GEO MORPHOMETRY
PERUGIA ITALY
2025
JUNE 9-13

Coupling UAV-derived Lidar and geophysical data for the reconstruction of high-resolution 3D model of active faults: an example from the Piano di Pecore intramontane basin (Mt. Marzano, southern Italy)

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Abstract— **We explore the integration of UAV-derived LIDAR DTM and multiple geophysical data to derive a 3D model of an area (e.g., the Piano di Pecore intramontane basin) affected by the co-seismic rupture during the M 6.9, 1980 Irpinia earthquake. Surface expression of late Quaternary faulting was reconstructed by interpreting an ultrahigh-resolution LIDAR-derived 3D model whereas seismic prospections (i.e. MASW; ESAC and HVSR) allowed us to define the thickness of the basin infill and to reveal a complex architecture of the fault zone. Our approach can represent an effective workflow in modern morphotectonic studies and can be able to reconstruct surface and subsurface features of tectonically active landscapes.**

I. INTRODUCTION

Reconstruction of the surface and subsurface expression of active faults is a crucial step for many derivatives of seismotectonic studies, including the assessment of the seismic hazard and the definition of the magnitude and recurrence time of the stronger earthquakes [1, 2]. In the seismogenic belt of the southern Apennines, geomorphic evidence of Holocene faulting is frequently obliterated by erosion processes, deposition of colluvial slope deposits and human activity. The low degree of conservation of co-seismic fault ruptures and/or their subtle topographic expression mislead to contrasting and debated structural models for active faulting of the southern Apennines [3-6]. Therefore, there is a growing interest in developing new methodologies and procedures to define the detailed geometry of active fault segments. Useful to this topic are high-resolution (less than 1 m of horizontal resolution) digital terrain models and geophysical analyses. The former may reveal the surface evidence of active faulting while the latter may constrain the subsurface geometry of these structures, although an in-depth integration between these techniques is lacking. Moreover, emerging but limited applied techniques such as Unmanned Aerial Vehicle (UAV)-derived LIDAR can be an effective approach to derive high-resolution DTMs of tectonically areas, even when vegetated. In this work, we explore the integration of UAV-derived LIDAR DTM and seismic prospections with the goal of building a 3D model of the area affected by co-seismic rupture during the M 6.9, 1980 Irpinia earthquake (e.g., the Piano di Pecore intramontane basin, [7-8]).

II. STUDY AREA

The study area is the Piano di Pecore intramontane basin (Fig. 1), a small tectonic depression located in the north-western sector of the Marzano Mt. The latter is a carbonate massif located in the axial belt of the Southern Apennines. This area has been struck by normal faulting-related moderate to high magnitude earthquakes [9], the last of which was the destructive M 6.9, 23 November 1980 Irpinia earthquake [8]. Related to the 1980 earthquake is the formation of 50 to 70 cm high co-seismic fault scarps both in the core of the Mt. Marzano and in the adjoining San Gregorio Magno basin [5, 6].

In the Mt. Marzano area, the trace of the co-seismic fault scarp crosses the Piano di Pecore basin in its southwestern sector. Available 2D P-wave seismic analysis, Electrical Resistivity Tomography (ERT) and Horizontal to Vertical Spectral Ratio Analysis (HVSR) measurements indicate a maximum thickness of ca. 40 m of the late Quaternary filling of the basin [5, 6, 10]. These analyses provide a detailed subsurface reconstruction along a single profile trace, but a reconstruction of the 3D subsurface geometry of the entire Piano di Pecore basin has not been carried out up to now. Moreover, geochemical analyses on gas emissions reveal a complex subsurface setting of the Piano di Pecore basin, whit the occurrence of small E-W trending fault strands in the southern and northern sectors of the basin [11].

III. METHODS

Our approach includes the integration of traditional and consolidated tools of morphotectonic analysis (i.e., fieldwork and geomorphological analysis of detailed scale topographic maps) with high-resolution point cloud from LIDAR UAV survey and geophysical prospections. Quantitative geomorphic analysis of LIDAR-derived 3D model adopts common techniques of geomorphological photointerpretation and visual inspection of DEM derivatives for the delineation of active fault traces (Fig. 2).

