Joint geophysical modelling constrained by geological and petrophysical data for assessing the geothermal energy potential of the Romagna and Ferrara folds (RFF), Eastern Po-plain

Basant R.*[1], Tesauro M.[1-2], Cortassa V.[1], Gola G.[3], Nanni T.[3], Slupski P.M.[4], Galgaro A.[4] & Manzella A.[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

1. 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 for 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 Ferrara Folds (RFF), in order to implement a consistent 3D geophysical model to use as input for the evaluation of geothermal resources

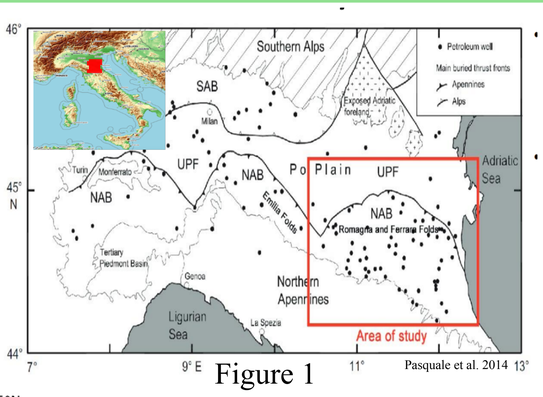


Figure 1

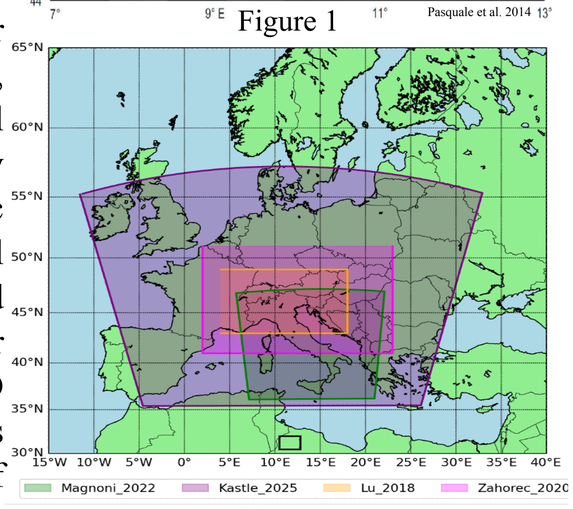


Figure 2

2. GEOPHYSICAL MODELLING WORKFLOW

The aim of the geophysical modelling section of the InGEO involves both seismic and gravity modelling. Figure 3 shows the workflow we designed to achieve this aim. The workflow is divided into three main section 1) INPUT 2) PROCESSING and 3) OUTPUT. For this study, we utilized only the steps for seismic tomography and gravity analysis. Sonic well logs are utilized in validating our models.

