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SCIENCE

Mass movements inventory map of the Rubbio stream catchment (Basilicata – South Italy)

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In the Basilicata region (South Italy) slope movements, caused by soft rocks, rapid tectonic uplift, earthquakes, and seasonally heavy precipitation, constitute one of the major geologic hazards. For this reason a detailed inventory map of mass movements has been created in a test area of south-eastern Basilicata. The map was compiled from field surveys and multi-temporal air photo interpretation. For each landslide, the map depicts the state of activity and dominant type of slope movement. The integration and analysis of the data obtained by using a geographic information system has produced the mass movements inventory map at a scale of 1:25,000.

Mass movements are widespread and play a key role in the landscape evolution of the study area. A total of 175 landslides were recognized, occupying a surface area of 16.2 km^2, about 9% of the whole basin of interest. The spatial distribution and type of mass movements are mainly related to the lithology and structural features. Field surveys coupled with interpretation of multi-temporal aerial photos allowed us to distinguish between active (20.6%) and inactive (79.4%) landslides. Mass movements, mapped on the basis of movement type, are represented by slides, flows and complex landslides. The complex and slide type movements are very common, and represent more than 86% of the landslides mapped.

Keywords: Mass movements; GIS; Basilicata; southern Italy

1. Introduction

Landslides are landscape shaping processes, often with associated risks characterized by important potential environmental and economic consequences in many areas of the Italian Peninsula (e.g. Catenacci, 1992; Catani, Casagli, Ermini, Righini, & Menduni, 2005; Conforti, Robustelli, Muto, & Critelli, 2012a; Conforti, Pascale, Robustelli, & Sdao, 2014a; Conforti, Muto, Rago, & Critelli, 2014b; Guzzetti, 2000; Luca, Robustelli, Conforti, & Fabbricatore, 2011). In the Basilicata region (southern Italy), mass movements cause considerable damage to human activity and property every year (Bentivenga, Palladino, & Caputi, 2012; Caniani, Pascale, Sdao, & Sole, 2008; Conforti, Pascale, Pastore, Pepe, Sdao & Sole, 2012b; Conforti, Pascale, Pepe, Sdao, & Sole, 2013; Dal Sasso et al., 2014; Pascale, Sdao, & Sole, 2010; Pascale et al., 2013; Sdao &

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Simeone, 2007). Their occurrence is controlled both by a series of predisposing factors (e.g. geological, geomorphological, climatic, hydro-geological) and triggering factors (seismicity, heavy rainfall, human activities); the different combinations of these geo-environmental features produce a wide variety of mass movements in terms of typology, kinematic mechanisms, evolution and dimensions (Caniani et al., 2008; Conforti, Pascale, Pastore, Pepe, Sdao & Sole, 2012b; Conforti, Pascale, Pepe et al., 2013; De Bari et al., 2011; Pascale et al., 2013).

Mass movement inventory maps are among the most important tools used to recognize and evaluate the morphodynamic framework of a territory, by providing information about the past and present landscape, and giving insights into its possible future evolution (Dramis, 2009). For this reason, the geomorphological survey and mapping of landslide areas plays a crucial role in land management and planning, as well as in assessment and prevention of geological hazards (Guzzetti et al., 2012; Van Den Eeckhaut & Hervás, 2012).

This work presents a case-study of a mass movements map in an area of south-eastern Basilicata, which is very susceptible to gravitational processes.

2. Material and methods

Geomorphological analysis was carried out, followed by processing and management of collected data within a geographic information system (GIS) and the production of the mass movement inventory map. In particular, mapping of mass movement features was based on an interpretation of air-photos taken in 1955 and 1991 at a scale of 1:33,000, and in 2006 at a scale of 1:8000 and field surveys. These photos were a key source for assessment of the activity state. The type and state of activity of mass movements were attributed following the classification proposed by Cruden and Varnes (1996).

In order to compile the mass movement inventory map, the surveyed mass wasting processes were plotted on topographical maps at 1:25,000 scale (published by the Italian Military Geographic Institute). These maps were scanned, georeferenced, and the geomorphic processes digitized as polygons or lines, using a GIS. The area, the type of movement and the activity of the landslide were entered into a geodatabase linked to the mass movement inventory.

