Machine Learning Based Joint Interpretation of Geophysical data for the geothermal potential assessment of the Romagna and Ferrera Folds (Italy)

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

[1]Dipartimento di matemtica, Informatica e Geoscienze, Universita di trieste, Italy, [2]Utrecht University, Netherlands, [3] Istituto di Geoscienze e Georisorse, CNR, Italy, [4] Dipartimento di Geoscienze, Universita di Padova, Italy

Finanziato dall'Unione europea NextGenerationEU · Ministero dell'Università e della Ricerca · Italiadomani

Introduction

The InGEO project (Innovation in GEOthermal resources and reserves potential assessment for the decarbonization of power/thermal sectors, www.ingeo.cnr.it), seeks to develop an innovative exploration workflow integrating geological, geophysical and petrophysical datasets. **The aim of this study is to jointly interpret seismic tomography, gravity and well log data in the Romagna and Ferrera Folds (RFF), in order to implement a consistent 3D geophysical model to use as input for the evaluation of the geothermal resources in that area.**

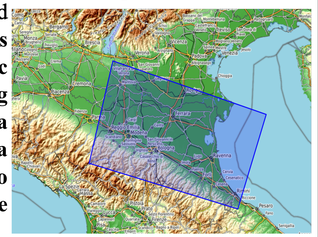

Figure 1: *Study area (RFF region)*

Geophysical Data

The data used in this study include seismic tomography data, gravity and well log datasets acquired over the RFF region, delimited by the red box displayed in Figure 2 (a-e).

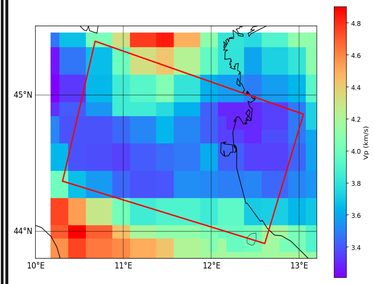

Figure 2a: *P- wave veliocity model from Kastle et al. (2025) at 2kmbsl*

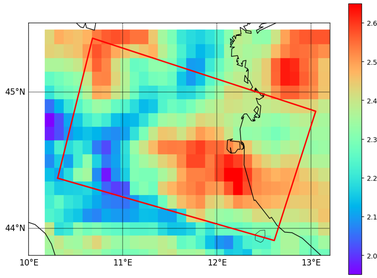

Figure 2b: *S- wave velocity model from Magnoni et al. (2022) at 2kmbsl*

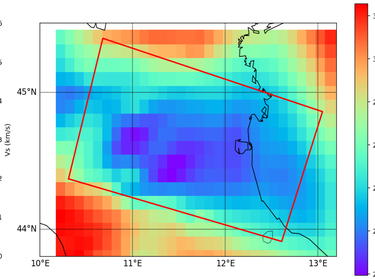

Figure 2c: *S- wave velocity model from Lu et al. (2020) at 2kmbsl*

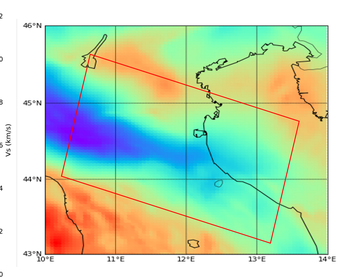

Figure 2d: *Complete Bouguer anomlay data after Zahorec et al. (2021)*

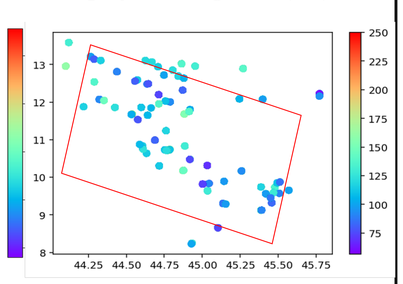

Figure 2e: *Wells within the RFF region which show variation in sonic data in sand lithology*

Outlook

The resulting 3D geophysical models contribute to the preliminary delineation and constraint of shallow structural features within the RFF. This information will be used as input parameters for the development of a thermal model 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 deep heat exchangers solutions in Italy, but with potential to extend the approach in different geological contexts. The workflow of InGEO project will be used as a decision support system for developing geothermal projects in Italy.

References

Cortassa, V, Tesauro, M., Basant, R., Gola, G., Nanni, T., Galgaro, G., Manzella, A., 2025. A 3D Geological Model of the Romagna and Ferrara Folds (Eastern Po Plain)for advanced deep geothermal exploration, EGU 2025

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.

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..

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.

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. Geophysical Journal International, 214(2), 1136-1150.