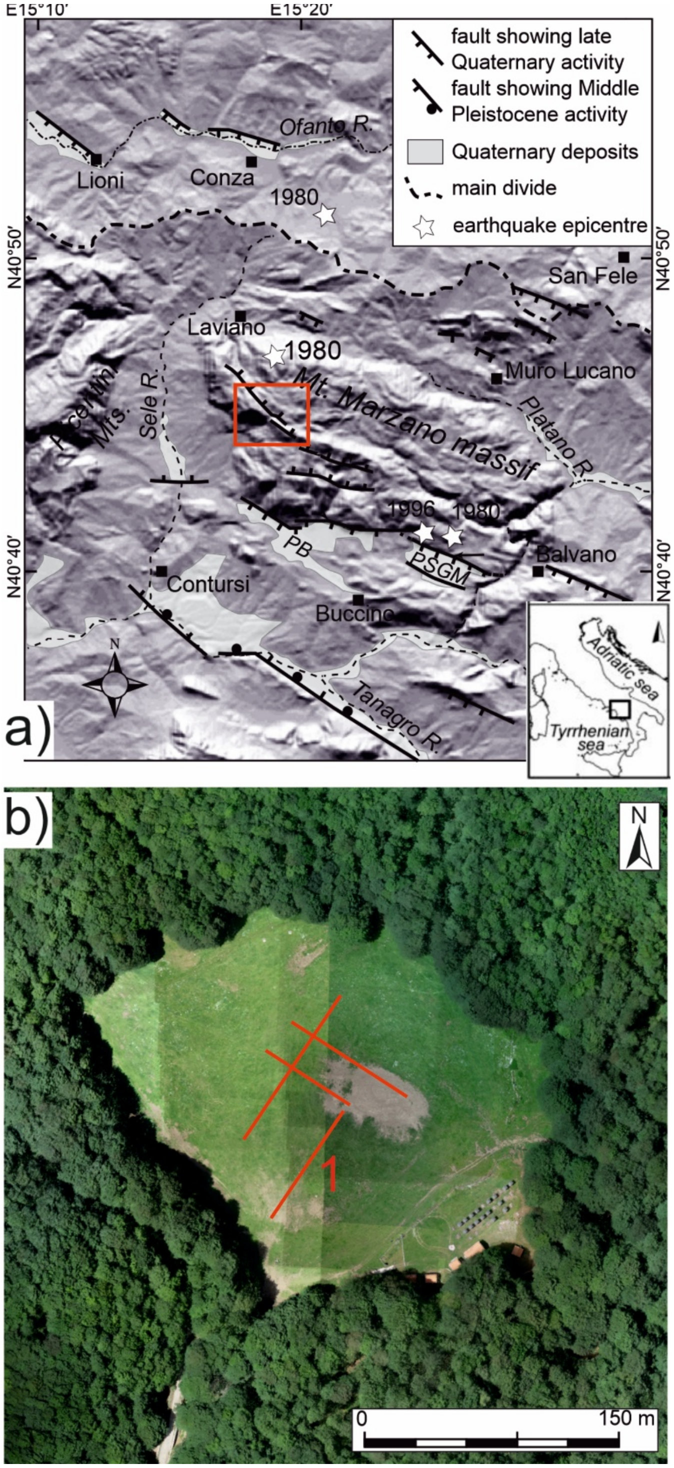

Figure 1. a) Hillshade of the Marzano Mt area showing the main Quaternary faults. The red box portrays the study area (mod. after [7]). b) Orthophoto derived by UAV survey showing the traces of the seismic prospections.

Lidar data acquisition was carried out using a DJI Matrice 300 equipped with the Zenmuse L1 Lidar sensor. The study area is about 66 ha, the point cloud acquired is approximately 440 million points. The point cloud obtained was processed by CloudCompare software. The workflow followed several steps: i) filtering the cloud from vegetation; ii) applying the kriging interpolator on the point cloud to obtain more robust data; iii) identifying the surface break trace and generating the topographic profile.

Geophysical prospections consist of active and passive seismic data (Fig. 3). More specifically, seismic dataset includes multi-component surface-wave analysis (single-offset MASW), ESAC and HVSR along key sectors of the basin. The integration between the different seismic survey methods provided robust information at different depths. ESAC and MASW have been used for the delineation of the shallower layers whereas HVSR furnished information at a depth higher than the thickness of the basin infill. 3D model of the surface and subsurface features of the study area provides new constraints on the morphotectonic framework of the tectonic basin.

IV. PRELIMINARY RESULTS

Here, we present some preliminary results regarding both the geomorphic and the geophysical (HVSR and ESAC data) investigations.

3D LIDAR-derived model allowed us to delineate the trace of the scarp as well as its height, orientation and slope. The trace of the different segments of the fault scarp can be delineated across the dense-vegetated carbonate slope crossing the Piano di Pecore endorheic basin. The scarp exhibits a clear geomorphic expression, which can be preliminarily ascribed to the co-seismic ruptures of the Irpinia earthquake.