The final map (Main map) was compiled at scale of 1:25,000 and the legend mainly follows the schemes of Brancaccio et al. (1994) and Conforti, Pascale, Pepe et al. (2013). Different colors and symbols were assigned to each morphogenetic landform. Red was used for active mass movements and orange for inactive ones; green was used for fluvial landforms, blue for the hydrographic network and black for anthropogenic features.

The simplified topographic base, with a 25 m contour interval and elevations of the main summits, was obtained from a digital elevation model (DEM) digitized from contour lines and points of the 1:25,000 scale topographic maps.

3. Geological and geomorphological setting

The study area is the Rubbio stream catchment which is the right tributary of the Sinni River (Figure 1). It flows on the south-eastern side of the Basilicata region (South Italy) and covers an area of more than 55.3 km^2; this sector of the region is sensitive to extensive and severe slope movements (Guerricchio, Lupo, & Melidoro, 1987; Pascale et al., 2013).

Elevation ranges from 283 to 1581 m a.s.l., with an average value of 872 m (Figure 2(a)). Slope gradients, computed from the DEM, range from 0 to 64.1 degrees, with an average of 13.4 degrees (Figure 2(b)).

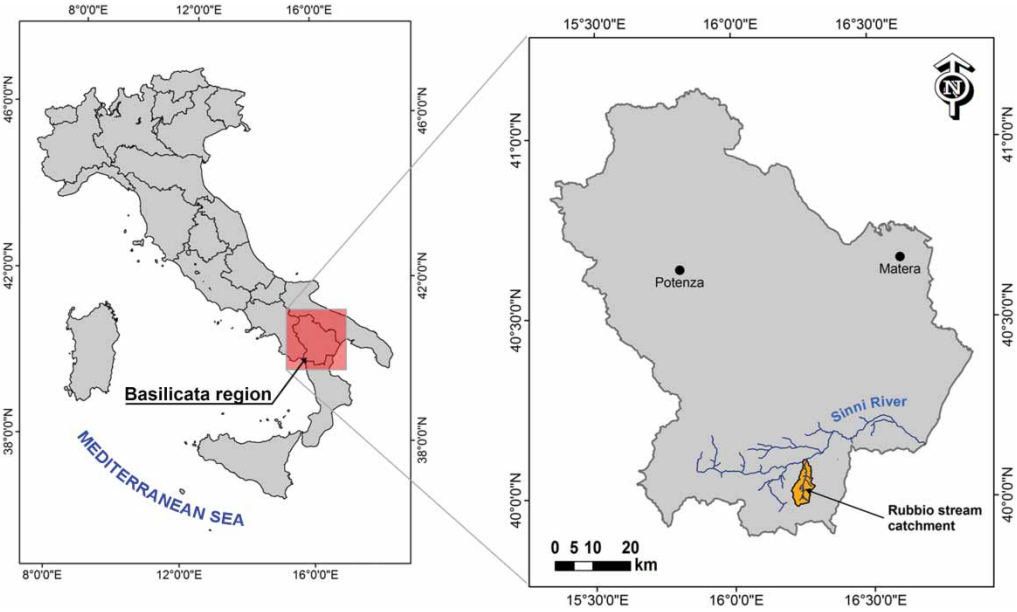

Figure 1. Location of the study area.

