PRELIMINARY RESULTS FROM AN INTEGRATED SHALLOW GEOPHYSICAL INVESTIGATION IN THE NORTH-EASTERN SECTOR OF THE MALTA ISLAND

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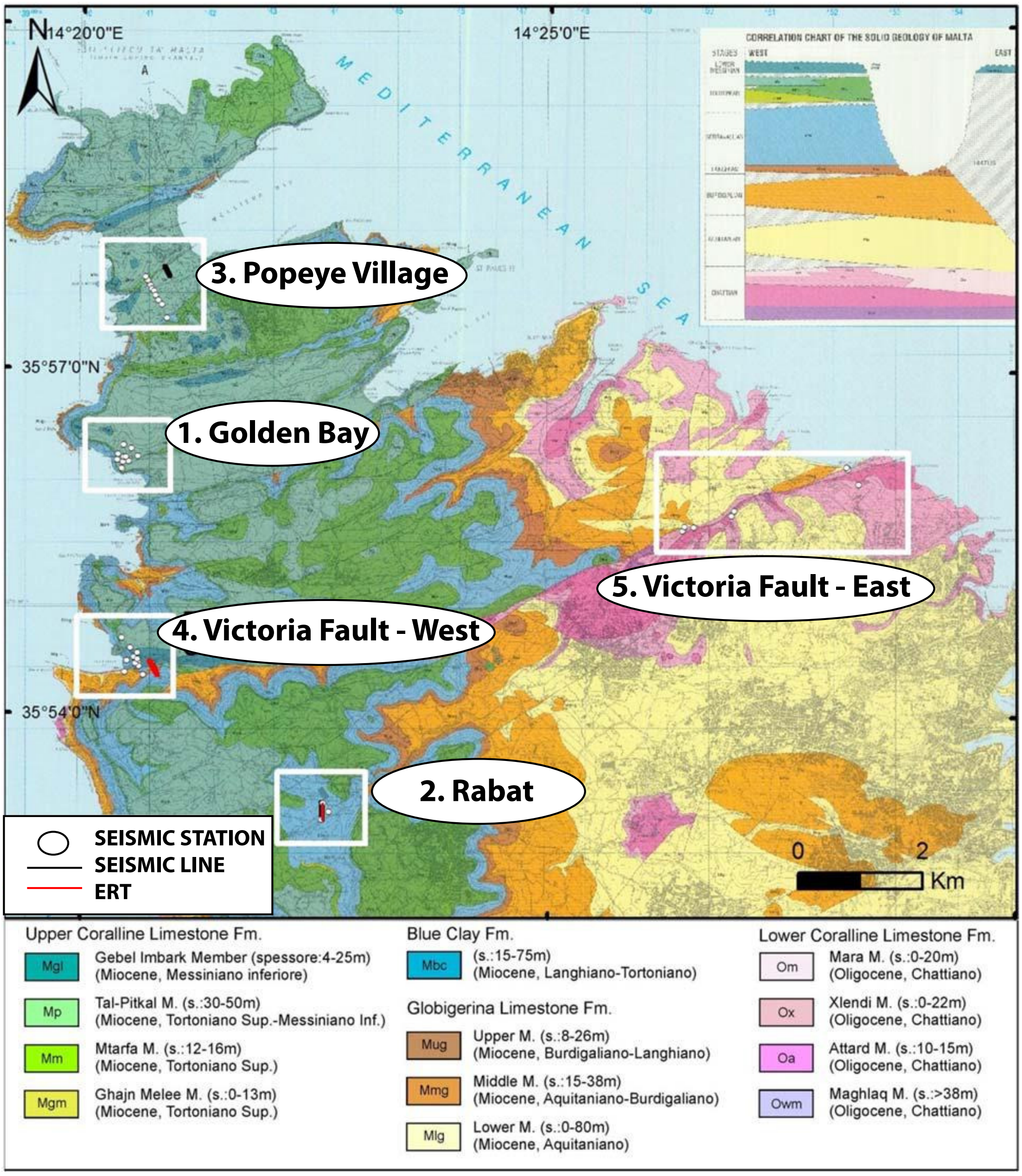
Introduction