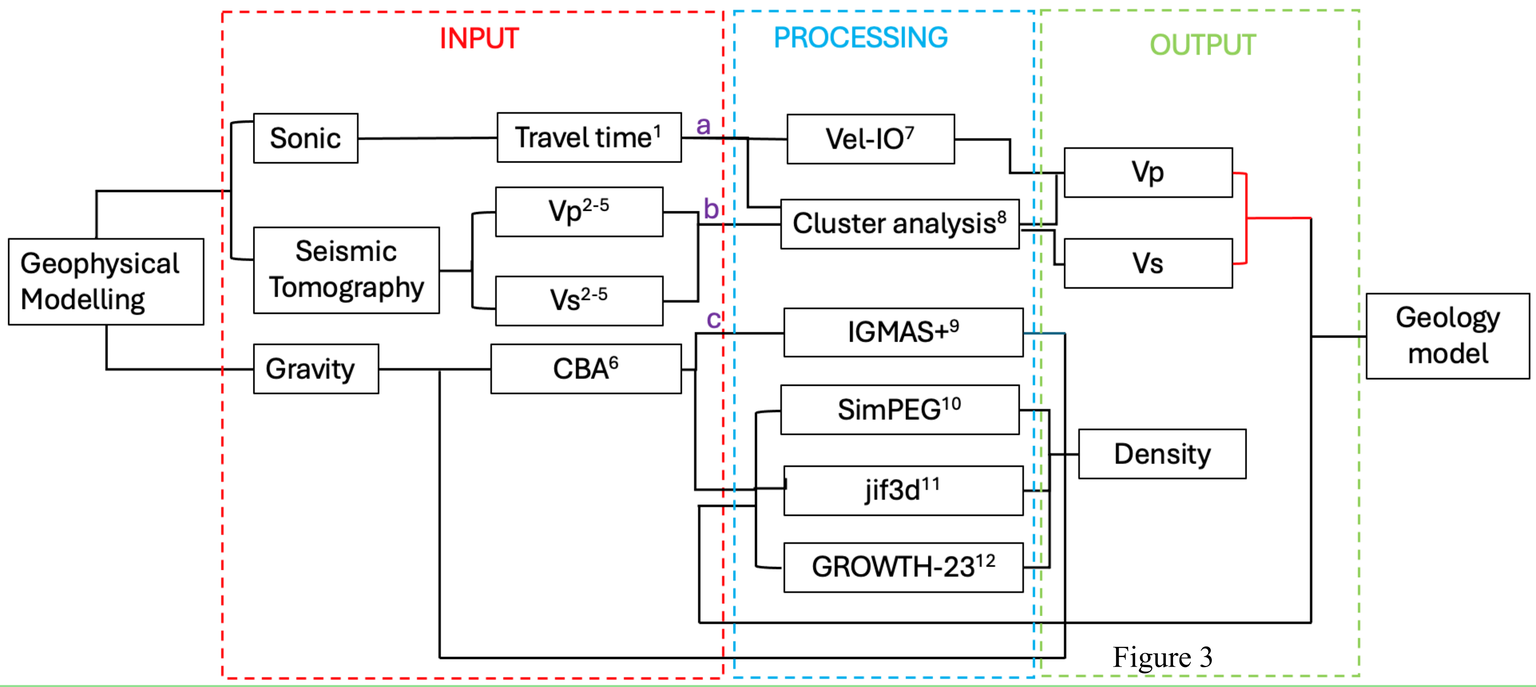


Figure 3

3. RESULTS

A. Seismic Tomography

Step 1: Interpolation of datasets [b]

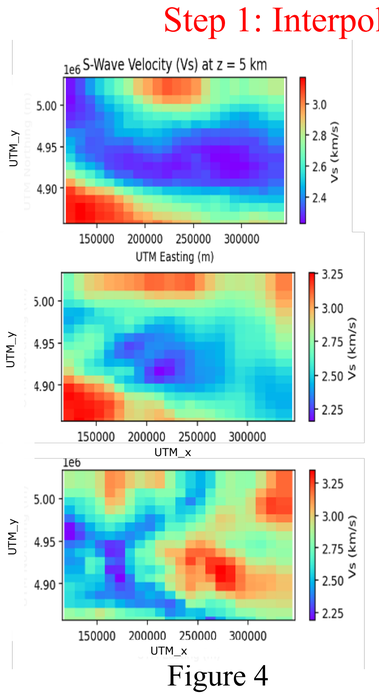


Figure 4

Seismic Tomography models (S-wave) were displayed over the RFF domain. Figure 4 shows a low velocity anomaly over the RFF region. The data were interpolated over a 10 km interval spacing so that each point within the grid was characteristic of a S-wave velocity of each model.

Step 2: Applying clustering algorithm

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

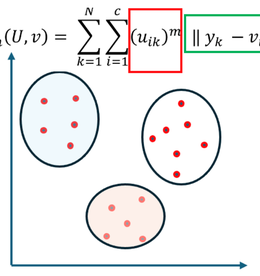


Figure 5

Clustering algorithms can be used to class similarities amongst datasets. The Fuzzy c-means (FCM) alogrithm was used to classify the S- wave seismic tomography models.

Step 3: Selecting optimal number of clusters

The membership values and 3D plots suggest that four clusters may be the optimal grouping.

