GEOPHYSICAL AND GEODETIC SURVEYS FOR THE CHARACTERIZATION OF THE SANTA BARBARA MUD VOLCANO SUBSOIL (CALTANISSETTA, SICILY): PRELIMINARY RESULTS

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Introduction. Mud volcanism is common worldwide, about 1,100 mud volcanoes have been identified onshore (Milkov 2005). Sixty-one mud volcanoes have been identified in Italy, mainly located on thick sedimentary sequences within zones of active tectonic compression.

Mud volcanoes are considered pseudo-volcanic manifestations, originating from the presence of natural gases under pressure in the subsurface. These gases tend to rise through preferential migrating pathways due to the presence of permeable rocks and/or lithological discontinuities, carrying water, mud, rock fragments and hydrocarbons as they ascend.

This study presents the preliminary results of geophysics and geodetic field surveys involving the Santa Barbara mud volcano area, aimed at characterized its subsoil. The Santa Barbara mud volcano area is located in central sector of Sicily (Fig. 1a), on the eastern outskirts of the Caltanissetta district (Fig. 1b), at about 520 m a.s.l..

Geological and structural framework. On a regional scale, mud volcanoes in active fold-and-thrust belts may occur over wider areas or may cluster along discrete structures, where the generation of overpressures is expected to establish a positive feedback loop allowing for fault movement and mud volcanism.

The mud volcanoes in Sicily, are all located along the Sicily Thrust Belt Front (Lavecchia *et al.,* 2007; De Guidi *et al.,* 2015). The Sicilian belt is part of the complex collisional boundary between African and Europe convergent plates.

The central sector of Sicily consists of four groups of terrain, three represent tectonic complexes, while the latter consists of piggy-back deposits deposited on the back of the three tectonic complexes.

The geological succession, outcropping in the area of the Santa Barbara Mud Volcano, is represented, form the bottom to the top, by Terravecchia Formation (Low Tortonian - Messinian), Calcare di Base (Low Messinian), Trubi Formation (Zanclean), Enna Formation (Piacenzian), Geracello marly clays (Gelasiano) and Lannari sand (Calabrian) (Tortorici *et al*., 2014). In particular the mud volcano area is characterized by the clayey member of Trubi Formation, consisting by clays and olistostromic intercalations; Trubi Formation outcropps also southward up to Imera Meridionale River (Fig. 1c).

Geophysical and geodetic surveys: methods and data processing

To identify the impedance contrast between the material ejected and the rock from which it arises a geophysical survey has been carried out using passive seismic single-station (HVSR) and active seismic (MASW) prospections (Imposa *et al*., 2016) (Fig. 1d).

A grid was designed on the Santa Barbara mud volcano area, measuring 110x120 m and with a 10 m spacing between sampling points.

