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SCIENCE

Large-scale landslide and deep-seated gravitational slope deformation of the Upper Scrivia Valley (Northern Apennine, Italy)

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The Scrivia river is a right tributary of the Po river, the main Italian water course, which flows eastwards into the Adriatic Sea. The head of the Scrivia valley is located in the Northern Apennines, a very short distance from the Ligurian Sea. Its catchment is characterized by landslide areas greater than both the regional and national average. In this work, the causes of this high landslide density have been investigated and a large-scale map of landslide phenomena is produced. Based on geomorphological constraints, several previously unknown deep-seated gravitational slope deformations (DSGSDs) were also identified. DSGSDs have been distinguished in sackungen and lateral spreads. Their characteristics were analyzed in a geographical information system (GIS) environment and compared with landslide distribution. Field surveys, aerial photo-interpretation and GIS analyses led to the production of a large-scale landslide and DSGSD overview map at 1:35,000. The massive presence of DSGSDs and their connection to landslide distribution and activity raise important implications for both geological mapping and land planning.

Keywords: mass movement; sackung; lateral spreads; natural hazards; land planning

1. Introduction

Landslides are the most frequent natural hazard in the Italian territory. According to the Italian Inventory of Landslides phenomena (IFFI = *Inventario dei Fenomeni Franosi Italiani*), there are approximately 470,000 landslides in Italy covering an area of 20,000 sqkm, roughly 7% of the country (Istituto Superiore per la Protezione e la Ricerca Ambientale [ISPRA], 2008). Although casualties and damage are fewer than those caused by earthquakes, over the last 25 years, a number of catastrophic events occurred, that is, the landslides of Stava Valley (1986), Pola Valley (1987), Sarno and Quindici (1998), Canale Valley, Maierato and Messina (2010), and in Liguria, Varazze and Sestri Ponente in 2010 and Cinque Terre in 2011. Conclusions drawn by the Intergovernmental Panel for Climate Change (IPCC, 2013) agree in considering climate changes as the most frequent trigger mechanism of these natural events and similar conclusions have been suggested by several studies on local climatology (Faccini, Robbiano, &

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Sacchini, 2012; Pasquale, Russo, Sacchini, & Verdoya, 1994; Russo, Eva, Palau, Caneva, & Sacchini, 2000).

Liguria region presents geological, geomorphological, hydrogeological and climate features predisposing for landslide hazards (Cruden & Varnes, 1996; Popescu, 2002; Varnes & IAEG, 1984); the IFFI inventory describes 7500 landslides, about the 8% of the regional territory (Figure 1) and, among these, identifies the 20% of active landslides, characterized by recent movements. The majority of these landslides are of complex type, followed by slide; other types are less frequent at least by one order of magnitude, including the d*eep-seated gravitational slope deformations* (DSGSDs), which, by their nature, have a wider extent but are fewer in number.

The Ligurian sector of the northern Apennines presents a landslides' density greater than both the regional and national average; in this context, this work investigates the Ligurian Scrivia Valley, corresponding to the upper sector of the catchment, where the listed IFFI landslides cover more than 10% of the total area.

2. Geology of the study area

The Scrivia river is a right tributary of the Po river, converging with it after flowing north for about 100 km (Figure top left on the map). The Scrivia trunk channel winds across Liguria for about 50 km (Figure 2) and its total catchment area is spread over 500 sqkm (over 250 sqkm in Liguria). Its valley head represents the southern watershed of the Po river valley and reaches a distance of 15 km from the Ligurian coast. The highest peak in the Ligurian sector of the divide is Mt. Antola (1597 m). The watershed passes here at very low altitudes: the Crocetta d'Orero gap (465 m a.s.l.) is the lowest sector of the entire Po–Ligurian divide. Thanks to its geographical features, the Scrivia Valley has been the main communication route since Roman Age between the Po catchment and the port of Genoa; during the Middle Ages, the 'salt routes' and trade roads of the Genoa Republic crossed this area connecting Europe to the Mediterranean Sea; more recently, the first railway line (1859) between Genoa, Turin and Milan, the ancient State Road n. 35 'dei Giovi' (1821) and one of the earliest Italian motorways (1936) – the current

