SUBMERGED LANDSLIDE MORPHOLOGIES IN THE ALBANO LAKE (ROME, ITALY)

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ABSTRACT

The geomorphological interpretation of the high resolution bathymetry of the Albano lake (central Italy), together with conventional geological and geomorphological investigations for the subaerial slope, allowed us to identify several subaerial and submerged morphologies due to slope failures of different size and presumably age. Two main landslide categories will be decribed in this paper: totally submerged, combined subaerial-submerged landslides. Furthermore a detailed description of two past large slope failures (volume of $10^6 m^3$) and the 1997 subaerial and submerged debris flow are presented. The wave induced by the 1997 debris flow testifies also the tsunamigenic potential of these phenomena which is still more serious if the presence of coastal settlements is taken into account.
Keywords: Albano lake, bathymetry, submerged landslide, submerged slope failure, debris-flow, tsunami.

1. INTRODUCTION

Ongoing research activities were devoted to evaluate the landslide hazard of the slopes surrounding the Albano lake, located about 25 km southeast of the city of Rome in the Colli Albani volcanic district, and the related tsunami hazard in the shore villages. An high resolution multibeam swath bathymetric survey of the lake, performed using ultra high resolution instruments (Anzidei et al. 2006), allowed us to extend the geomorphological analysis of the area also to the submerged slopes of the Albano lake. In fact, both the impact of subaerial landslides on the water and the occurrence of submerged slope failures have to be taken into account in order to deal with tsunami hazard. This paper mainly focuses on the results of the morphological interpretation of the Albano lake submerged slopes, which is part of the landslide mapping undertaken for both subaerial and submerged slopes.
The Albano lake partially occupies a volcanic depression recently originated as a multiple maar. The overall morphology of this multiple maar is featured by a low aspect ratio edifice characterized by gently dipping outer slopes and steep inner slopes that correspond to the crater walls (fig.1). The latter form an elliptical crater rim, which has an axis maximum of about 4300 m and an axis minimum of about 2800 m; the Albano lake has a maximum water thickness of about 165 m.

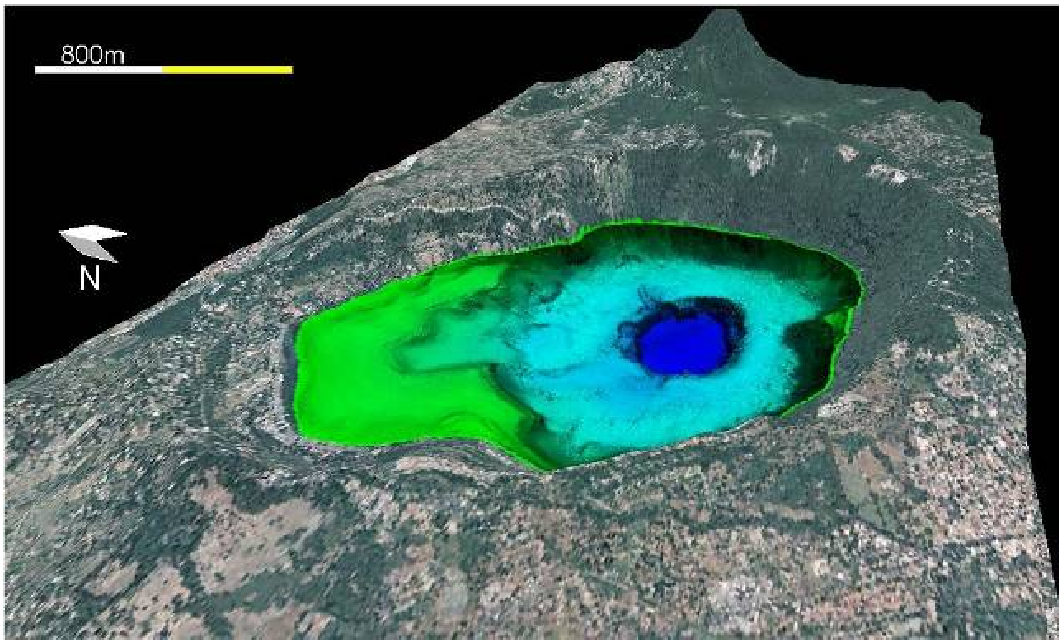

Fig. 1: 3D recontruction of the subaerial and subaqueous Albano lake morphologies

As regards the geological setting, in the inner slopes of the Albano maar the hydromagmatic deposits (alternation of scoria lapilli beds and ash-rich layers, generally cemented for the zeolitisation and massive and chaotic, ash-matrix supported, up to 30 m thick ignimbrite deposits) related to the Albano maar activities locally overlay thick banks of lava and scoria deposits ascribed to previous volcanic phases.

