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Evidence of surface faulting in the archaeological site of Santa Venera al Pozzo (Catania-Eastern Sicily): first results from geological and geophysical investigations

Carla Bottari[1], Patrizia Capizzi[2], Danilo Cavallaro[1], Mauro Coltelli[1], Antonino D'Alessandro[1], Luigi Lodato[1], Raffaele Martorana[2.1], Antonino Pisciotta[1], Salvatore Scudero[1]

[1] Istituto Nazionale di Geofisica e Vulcanologia (carla.bottari@ingv.it)
[2] Università degli Studi di Palermo, Dip. di Scienze della Terra e del Mare

***Abstract* – We present the first results of a preliminary geological and geophysical survey carried out in the archaeological site of Santa Venera al Pozzo (Catania, Italy). The site dates back to the Roman Age, (1st century BC). Geological surveys highlighted a set of remarkable fractures affecting some archeological remains, suggesting the occurrence of a capable fault zone through the area. Multidisciplinary geophysical surveys (seismic refraction and electrical resistivity tomographies, together with aerial photographic and thermographic survey) identified a main tectonic discontinuity ascribable to the fault zone, allowing us to infer that the fractures observed at surface could be the evidence of coseismic ruptures.**

I. INTRODUCTION

The archaeological site of Santa Venera al Pozzo is located along the lower eastern flank of Mt. Etna volcano in the municipality of Aci Catena (Sicily, Italy).The site dates back to the Roman period, two different buildings have been uncovered by archaeologists: a building interpreted as Roman temple, and a thermal bath. The first building was dated between 1st century BC and the 1st century AD, and it is relative to first site phase, whereas the bath belongs to the second site phase and it was dated between the 3rd and 4th century AD. In the archaeological area is also a church built on the ruins of ancient remains.

The Roman thermal bath, well known since Roman times, consists of a natural thermal spring with sulphur water. The presence of natural thermal spring is the most likely reason of this settlement.

The area is clearly affected by a set of sharp fractures generating a ~4 m wide fracture zone. The main fracture extends for about 40 m with a ~N-S direction, offsetting the foundations of a small Roman temple, a tank and some minor walls. It shows an extensional regime with a downthrown up to 5-8 cm and a right-lateral component with an offset up to 4 cm.

Normal faults and fracture zones are quite common in the lower eastern flank of Mt. Etna that is dissected by several active fault segments [1]. The archaeological site is placed in proximity of one of these tectonic lineaments (Fig. 1), belonging to the NNW to NNE oriented normal fault system called the "Timpe" system [2]. In order to achieve a more detailed image of the possible relationship between the presence of an unknown fault segment and the damaged historical buildings, we performed an integrated geophysical survey by means seismic refraction and electrical resistivity tomographies. We used a UAV (Unmanned Aerial Vehicle) to map adequately the investigated area and to locate properly geophysical survey. An aerial photogrammetric relief was carried out in order to obtain a detailed Digital Surface Model (DSM) of the archaeological site.

II. 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 in the order of some cm/yr, reaching even faster peaks in some restricted places or periods, sometimes in association with eruptive episodes [3, 4]. 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 [5]. The most important of these lineaments are arranged to form a system (called Timpe system) of several parallel fault segments, mostly dipping eastward, reaching lengths up to 5-8 km and forming tens of meters fault scarps. 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 [1].

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 [6]. Because of the shallow foci depth (<2–3 km), earthquakes have often caused significant damage, even though localized.