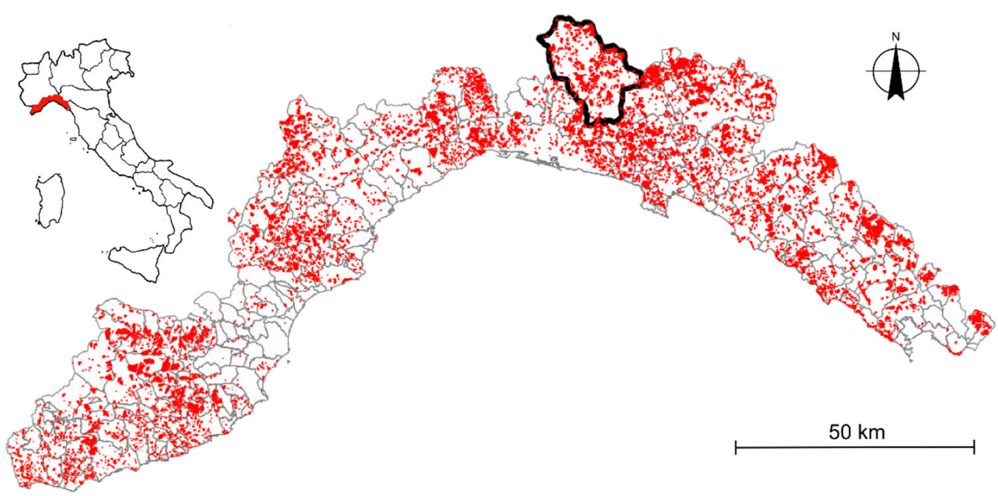

Figure 1. Overview map of Ligurian landslides from IFFI Project database (ISPRA, 2008). Black bold line indicates the Ligurian catchment of the Upper Scrivia valley.

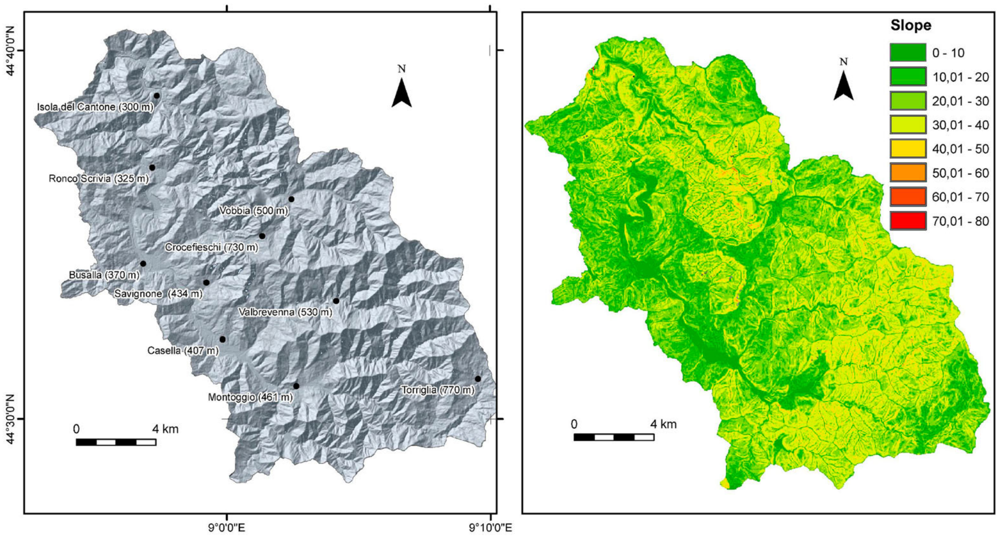

Figure 2. Ligurian catchment of the Scrivia Stream (Digital Terrain Model 5 m resolution) and map of slope gradient (right).

A7 – were built here from 'Passo dei Giovi' and Busalla to Isola del cantone. Nowadays, new major railway networks of European strategic value have been planned here through the so-called *Terzo Valico* (Third Pass) from Genoa to the Po river plain.

Geological data as well as general tectonics and landslide diffusion in the Upper Scrivia Valley have been previously studied (Ellero, 2000 and references therein). The valley registered both Alps and Apennines tectonic deformations and presents rock masses with different geomechanical characteristics; it represents therefore a good case study for investigating large-scale slope dynamics. The area is characterized by several geologic formations along the Alps–Apennines junction, right to the east of the Sestri-Voltaggio zone (Agenzia per la Protezione dell'Ambiente e per i Servizi Tecnici [APAT], 2008) (Figure 3).

