Integration of Ground Penetrating Radar and Seismic Refraction tomography for buried active fault detection

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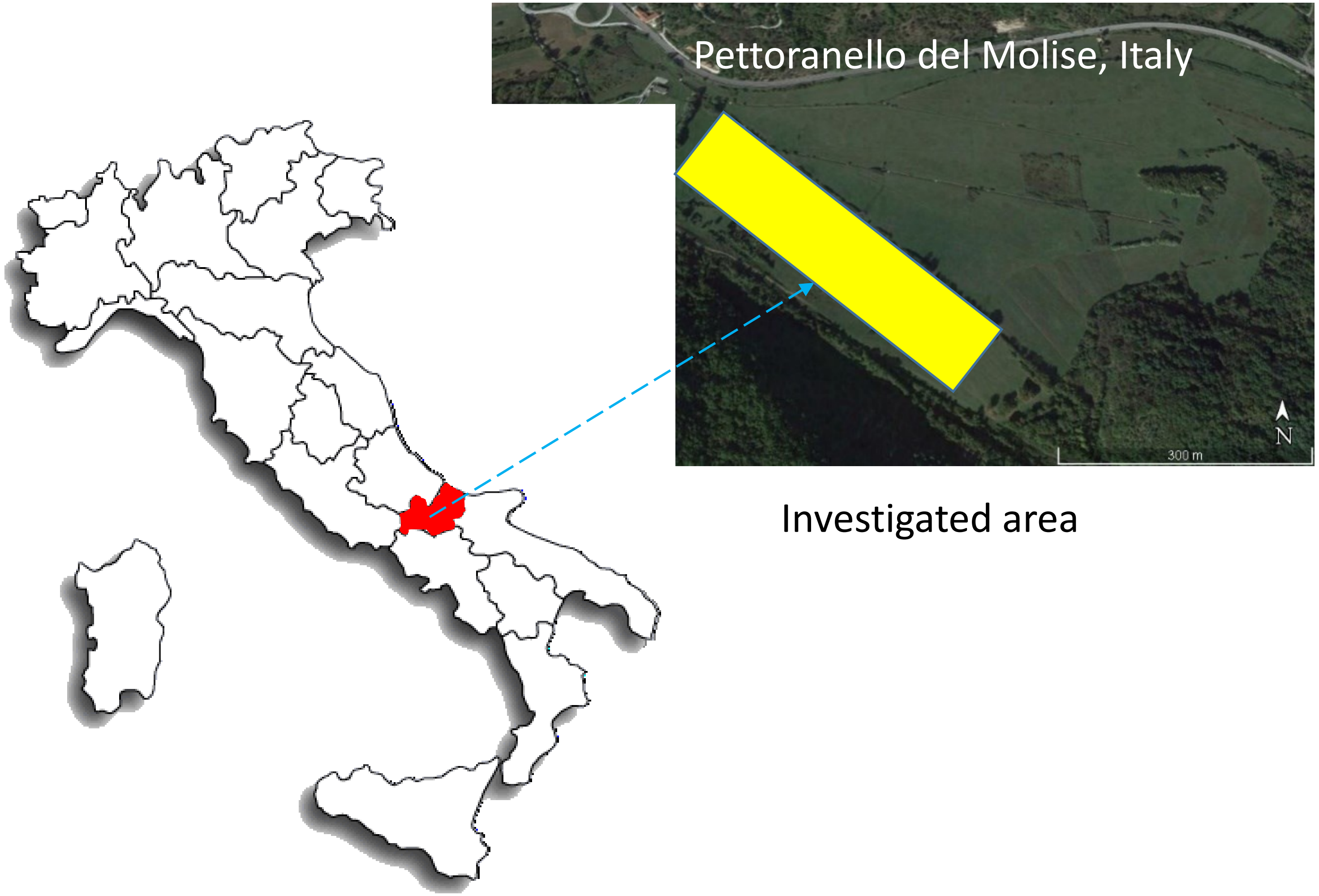
INTRODUCTION

This study aimed at the detection and characterization of active fault segments by means of geophysical surveys integrated with traditional geomorphologic and structural observations.

The active buried fault system bordering the western edge of the “Il Lago” Plain (Pettoranello del Molise, Italy) through the combination of seismic refraction tomography and low-frequency Ground Penetrating Radar (GPR) has been investigated.



