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Integrated geophysical and geomorphological approach to investigate the snowmelt-triggered landslide of Bosco Piccolo village (Basilicata, southern Italy)

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ABSTRACT

Most of Basilicata region in the southern Italian Apennines is characterized by landslides often developing in clayey–marly formations. Many events have been triggered by extreme rainfall or snowmelt. The most important happened (on February–March 2005) at Bosco Piccolo 5 km far from Potenza. This landslide developed subsequently to rapid snowmelt occurred during alternating short periods of high temperatures and intense and continuous snowfalls. This complex landslide affected 4 ha of surface and reached a maximum depth of 20 m inducing damage and collapse of about 80% of the buildings in the village. An integrated multidisciplinary approach has been adopted to study the landslide. A multitemporal aerial photo interpretation and detailed geomorphological surveys have been carried out. Combined Electrical Resistivity Tomography (ERT) and Self-Potential (SP) measurements have been performed and calibrated with boreholes stratigraphy. Such an integrated approach allowed us to partially reconstruct the geometry of the investigated body and to evaluate the effectiveness of drainage system planned for the area.

1. Introduction

In respect of the national average, Basilicata region (southern Italy) exhibits the highest density of landslides with more than 27 landslide areas every 100 km^2 (Guzzetti, 2000). This high landslide density is related to predisposing conditions such as prevailing clayey materials as well as morphological setting of the slopes, and to determining conditions such as extreme rainfall events (Piccareta et al., 2004) or human activity, such as cave excavation (Lazzari et al., 2006), deforestation (Boenzi and Giura Longo, 1994) and intense urbanization and industrialization. Many landslide events have been historically triggered by extreme rainfall or snowmelt occurrences. The Basilicata region can be therefore considered a natural outdoor laboratory to apply geophysical methods to investigate the complex geometry of landslide bodies.

To answer unsolved questions in geomorphology research regarding for example the thickness and internal structures of landslides, several geophysical techniques can be used. The success of their applications is determined by the following fundamentals factors: contrast of the physical properties of involved materials, depth of the target, high space and temporal resolution of the data, signal-to-noise ratio. Their advantages are to be fairly flexible and relatively easy to deploy on mountainous area and to provide highly pertinent two or three-dimensional subsurface information in a non-invasive way. The main drawbacks are their decreasing resolution with depth, the non-uniqueness of their solution, the indirect information they yield (geophysical parameters), and the resulting need of calibration. Since a few decades, the use of geophysical methods for landslide characterization is commonly increasing. These methods include seismic reflection or refraction, seismic noise, electromagnetic, magnetometry, gravity, and thermometry (Hack, 2000; Jongmans and Garambois, 2007; Schrott and Sass, 2008 and references therein), although the most applied are ground-penetrating radar, electrical resistivity and seismic refraction (Bichler et al., 2004; Lapenna et al., 2005; Meric et al., 2005; Godio et al., 2006).

Recently, considerable attention has been devoted to two geoelectrical methods: the electrical resistivity tomography (ERT) or electrical imaging, and the self-potential (SP) or streaming potential method. These two methods are relatively time and cost effective when working on large area and are reasonably user-friendly for geomorphologists.

The efficiency of the electrical resisitivity method mainly depends on the electrical resistivity contrast induced by the soil. This contrast can be due to variations in the lithology, the weathering, an increase in water content and presence of a water table (Jongmans and Garambois, 2007). Numerous papers have dealt with this electrical method to assess, in clayey or metamorphic environments, the depth and geometry of complex landslides, to identify the discontinuity between

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the landslide material and bedrock, and to locate possible sliding surfaces (Perrone et al., 2004; Lapenna et al., 2005; Meric et al., 2005; Sass et al., 2008). Thanks to the high variability of electrode spacings and configurations, Agnesi et al. (2005) and Lebourg et al. (2005) used the electrical resistivity methods to study deep-seated landslide.

The self-potential method (SP) involves the passive measurement of the electrical potential distribution at the ground surface of the Earth with non-polarisable electrodes. SP anomalies are associated with different charge polarization mechanisms occurring at depth. In the case of landslides, the SP method is sensitive to groundwater flow through the electrokinetic effect (see therein Lorne et al., 1999; Revil et al., 1999). As concentrated water seepage and high level of groundwater are causes in landslides triggering, drainage systems are often installed. Therefore, detecting electrokinetic effect due to water seepage based on SP survey can allow zoning of infiltrating water recharge and run-off areas, and can determine the extent of effects of subsurface drainage works. Interesting results have been obtained in landslide areas using SP method (Bogoslovsky and Ogilvy, 1977; Bruno and Marillier, 2000). Thanks to SP maps, Perrone et al. (2004) and Colangelo et al. (2006) described the main patterns of the subsurface fluid flow in a clayey landslide, locating source and accumulation areas. Combined with further geophysical methods, Meric et al. (2005) performed SP profiles and observed sharp SP variations at the boundaries of a large rocky landslide and strong positive anomalies over the high motion zone.

In this paper, we present a combined geoelectrical (ERT and PS) geomorphological and geotechnical (boreholes and inclinometer) investigation of one of the most important landslides happened between the end of February and the beginning of March 2005 on Bosco Piccolo countryside, 5 km far from Potenza town, along the axial zone of southern Apennines chain (Fig. 1). Compared to previous work, the novelty of this paper results in the self-potential method, which has been applied to delineate the limit of clayey landslide limits and to determine the efficiency of a drainage network installed just after the landslide events. In addition the sliding surface is not occurring at a lithological interface.