2. GRAVITY-INDUCED LANDFORMS

Several gravity-induced landforms related to both past and ongoing landslide processes along the subaerial and submerged slopes of the lake have been found. Geological and geomorphological surveys of the subaerial landforms have been performed by coupling field activities and aerial-photograph interpretations in order to complete the frame of the whole inner crater slope. The geomorphological survey of the subaqueous slopes has been carried out by means of an analysis of the very detailed (1m x 1m square grid) LDEMs (Lacustrine Digital Elevation Models) and the LDEM-derived thematic maps (slope, aspect, curvature) together with specific software which permits a “virtual flight” above the bathymetry 3D model. These kind of analyses have been supported by morphometric computations of both surfaces and volumes of the main scars and accumulation areas. Such an integrated analysis of the whole subaqueous-subaerial slope system highlighted the presence of three main conditions: completely subaerial landslides, totally submerged landslides, combined subaerial-submerged landslide. The latter are represented by a subaerial detachment area with a transportation route and a depositonal area extending in the submerged slope. Only the totally or partially submerged landslides will be discussed, the small and medium sized ones in the paragraphs 2.1 to 3, and the large ones in the paragraph 4.

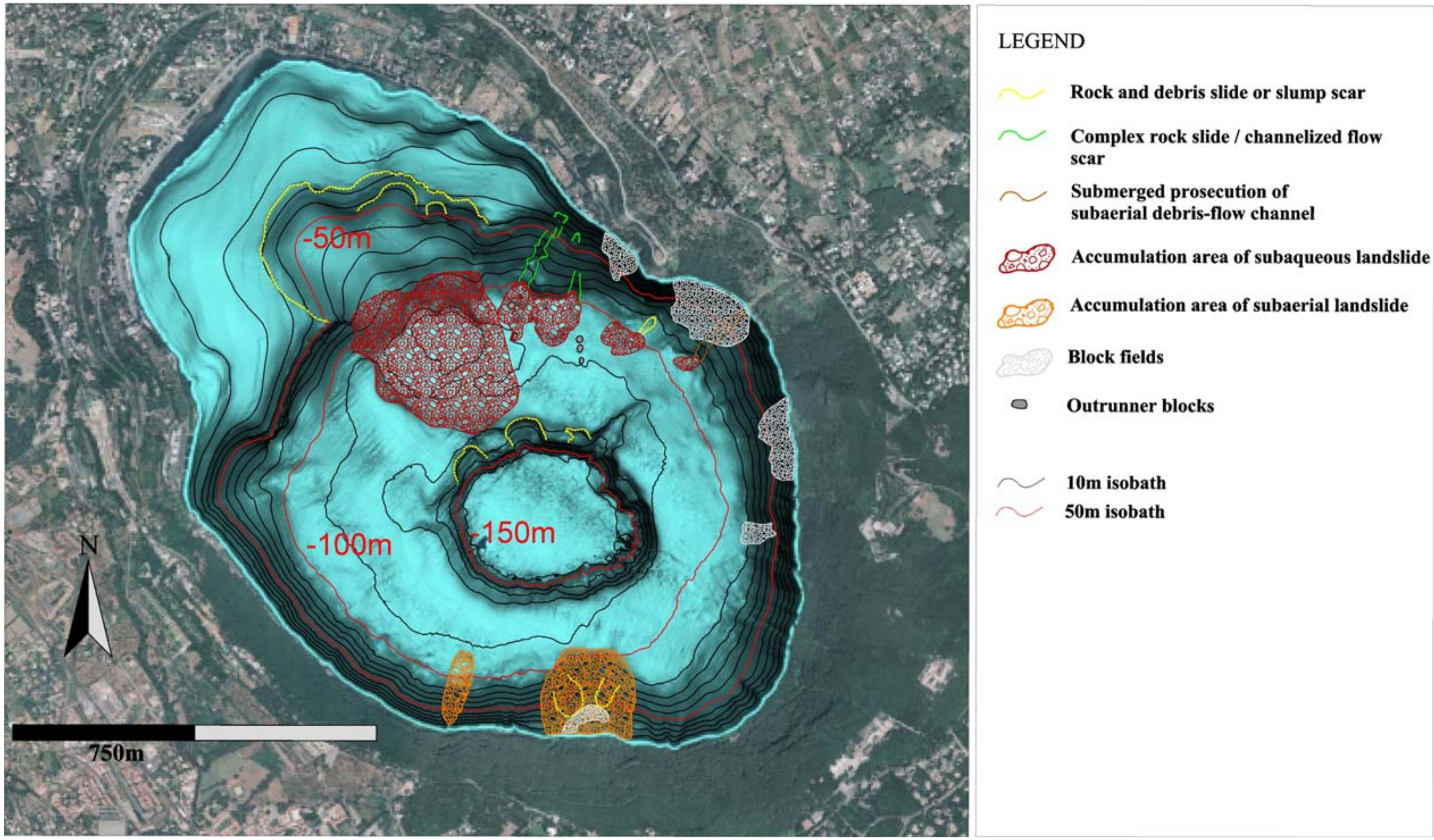

Fig. 2: Inventory map of the main subqueous gravity-induced landforms discussed in the text, plotted on the Albano lake bathymetric map produced in the frame of the INGV-DPC 2005-2007 project V3_1 by M.Anzidei (UR8, Responsible: F. Riguzzi).

2.1 Totally submerged landslides

According to the classifications by Cruden and Varnes 1996, Mulder and Choconat 1996 and Hungr et al 2001, the completely submerged landslides mainly consist of:

Complex rock-slide / channelized flow-like movement: these processes start as block slides, with involved volumes of about 10^3-10^4 m^3, and evolve in channelized flows with a high entrainment capacity. The channels develop on about 10° dipping slopes and are between 50-200 m long, 20-50 m wide and about 5 m deep. The accumulation areas are usually characterized by a main deposit at the end of the channel and by the presence of some outrunner blocks (De Blasio et al. 2006), with dimensions up to 10^3 m^3, that reach distances up to 300 m far from end of the channel. Two phenomena ascribable to this kind of process are shown in fig.3; the differences in sharpness of the respective landforms may reflect their different age of the movement.