Investigated area

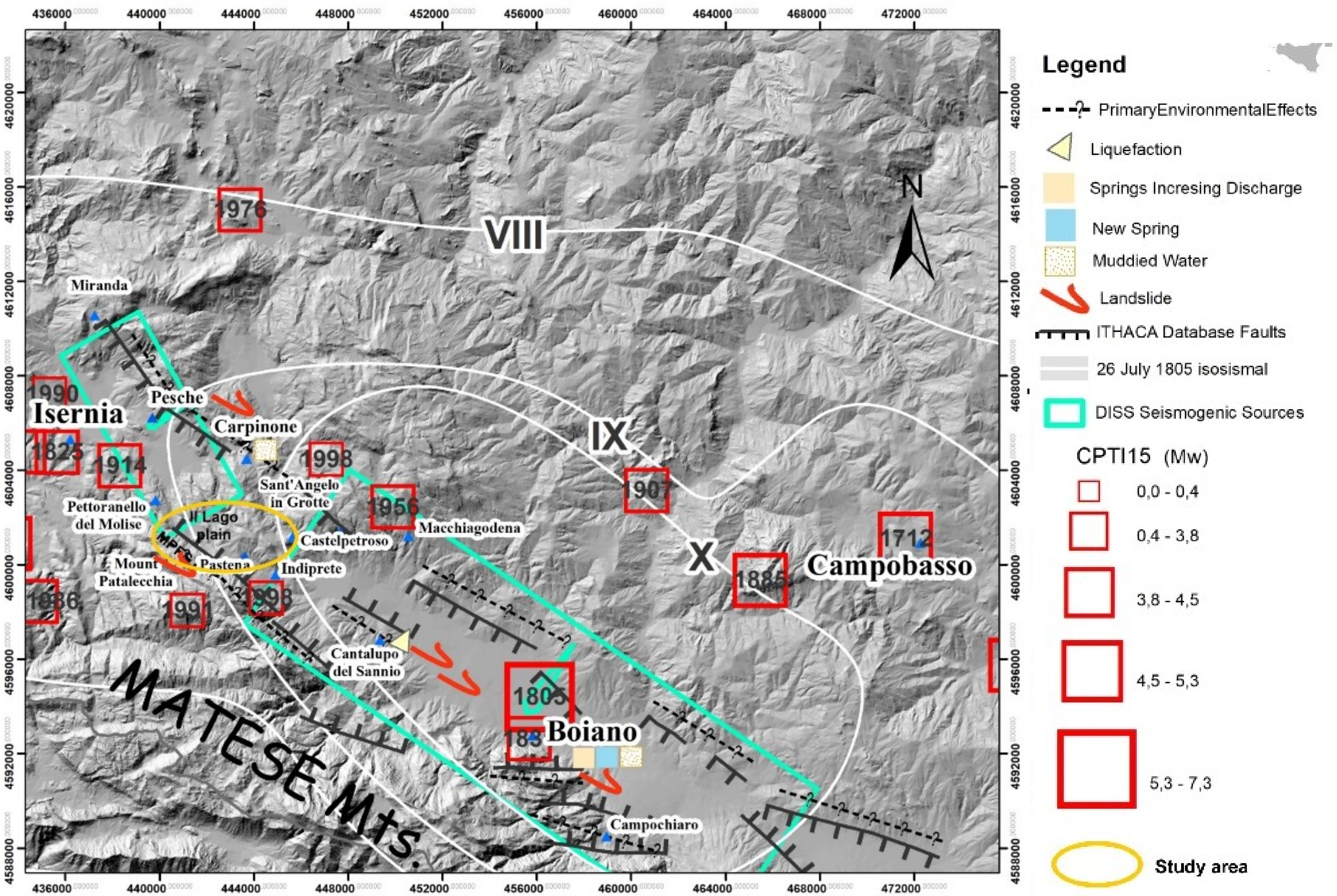
INTRODUCTION

The “Il Lago” is a small endorheic basin that closes the structure of the NWSE Quaternary Bojano basin towards NW.

This fault system is considered one of the most seismically hazardous structure of the Apennines:

- 5 December, 1456 earthquake (I = XI MCS; Mw = 7.2;
- 5 June, 1688 earthquake (I = XI MCS, Mw = 7.1)
- S. Anna earthquake of 26 July, 1805 (I = X MCS, Mw = 6.7 whose epicentral area was the Bojano basin.

The normal fault bordering the plain to the SW is a poorly known structure, weakly expressed at the surface by small morphological scarps/warps



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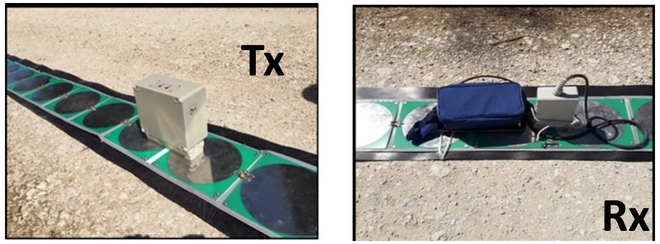
Materials and Methods