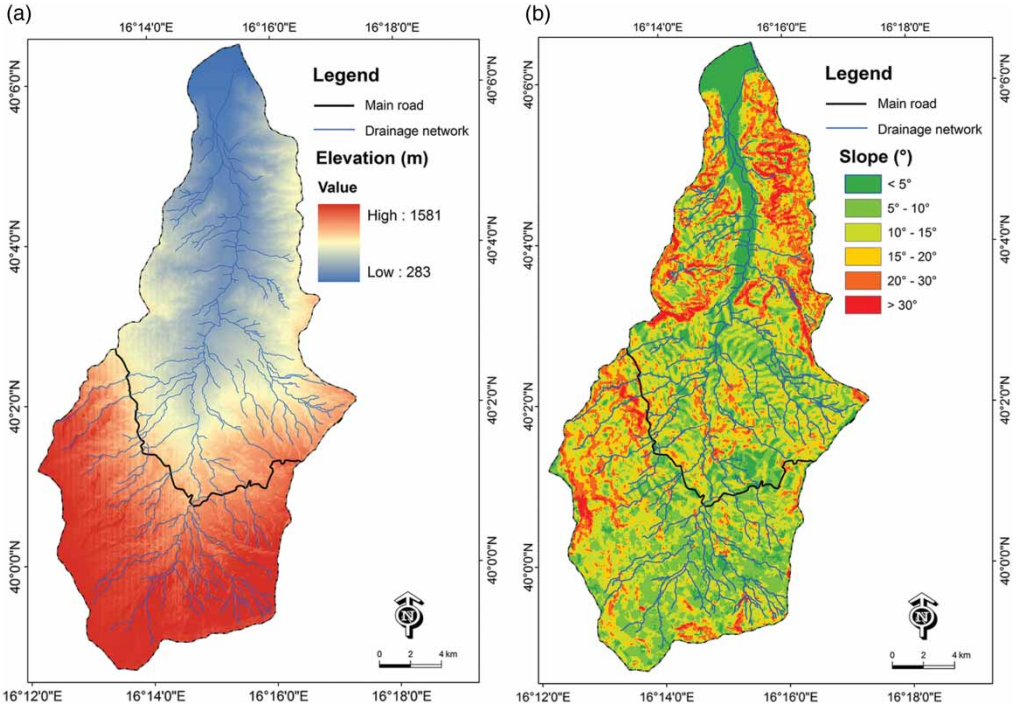

Figure 2. Elevation map (a) and slope map (b) of the study area.

The Rubbio stream catchment, rising on the northern slope of the Pollino Ridge, has an elongated shape and is a fifth- order basin, at 1:25,000 map scale, with a sub-dendritic drainage pattern and low drainage density (3.15 km^{-1}).

The climate of the study area is typical of the Mediterranean area, with an average annual precipitation of about 820 mm and mean annual temperature around 13°C. Rainfall is concentrated in autumn and winter, with peaks in December and January; conversely, the summers are dry and hot, with minimum rainfall in July and August (Caloiero & Mercuri, 1982; Piccarreta, Capolongo, & Boenzi, 2004).

From a geological perspective the investigated area is located on the Calabria-Lucania border, between the Pollino carbonate ridge to the south and the Pliocene-Quaternary Sant'Arcangelo basin to the north (Figure 3).

The Rubbio stream catchment consists of ophiolite-bearing successions (internal units or Liguride Units) thrust on the Campania-Lucania carbonate platform (Figure 3), and forming the uppermost tectonic element of the southern Apennines (Bonardi et al., 1988; Catalano, Monaco, Tortorici, & Tansi, 1993; Critelli, Muto, Tripodi, & Perri, 2011; Critelli, Muto, Tripodi, & Perri, 2013; Knott, 1987; Monaco, Tortorici, Morten, Critelli, & Tansi, 1995; Schiattarella, 1996, 1998). The Liguride Units, also, known as '*internal drives*' for their palaeogeographic and structural arrangement in the southern Apennine chain (Critelli et al., 2013), are represented by two main groups of terrains: the Frido Unit, Cretaceous-Oligocene in age, and composed of polydeformed metamorphic rocks with associated blocks of ophiolite-bearing and continental-type rocks; the Cilento Unit, represented by a sedimentary succession consisting of a turbiditic sequence tectonically covered by the Frido Unit, and made up, from the bottom to