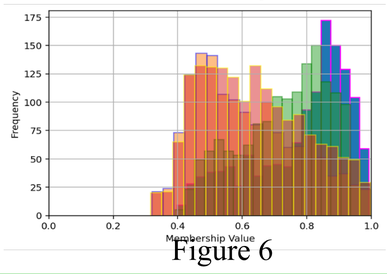


Figure 6

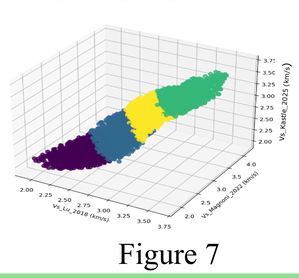


Figure 7

B. Gravity Modelling

Step 1: Gravity residual calculation [c]

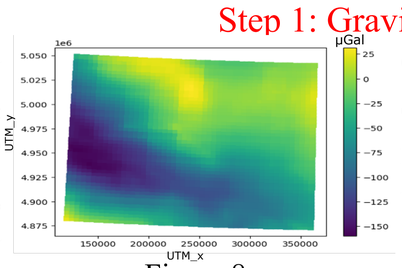


Figure 8

Gravity dataset consisting of land and marine acqusitions over the RFF. The complete Bouguer anomaly (Figure 8) shows a low NW-SE anomaly spatially coindicent with the seismic tomography. The residual CBA is shown in Figure 9.

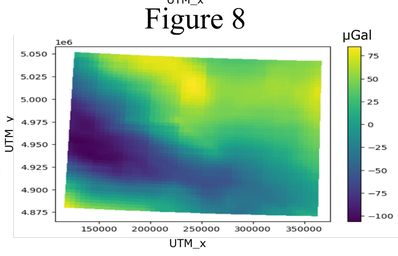


Figure 9

Step 2: Inversion Mesh

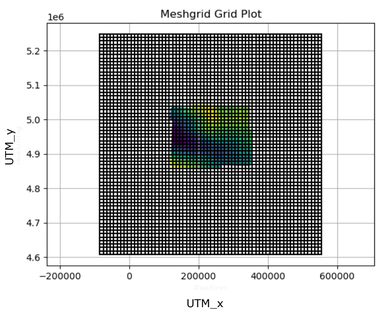


Figure 10

The inversion model was built by a volume discretized in voxels of 64 x 64 x 50. Horizontal resolution was set as 10 km and vertical resolution was set at 1 km respectively.