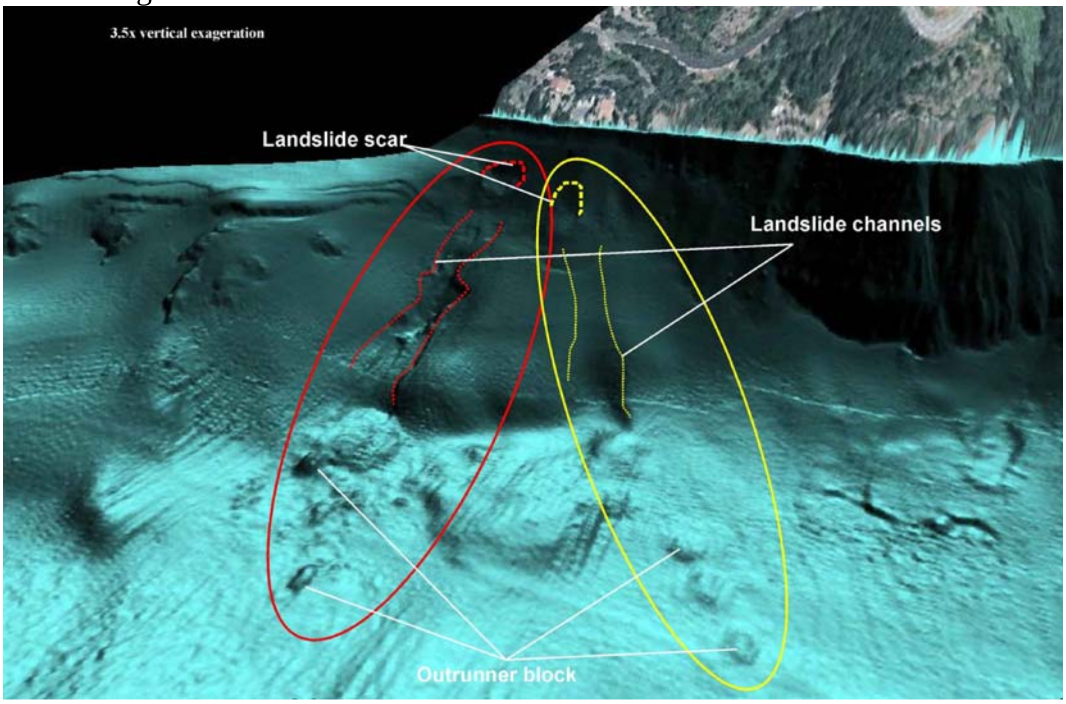

Fig. 3: Two examples of completely submerged complex rock-slide / channnelized flow in the northern part of the Albano lake floor.

Debris and rock slide or slump: the main landforms related to this kind of processes mainly affect the edge of the most internal maar crater, and could be related to local, syn-eruptive collapses (Németh 2000). Similar landforms are present upon a huge landslide deposit (par.4) and testify its remobilization. In both cases the detached volumes range between 10^4-$10^5 m^3$, while the corresponding accumulation areas are not clearly visible. Finally, also a large slope failure is ascribable to this kind of process and will be described in detail in par.4.

2.2 Combined subaerial-submerged landslides

The peculiar morphology of the basin featured by steep subaerial slopes and by the lack of a well developed coastal platform or shore (except for the northern sector of the lake), frequently allows the subaerial landslides to extend their runout in the submerged slopes. In these cases the main depositional, submerged landforms are represented by:

Rockfall / topple deposits: areas with a diffuse presence of single blocks deriving from subaerial failures and that can be defined as **“block fields”**.

Rock-slide deposits: are featured by well defined accumulation areas located downslope the rock-slide scars. The most significant one is related to a large rock-slide that will be discussed in par. 4.

Complex rock-slide / debris flow deposits: are featured by accumulation areas located at the toe of the main transportation channels, that can whether completely develop in the subaerial slopes or partially continue in the submerged slopes.

Most of these landslides affect the eastern sector of the lake: based on some geomorphological evidence, the most recent ones seem to be the partial reactivation of larger, past phenomena. From this point of view the 1997 debris flow occurred along the eastern slope is particularly significant and will be described in detail in the next paragraph.

3. THE 1997 DEBRIS-FLOW

After an intense rainfall event (128 mm in 24 hours), a debris flow occurred in the eastern slope of the Albano lake on the 7th of November 1997.

