EVIDENCE OF ROMAN EARTHQUAKE SURFACE FAULTING AT SANTA VENERA AL POZZO (CATANIA, SOUTHERN ITALY): A PROBABLE SEISMIC EVENT IN 251 AD?

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Introduction. The record of historical seismicity of Catania and its neighbourhood during the first millennium AD is largely incomplete due to the scarcity of sources reporting information on earthquake damage. Although numerous historical sources provide plentiful description of past Etnean eruptions affecting the Catania area, only a vague picture of the local seismicity is available for ancient times. This study provides new insights on seismic history of Catania, which was struck by large earthquakes during its recent history (i.e. 1542, 1693, and 1818 earthquakes). During the first millennium, the only documented earthquake occurred in 251 AD, a year before of the big Etna eruption of 252 AD (Guidoboni et al., 2014). This earthquake left well-visible traces in the archaeological site of Santa Venera al Pozzo (Catania), which was continuously inhabited since 3000 BC, due to the presence of sulphur warm water springs. The buildings uncovered by archaeologists are a podium of a Roman temple; a thermal bath provided with five different pools at least; a Roman rural Villa; and a church of Byzantine age. The site is located on the eastern flank of Mt. Etna volcano, where seismic activity has often caused significant damage, even though localized, especially when associated with remarkable flank eruptions. Evidence of Roman age faulting has been observed in the archaeological site, which is clearly affected by a set of sharp fractures generating an overall ~ 4 m wide fracture zone. The main fracture extends for about 40 m with a ~N-S direction, offsetting the foundations of a podium, some pools and minor walls. It shows an extensional displacement of up to 5-8 cm and a right-lateral component with an offset of up to 4 cm. Fracture zones related to normal faults are quite common in the lower eastern flank of Mt. Etna (Azzaro et al., 2012). Some of these structures are also characterized by anomalous diffuse CO2 emissions from the soil (Giammanco and Bonfanti, 2009). The archaeological site is placed in proximity of one of
these tectonic lineaments (Fig. 1), belonging to the NNW oriented normal fault system called the “Timpe” system. The finding of this earthquake damage and its time constraints represents the starting point for archaeoseismological research in the Etnean area.

**Geological framework.** Geological, seismological and geophysical evidence indicate that the lower eastern flank of Mt. Etna is affected by a slow but continuous fault-controlled seawards extension, with prevailing ESE-WNW direction, interpreted as due to flank instability. This sector is basically confined within two ~E-W oriented boundaries (Fig. 1). Geodetic measurements over the last decades suggest a short-term deformation rate of some cm/yr, reaching even faster peaks in some restricted places or periods, sometimes in association with eruptive episodes (Alparone et al., 2013). This unstable area is dismembered into different blocks characterized by homogenous kinematics and bordered by tectonic lineaments where abrupt changes in the ground velocity field have been marked (Bonforte et al., 2011). The most important of these lineaments is arranged to form a system of several parallel fault segments, mostly dipping eastward, reaching lengths up to 5-8 km and forming tens of meters fault scarps (called Timpe system). The archaeological site of Santa Venera al Pozzo lies just to the north of one of above mentioned fault segment (Fig. 1), which offsets, with a N-S direction, some volcanic products of an ancient phase of Mt. Etna, dated at ~120 ky (Branca et al., 2011a).
The fault segments located in the lower eastern flank of Mt. Etna, have been responsible, both in historical and recent times, for earthquakes with magnitude up to 4.5 (Azzaro et al., 2004; De Guidi et al., 2012). Because of the shallow foci depth (<2–3 km), earthquakes have often caused significant damage, even though localized, especially when associated with remarkable flank eruptions. Some examples are the Santa Venerina earthquake connected with the 2002 eruption, the 1865 earthquake that occurred at the end of a large flank eruption, and the seismic activity associated with the 252 AD eruption (Guidoboni et al., 2014).

Field data. Geophysical investigation. A multi-techniques geophysical survey was carried out at Santa Venera al Pozzo, in order to investigate a deeper portion of the subsoil and to verify the presence of a fault zone. The survey consisted of seismic refraction tomography (SRT), electrical resistivity tomography (ERT), ground-penetrating radar (GPR), and a magnetic survey in addition to remote sensing applications using unmanned aerial vehicles (UAVs), which provided new data for ultra-high resolution mapping.

As suggested by the surficial evidence of displaced archaeological structures, the inferred fault should be oriented N-S. For this reason, we mainly performed the geophysical investigations along a 90 m long profile, directed almost perpendicular to the presumed fault (Fig. 2).

The SRT reveals a reliable P-wave velocity model down to a depth of ~ 20 m. Seismic velocities ranged from about 400 m/s to about 2900 m/s (Fig. 3a). A portion characterized by
Fig. 3 - a SRT; b 2D ERT; c GPR profile; d Magnetic sampling line along the AA’ profile shows the comparison between observed and calculated data and the related magnetic susceptibility model.
low P-velocity is recognizable from 30 to 50 m depth along the profile, which was interpreted as fractured material confined within two more compact blocks (dashed black line).

