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LIDAR monitoring of mass wasting processes: The Radicofani landslide, Province of Siena, Central Italy

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A B S T R A C T

The Radicofani Basin, stretching about 30 km NW–SE, is an intra-Central Apennine basin connected to Pliocene–Pleistocene extensional tectonics. It consists of an Early to Middle Pliocene succession including essentially shelf pelites. In the Radicofani area, province of Siena (Tuscany region), morphodynamic processes are very frequent with widespread badlands and rapidly evolving mudflows. In order to evaluate the general instability of the Radicofani area, geological and geomorphological surveys were carried out. The 1954, 1990 and 2003 aerial surveys allowed a comparison of the changes in the various morphological aspects of the study area, which suggested an increase in slope instability with time. A new complex translational landslide evolving into mudflows, activated during the winter of 2003, was monitored using an experimental system based on terrestrial LIDAR (Light Detection and Ranging) and GPS (Global Positioning System) technologies. This system allowed the monitoring of the morphologic and volumetric evolution of the landslide. A comparison of the monitoring data of October 2004, June 2005, May 2006 and May 2007 points out that the evolution is characterised by the sliding of displaced materials. A volume of about 1300 m^3 of materials was removed during the period 2004–2005, 300 m^3 for 2005–2006, and 400 m^3 for 2006–2007. The greater initial mass movement probably reflects a greater static imbalance during the early period of landslide movement and increased rainfall. Therefore, the proposed monitoring system methodology allows the numerical evaluation of the landslide morphological evolution and to validate the landslide evolution model based on geological and geomorphological field surveys.

1. Introduction

The choice of LIDAR (Light Detection and Ranging) for studying the evolution of natural processes has gained wider acceptance in earth sciences (White and Wang, 2003; Hunter et al., 2003; McKean and Roering, 2004; Gold, 2004; Schulz, 2004; Lawler, 2005; Thoma et al., 2005) thanks to the increasing availability of LIDAR systems (Baltsavias, 1999; Glenn et al., 2006). The interest in this type of instrument in the study of natural phenomena is due to the possibility of obtaining a high precision Digital Terrain Model (DTM) in a simple and rapid way. In this context, terrestrial and aerial LIDAR systems allow us to focus on methods of data handling and to evaluate the evolution of landforms (Saye et al., 2005) such as landslides (Chigira et al., 2004; Corsini et al., 2006; Lollino et al., 2007a,b) and streams (Cobby et al., 2001; French, 2003; Lollino et al., 2005a; Heritage and Hetherington, 2007). The present study is an example of this type of application, showing the advantages of the use of the terrestrial LIDAR to acquire qualitative and quantitative data for a particular landform otherwise surveyed with a great difficulty.

In particular, a purpose of the present study is to propose a methodology to utilize LIDAR data for the analysis of geomorphologic processes in an effective way. This study is surely not the first work about this theme, but other studies tend to focus on particular aspects like the creation of DTMs (Hunter et al., 2003; French, 2003), computing DTM derivatives to represent the morphology of an area (Glenn et al., 2006; Van De Eeckhaut et al., 2007; Cavalli and Marchi 2008), evaluating variations of DTMs obtained through different survey techniques (Bitelli et al., 2004; Lollino et al., 2007a,b), and estimating volumetric changes in landforms (Woolard and Colby, 2002; Shrestha et al., 2005). In this work, an effort has been made to provide a methodological procedure that can integrate steps and products already introduced in the scientific literature based on the optimization of the LIDAR dataset.

2. Study site

The study was conducted on a landslide area in the San Francesco locality (Podere Ghino di Tacco), a municipal territory of Radicofani (Fig. 1), Province of Siena (Tuscany region) in Italy, about 12 km east of Mt. Amiata. The area comprises the upper valley of the River Paglia which flows into the River Tiber near Allerona. This section of the