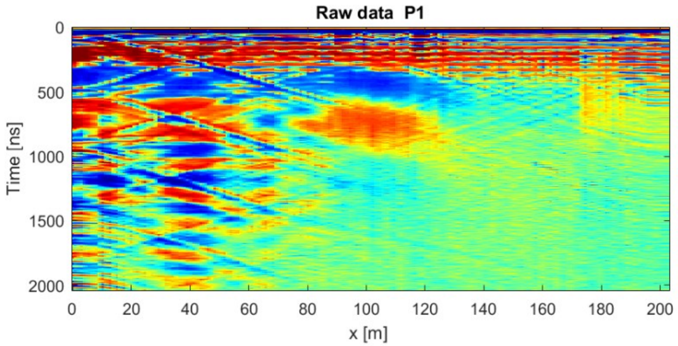


Loza GPR 2N system

GPR Data Acquisition

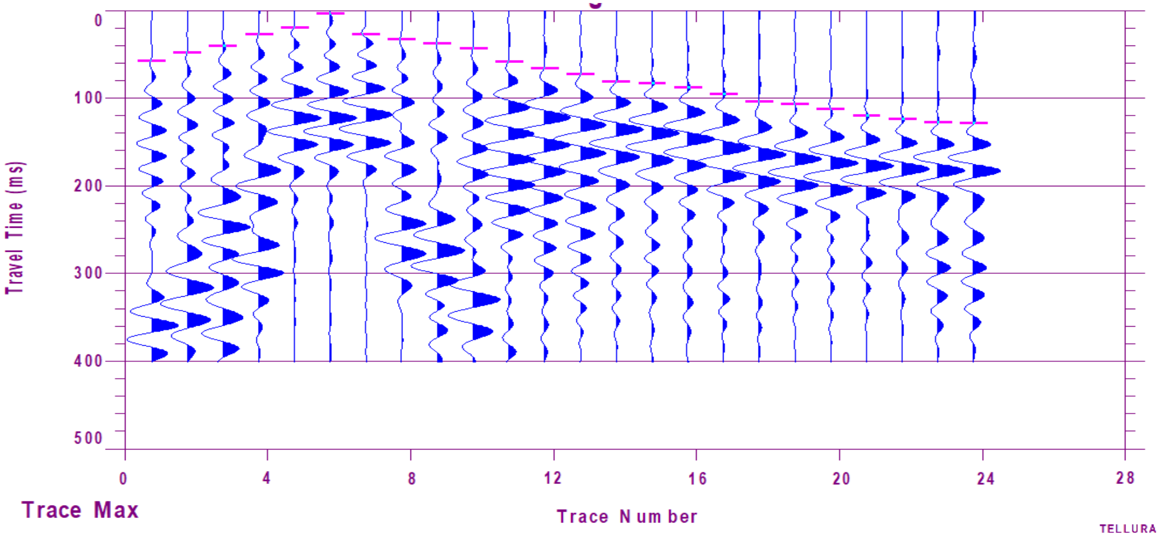
Loza GPR 2N system was designed especially for high-conductivity soils (wet clay, loam), at the IZMIRAN.

Example of the raw GPR data



Loza GPR is equipped with two not-shielded monostatic antennas (Tx/Rx) and working in the frequency band of tens of MHz.

Seismic Refraction Data Acquisition

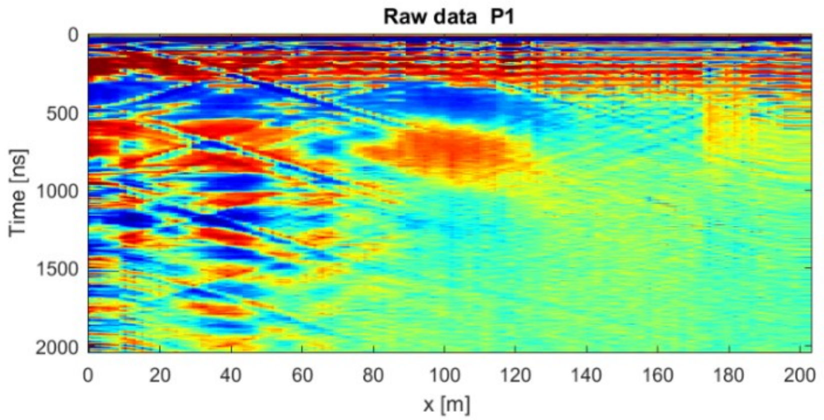


The seismic source consisted of a 15 kg sledge hammer that showed to produce clear first arrivals along the whole profile, thanks to the very good signal-to-noise ratio in the area.

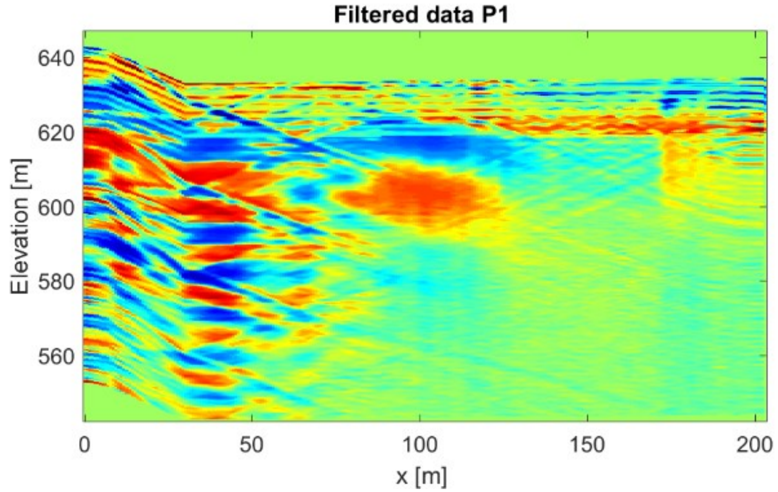
Materials and Methods

GPR Data Processing

Raw radargram → DeWoW | Median filter | Zero Timing | Time Gating | BKG removal | Topographic correction → Filtered radargram