Step 3: Gravity inversion

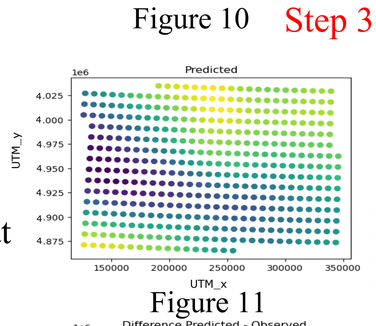


Figure 11

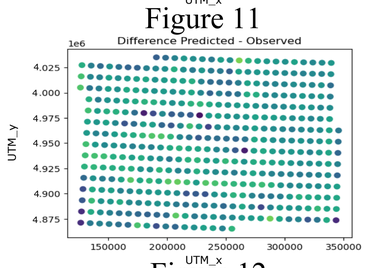
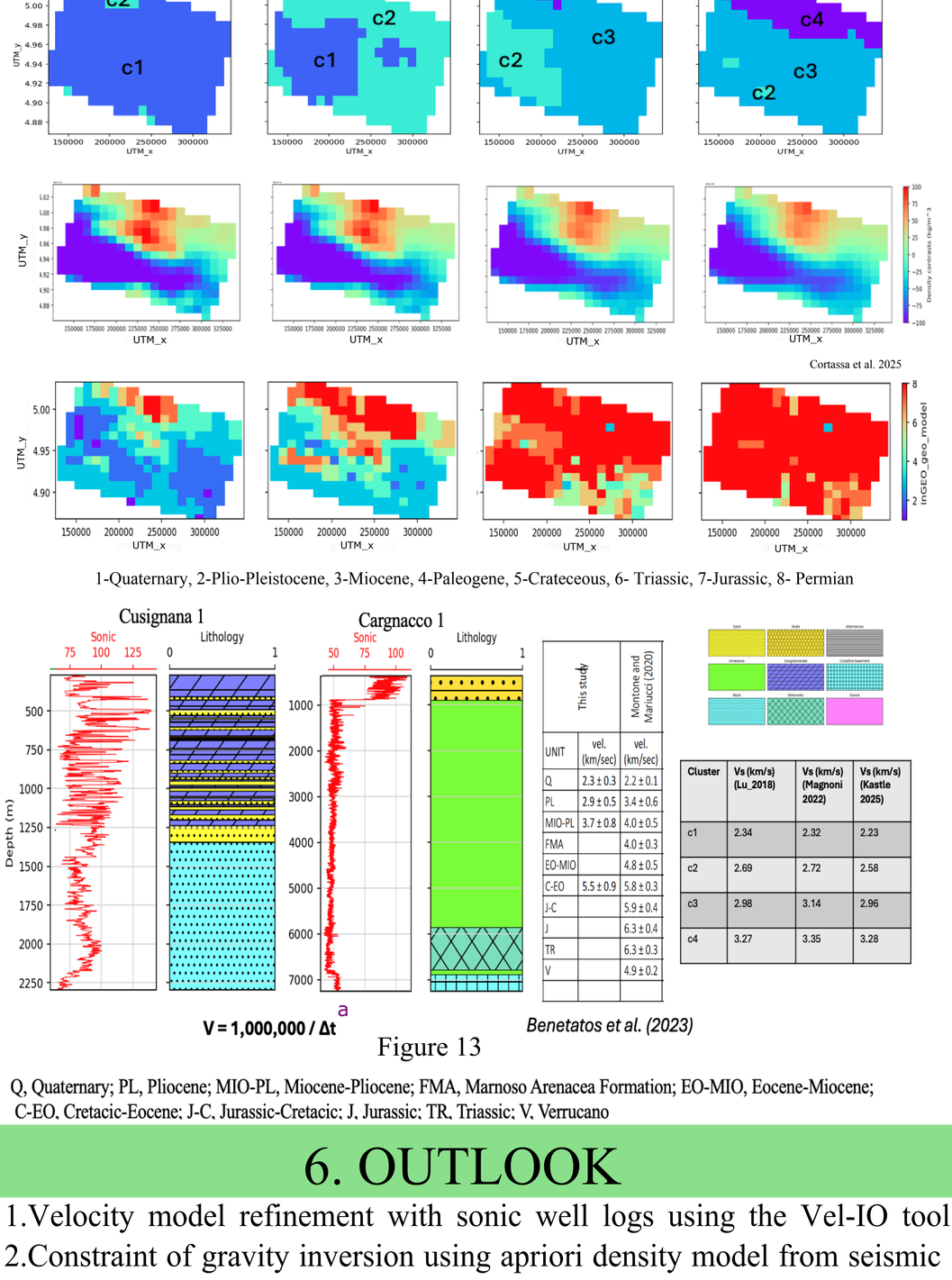


Figure 12

Figure 11 shows the computed or predicted gravity. Comparison with the observed gravity (Figure 8) shows the NW-SE trending low anomaly. Figure 11 shows the residuals (difference between observed and predicted) are low. RMS =2.28

4. DISCUSSION

The cluster model and density contrasts model highlight increasing S-wave velocity and density contrasts respectively with depth. The main anomalous region include the low velocity anomaly (c1) coincident with the low density anomaly. The geology model and well logs show that this anomaly can be interpreted as Plio-Pleistocene sediments.



1-Quaternary, 2-Plio-Pleistocene, 3-Miocene, 4-Paleogene, 5-Crateceous, 6- Triassic, 7-Jurassic, 8- Permian

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

Figure 13

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

5. CONCLUSIONS

1.Three-dimensional modelling and constraint of the anomalous regions in the RFF.
2. Lowest velocity and lowest density interpreted as sediments of the Plio-Pleistocene geological unit.
3.High velocity and high density anomalies interpreted as older geological units.
4.Validation of the cluster and density contrast model with geological model and sonic well logs.

6. OUTLOOK

1.Velocity model refinement with sonic well logs using the Vel-IO tool
2.Constraint of gravity inversion using apriori density model from seismic
3.Uncertainty analysis of both seismic and gravity datasets
4.Implementaion of a consistent geological/geophysical model to utilize in a numerical model that will characterize the geothermal reservoir potential
5.Working towards a workflow that is reproducible and can be applied to de-risk future geothermal prospects in any region/area.

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