In the framework of the project "SIMIT" and under an agreement between Istituto Nazionale di Geofisica e Vulcanologia (INGV) and DPC of the Regione Siciliana, seismic hazard estimates were performed, resulting in the distribution of the expected peak ground acceleration values (PGA). These estimations refer to stiff-rock sites, and do not include the contribution of the site-local geological condition. In order to take the subsoil response into account in the hazard assessment of the Maltese islands, on November 2014 we performed several geophysical investigations including seismic and electrical 2D-tomography, MASW profiles, 2D arrays and single-station measurements using ambient noise (see Figure 1). The final goal was to combine different geophysical methods which allow the reconstruction of geometries at depth (tens of meters) and the evaluation of shear-wave velocities in the most common geological formations outcropping on the islands. The geology of Malta is characterized by a succession of Tertiary marine sediments, from the bottom to the top: Lower Coralline Fm.; Globigerina Limestones; Blue Clay Fm., Green Sand Fm., Upper Coralline Fm. Moreover the velocity profile has been related to Vs30 parameter that is used to classify soils by the European seismic code (Eurocode8, 2003).

Previous studies performed in Malta by several authors have pointed out that even rock-sites can show site amplification as the effect of cliff-edge and unstable boulder collapse (Panzera et al. 2012; Galea et al., 2014) as well as to the strong impedance contrast between the Blue Clay Fm and the Globigerina Limestone Fm buried under tens of meters of the Upper Coralline Limestone Fm (Vella et al., 2013). Both these situations are quite common in the Northern sector of Malta Island that is characterized by a wide plateau of Upper Coralline Fm. bordered by steep cliffs with large slope failures, representing a threat for human activity in the area. The presence of the stratigraphic contact between the Blue Clay Fm and the Globigerina Limestone Fm under the Upper Coralline Limestone is responsible for an amplitude peak between 1 and 2 Hz.

We decided to focus the attention on the problem of amplification at sites where the Upper Coralline Limestone outcrops. In fact in southern sector of the



Geophysical Prospecting	ACTIVE INVESTIGATIONS			PASSIVE INVESTIGATIONS	
SITE	Seismic tomography	MASW	Electric tomography	Array measurements	Single station HVSRs
1.Golden Bay	-	-	-	X	X
2. Rabat	X	X	X	-	X
3.Popeye Village	X	X	-	-	X
4.Victoria Fault West	X	X	-	-	X
5.Victoria Fault East	-	-	-	-	X

Figure 1. Geologic map with location of the studied sites and geophysical prospecting carried out.

Malta Island where the Lower Coralline Limestone Fm and the Globigerina Limestone Fm outcrop, no site amplification has been observed so far. All the survey sites are close to a set of NE-trending normal faults that are another common and persistent feature in Malta (Reuther, 1984; Pedley, 1987; Gardiner et al., 1994). These faults belong to the north Malta graben system where the main tectonic feature is the Victoria Line, a complex system of NE-trending strike-slip and normal faults with a prevailing normal component of slip (Putz-Perrier and Sanderson, 2010). For this reason we also decided to study two sites across the Victoria fault.

We finally selected the following sites: 1. Golden Bay; 2. Rabat; 3. Popeye Village; 4. Victoria Fault - West; 5. Victoria Fault - East. In each site we carried out different experiments depending on site-specific geological and logistic conditions. Site location and geology are shown in Figure 1 as well as geophysical investigations performed at each site. In the following sections we describe results of active (seismic and electrical 2D-tomography, MASW profiles) and passive (2D arrays and single-station measurements using ambient noise) geophysical investigations.

Results of active seismic and electrical investigations

We report preliminary results from the active seismic survey performed in site "Victoria Fault–West", across the Victoria Line close to the Fomm Ir-Rih Bay. The 142 m long, NW-trending seismic transect crosses a portion of the fault that does not outcrop because of extensive colluvial cover. The footwall hosts the Globigerina Limestone Fm., whereas the hanging wall hosts the Blue Clays and the Upper Coralline Fm. Probably, at this site the Victoria Line is made of several splays. We provide a high-resolution Vp tomogram (obtained through a non-linear inversion of first arrival traveltimes; see Improta et al. 2002 for details about the method) indicating that between 60 m and 120 m from the NW corner of the line a wide area of low Vp (< 1500 m/s) represents a possible interruption of a 10 m deep refractor. Although additional geophysical and structural investigation is needed, we interpret this feature as the effect of a shallow fault zone. There is no hint of recent faulting because the shallower layers seem undisturbed. The dispersion of surface waves indicates that the shallow layers have Vs slightly higher in the NW part of the profile with respect to the SE part (150-300 m/s and 120-200 m/s respectively). This seems in accordance with the presence of the Upper Coralline Fm. in the hanging wall and the Globigerina Limestone Fm. in the footwall.