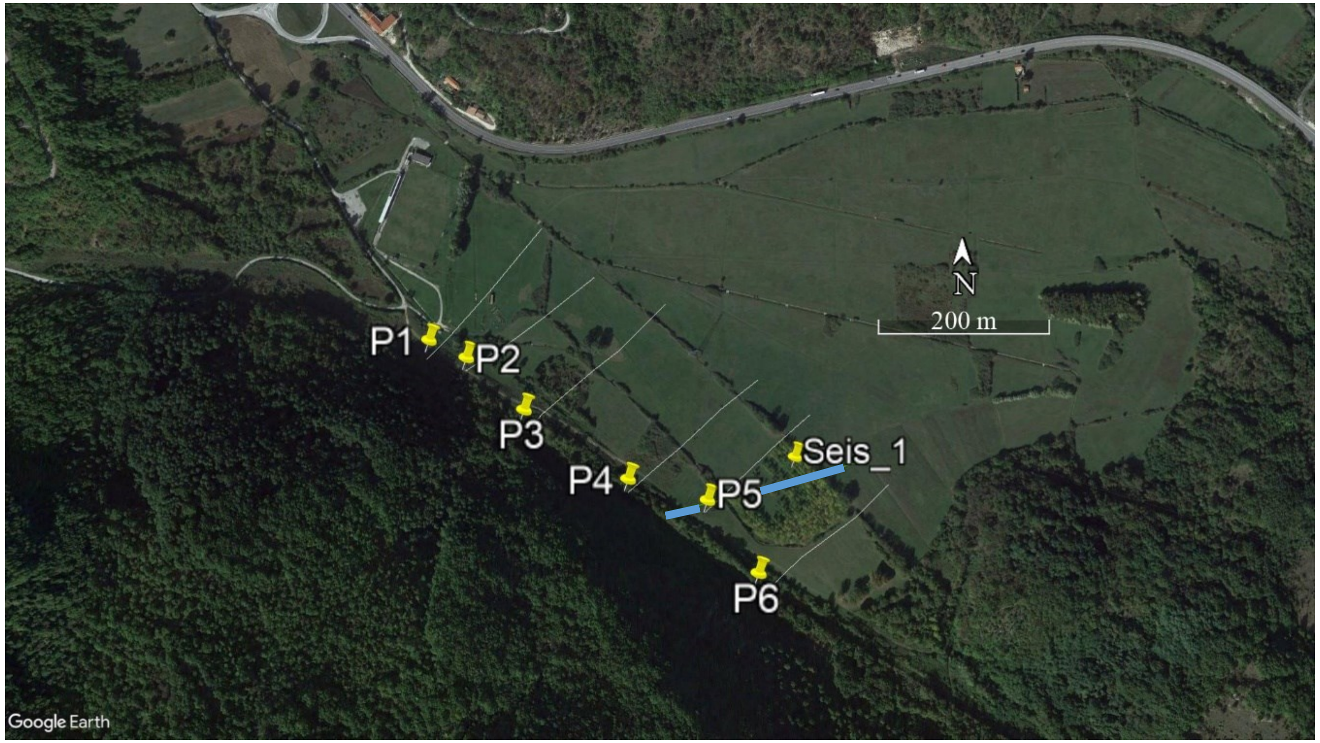
The strategy takes as input the raw radargram, i.e. the radar signals collected at each measurement position versus the fast-time. The final output is a filtered radargram and more easy interpretable image



Seismic Refraction Data Processing

The Vp model was determined by a tomographic algorithm, by using a non-linear Least Squares method. This method starts with an initial velocity model, and iteratively traces rays through the model with the goal of minimizing the RMS error between the observed and calculated traveltimes.

RESULTS



Map of the seismic refraction (Seis_1) and GPR (from P1 to P6) profiles

Seismic Refraction

24 horizontal geophones with a frequency of 40Hz spaced 10 m apart over a profile of 230 m have been deployed.

9 hammer blows along the profile, with blows at G1, G3, G6, G9, G12, G15, G18, G21 and G24 have been performed.
From data acquired along the seismic profile, we inverted the 216 first arrivals, previously handpicked on 9 records