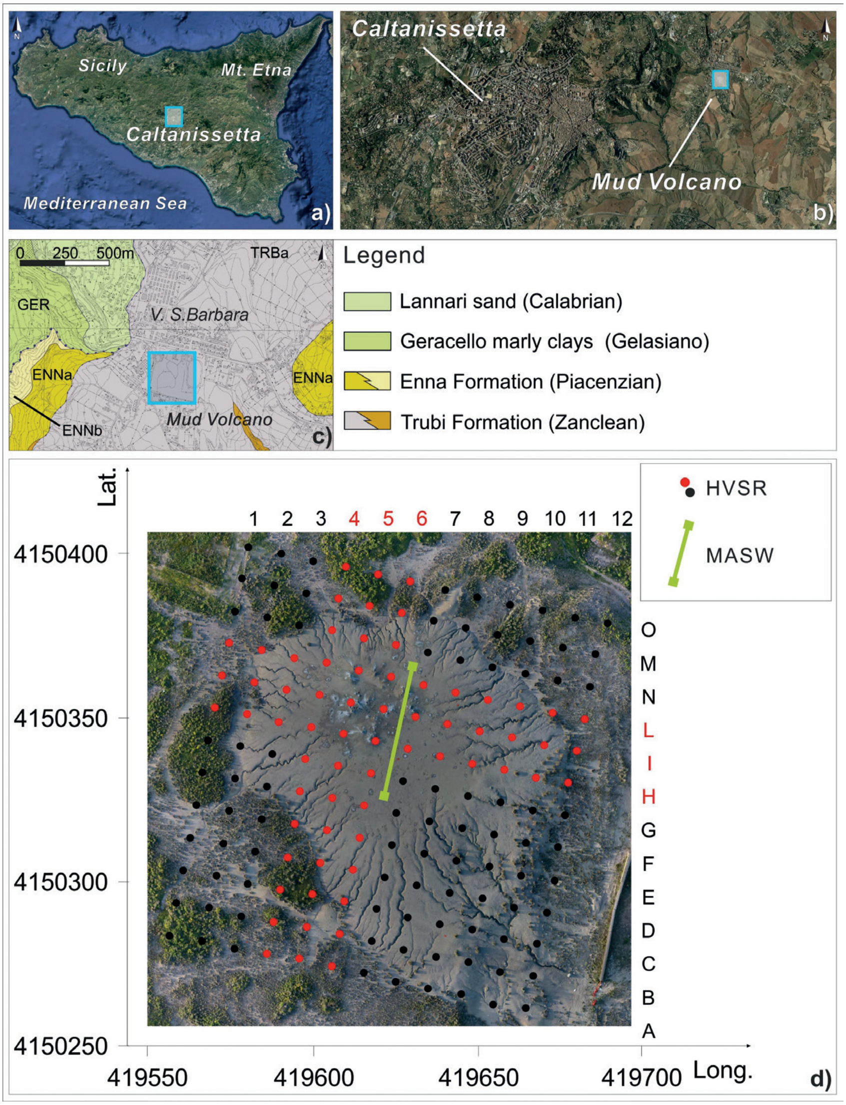

Fig. 1 - a) location of Caltanissetta town; b) location of the Santa Barbara mud volcano area; c) geological map of the Santa Barbara mud volcano area (extracted from the Geological Map of Italy 1:50000, F. 631- Caltanissetta, ISPRA), d) geo-referenced grid obtained through GNSS survey, with location of seismic noise sampling sites (dots) and MASW survey (yellow line): the red dots highlight the sampling points used for obtain the seismic impedance contrast sections (an alphanumeric reference was used to name HVSR samplings).

In order to determine the position of each measuring point and so create a geo-referenced grid (Fig. 1d), a GNSS survey (Global Navigation Satellite System) was carried out using a Topcon HiperSR (a dual frequency receiver, 256 channels). The GNSS receiver has been configured in Stop and Go mode.

Normally this method is based to use a reference point (of known coordinates). For this survey the permanent station RESU (Resuttano), belonging to RING network (INGV RING Working Group, 2016) was chosen as reference site, and a second receiver (rover), is used to acquired points, moving at regular intervals on the studied area. The Stop and Go method require the continuous recording of at least four satellites. During the recording, 18 satellites were visible. The data acquired has been post-processed with Magnet Office Tool software.