2. Study area

2.1. Geological and geomorphological setting

The Bosco Piccolo landslide is located along the southern border of the Cozzo Staccata–Piano Grande ridge that divides the hydrographic basin of Tiera river (left hand tributary of Basento river) from that of Arvo river (right hand tributary of Bradano river). The slope is mainly characterized by the oldest Apennine formational units (Cretaceous–mid-lower Miocene) mainly represented by clayey–marly–arenaceous deposits (Argille Varicolori Formation — AVF), and by marly limestones of the Corleto Perticara Formation (CPF lower Miocene–Oligocene, (Pescatore et al., 1988), both particularly susceptible to landsliding (Fig. 2) as shown by Fig. 3. Besides, the Corleto Perticara Fm. defines the local morphology with calcareous ridges less erodible than the surrounding clayey deposits. In this area, the average annual temperature is 12 °C and average rainfall ranges between 650 and 800 mm/year. Nevertheless, during the last fifty years, more extreme events characterized by an increase in the rainfall-snowfall intensity and a progressive decrease in rainy days, have been recorded. The lithology of the substratum (clayey–marly–arenaceous) and the extreme metereological events are the two main factors responsible for the slope evolution and landslides triggering of Bosco Piccolo countryside.

The landslide hazard scenario was mapped during the last sixteen years through an integrated approach of geomorphological field surveys and the interpretation of multiple sets of stereoscopic aerial photographs (1954–55, 1989, 1990, 1999, 2001 and 2004). The results show that the whole slope, on which the village is located, has been repeatedly affected by landslide movements during the last fifty years (Fig. 3).

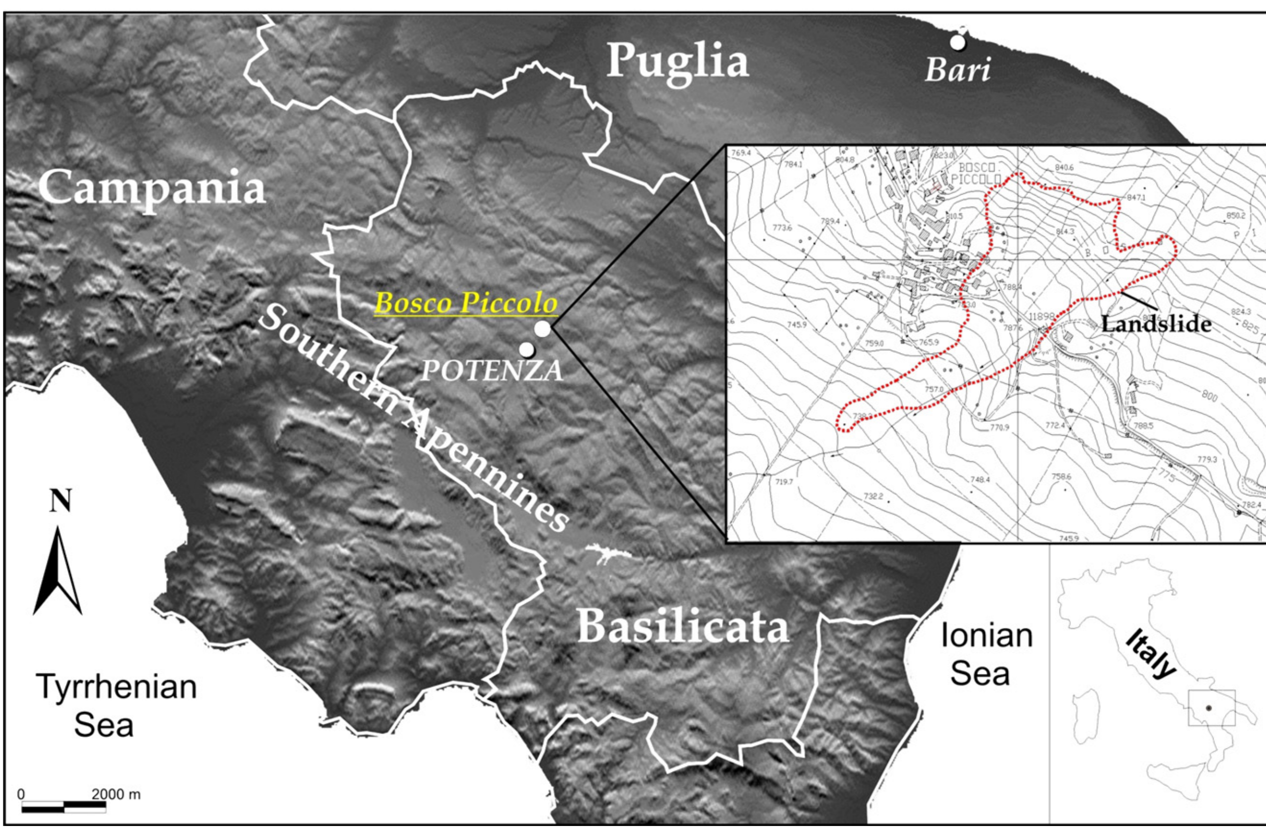

Fig. 1. Geographical location of the study area in the Basilicata region, and the Bosco Piccolo landslide (in red in the left window). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)