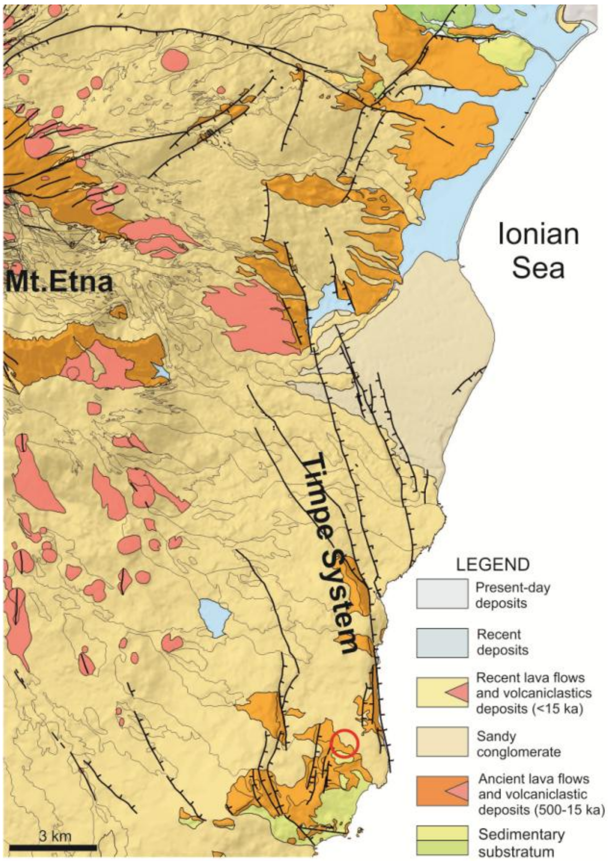

Fig. 1. Map of the eastern flank of Mt. Etna. The red circle indicates the study area.

III. MULTIDISCIPLINARY SURVEYS

In order to investigate the deeper portion of the subsoil subsoil of the archeological site of Santa Venera al Pozzo and verify the presence of the fault zone, a multidisciplinary geophysical survey has been carried out by means of Seismic Refraction Tomography (SRT) and Electrical Resistivity Tomography (ERT), together with aerial thermography and photogrammetric relief by UAV (Fig. 2).

Electrical resistivity tomographies have been carried out using the MAE X612-EM+resistivity meter. This multichannel instrument allows using contemporary 96 integrated electrodes and consequently high-speed measurements, if an optimized electrode sequence is used. The electrical resistivity tomography was performed following three main profiles (Fig. 2): two linear and a C-shaped one. Lines A-B and C-D were performed using 48 electrodes 2 meters spaced, while for the C-shaped profile 48 electrodes 1 m spaced were considered. We chose a combined sequence of symmetrical beta array set [7, 8] and multi-coverage multiple gradient set [8], for a total of more than 4000 measures for each tomography. We show the inverse model resistivity section for the A-B profile (Fig. 3). The results show a generalized low resistivity of the terrain (10^1 – 10^2 Ωm). In fact, below a thin layer of weathered volcaniclastic rocks, a sandy-clayey deposit related to the sedimentary substrate of the volcanic edifice occurs. The sub-horizontal marker (dashed line in Fig. 3) corresponds to the presumed horizontal limit between the volcaniclastic layer and the sedimentary substrate; it appears to be offset of about 4 m in correspondence of the fracture zone detected during the geological survey. At depth, this portion is characterized by the lowest resistivity values (blue spot in Fig. 3).