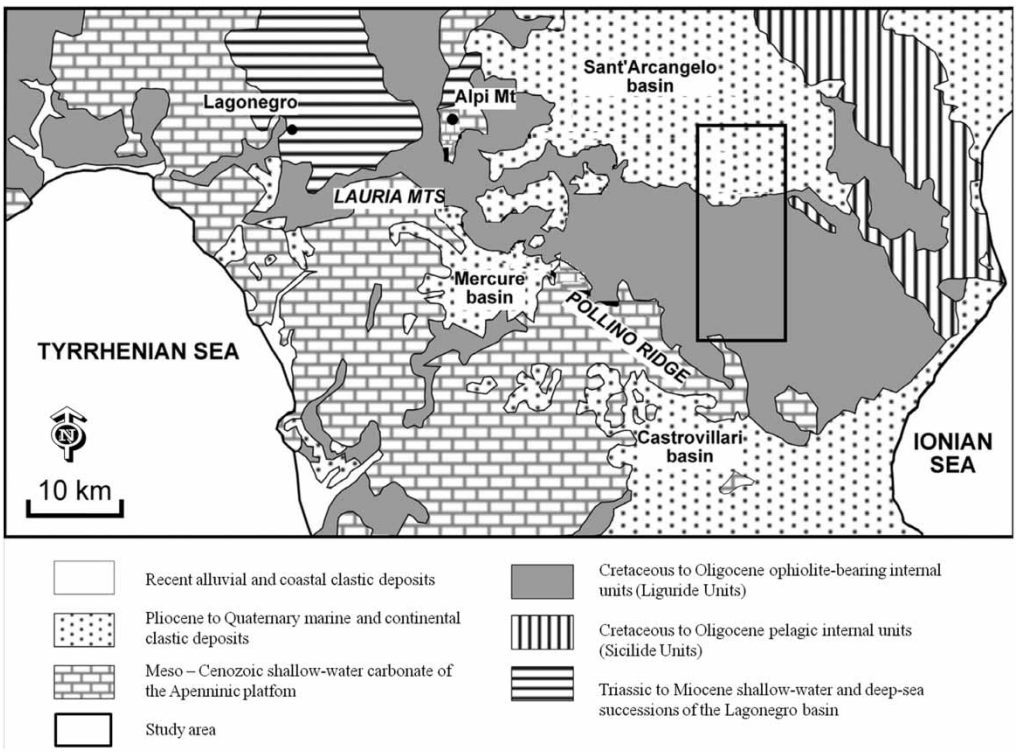

Figure 3. Geological sketch map of the Calabria-Lucania border. (modified from Beneduce et al., 2012).

the top, of Crete Nere, Saraceno and Albidona Fms. Marine to continental Pliocene-Pleistocene coarse-grained and pelite successions of the Sant'Arcangelo Basin (Beneduce, Di Leo, Giano, & Schiattarella, 2012; Giannandrea & Loiacono, 2003; ISPRA, 2011) in the study area are present and unconformably overlie the tectonic and stratigraphic units in the northern portion of the Calabria-Lucania border (Figure 3).

The main lithologies recognized in the study area are carbonate rocks, schist and metabasite rocks, flyschoid rocks, sandy deposits, conglomeratic deposits, slope and/or landslide deposits and alluvial deposits (Figure 4). The carbonate rocks, exposed in the southern sector of the study area, are represented by Triassic-Jurassic, carbonate-dolomite successions. The flyschoid rocks, represented by deep deformations, are middle Triassic to Eocene Flysch and made up of clay, silty clay marl, siltstone, sandstone and marly limestones. These deposits belong to several units, in different palaeogeographical domains, such as the Liguride (Crete Nere, Saraceno and Frido Formation) (Perri et al., 2012), and the Sicilide (Argille Varicolori Fm.) palaeobasins (Bonardi et al., 1988; Critelli et al., 2011, 2013).

The sandy, clayey and conglomeratic deposits belong to the Lower Pliocene to Pleistocene Sant'Arcangelo basin infill. Finally, alluvial deposits fill the main valleys.

The geomorphological setting reflects the complex interplay between geological and structural conditions of the study area. The upper and middle sectors of the basin are characterized by mountainous to hilly landscapes. The rough landforms, formed on carbonate and metamorphic rocks, contrast with the gentler slopes and wider valleys formed on soft rocks. In addition, this part of the catchment is characterized by breaks of slope and strike-valleys controlled by structure. In these areas, the dominant slope processes are related to mass movements.

Mesas formed in Pliocene to Pleistocene clastic sediments are primarily found in the lowest sector of basin. These landforms are dissected by narrow V-shaped valleys with steep slopes, along which landslides often occur. In addition hillslopes carved into sand and conglomeratic deposits, are locally affected by slope wash processes (sheet, rill, and gully erosion). These hillslopes are also often deeply gullied as a result of erosion caused by ephemeral streams (Conforti et al., 2011; Lucà, Conforti, & Robustelli, 2011). Gully landforms are characterized by vertical sidewalls, with a high degree of lateral expansion in relation to head retreat or linear advance due to the frequent failure of gully walls.

