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Shallow subsurface imaging of the Piano di Pezza active normal fault (central Italy) using high-resolution refraction and electrical resistivity tomography coupled with time-domain electromagnetic data

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Abstract: *The Piano di Pezza fault (PPF) is the north-westernmost segment of the >20 km long Ovindoli-Pezza active normal fault-system (central Italy). Although existing paleoseismic data document high vertical Holocene slip rates (~1 mm/yr) and a remarkable seismogenic potential of this fault, its subsurface setting and Pleistocene cumulative displacement are still unknown. We investigated the shallow subsurface of a key section of the PPF using seismic and electrical resistivity tomography coupled with time-domain electromagnetic measurements (TDEM). We provide 2-D Vp and resistivity images showing details of the fault structure and the geometry of the shallow basin infill down to 35-40 m depth. We can estimate the dip and the Holocene vertical displacement of the master fault. TDEM measurements in the fault hangingwall indicate that the pre-Quaternary carbonate basement may be found at ~90-100 m depth.*

Key words: *Central Apennines, refraction tomography, electrical resistivity tomography, time-domain electromagnetic measurement, active fault.*

INTRODUCTION

The inner sector of the central Apennines of Italy is characterized by a complex network of Pliocene-Quaternary normal faults (Cavinato & de Celles, 1999; Ghisetti & Vezzani, 1999) that originated several intramontane continental basins (Bosi et al., 2003; Giaccio et al., 2012; Pucci et al., 2014). Under the current NE-directed extensional stress regime, the high crustal seismicity rate is mainly released by normal-faulting earthquakes (Chiarabba et al., 2005; Chiaraluce, 2012 and references). Paleoseismic analyses have unravelled the late Holocene slip-history of many active normal faults in this sector of the chain (Galli et al., 2008 and reference therein; Cinti et al., 2011). Notwithstanding the wealth of geological data constraining the recent evolution of most normal faults, only in few cases detailed subsurface information is available to provide a proper structural model of the basins they originated. Shallow geophysical investigation of active faults may extend the limited investigation depth typical of paleoseismic trenching, moreover it can yield valuable information on long-term fault displacement and unravel minor structures (e.g.: Villani et al., 2014).

Figure 1: geological sketch of the Piano di Pezza basin. The blue lines indicate normal faults, the red lines thrusts.

As a case-study, we selected the Piano di Pezza fault (hereinafter PPF, Figure 1). The PPF is the north-westernmost segment of the >20 km long active Ovindoli-Pezza normal fault system, and according to paleoseismic data it exhibits one of the highest Holocene vertical slip rates in the Apennines (~1 mm/yr; Pantosti et al., 1996), with large inferred vertical displacement per event (> 2 m). This fault bounds to the north a 5 km long continental basin (Piano di Pezza; Figure 1) filled with glacial, lacustrine and fluvial deposits, and its footwall exposes Mesozoic-Tertiary marine limestones. The subsurface structure and infilling thickness of this basin are unknown, nor the shallow geometry of the bounding fault is well constrained.

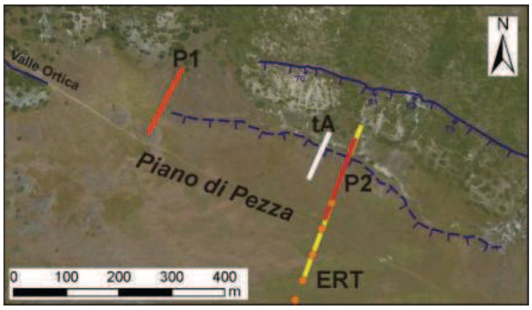

Figure 2: close up view of the survey area showing seismic, electrical resitivity profiles and TDEM measure points (orange); the PPF exhibits two splays: we investigated the shallow subsurface of the lower one, where it displaces late Holocene alluvial fans; tA is trench A after Pantosti et al., 1996.

With the aim of extending information from previous paleoseismic analyses and very shallow GPR investigations (Jewell & Bristow, 2006), we performed an integrated geophysical survey focusing a key section of the PPF (Figure 2). We acquired 2 high-resolution seismic profiles, 1 electrical resistivity profile and 7 time-domain electromagnetic soundings (TDEM) crossing the fault where it displaces some small late Holocene alluvial fans, originating a ~5 m high fault scarp.
We try to infer the subsurface fault geometry and recover the depth of the pre-Quaternary basement.

METHODS AND DATA ACQUISITION

Traveltime tomography proved successful in imaging complex media, such as fault zones (Morey & Schuster, 1999; Sheley et al., 2003), so we conceived our seismic investigations to get tomographic images of the Piano di Pezza fault at depth. The 2 seismic profiles (named P1 and P2) are 142 m long each, and they were acquired using a 72 vertical geophones array (40 Hz eigenfrequency) with 2 m spacing and a sledgehammer as energy source. We handpicked ~20,000 first-arrival traveltimes that were input to a non-linear tomographic code to produce 2-D Vp models of the shallow subsurface (details of the method in: Improta et al., 2002).
Electrical resistivity tomography (ERT) is a powerful tool to investigate shallow faults and complex structures as well (Griffits & Barker, 1993; Storz et al., 2000). We acquired 1 ERT profile paralleling seismic line P2. We deployed a 64 electrodes and 315 m long array with both Wenner-Schlumberger and dipole-dipole configurations of quadrupoles. The apparent resistivity data were inverted through a linearized least-squares algorithm to obtain true resistivity sections (Constable *et al.* 1987; Loke & Dahlin 2002).

