.5194/essd-15-4261-2023>.

Lu, Y., Stehly, L., Paul, A., AlpArray Working Group, 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., Casarotti, E., Komatitsch, D., Di Stefano, R., Ciaccio, M.G., Tape, C., Melini, D., Michelini, A., Piersanti, A., Tromp, J., 2022: Adjoint tomography of the Italian lithosphere. *Commun. Earth Environ.*, 3(1), 69, <https://doi.org/10.1038/s43247-022-00397-7>.

Magrini, F., Diaferia, G., El-Sharkawy, A., Cammarano, F., van Der Meijde, M., Meier, T., Boschi, L., 2022: Surface-wave tomography of the central-western Mediterranean: New insights into the Liguro-Provençal and Tyrrhenian Basins. *Journal of Geophysical Research: Solid Earth*, 127(3), p.e2021JB023267. <https://doi.org/10.1029/2021JB023267>.

Pasquale, V., Chiozzi, P., Verdoya, M., 2013: Evidence for thermal convection in the deep carbonate aquifer of the eastern sector of the Po Plain, Italy. *Tectonophysics*, 594, 1-12. <https://doi.org/10.1016/j.tecto.2013.03.011>.

Pasquale, V., M. Verdoya, Chiozzi, P., 2014: Heat flow and geothermal resources in northern Italy. *Renewable and Sustainable Energy Reviews*, 36, 277-285, <https://doi.org/10.1016/j.rser.2014.04.075>.

Slupski, P., G. Gola G., Basant, M., Cortassa, V., Facci, M., Nanni, T., Tesauro, M., Manzella, A., Galgaro A., 2025: The importance of measuring thermal and acoustic properties on rock analogues in geothermal potential assessment studies: the example of Northern Apennines Triassic carbonate platform and underlying basement rock. 43° National Conference NGGTS, Bologna, 11-14 February 2025.

Zahorec, P., Papčo, J., Paštka, R., Bielik, M., Bonvalot, S., Braitenberg, C., Ebbing, J., Gabriel, G., Gosar, A., Grand, A., Götze, H.-J., Hetényi, G., Holzrichter, N., Kissling, E., Marti, U., Meurers, B.,

Mrlina, J., Nogová, E., Pastorutti, A., Salaun, C., Scarponi, M., Sebera, J., Seoane, L., Skiba, P., Szűcs, E., and Varga, M., 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>.

Corresponding author: mtesauro@units.it