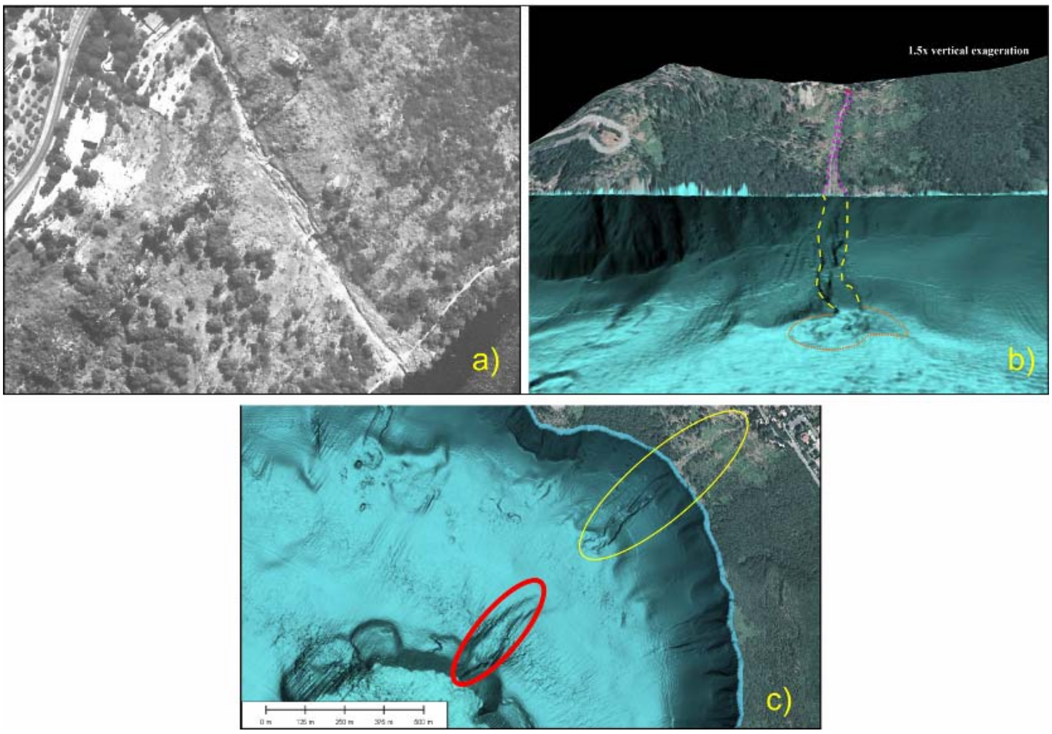

Fig. 4: a) Aerial view of the subaerial channel generated by the 1997 debris-flow; b) subaqueous continuation of the channel and the deposit; c) in red circle the continuation of the subaqueous channel.

According to local witnesses, a little tsunami wave generated after the impact of the mass onto the water and reached and flooded the ground floor of some houses along the coastline. This landslide began as a soil slide, which involved about 300 m^3 of eluvial material that slid along the contact with the bedrock. The so mobilized mass was channeled within a steeply dipping impluvium (about 40°)

and thus evolved as a debris flow which entrained a large amount of debris material along the bottom of the channel and reached an estimated volume of some thousands of cubic meters during the subaerial path. The bathymetry data point out that the channel continues along the submerged slope until a depth of about 100 m below the lake level; in addition, it is wider than in the subaerial part and is about 3 m deep. Part of the landslide mass was deposited on the coastline immediately after the impact on the water, while the largest part of the deposit should have deposited in the submerged part. In addition, the above described submerged channel forms a lineation with a wider one that reaches a depth of about 130 m below the lake level (fig.4) and is up to 100 m wide, 10 m deep and has a slope angle less than 8°.

4. EVIDENCES OF GREAT PAST LANDSLIDES

Geomorphic evidence of past large landslide events with volumes of 10^6 m^3 are present in the Albano lake beyond the above described landslides, whose volumes do not exceed 10^5 m^3.

In the southern part of the lake inner slope, a wide, markedly concave slope sector, whose shape is ascribable to the scar area of a past subaerial massive rock slope failure is present (fig.5). In addition, in the submerged part just downslope this "negative" landform, a huge, convex positive landform is present and can be regarded as the debris accumulation corresponding to the above mentioned scar area. Furthermore, geological reconstructions point out that the involved material is constituted by massive and chaotic, ignimbrite deposits with a dip slope attitude, overlaying thick banks of plane parallel to low-angle scoria lapilli beds and lava lenses. Based on the morphologic evidence and on the geological-structural setting, this landslide can be classified, according to Hungr and Evans 2004, as a simple translational rockslide – structurally controlled. A reconstruction of the hypothesized pre-landslide topography allowed us to estimate a detached volume of about $3 \cdot 10^6 m^3$, that fits well with the submerged debris volume of about $2.5 \cdot 10^6$ m^3.