GPR Data

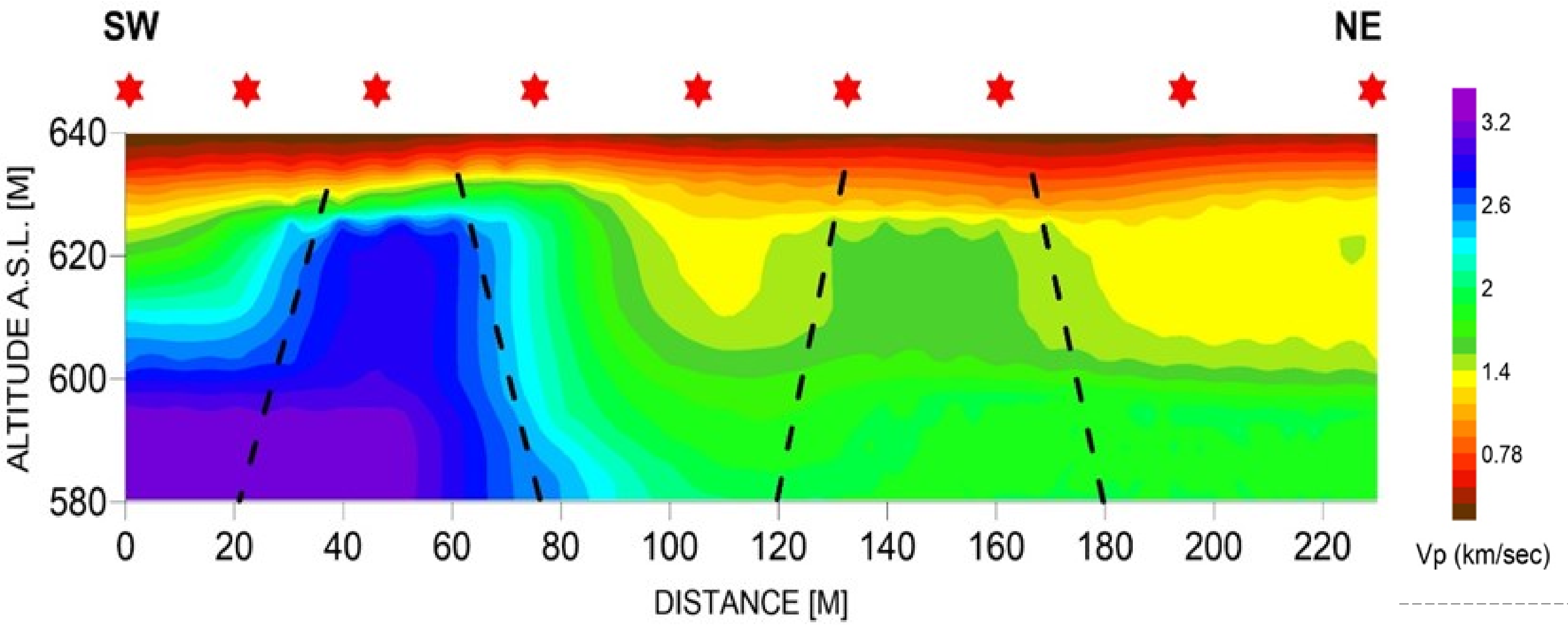
Six parallel approximately 200 m long GPR radargrams, named P1 to P6, spaced about 150 m each other.
These profiles trend SW-NE, orthogonally to the main direction of the valley

RESULTS

The analysis on seismic data showed two areas with sub-vertical P-velocity variations, at 20–80 m and at 120–180 m

the velocity variations to be caused by sub-vertical systems of faults, showing two horst and graben decametric structures, with NE-dipping synthetic and SW-dipping antithetic faults

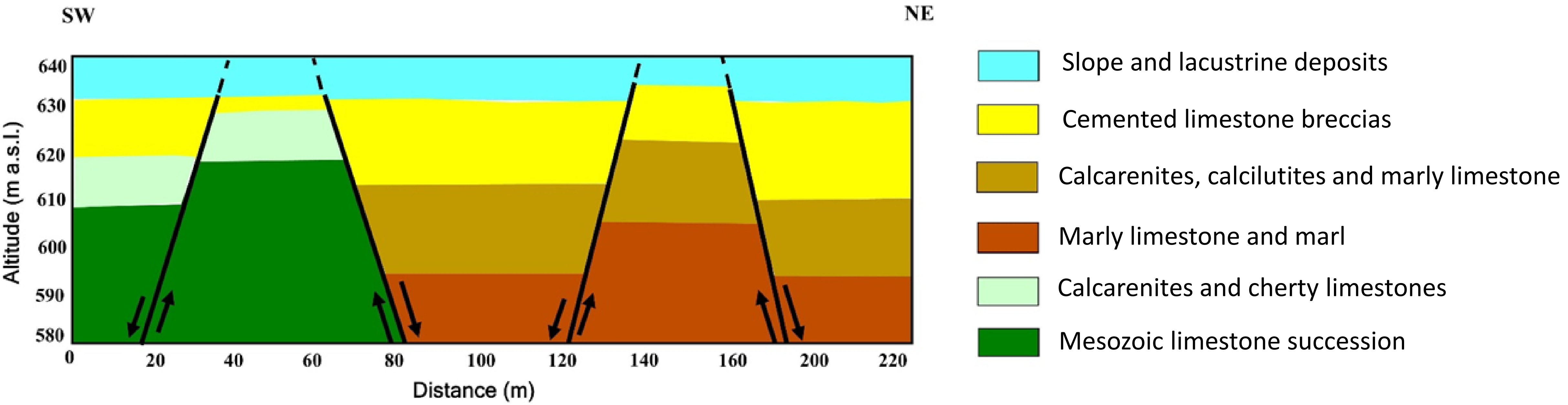
- low velocity layer 0.3 <V_P <1 km/s
- intermediate velocity V_P ≅1.4 km/s
- medium-high velocity 1.6 < V_P < 2.2 km/s
- high-velocity layers (V_P >2.6 km/s)



RESULTS

The interpretative geological cross section shows four sub-vertical normal faults, two faults dipping towards the SW and two faults dipping towards the NE.

- the top to the faults is at about 10 m depth (starting from 630 m a.s.l.) and the inferred system forms a horst and graben structure.