In the site "2. Rabat" we performed an electrical resistivity tomography (ERT) across a N-trending, 256 m long line. The main purpose of the investigation was the determination of the thickness of the Blue Clay Fm. We inverted apparent resistivity data acquired with a Wenner configuration of quadrupoles. Our results indicate that the thickness of the Blue Clay Fm. in this site may exceed 40 m (resistivity in the 10-50 Ohm*m range), and probably the deeper part of the ERT section indicates at 45 m depth the transition with the underlying Globigerina Limestone Fm. We acquired also active seismic data parallel to the ERT line.

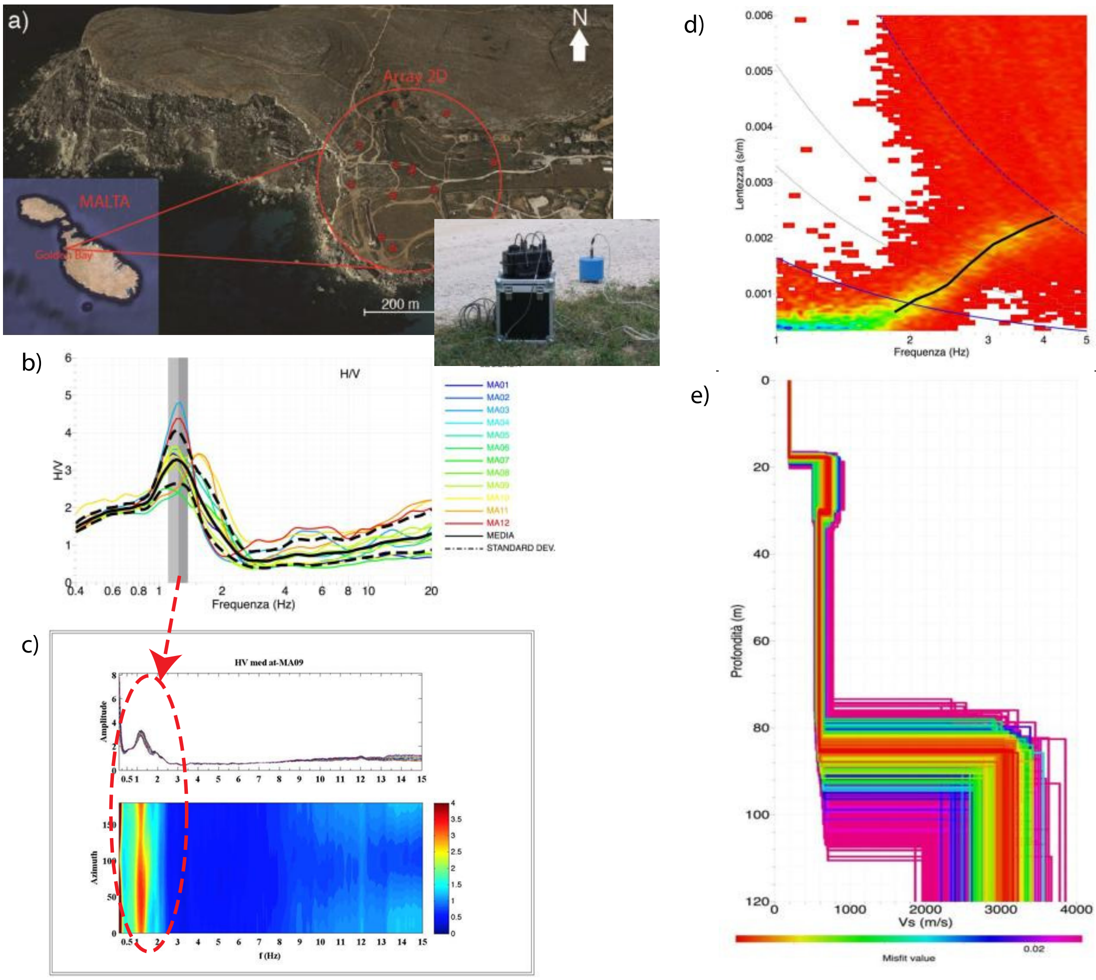


Figure 2 – Passive measurements performed at site "1. Golden Bay". Instrument and array geometry is shown in panel a). Panel b) HVSR calculated at stations, all showing a peak at 1.2 Hz. This peak has the same amplitude on N-S and E-W components, as shown in panel c). In Panel d) we report the dispersion curve obtained from f-k analysis. The Vs velocity profile resulting from the inversion is drawn in panel e).

