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Joint Rayleigh and Love wave nodal ambient noise tomography in the Northern Apennines hinterland, Roccastrada-Ribolla basin, Italy.

Douglas Stumpp[1], Iván Cabrera-Pérez[1], Geneviève Savard[1], Konstantinos Michailos[1], Elliot Amir Jiwani-Brown[1], Francisco Muñoz Burbano[1], Juan Porras Loria[1], Sarah Borotau[1], Domenico Montanari[2], Riccardo Lanari[2], Samuele Papeschi[2], Marco Bonini[2], and Matteo Lupi[1]
[1]University of Geneva, Faculty of Sciences, Department of Earth Sciences, Geneva, Switzerland (douglas.stumpp@unige.ch)
[2]Institute of Geosciences and Earth Resources - CNR, Firenze, Italy

Geothermal energy plays a crucial role in the global energy transition. Tuscany hosts Italy's active geothermal fieds of Larderello-Travale where geothermal power generation was pioneered in the early 20th century. The region is characterized by an anomalously high heat flow rate of up to 1000 mW/m^2 and extreme geothermal gradients (locally exceeding 150°C/km). These conditions drive regional-scale hydrothermal circulation where temperatures can exceed 500°C at about 3 km depth. While the exploration of deep horizons within established steam fields remains vital for identifying new targets with reservoirs characteristics, the investigation of unexplored regions is equally crucial to expand geothermal exploitation in different geological contexts and to understand the broader system dynamics. This study examines the tectonic history of the northern Apennine belt in the understudied Roccastrada-Ribolla basin and evaluates the seismic signature of potential deep productive targets therein.

We applied the nodal ambient noise tomography (NANT) method to generate a high-resolution shear-wave velocity (Vs) model of the upper crust. The method leverages depth-sensitive surface waves that dominate virtual seismograms estimated from ambient noise cross-correlation. In addition, the joint inversion of Rayleigh and Love wave dispersive properties provides higher resolution information about the distribution of seismic velocity anisotropy in the subsurface. We use continuous seismic data from a dense local network of 189 three-component short-period geophones (250 Hz sampling rate) deployed for one month during June-July 2023. The critical step of surface wave dispersion curves extraction is treated automatically as a semantic segmentation problem through a deep convolutional neural network approach while a two-step inversion scheme is used to retrieve the 3-D shear-wave velocity model: (non-)linear 2-D travel-time tomography inversions, followed by a trans-dimensional Markov chain Monte Carlo probabilistic search algorithm for 1-D Vs depth inversions. The jointly inverted 3-D Vs model for Rayleigh and Love waves reveals structures consistent with local basin geology and aligns with features identified by deep active seismic exploration profiles made in the central Mediterranean and Italy

(CROP Project). This promising exploration campaign not only presents new prospects for the exploitation of deep geothermal systems but also advances our understanding of complex tectonic settings while demonstrating the efficacy of rapid, semi-automated, and cost-effective seismic imaging for industry applications.