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Integrated remote sensing and geophysical techniques to assess landslide hazard along the north-western coast of the Island of Malta.

Emanuele Forte (1), Stefano Devoto (2), Matteo Mantovani (3), Arianna Mocnik (1), Alessando Pasuto (3), Daniela Piacentini (2), Michele Pipan (1), and Mauro Soldati (2)

(1) Department of Geosciences, University of Trieste, Trieste, Italy (eforte@units.it), (2) Department of Earth Sciences, University of Modena and Reggio Emilia, Modena, Italy (stefano.devoto@unimore.it), (3) Research institute for the hydro-geological hazard protection, Italian National Research Council, Padova, Italy (matteo.mantovani@irpi.cnr.it)

The north-western coast of the Island of Malta is largely affected by different types of landslides, such as rock falls, block slides, earth flows and rock spreading. These phenomena locally imply risk issues with respect to the recreational infrastructures of this area and to the tourists that visit this stretch of coast. In fact, this area has limestone cliffs often affected by rock falls and lateral spreading triggered by the behaviour of the underlying clays.

Geomorphological surveys were carried out and a detailed inventory map of coastal landslides was completed. The surface data were integrated by remote sensing analyses and geophysical surveys. We used Advanced Differential Interferometry techniques (A-DInSAR) to preliminarily evaluate the active zones within an area of about 12 sq km. A GPS monitoring network has been active since 2005, with more than 20 benchmarks spread all over the unstable areas. Extensometric measurements have been acquired on specific places in order to evaluate single block movements or spreading along selected fractures.

From the initial data, we inferred that all landslides phenomena are combinedly influenced by tectonic, lithological and geomechanical causes. Therefore, we planned some geophysical surveys to obtain additional subsurface information. Geophysical methods are usually applied to identify the sliding surface of slope failures, at different scales, but there are only few examples related to lateral spreading phenomena.

Geophysical data were acquired mainly with these two distinct objectives:

1) To make a large-scale evaluation of the lithological sequence and the tectonic structure within specific areas.

2) To obtain an accurate reconstruction of the 3D discontinuity network below the topographic surface.

Combined Electrical Resistivity Tomography (ERT) and 2D and 3D Ground Penetrating Radar (GPR) techniques were tested at different sites.

ERT surveys encompassed 2D profiles obtained with various electrode geometries and spacing. Short profiles (length not exceeding 60 m) allow a good characterization of the first few meters below the surface, imaging the contact between alluvial/colluvial materials above the limestones and allowing to discover limestone blocks within the soft soil and voids inside the carbonates.

Long ERT profiles (total length from 60 m to 460 m) are suitable to locate main tectonic discontinuities (sub vertical zones with lower resistivity as compared to surrounding values) and the contact between limestone and clay. Within the study area there are several different rocks roughly described as "limestones" but including cross-stratified grainstones, channelled packstones, pure carbonate mudstones and also carbonate sandstones (wackes). ERT allowed not only to obtain an overview of the main subsurface features but also to roughly classify the rocks from the geo-mechanical point of view. In fact, calibrating the ERT measures with direct data deduced from rock outcrops we inferred that within the study area the tectonic drive is important but also the lithology plays a very important role. Moreover, the resistivity can be considered a good physical parameter to estimate the quality of rock materials.

On GPR data, acquired using two different antennas pairs (300 and 500 MHz), we applied both standard and specific processing procedures including 2D and 3D attributes analyses (instantaneous attributes, coherency measurements, spectral decomposition, texture attributes) to extract all the information embedded within the data and hardly accessible especially on low signal to noise ratio environments. The EM signal penetration was high enough to image the limestone-clay contact to a maximum depth of about 12m. In addition, the high-frequency GPR data were essential to reconstruct the discontinuity network and to understand the joint properties below the topographic surface.