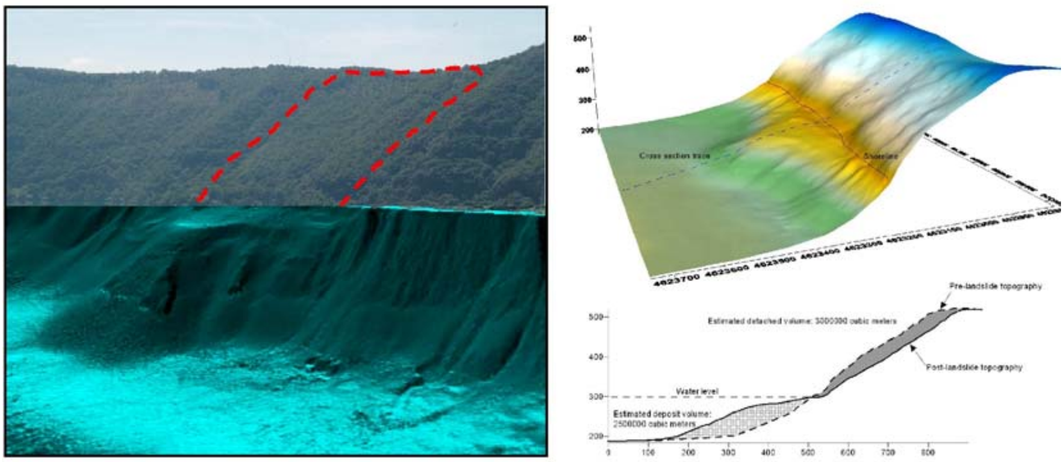

Fig. 5: On the left the subaerial scar and subaqueous deposit of the large Albano Lake rock-slide; on the right is the 3D subaqueous/subaerial model and the profile with the pre-failure topography reconstruction.

As regards the completely submerged slopes the largest landform explainable as a slope failure is present in the northern sector (fig.6). The total scar area is 365000 m^2 wide corresponding to an estimated total detached volume of about $7*10^6$ m^3. At the toe of the scar area a slight morphologic bulge is present and could represent the debris accumulation. This deposit shows a peculiar shape because of the presence of an inner depressed zone, similar to the ones surveyed in other kinds of landslides in closed basins such as fjords (Blikra et al. 2006) and lakes (Bacon et al. 2002). In our case, this shape could be related whether to the presence of a preexisting volcanic depression or to some peculiar depositional mechanisms.
As regards the dating some indirect constraints are given by the age of the maar activity responsible for the formation of the scarp involved in the slope failure (about 70 ky BP), and the first lacustrine deposits that mantle the scar area that is of about 30 ky BP according to Chondrogianni et al.1996.

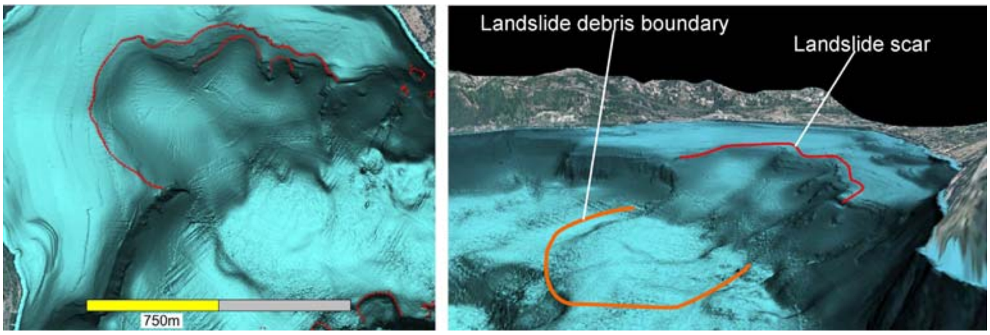

Fig. 6: Two different side view of the completely subaqueous big slope failure in the northern part of the lake Albano floor.

5. CONCLUSIONS

The relevance and importance of the landlside recognition and analysis in the Albano lake area is related to the presence of human activities around the coastline.
Several case studies highlight the tsunamigenic potential of subaquaeous and subaerial landslides that impact on the water (Papadopoulos and Kortekaas 2003), especially in closed basins related to both large-sized (Schnellmann et al. 2002; Panizzo et al. 2005) and smaller (10^5 m^3) events (Jorstad 1968; Wagner et al. 2003). The Albano lake slopes show an intense small- and medium-sized landslide activity. In addition evidence of past large slope failures is present. The tsunamigenic potential related to possible other failures is also enhanced by the considerable relief energy and the high velocity of such events as debris flows. The landslide mapping and preliminary interpretations presented in this paper should be thus considered as the basis on which further and more detailed studies will be carried out in order to achieve a final landslide and tsunami-related hazard assessment.

6. ACKNOWLEDGEMENTS

This research is financially supported by INGV-DPC 2005-2007 project V3_1- UR12 (Responsible: F. Bozzano). The bathymetry of the Albano lake is produced by UR8 (Responsible: F. Riguzzi) in the frame of the same research project. The authors thank M. Anzidei for the helpful discussion about the subaqueous topography.

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