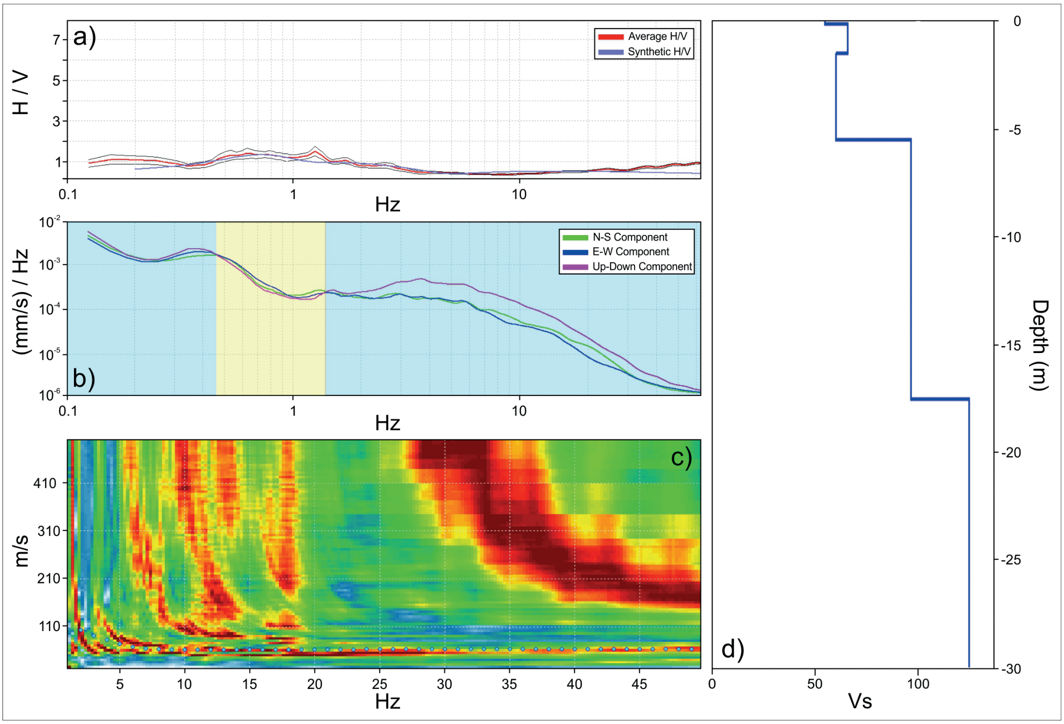

Fig. 2 Joint fit between HVSR spectrum (a), relating to one seismic ambient noise record (G6) acquired near the MASW survey (see fig. 1d for location) and Rayleigh waves dispersion curve (c), obtained from the MASW survey; b) example of single component spectra, related to one seismic ambient noise sampling (G6) (the area highlighted in yellow show the typical eye-shape, the two blu area highlight the possible presence of areas characterized by velocity inversion) d) velocity-depth profile obtained from MASW-HVSR joint fit.

The environmental noise records were performed at the 156 grid nodes (Fig. 1d), using 6 portables 3-component digital 'tromographs'. At each node, the environmental noise was recorded for 16 minutes with a sampling frequency of 128 Hz. The records were elaborated, with the H/V spectral ratios technique (Nakamura 1989).

The single component spectra, related to almost all the acquisitions carried out, suggest the presence of two areas characterized by velocity inversion, indeed it is possible to observe the decrease of the horizontal components below the vertical one (Fig. 2b). Moreover, even if the H/V>2 SESAME (2005) criterion fails, so no significant resonance peaks are observed (Fig. 2a), however a stratigraphic interpretation can be make (Castellaro and Mulargia, 2009). It is possible to observe, indeed, local minima in the vertical component, which produce the typical eye-shape (Fig. 2b), indicating the presence of a stratigraphic transition in the subsoil.

Based on the geological knowledge of the investigated area, which does not indicate lithological variations within the site, one MASW survey (Park *et al.*, 1999) has been undertaken to obtain the shear waves velocity profile using a multichannel digital system (SoilSpy Rosina). The survey was performed along an alignment oriented SSW-NNE and located on the central portion of the seismic ambient noise acquisition grid (Fig. 1d). The array was arranged using 25 geophones with natural frequency of 4.5 Hz and spacing of 2 m, with an overall length of 48 m.

To obtain the Vs depth profile for the studied area, a joint fit was made between the dispersion spectrum of Rayleigh waves (Fig. 2c) and one of the H/V spectra acquired near the alignment (Fig. 2a). Starting from a subsoil model, characterized by values of thickness, Vs, Vp, density and Poisson's ratio, assigned on the basis of geological knowledge of the site, the program calculates a dispersion curve and a theoretical H/V spectrum, that are displayed in superposition