Two ERT profiles were also performed, the first one is a 2D ERT profile acquired along the road that runs from west to east, whereas the second one is a quasi-3D ERT profile.

The 2D ERT profile shows a generalized low resistivity of the terrain \((10^1 < \rho < 10^2 \, \Omega m)\). This would find correspondence with the stratigraphy of the area characterized by a marine silty-clayey deposit below a thin layer of weathered volcaniclastic rocks, as revealed by some geognostic boreholes (Ferrara, 2010). At about 5 m depth, the portion between 30 and 50 m, is characterized by the lowest resistivity values (black-dashed line in Fig. 3b, which encloses a zone with \(\rho < 5 \, \Omega m\), blue circle) and it can be interpreted as a layer of water-saturated material.

The GPR profile shows some truncations and offsets of the reflections, interpreted as fractures along a fault plane. A change in the electromagnetic facies is recognizable between the progressive distances of 35 and 50 m (the yellow area in Fig. 3c). This was interpreted as a physical separation between the western and eastern zones, characterized both by high reflectivity and by high absorption of the electromagnetic signal. Furthermore, the electromagnetic facies in the westernmost part of the radargram can be correlated with the shallow zone having higher velocity in the SRT (Fig. 3c), where the anomalies found are likely associated with buried structures.

The magnetic survey revealed two main bipolar anomalies: a smaller one, about 10 m wide, with amplitude of about 60 nT, and a larger one (40–45 m wide) with amplitude of about 570 nT (Fig. 3 d). The first one is probably due to a buried pipe, while the second one is ascribable to a geological source.

**Geochemical investigation.** Soil CO\(_2\) effluxes were measured using the accumulation chamber method, which consists of measuring the rate of increase of CO\(_2\) concentration inside a cylindrical chamber open at its bottom and placed on the ground surface (Parkinson, 1981). The change in concentration during the initial measurement is proportional to the efflux of CO\(_2\) (Tonani and Miele, 1991).

Anomalous diffuse CO\(_2\) emissions at Mt. Etna are caused by deep magma degassing through tectonic lines at lithospheric and shallow levels. The spatial distribution of CO\(_2\) effluxes revealed three main areas of anomalies at the site. The first one, located to north, displays anomalies aligned with an existing fault line belonging to the Timpe system. The second area, located to south, seems correlated to a buried ~NE-SW oriented fault. Finally, the third area, located in the central part, shows anomalies of lower intensity than the previous, and are scattered over a larger surface, around the emission points of slightly thermalized sulphurous waters. In this case, soil gas anomalies may represent degassing of deep CO\(_2\) exsolved from a thermal aquifer along its underground path.

Continuous monitoring of bubbling gases emitted in a thermal well have been performed in order to better identify the components of hydrothermal system and to assess variations in chemical composition in the short period. Cromatography Monitoring Station (CMS) offers a high frequency of automatic gas analysis (our gap was 30’) allowing to identify two anomalous degassing. At the end of January, the chemical composition changed drastically with detectable concentration of H\(_2\)S and ethane associated with very high concentration of CH\(_4\) (70%) without sensible variations of CO\(_2\). The correlation among CH\(_4\) and H\(_2\)S and ethane suggest that the hydrothermal end member (methane dominant) has a mix with a superficially component more rich in CO\(_2\).

Finally, we measured the temperature of the thermal waters every 15’ by using a Tinytag datalogger. The data showed regular daily fluctuations and a seasonal trend. Instead, the hydrothermal fraction is mainly composed of low-enthalpy gases (CH\(_4\)) that do not affect significantly the water temperature; therefore, any future ascent of hot fluids would be immediately emphasized.

**Conclusions.** The integration of geophysical and geological data allowed the recognition and characterization of coseismic faulting affecting the archaeological site of Santa Venera al
Pozzo. In addition to the identification of a tectonic discontinuity, whose surface expression is the fracture zone offsetting the thermal bath of the site. Unfortunately, the investigation has not allowed imaging a clear fault plane at depth, but rather it highlighted a broad anomalous zone interpretable as a fault zone. This is ascribable to the shallow depth of geophysical investigation, to the lithology of outcropping rocks and to the circulation of fluids in the subsoil. The geochemical surveys suggest that the fault affecting the archaeological site could be still active and that the local hydrothermal system could record changes in the heat/gas flux coming from the magmatic system of Mt. Etna.

Geoarchaeological evidence suggests the occurrence of an earthquake that produced a displacement of man-made structures and destructive effects on the ancient Roman remains, possibly in the middle-end of the third-century AD. Time constraints are inferred through the dating of the different buildings phases and on archaeological findings. This event was conceivably a local earthquake with a severe impact on archaeological structures. Unfortunately, the extension of the fracture zone at the surface does not provide reliable information on earthquake magnitude. The lack of well-documented historical accounts of seismic activity does not help with the recognition of coseismic deformation elsewhere. Consequently, this event could be either associated to the volcano-tectonic earthquake of 251 AD preceding the 252 AD eruption (see Guidoboni et al., 2014), or alternatively to a local pure tectonic earthquake not mentioned in the Italian seismic catalogue.

References