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Geophysical characterization of the shallow subsurface in sites P2 and P3 from high-resolution active-source seismic profiling and downhole data: preliminary results

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In the framework of the Project Einstein Telescope Sos Enattos, we report the preliminary results of the active-source seismic surveys performed by the INGV team in sites P2 (labelled as Onani) and P3 (labelled as Bitti) in July and September 2021. The main goal of these surveys was the reconstruction of the shallow subsurface velocity structure in correspondence of the two drilling sites.
In site P2, we acquired a 355 m-long high-resolution seismic profile using an array of 72, 5 m-spaced 4.5 Hz vertical geophones centred on the 245 m-deep borehole. The survey was complemented by a downhole seismic testing with average vertical shot spacing of 2 m and a maximum recording depth of 230 m. In both cases, the source of elastic energy was provided by a buffalo gun. We remark that unfavourable local logistic conditions prevented the deployment of a longer geophone array, as well as the use of a vibroseis source. Shots of the 2-D seismic survey were also recorded by two linear arrays of 3-component nodes operated by the Karlsruhe Institute of Technology (KIT) in the surroundings of the drilling site. First arrival traveltime data from the seismic profile have been handpicked and inverted using two different tomographic techniques: 1) a linearized inversion based on the iterative perturbation of an initial smooth gradient Vp model; 2) a fully non-linear inversion with no a priori constraint based on a multi-scale imaging strategy. In this case, synthetic traveltimes are computed by an advanced and high-precision finite-difference Eikonal solver that avoids ray-tracing and allows accounting for transmitted, diffracted or head waves in the presence of strongly heterogeneous medium. The multi-scale refraction tomography enabled a maximum investigation depth of about 90 m in the middle of the profile, and an average spatial resolution of about 10 m. The resulting 2-D P-wave velocity model shows a shallow layer of relatively low Vp about 15 km thick characterized by velocities rapidly increasing with depth from 1000 m/s to 3000 m/s. The upper layer can be interpreted as a high-to-weakly weathered and possibly water-bearing zone in the granitoid (Goceano-Bittese Granitoid Complex). It overlies very-high velocity rocks (from 4700 m/s to 6200 m/s) attributable to weakly fractured granitoids. Some important lateral velocity variations are evident, including a relatively low-velocity sub-vertical zone in the central part of the model. The low-velocity zone with Vp in the 4000-4500 m/s range is embedded in a fast region (Vp around 5000 m/s) and it shows an apparent dip to the south-west. It is located about 30 m to the west of the borehole. Results from the linearized approach provided similar results but in this case the penetration depth is shallower (about 60 m). The comparison with the resistivity model obtained by the co-located ERT survey performed by University of Sassari unravels very similar features, with low-Vp and high-Vp structures corresponding to conductive and high-resistivity regions. We stress that the sub-vertical low-Vp anomaly matches a comparable conductive structure. Therefore, it might represent a fractured region associated with a fault-zone.
In site P3, local logistical conditions enabled us to acquire two intersecting and nearly orthogonal seismic profiles that are 835 m and 715 m long. We deployed two fixed arrays of 168 and 144 5-m-spaced 4.5 Hz vertical geophones, respectively. One of the two profiles is tied to borehole P3, which was used for a downhole seismic testing with average vertical shot spacing of 2 m down to a depth of 230 m. We used a vibroseis (IVI Minivib) as a source of elastic energy, with shots spaced on average 10 m. The acquisition geometry is not conventional, since it is based on the advanced multi-fold wide-aperture seismic profiling that allows the collection of both large-offset refraction data and high-fold near-vertical/wide-angle reflection data. In addition, the used source allows recording far offset refraction data up to maximum source-receiver distances

of 700-1000 m and usable near-vertical deep reflections down to 500-1000 m depth, depending on the local environmental and geologic conditions. During the acquisition of the profile tied to the borehole, we also installed a downhole geophone. The in-line shots were recorded at three different depths (100, 150, and 200 m, respectively) to provide complementary borehole measurements for the non-linear refraction tomography. In-line shots were also recorded by a large-aperture/dense 3-D nodal array and by a DAS vertical array both installed by KIT. The seismic survey required the accurate GPS positioning of all shot points and geophones to take into account the rough topography. The pre-processing of both seismic profiles is in progress.

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