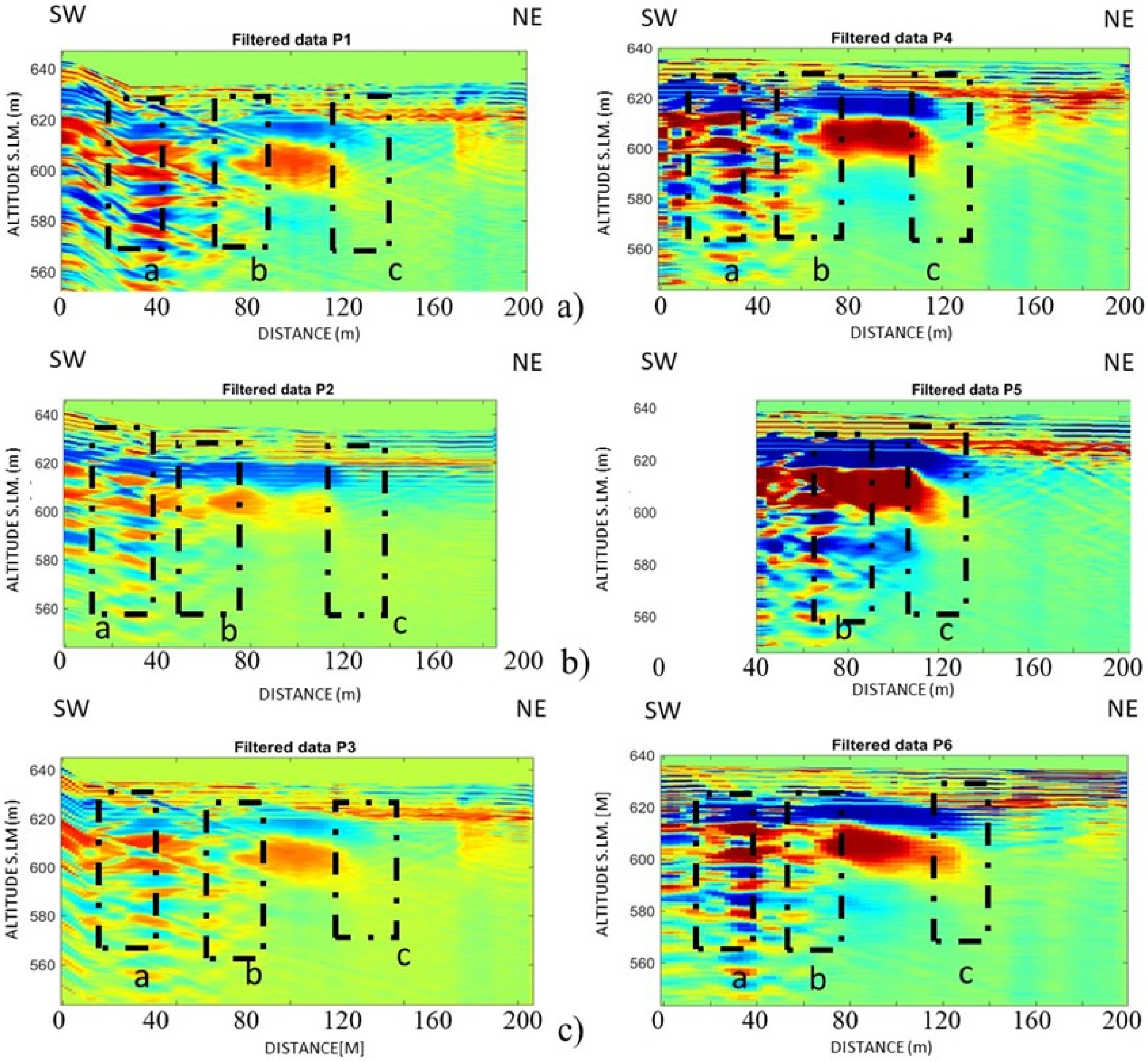


Results

The filtered data allow identifying three main areas, with strong reflections due to variations of the dielectric permittivity of the subsoil.

a) the reflective area with a depth-to-the top of about 10 m (630 a.l.s.) and a lateral extension of about 25 m
b) This GPR anomaly ends with a new discontinuity that could be associated with the presence of a second change in the geological condition
c) a third anomalous area between the distances of 100-130 m where a third geological structure is expected

The sequence of the three main anomalies (a, b and c) placed at a limited distance generally smaller than 50 m, is well kept for all the radargrams that are acquired in the investigated foothills.