Traveltime tomography is still in progress. MASW results indicate that the shallow subsurface is characterized by a roughly homogeneous Vs profile, in the 150-200 m/s range, and these values are typical of clayey deposits.

Results of passive seismic investigations

In the site "1. Golden Bay" we performed passive noise measurements using a 12-stations array with a spiral-shape, the minimum and maximum distances being 11 and 400 m, respectively in order to resolve 80-200 m at depth. Stations were composed of velocimetric Lennartz sensors Le3d-5s and Reftek R130 digitizer. Time synchronism was provided by GPS connection. At all stations, HVSRs show an amplitude 4 peak at about 1.2 Hz, that is caused by the impedance contrast between Globigerina Limestone Fm. and Blue Clay Fm., which is overlain by the outcropping Upper Coralline Limestone Fm. The dispersion curve obtained by applying the f-k analysis, was inverted to obtain the Vs velocity profile which is characterized by 3 layers lying on the Globigerina Limestone bedrock (Vs≈3000 m/s): the first layer (Vs≈200 m/s; h≈18 m) is represented by superficial weathered limestones belonging to the Upper Coralline Fm.; the second layer (Vs≈700 m/s; H≈15 m) is associated to unweathered limestones of the Upper Coralline Fm.; the third layer (Vs≈600 m/s an h≈55m) represents the Blue Clay Fm. The analysis of directional amplification has shown that the 1.2 Hz peak is isotropic, the two horizontal component of ground motion NS and EW showing the same amplitude levels. Conversely, at frequency higher than 4 Hz, stations located closer to the cliff show a slight broadband directional amplification effect with a variable direction.

The same analysis was also applied to noise measurements carried out using 3 single stations at site “2. Rabat”, where the Blue Clay Fm outcrops. Here the analysis of directional HVSR revealed the presence of a 2 Hz peak that, consistently to site “1. Golden Bay”, is related to the impedance contrast between the Blue Clay Fm. and the underlying Globigerina Limestone Fm. The higher frequency observed at this site could be explained by a smaller thickness of the Blue Clay Fm. and to the absence of the Upper Coralline Fm. After investigating amplification at rock sites related to stratigraphic impedance contrasts we have focused our attention at amplification of rock sites close to fault zones and related to fractured rocks in the fault damage zone (Rigano et al., 2008; Di Giulio et al., 2009; Pischiutta et al. 2012, 2014; Panzera et al., 2014). We have chosen three sites (3. Popeye Village, 4. Victoria Fault-West and 5. Victoria Fault-East) where we have performed passive noise measurements using single stations realizing transect crossing the mapped faults. The Popeye Village prospecting results are not reliable because measurements were strongly affected by anthropogenic noise source resulting in narrow frequency amplitude peaks.

Preliminary results obtained at site “4. Victoria Fault-West” are encouraging because stations installed on the fault footwall do not show any directional amplification and stations at about 1.5 km far from the fault hanging wall show only the stratigraphic peak previously described. Conversely, stations installed on the fault hanging wall show a maximum amplification along NE-SW direction with amplitudes up to a factor of 4 in a broad frequency band (3-8 Hz). This same azimuthal direction was found on one measurement site at “5. Victoria Fault–East” site. Further investigations are needed to check the recurrence of this direction and to interpret its relation to fracture distribution in the fault damage zone.

Conclusions

With our preliminary geophysical investigation in the north-eastern sector of the island of Malta we were able to provide a subsoil characterization of some sites which represent a typical situation where the outcropping fractured limestones of the Upper Coralline Fm. overlies the plastic Blue Clay Fm.

Micro-tremor analyses revealed a typical peak in the H/V curves in the 1-1.5 Hz range, most probably related to the interface between the two formations.

Directional analyses close to some important fault zones revealed the presence of a recurrent NE-SW peak that needs to be thoroughly studied.

Shallow geophysical investigation of the Victoria Line close to the Fomm Ir-Rih Bay revealed a shallow fault zone, however further studies are needed to assess the possible recent activity of this complex fault system at this site.

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