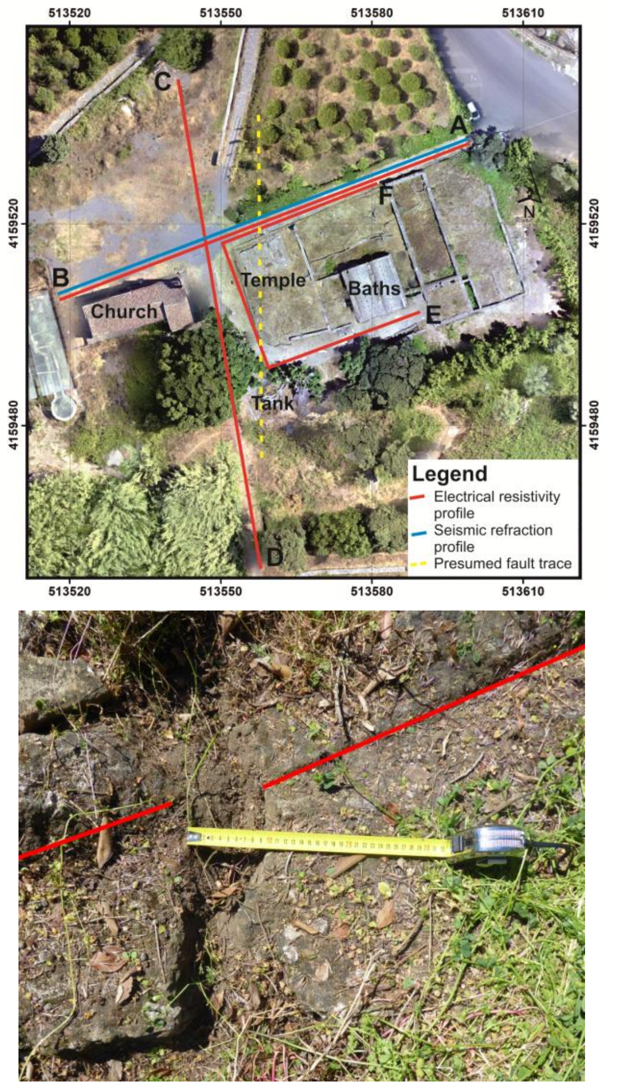

Fig. 2. Top: map of the investigated area; bottom: the offset floor of the tank.

A seismic refraction tomography has been carried out along the same line A-B. The seismic velocity ranges from about 400 to 2300 m/s (Fig. 4). The velocity model shows a similar arrangement with respect the electrical resistivity model, since in correspondence of the fracture zone, there is evidence of a ~4 m step with the lower side to the west.

Recent developments in the use of Unmanned Aerial Vehicles (UAVs) for remote sensing applications provide new opportunities for ultra-high resolution environmental mapping and monitoring. An aerial photographic and thermographic survey was performed in order to produce a high resolution DSM and a thermal map of the archaeological site, contributing to a reconstructive history of architectural structures. The system consists a lightweight (1.1 kg) UAV equipped with an on-board digital camera, GPS and autopilot system. We used a quadricopter Phantom 3 Dji, well-suited photogrammetry and mapping (Lens FOV 94° - 20 mm, Sony Sensor EXMOR 1/2.3", effective pixels resolution of 12.4 M). Moreover, the UAV was also equipped with a thermal imaging camera Optris PI 640, with an optical resolution of 640x480 pixels, the PI 640 delivers pin-sharp radiometric pictures and videos in real time with Frame rate of 32 Hz. Spectral range 7.5 - 13 µm, temperature ranges from –20 °C to 1500 °C and accuracy: ±2 °C. Data acquisition from the entire survey was accomplished by a combination of two missions in a uniform crossed grid pattern. The coverage of the entire area has been achieved by acquisition of 1714 frames for the visible spectrum and 60 for the thermal one. The locations of the selected geo-points were determined using a GPS NAVCOM SF-3040 with angular accuracy of 1 cm. The survey has been performed at an altitude of 30 m and a speed of 3 m/s. Photo overlap is user-set in the 75-85% range, allowing for high-quality photogrammetric image matching. A set of ground control points have been used for geo-referencing the Digital Model. The aerial photographs were processed into georeferenced orthoimages, a high-resolution DSM and DEM, using the photogrammetric

3D reconstruction technology software by AgiSoft PhotoScan [9]. The DSM generated has a ground