Figure 2 shows the UAV derived DSM with a horizontal resolution of 5 centimeters (Figure 2a) and the derived slope map (Figure 2b). The DSM enhanced the occurrence of a low elevation area in the core of the Piano di Pecore basin. The lowest altitude area is roughly N-S oriented and is interrupted by a NW-SE scarp that is the co-seismic scarp of the 1980 Irpinia earthquake. The scarp is also recognizable in the slope map despite the diffuse presence of a sparse vegetation that causes local increments in the slope values. Improvement of the terrain model will be the next step of the research. Furthermore, high slope values in the southern portion of the Piano di Pecore basin are aligned along a NW-SE trend that mirrors the co-seismic scarp. The scarp is also highlighted through a topographic profile (Figure 2c) which enhances the ca. 35 cm high scarp.

Geophysical prospections provide additional information on the subsurface features of the Piano di Pecore endorheic basin, highlighting a high degree of structural complexity of the basin. For example, HVSR curves (Fig. 3a) show a maximum at a relatively high frequency which can be correlated to a strong surficial discontinuity in the Vs profile.

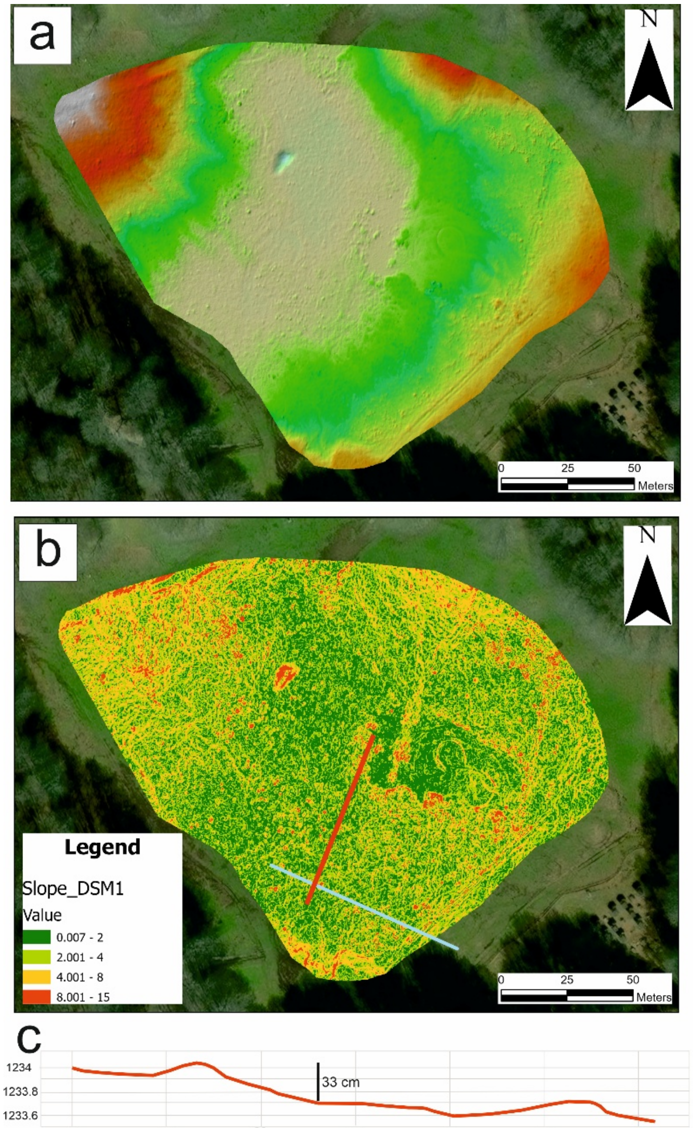

Figure 2. a) UAV derived DSM of the Piano di Pecore basin; b) slope map of the Piano di Pecore basin; c) topographic profile across the 1980 Irpinia earthquake co-seismic scarp. Blue line in maps a and b is the co-seismic scarp trace. Red line in map b is the trace of the topographic profile in figure c.

The 2D-section of the Vs derived by the ESAC array (Fig. 3b) also highlights a complex alternation of subvertical zones with a high discontinuity of the Vs velocity, which can be interpreted as due to the presence of different fault segments. HVSR and ESAC data clearly depicted a strong Vs contrast, which can be correlated to the abrupt discontinuity between unconsolidated basin deposits and carbonate bedrock. Such discontinuity can be roughly observed at a depth of about 10-15 m in the south-west sector of the seismic line (Fig. 3b). The main peak in the H/V curves tends to move towards lower frequencies from lower inline values to higher ones (red tones in Fig. 3a).