A large alluvial fan occurs at the confluence of the Rubbio stream with the Sinni River. Minor alluvial fans were also mapped along the confluence of several tributary valleys of the main water courses.

4. Mass movements inventory mapping

A detailed mass movement inventory map of the Rubbio basin was compiled at a scale of 1:25,000 (Main map). The geomorphological survey shows that mass movements are widespread in the study area and locally play an important role in present-day landscape evolution. Mass movements also represent one of the main geo-hazards as shown by slope instability along the roads and near several houses.

The 175 mapped landslides cover an area of about 16.2 km^2, corresponding to 9% of the investigated area. The landslide frequency is about 3.2 landslides/km^2 and the mean landslide area is 92,714 m^2 (ranging from 7167 to 736,814 m^2).

The spatial distribution and type of mass movement is closely related to the geological and morphological setting, including structural-stratigraphic setting (alternating weak and hard rocks) and fluvial undercutting (Conforti, Pascale, Pastore, Pepe, Sdao & Sole, 2012b; Conforti, Pascale, Pepe et al., 2013; Robustelli, Muto, Scarciglia, Spina, & Critelli, 2005). The interaction between landsliding and lithology shows that mass movements mainly affect slopes carved in

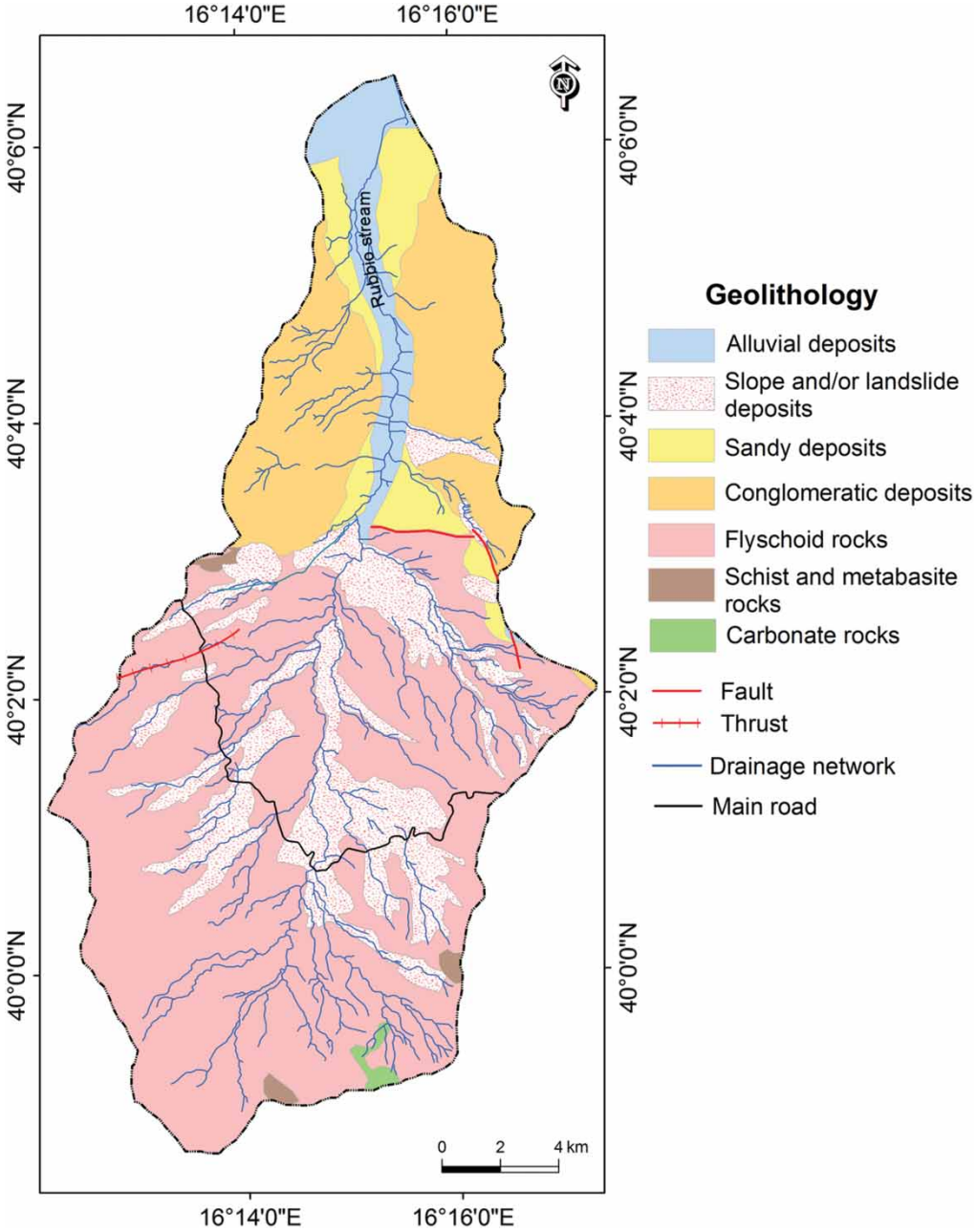

Figure 4. Geolithology map of the study area.