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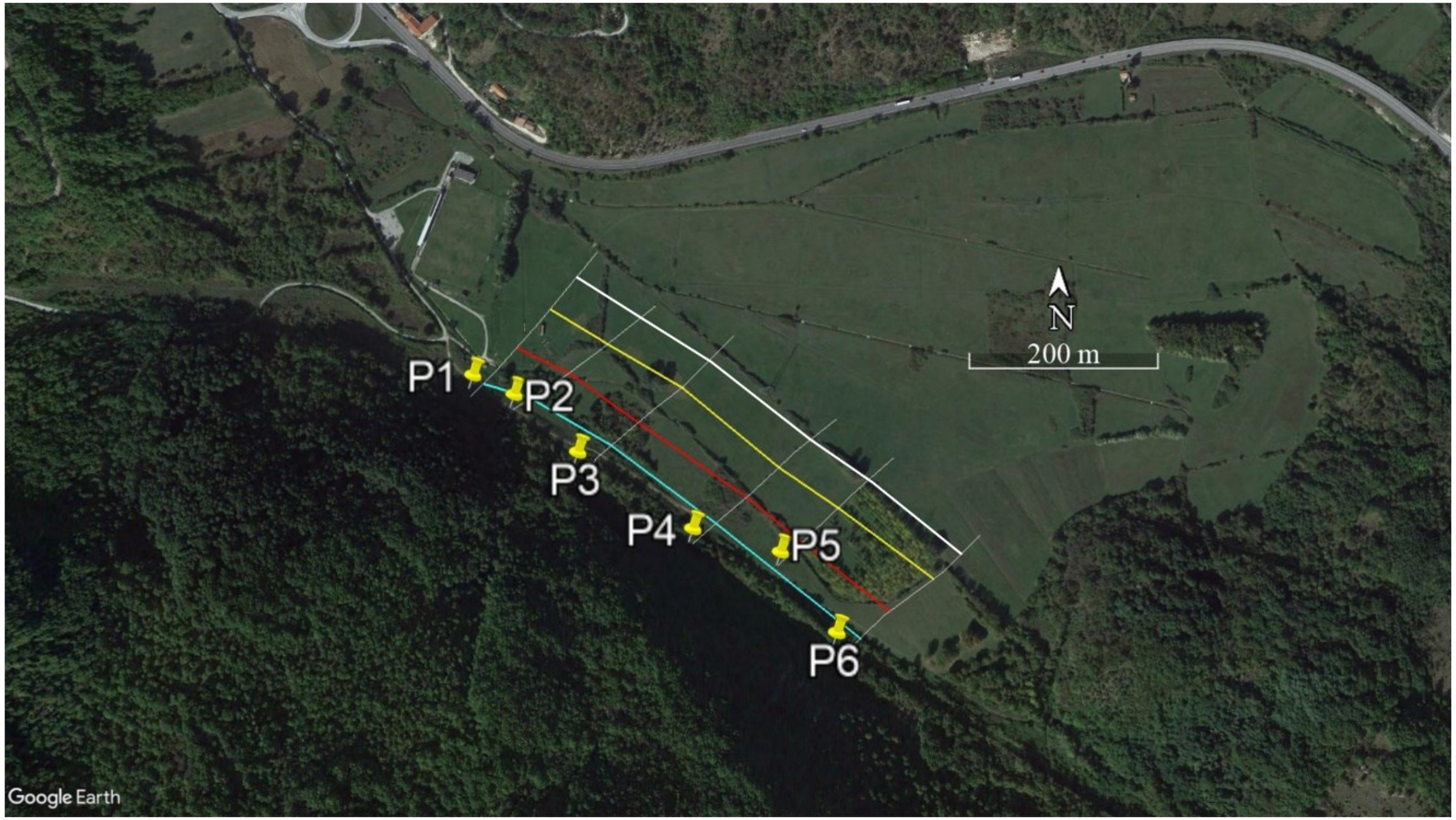
RESULTS

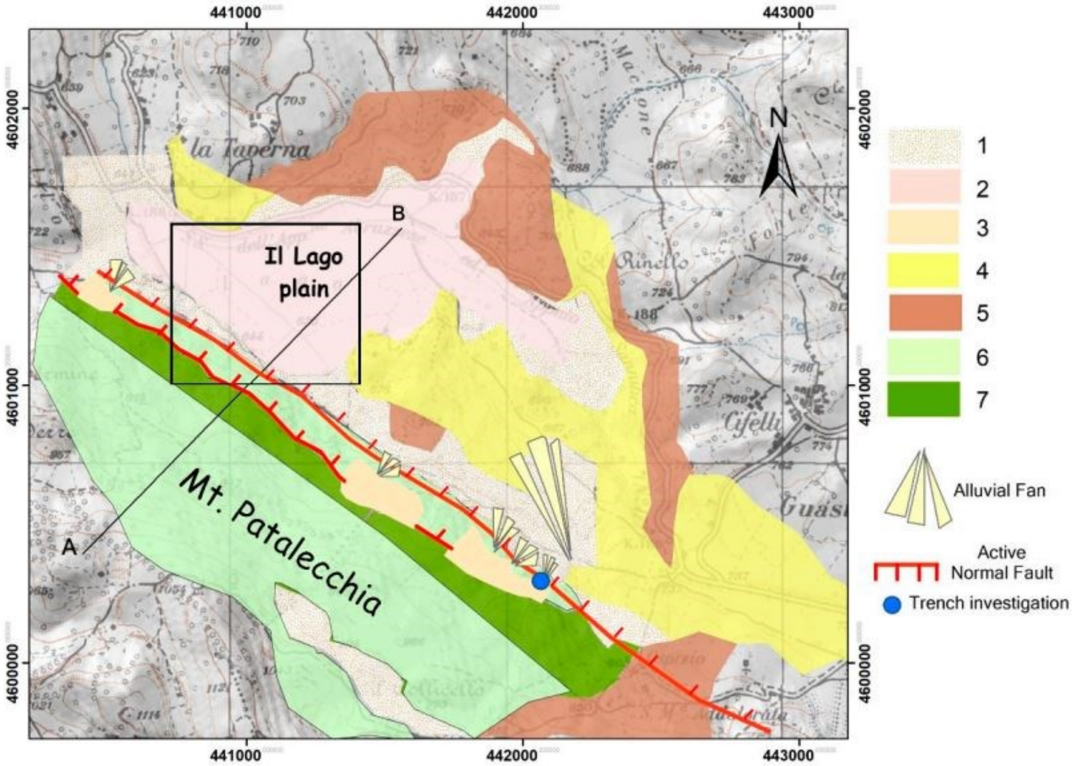
- The GPR and seismic refraction data highlighted the spatial continuity of the two buried fault systems along the southwestern side of the "Il Lago Plain" for a length of about 0.5 km.