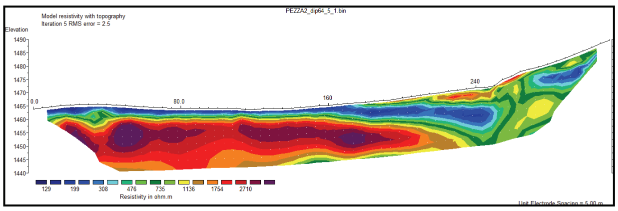

Figure 3: shallow electrical resistivity model across the Piano di Pezza fault.

In order to infer the pre-Quaternary basement depth in the hangingwall of the PPF, we also performed 5 time domain electromagnetic measurements (TDEM). The method is based on the induction of a time-varying secondary magnetic field produced by decay current in the ground. This secondary magnetic field is measured by an induction receiver coil generally placed inside of a transmitter loop. As the current diffuses deeper into the ground (at later time), the signal measurements provide information on the conductivity of the lower layers. Our data were collected using a high frequency 1D receiver coil, placed at the centre and outside a transmitter square loop of 50 m size. We acquired very early time gates data starting from ~ 9 µs (after current turn off) up to 800 µs using a Geonics 47 transmitter. Random electromagnetic noise were also collected and checked against measured voltage data in order to discharge biased late time gates before data inversion. Data from field measurements were processed and inverted using SiTYEM\SEMDI software in order to obtain 1D resistivity models of the subsoil (Hydrogeophysics-Group, 2001)

PRELIMINARY RESULTS AND DISCUSSION

We show some preliminary results of our integrated geophysical surveys. The ERT model (Figure 3) with dipole-dipole configuration across the fault scarp clearly depicts the ~50° SW-dipping fault zone involving alluvial fan deposits with resistivity <500 Ωm and their concurrent thickening in the hangingwall. Moreover, the top-surface of the underlying high-resistivity body (>1000 Ωm) shows an evident dip towards the fault, suggesting back-tilting due to fault activity. We interpret the shallower layers as Holocene alluvial fan gravelly and sandy deposits (recovered in the trenches by Pantosti et al., 1996) laying over a > 20 thick Last Glacial Maximum till (~21-18 ka; Cassoli et al., 1986; Giraudi, 1989). Vp tomograms suggest this alluvial fan is affected by > 10 m vertical displacement (Figure 4). They also help defining the fault-zone down to 35-40 m depth suggesting it has a ~50° dip.

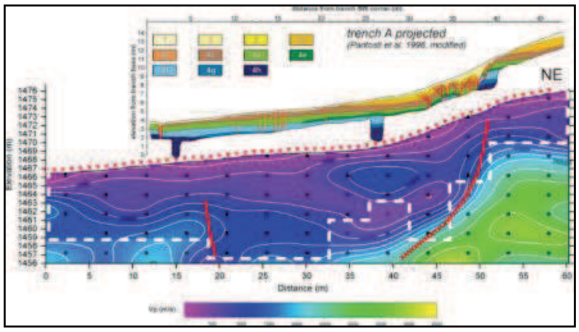

Figure 4: detail of the Vp tomogram of seismic line P2 across the PPF compared with trench A (after Pantosti et al., 1996).

TDEM data inversion yielded 1-D vertical resistivity models (Fig. 5): they indicate that ~200 m far from the surface fault trace the pre-Quaternary carbonate basement is 90-100 m deep, thus giving a robust constraint to the evaluation of the cumulative offset of the PPF (~150 m). Moreover, for the uppermost part of the subsoil, TDEM and ERT model significantly agree in terms of depth and thicknesses of the shallower resistivity layers.

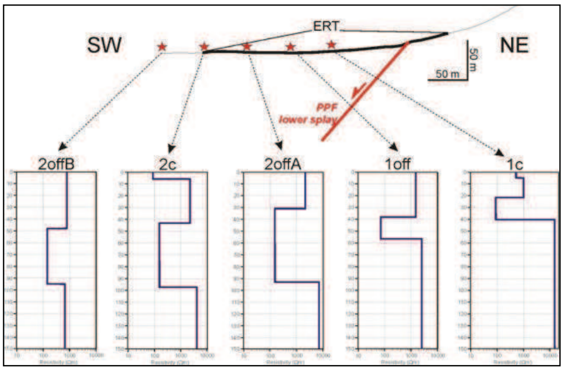

Figure 5: 1-D resistivity models obtained through inversion of TDEM data (position of soundings along the ERT profile is idicated by red stars). A deep resistive layer (>5000 Ωm), interpreted as the carbonate basement, is evidenced at 90-100 m depth (beneath soundings 2offB, 2c and 2offA) in the hangingwall of the PPF. Data from soundings 1off and 1c are less reliable in the deeper part due to strong 3D effects.

Our geophysical data yield for the first time valuable information on the subsurface setting of an important active normal fault exhibiting one of the highest Holocene slip rates in the central Apennines. These data are crucial to understand the middle- to long-term behaviour of this fault, its overall displacement and possibly its inception age.

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