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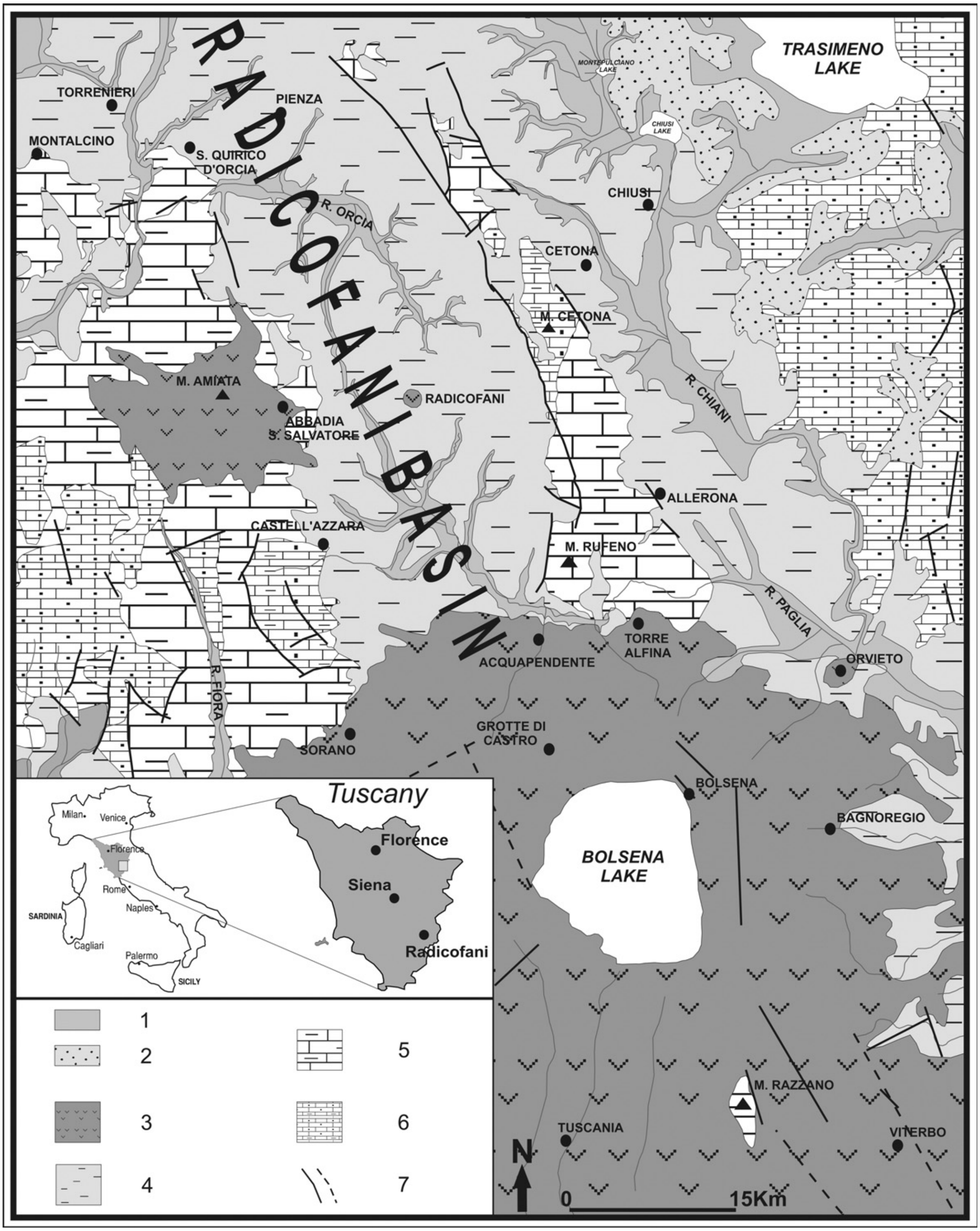

Fig. 1. Location and geology of the study area. 1) alluvial deposits (Holocene); 2), conglomerate, sandstone, siltstone, and claystone of fluvial-lacustrine environment (Pleistocene and Holocene); 3) volcanic units (Pleistocene); 4) mudstone, sand, and conglomerate (Pliocene and Early Pleistocene), 5) claystone, marl, marly limestone, calcarenite, and sandstone of Ligurian domain (Eocene and Cretaceous); 6) Tuscan non-metamorphic units (Oligocene to Triassic); 7) normal fault and probable fault.

River Paglia watershed is subject to stream erosion and extensive landslides, rendering the entire territory highly unstable. The study focused on the evolution of a landslide that had activated in December 2003, involving a portion of the eroded area near Radicofani.

Since the area contains only a few man-made structures (chiefly primary and secondary roads), the landslide has developed naturally without the interventions by artificial stabilization. This situation permitted us to evaluate its evolution using an integrated monitoring system based on LIDAR technology combined with a geodetic positioning network and a global positioning system (GPS). The use of this instrumentation was necessary to overcome a series of difficulties related to the area's particular lithology which, as will be explained below, does not allow the placement of field survey points within the landslide mass.

2.1. Geologic setting

The study area lies in the Radicofani Basin (Brandi et al., 1970; Iaccarino et al., 1994; Barberi et al., 1994; Disperati and Liotta, 1998; Pascucci et al., 2006), an intra-Central Apennine basin belonging to a