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 rocks

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Regional-scale geothermal potential assessment relies on geological, petrophysical and thermal modelling strategies. The InGEO project aims to develop an innovative exploration workflow that integrates geological and geophysical data as well as other direct and indirect information to characterize the geological and thermal structures of the deep-seated Mesozoic carbonate reservoir in the Romagna and Ferrara buried folds sector. The Romagna and Ferrara folds represent the outer deformation front of the Northern Apennines thrust and fold belt, which is buried under a thick foredeep clastic sequence deposited during the Alpine (Eocene-Miocene) and the Apennine (Pliocene-Quaternary) sedimentation cycles. During the Neogene-Quaternary compressive tectonics the Mesozoic carbonate sequence has been significantly deformed resulting in multiple thrust structures and shallow ramp anticlines (Fig. 1). Locally, some site-specific surface heat flow values highlight positive anomalies attributed to the thermal convection within the Mesozoic limestones (Pasquale et al., 2013). The magnitude of these anomalies seems like correlated to the structural elevation of the buried anticlines. To investigate their possible origin as well as their spatial extension, a thermal numerical modelling approach will be applied integrating updated geological, structural and petrophysical models together with the available and corrected bottom hole temperatures from deep hydrocarbon exploratory wells. In this context, the measurement of acoustic velocities and thermal properties of the Mesozoic carbonate platform rocks and the underlying Permian siliciclastic and Palaeozoic metamorphic basement are pivotal for advancing the regional geological and thermal models. The deepest structures of the Apennine fold and thrust belt are poorly recognized and characterized due to the lack of direct evidence. For example, information about the depth of the boundary between the carbonate sequence and the Palaeozoic basement and their petrophysical characteristics are practically absent or poorly constrained. Conversely, the uppermost geological units have been investigated and characterized in previous studies (Livani et al., 2023; Pasquale et al., 2011). As the definition of the basal depth and the thickness of the regional carbonate reservoir has direct implications on the thermal and fluid-dynamic regimes, we conducted a field campaign aimed at collecting and investigating the physical properties (mechanical and thermal) of rock samples representative of the Northern Apennines Triassic carbonate platform and underlying basement rocks. As in the study area these geological units are deeply buried (> 5 km), we collected lithological analogues outcropping in the Southern Alps (Iseo Lake area), which rely to the Adriatic Plate Meso-Cenozoic passive margin and Hercynian basement (Fig. 1).

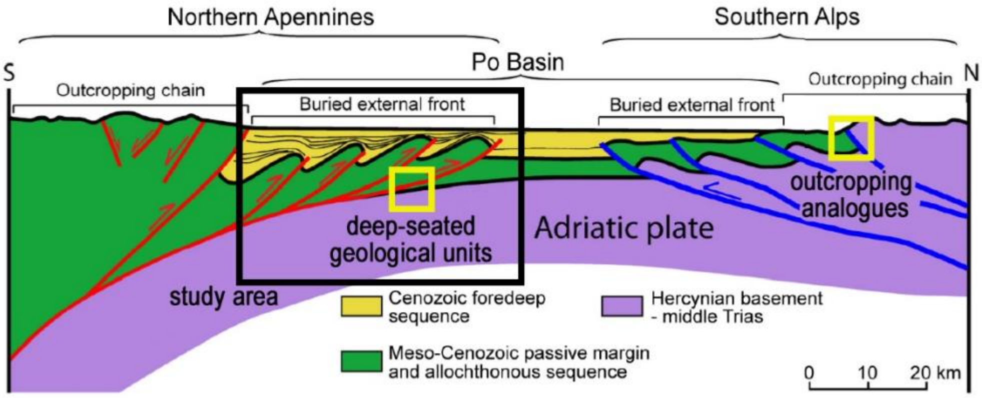

Fig. 1 – Simplified geological and structural setting of the study area (black rectangle) and the selection of the outcropping sites in Southern Alps aimed at sampling lithological analogues of the deepest portion of the Mesozoic carbonate reservoir and its basement (yellow rectangles) in the Apennine buried external front (modified from Livani et al., 2023).

Acoustic velocities, specifically compressional (P-wave) and shear (S-wave) velocities, are investigated to interpret subsurface seismic data and delineate the carbonate platform-basement interface tacking advantage of the distinct acoustic velocity contrasts. Thermal properties are explored to incorporate measured data into the thermal model. This information is critical for supporting numerical simulations aimed at predicting the behaviour of heat transport processes across the stratigraphic sequence, enabling improved interpretations of geothermal potential and aiding in sustainable resource management. These analyses were complemented by assessments of density, porosity, fluid saturation and petrographic analyses, providing a comprehensive dataset essential to evaluate the impact of mineral content, grain size, texture, and alteration on the investigated petrophysical properties.

The integration of thermal conductivity and acoustic velocity measurements enhanced the overall understanding of the subsurface architecture. Thermal conductivity data refine thermal models, which are crucial for predicting subsurface temperatures, while acoustic velocities provide critical input for seismic imaging and structural characterization. Together, these datasets enable the identification of key geological boundaries, such as the transition from the carbonate platform to the crystalline basement and support the development of robust geophysical and geological models as well as geothermal resource assessment.

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