flyschoid rocks and sandy and conglomeratic deposits. In areas where Flysch lithotypes crop out, the landslide type is closely linked to the prevailing lithology and the degree of fracturing. Moreover, a chaotic and disorganized tectonic assemblage (joints, faults, foliation and bedding), further promotes mass movements (Conforti et al., 2012a). Structural discontinuities provide high permeability and deep weathering of rocks, which have a strong influence on slope instability.

Table 1. Distribution of type, activity, number and area of mass movements mapped in the Rubbio stream catchment.

	Mass movement type											
	Slide			Flow			Complex			Total		
	N	Area		*N*	Area		*N*	Area		*N*	Area	
Mass movement activity	(−)	km^2	%	(−)	km^2	%	(−)	km^2	%	(−)	km^2	%
Active	15	0.8	4.9	2	0.1	0.6	19	1.9	11.7	36	2.8	17.3
Inactive	60	4.6	28.6	21	3.1	19.1	58	5.7	35.2	139	13.4	82.7
Total	75	5.4	33.2	23	3.2	19.8	77	7.6	46.9	175	16.2	100.0

Taking into account the Cruden and Varnes (1996) classification, the mapped landslides were classified on the basis of the prevalent type and activity of movement (Table 1). Mass movements in the study area include slides (both translational and rotational) (42.9%), flows (13.7%) and complex mass movements (43.4%).

Table 1 shows the spatial distribution of the different mass movement types. Complex landslides, characterized by the combination of two or more types of movement, are very common and represent about 47% of the unstable area. Rotational slides, that evolve into earth or mud flows,