Synthetic faults

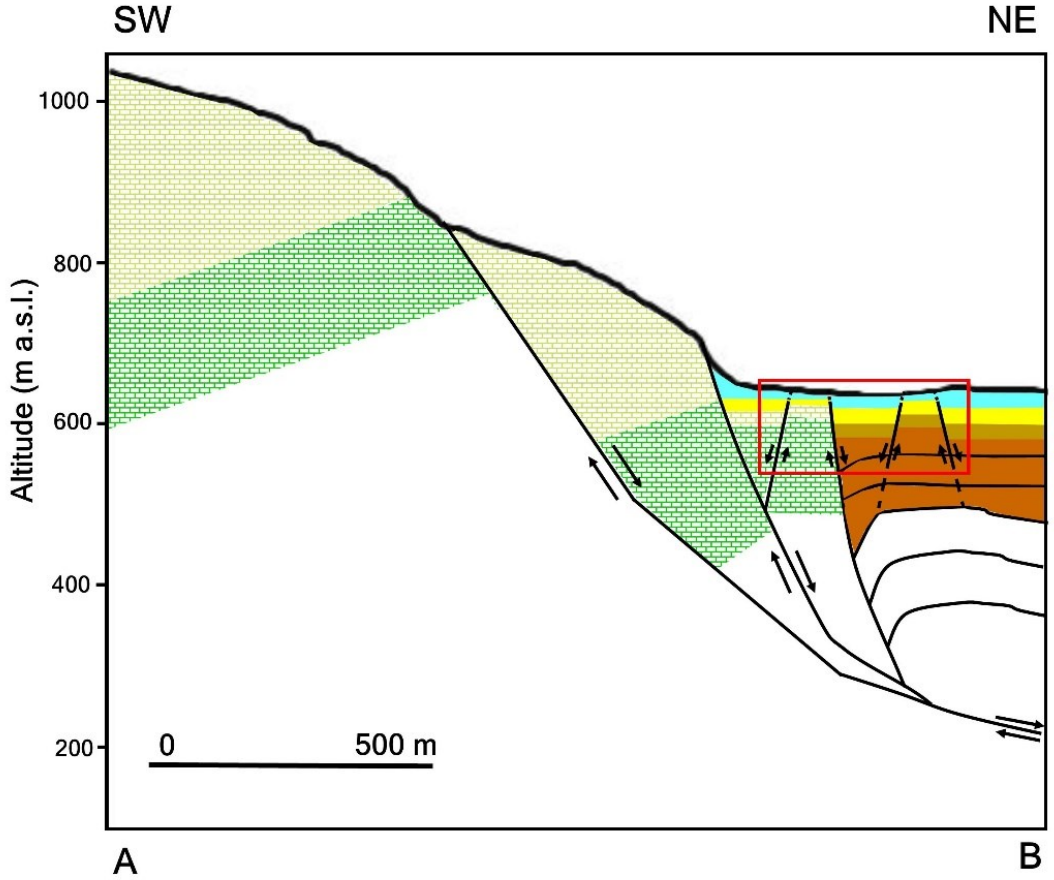
Antithetic faults

RESULTS



Geological sketch map of the investigated area:

1) colluvial and slope debris deposits;
2) lacustrine deposits;
3) cemented limestone breccias;
4) gray calcilutites;
5) marly limestone and marls
6) calcarenites and cherty limeScheme
7) Mesozoic limestone succession



Geological cross section along AB

CONCLUSIONS

- This study allowed us observing the optimal potential of combined seismic and GPR surveys for investigating buried faults at depth of tens of meters (60 m).
- Loza GPR system and seismic refraction allowed us obtaining the information related to the spatial continuity of the two buried fault system.
- However, the GPR resolution not allowed identifying the four fault systems, so it is advisable the integration with other geophysics systems such as Electrical Resistivity Tomography
- This procedure can be applied to young structures that, despite their probable seismogenic potential, have not yet developed mature geomorphic features or are buried under thick sequences of recent deposits.
- The results suggest that the application of these geophysical techniques may allow a quick fault-detection for an accurate choice of paleoseismological trench sites.

Reference: Nappi R, et al. Joint Interpretation of Geophysical Results and Geological Observations for Detecting Buried Active Faults: The Case of the “Il Lago” Plain (Pettoranello del Molise, Italy). *Remote Sensing*. 2021; 13(8):1555.

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