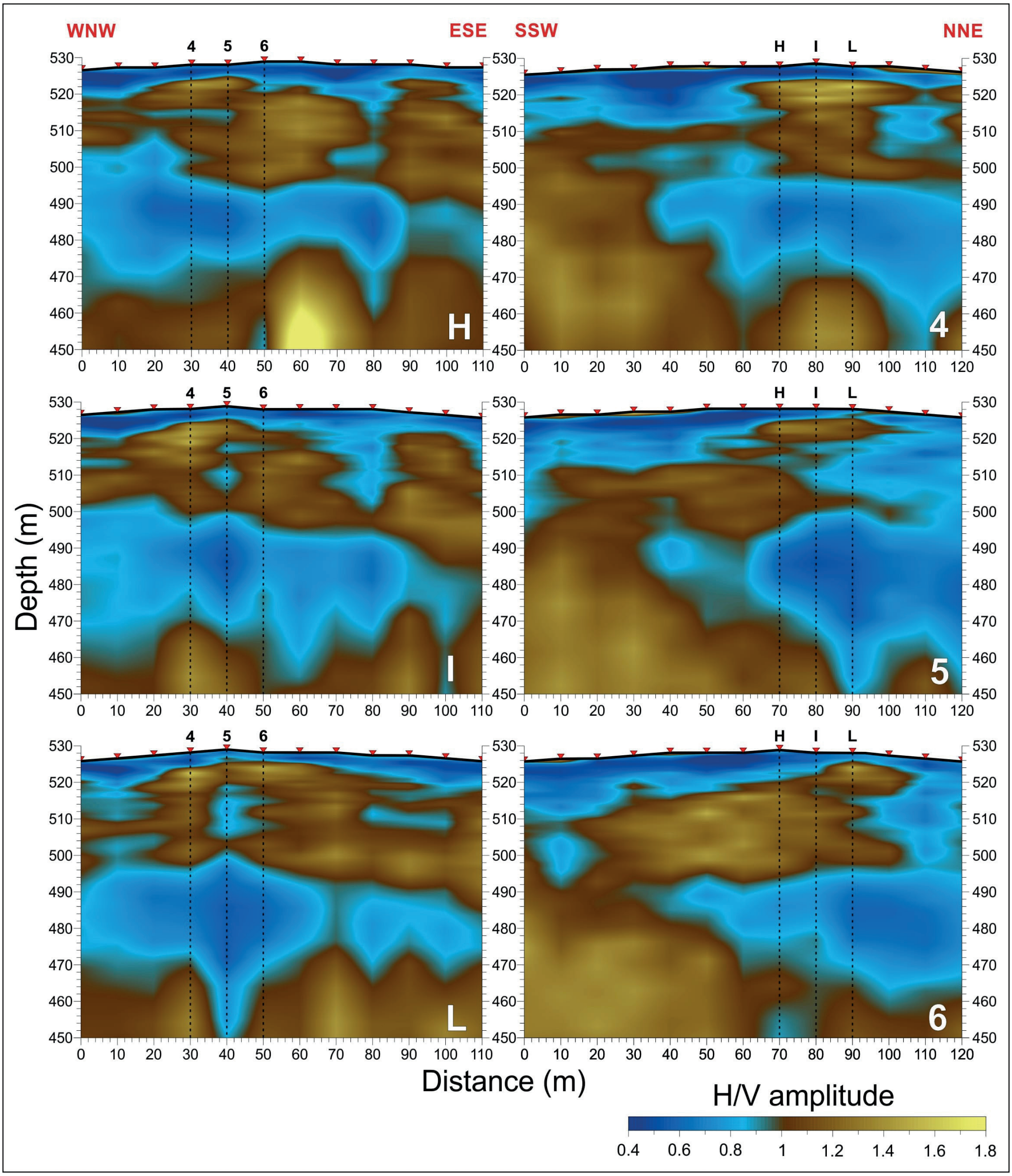

Fig. 3 - Impedance contrast sections obtained from seismic ambient noise samplings (see Fig. 1d for location).

on the dispersion spectrum of Rayleigh waves and the experimental H/V spectrum, respectively. The model is modified to ensure that the theoretical curves overlap the experimental ones as much as possible; the model for which there is maximum overlap provides the Vs-depth profile relative to the examined site. The velocity-depth profile obtained (Fig. 2d) by the MASW survey shows a small velocity inversion in the shallow subsoil, under this seismo-stratigraphic layer the velocity tends to increase slowly with depth. The result of this active seismic survey confirm that the subsoil of investigated area is characterized by low shear wave velocity values.

The noise samplings acquired along the six profiles highlighted in fig. 1d was further elaborated in order to obtained the related impedance contrast sections (Fig. 3). Substituted the V_0 value (shallow shear wave velocity) and α (proportionality coefficient between depth and velocity), obtained by the 1-D Vs profile in the equation of Ibs-Von Shet and Wohlenberg (1999):

$$h = [\frac{V_0(1-\alpha)}{4f} + 1]^{\frac{1}{(1-\alpha)}} - 1$$

the frequency values, present in the spectra were converted into depth values, thus allowing to view the distribution of amplitude values of the spectral ratio in the subsoil.

The x-axis in these sections shows the distance between the measuring points, with spacing of 10 m, and the y-axis the depth; variations in the amplitude value of the H/V spectral ratio are represented by colours associated with a chromatic scale (Fig. 3).

Preliminary results. Generally, the 156 spectra obtained show a H/V ratio below 1 for a wide range of frequencies (Fig. 2a), probably linked to the presence of velocity inversions in the shallow subsoil, in fact in the related single component spectra are observable the decrease of the horizontal components below the vertical one (Fig. 2b). In this condition, the small resonance peaks (amplitude value ≤ 2) present in the spectra, given by local minima in the vertical component, may indicate the presence of impedance contrasts in the subsoil, linked to stratigraphic discontinuities (Castellaro and Mulargia, 2009). In some spectra, resonance peaks with greater amplitude (2 - 4) can be observed at higher frequencies. These values indicate the presence of an impedance contrast at shallow depth.

The Vs-depth profile obtained through the MASW survey is characterized by low Vs values (Fig. 2d) that are consistent with the physical-mechanical characteristics of the lithological units at the investigated site and show a shallow velocity inversion, confirming the results of HVSR survey.

All the impedance contrast sections (Fig. 3) are characterized by low H/V amplitude (<1) in their shallow parts, probably linked to the presence of muddy material from about 1 to 5 meters depth. Another area at a depth of approximately 40 m, shows the same characteristics, highlighting the possible presence of another zone where this muddy material can be present. The parts of sections characterized by major H/V amplitude values can be related with the transition between the muddy material and the surrounding lithotypes.

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