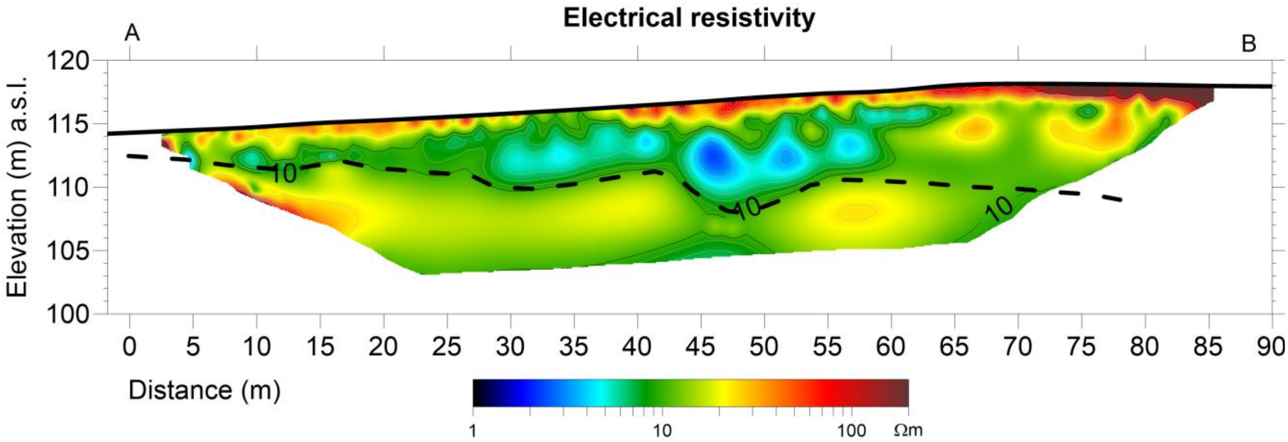

Fig. 3. Electrical resistivity section A-B

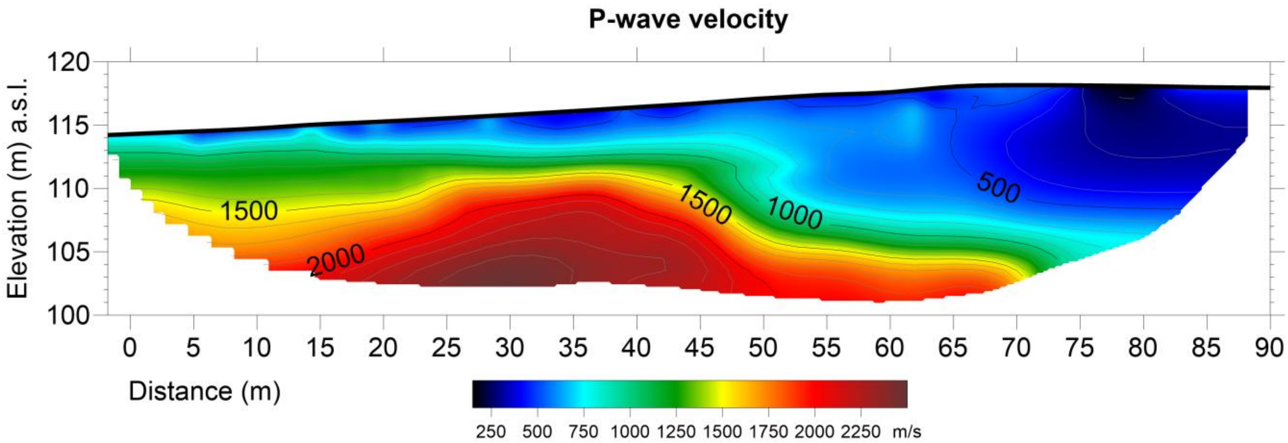

Fig. 4. Seismic tomography, section A-B.

resolution up to 4.0 cm. Advances in computer vision and image analysis are, however, generating innovative developments in photogrammetry through the technique of Structure-from-Motion (SfM), which offers an automated method for the production of high-resolution DSMs with standard cameras [10, 11, 12].

IV. DISCUSSION AND CONCLUSIONS

The multidisciplinary survey carried out in the archeological site of Santa Venera al Pozzo enabled to detect a remarkable lateral tectonic discontinuity (i. e. a fault), responsible of the fracture zone affecting some remains of the site. Considering the frequent episodes of surface faulting affecting the lower eastern flank of Mt. Etna [13], the fracture zone could be interpreted as an evidence of a coseismic rupture episode not correlated with previously mapped fault segments.

The extension of the fracture zone at surface does not provide reliable information on the size (i.e. magnitude) of the earthquake since i) the real extension of the rupture could be no longer visible, and ii) in the Mt. Etna area even moderate earthquakes ($M \leq 3$) that can cause remarkable displacement at surface [13, 14]. Therefore, trying to reconstruct the real extension of the fault through further geological and geophysical surveys, is essential to infer the seismic potential of the tectonic structure.

Similarly, deeper investigations will provide a temporal constrain to the rupture event. For this purpose, coupling appropriate archaeometric analysis with the performed high-resolution aerial photographic surveys, will contribute to a reconstructive history of the damaged architectural structures.

In conclusion, even if at this stage we are not able to hypothesize on the order of the size (magnitude) and on the time of the supposed earthquake, the results of this geophysical survey suggest that the knowledge on the faults' population on the eastern flank of Mt. Etna is probably not thorough, and therefore the seismic hazard of the area should be opportunely reconsidered.

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