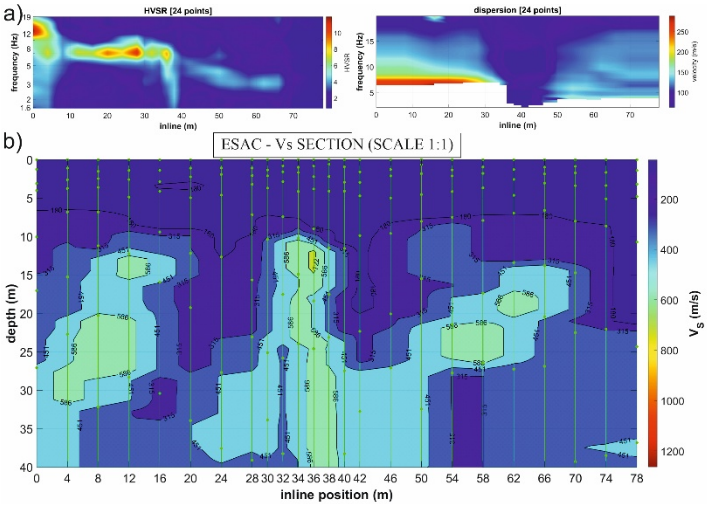

Figure 3. Main results of the passive seismic data (location in Fig. 1, trace 1: a) 2D section derived by the inversion of the HVSR (to the left) and ESAC dispersion curves (to the right); b) 2D-section of the Vs derived by the joint inversion of ESAC and HVSR data.

This pattern suggests a northward deepening of the bedrock depth, which should amount to about 35 m in the depocentral zone of the basin.

V. CONCLUDING REMARKS

In summary, the integration between morphometric analysis of LiDAR-derived data and geophysical prospections can represent an effective approach for the surface and subsurface characterization of areas with a high degree of geological complexity. Our data can support the reconstruction of the spatial distribution of fault scarps and the definition of the relationships among surface ruptures, fault zone geometry and basin infill.

VI. ACKNOWLEGMENTS

This work benefited from the support and discussion of the members of the AIGeo (Associazione Italiana di Geografia Fisica e Gemorfologia) Working Group of ‘SIStemi e TECnologie integrati per l'analisi morfoTettonica’ (SISTECT).

REFERENCES

1. Maurya, D.M., et al., *Mapping the near-surface trace of the seismically active Kachchh Mainland Fault and its lateral extension in the blind zone, Western India.* Near Surface Geophysics, 2022. **20**(5): p. 544-566.
2. Hinsch, R., K. Decker, and M. Wagreich, *3-D mapping of segmented active faults in the southern Vienna Basin.* Quaternary Science Reviews, 2005. **24**(3-4 SPEC. ISS.): p. 321-336.
3. Schiattarella, M., S.I. Giano, and D. Gioia, *Long-term geomorphological evolution of the axial zone of the Campania-Lucania Apennine, southern Italy: A review.* Geologica Carpathica, 2017. **68**(1): p. 57-67.
4. Ascione, A. and A. Cinque, *Fault scarps in the southern apennines: Origin, age and tectonic significance.* Alpine and Mediterranean Quaternary, 1997. **10**(2): p. 285-291.
5. Ascione, A., et al., *Late Quaternary faulting within the Southern Apennines seismic belt: New data from Mt. Marzano area (Southern Italy).* Quaternary International, 2003. **101-102**(1): p. 27-41.
6. Galli, P. and E. Peronace, *New paleoseismic data from the Irpinia Fault. A different seismogenic perspective for southern Apennines (Italy).* Earth-Science Reviews, 2014. **136**: p. 175-201.
7. Ascione, A., et al., *A decoupled kinematic model for active normal faults: Insights from the 1980, ms = 6.9 irpinia earthquake, southern italy.* Bulletin of the Geological Society of America, 2013. **125**(7-8): p. 1239-1259.
8. Pantosti, D., D.P. Schwartz, and G. Valensise, *Paleoseismology along the 1980 surface rupture of the irpinia fault: Implications for earthquake recurrence in the southern apennines, Italy.* Journal of Geophysical Research: Solid Earth, 1993. **98**(B4): p. 6561-6577.
9. Rovida, A., et al., *The Italian earthquake catalogue CPTI15.* Bulletin of Earthquake Engineering, 2020. **18**(7): p. 2953-2984.
10. Galli, P.A.C., et al., *Integrated near surface geophysics across the active Mount Marzano Fault System (southern Italy): seismogenic hints.* International Journal of Earth Sciences, 2013. **103**(1): p. 315-325.
11. Ciotoli, G., et al., *Soil gas distribution in the main coseismic surface rupture zone of the 1980, Ms = 6.9, Irpinia earthquake (southern Italy).* Journal of Geophysical Research: Solid Earth, 2014. **119**(3): p. 2440-2461.