Zahorec, P., Papčo, J., Pašteka, R., Bielik, M., Bonvalot, S., Braitenberg, C., Ebbing, J., Gabriel, G., Gosar, A., Grand, A. and Götze, H.J., 2021. The first pan-Alpine surface-gravity database, a modern compilation that crosses frontiers. Earth System Science Data Discussions, 2021, pp.1-72.

Acknowledgement

The InGEO project is part of the PRIN 2022 PNRRinitiative and is funded by the European Union's NextGeneration EU program.

Scan this code if you want to read the Abstract. Thank you for your attention!

Geophysical Modelling

A. Seismic and Sonic Velocity

1. Interpolation

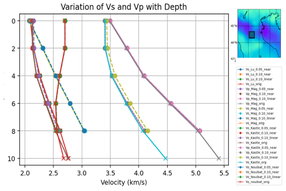

Figure 3a: *1D variation in P (Vp) and S (Vs)- wave velocity with depth on interpolated grid*

2. Optimal number of clusters

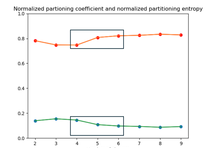

Figure 3b: *Variation in normalized paritioning entropy and normalized partitioning co-efficient*

3. Fuzzy c -means cluster analysis

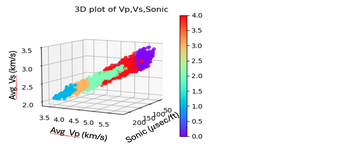

Figure 3c: *Classification of N-dimensional datapoints into 5 classes with Fuzzy c-means algorithm*

B. Gravity

1. Input Numerical Values

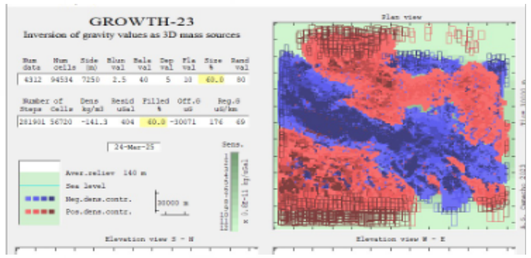

Figure 4a: *Numerical values for the inversiong modelling parameters and view of the resulting aggregation of model cells*

2. Inversion

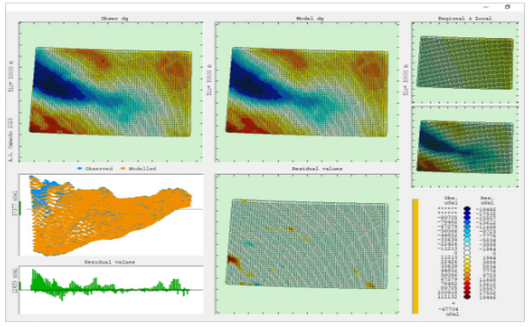

Figure 4b: *Results obtained from the inversion of gravity data (Zahorec et al., 2021) using the GROWTH-23 algorithm*

Joint Interpretation

A. Cluster model

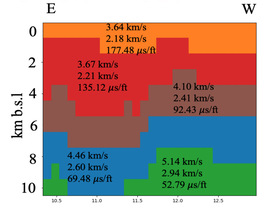

Figure 5a: *E-W cross section of Cluster model reflecting the variation in seismic and sonic velocity*

B. Density Contrasts Model

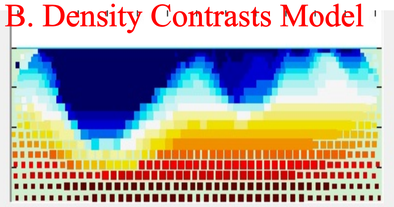

Figure 5b: *E-W cross section of density contrasts model from gravity inversion*

Validating models

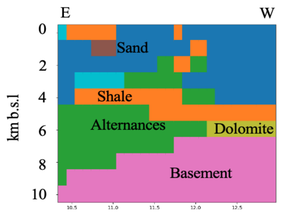

Figure 5c: *E-W cross section of 3D lithology model created from the well logs in Livani et al. (2023)*

By applying the Fuzzy c-means algorithm and the GROWTH-23 inversion technique, a preliminary 3D cluster and density contrasts model were obtained respectively. The E-W cross sections from the models are shown in Figues 5a and 5b respectively. The cluster model (Figure 5a) highlights increasing P- and S- waves velocity with depth. Decreasing sonic velocity with depth also obtained in the cluster model is in agreement with the increasing seismic velocities. The E-W cross section of the density contrast model (Figure 5b) also highlights decreasing density contrast with depth. We validate the models with an E-W cross section of a 3D lithology model created from well logs reported in Livani et al. (2023). Shallow low density, low seismic velocity and high sonic velocities are attributed to sandstones and shales while deeper high density, high seismic velocity, and low sonic velocities are attributed to dolomites and basement rocks These models will be further constrained with an ongoing developing geological model (Cortassa et al., 2025).