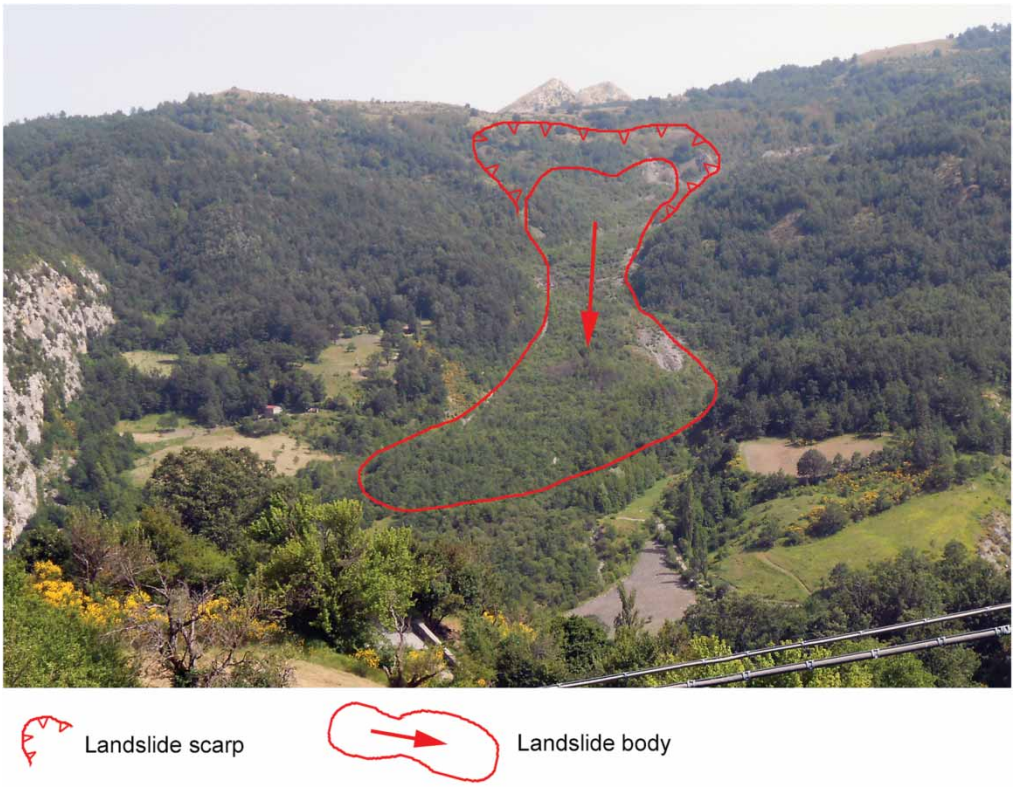

Figure 5. Overview of large earth flow.

are the most frequent. Complex landslides affect mainly slopes carved into Flysch rocks with high clay content.

Slides, mainly rotational, represent more than 33% of the landslide area; they occur where Flysch rocks, sandy deposits and conglomeratic deposits crop out. Translational slides are frequent along planar slip surfaces; in particular, they develop on slopes underlain by alternating clay, limestone and marly limestone, where shear stress is parallel to the dip of the strata.

Flows, accounting for 18.8% of unstable areas, are mainly earth flows (Figure 5); they usually involve clayey-Flysch rocks and old landslide deposits (Figure 4). Also, flow-type landslides were observed on the slopes characterized by concave morphology. The source areas of many mapped flow-type mass movements consist of several coalesced landslide scarps, with elongated accumulation zones ending in fan-shaped toes. During the field survey it was observed that many shallow landslides are active within their source areas, which causes a retrogressive evolution, or retreat of the scarps.

Multi-temporal aerial photo interpretation and field surveys allowed us to evaluate the activity of the mass movements (Table 1). Landslides that showed signs of activity after 2006 were considered active (e.g. bright light colors on the aerial photos, unvegetated landslide area, cracks visible in the source area, and a distinct bulge at the toe). Among the recognized landslides, 20.6% were assessed as active and the remaining 79.4% were considered inactive. Many active landslides are a reactivation of pre-existing dormant landslides. In addition, the analysis showed that the dominant evolutionary trend of landslides is retrogressive and/or enlarging (*sensu* Cruden & Varnes, 1996). Activation and/or reactivation of landslides occurred during heavy strong or prolonged periods of rainfall (Clarke & Rendell, 2006; Naudet et al., 2008; Polemio & Sdao, 1998).

5. Conclusions

Geomorphological analysis, obtained through multi-temporal aerial photo interpretation, field surveys, and data processing within a GIS, allowed the mapping of slope instability in the Rubbio stream catchment (Main map). This area is representative of south-eastern Basilicata (South Italy), where the landslides represent the main agents of the evolution of relief and one of the most common geohazards. Many buildings and other infrastructure are damaged and/or destroyed by mass movement activity.

A geomorphological survey showed that lithology and structural features are the main factors influencing the spatial distribution of slope instability. In particular, mass movements mainly affect slopes carved in flyschoid rocks with high clay content and along slopes with rocks strongly fractured and weathered.

Within the study area, 175 mass movements were mapped; they occupy a surface area of about 16.2 km^2, corresponding to 9% of the study area. From the total landslide number, 20.6% were mapped as active and the remaining 79.4% as temporarily inactive. Many active landslides represent a reactivation of pre-existing inactive landslides.

Complex and slide types of mass movement are widespread, and account for 80.1% of the unstable area.

Finally, the collected data were managed within a GIS, which allowed us to develop a cartographic tool that can be constantly updated and improved with new studies. The mass movement inventory map could also be used for landslide hazard and risk assessment.

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Software

The topographic base, the mass movements map and related layout were produced using ESRI ArcGIS 9.3. Data collected were georeferenced and digitized before being stored in a relational geodatabase containing attributes of the main observed features, for each mapped geomorphic process.

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