Geological Formations' ages range from the Cretaceous to the Miocene: the oldest is represented by the Valpolcevera Flysch Units, with shales (Mignanego, Montanesi and Ronco Shales) outcropping in the middle sector of the Scrivia Valley; the flysch of the Mt. Antola Formation (Antola Unit, Upper Cretaceous) overlies the Valpolcevera Flysch Units in the upper sector of the valley and all along the right slope, it outcrops in the lower valley too in the area between Ronco and Isola del Cantone (Figure bottom left in the map). This flysch is mainly composed of marly limestones, its base – the Montoggio Shales – discontinuously outcrops between Montoggio and Isola del Cantone, generally in very small sectors (APAT, 2008; Ellero, 2000).

The Valpolcevera Flysch Units are mainly composed of turbidites with shales and sporadic marly limestones. They formed at the beginning of the Upper Cretaceous in the abyssal plane of the Ligurian–Piemontese Ocean.

The Valpolcevera Flysch Units are overlaid by a short episode of tiny bedded emipelagic argillites (Montoggio shales) that represent the pavement of the Monte Antola Flysch Unit. This is characterized by marly turbidites with sandy and shale interlayers that represent the top of the coverage of the Ligurian–Piedmontese Ocean, spanning in age from the Upper Cretaceus to the Paleocene.

Oligo-Miocene Formations can be observed in the north of the study area, between the central valley and the piedmont confluence with the upper plain. These formations belong to the Tertiary

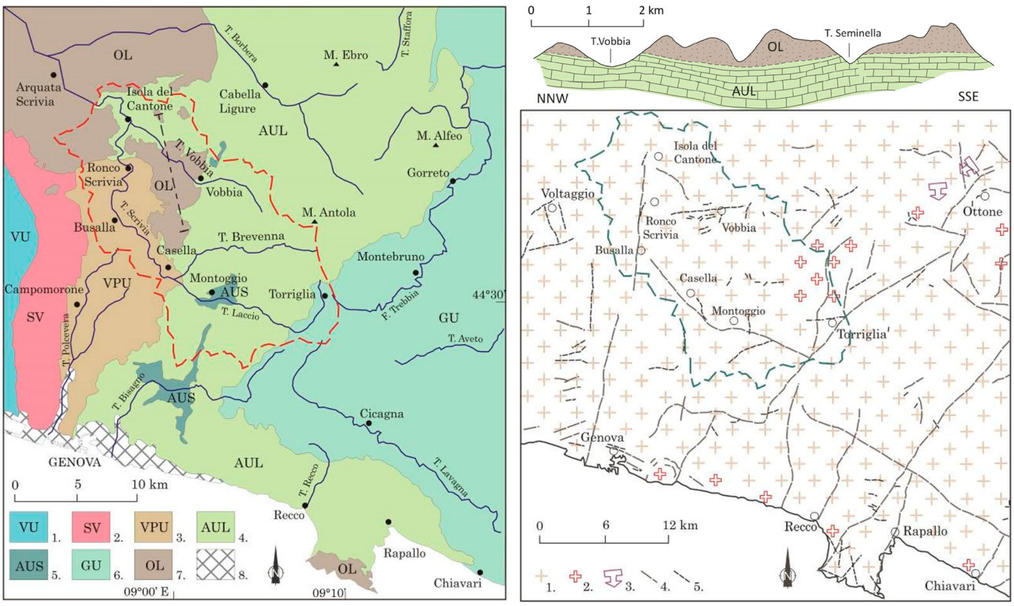

Figure 3. Geological-tectonic sketch map (left). Legend: (1) VU: Voltri Units; (2) SV: Sestri-Voltaggio zone; (3) VPU: Valpolcevera Flysch Units; (4) AUL: Antola unit, marly-limestone flysch; (5) AUS: Antola unit, Montoggio Shales; (6) GU: Gottero unit; (7) OL: Oligo-Miocene formations and (8) Genoa Urban area; black dashed dotted line indicates the geological -section trace and red dashed line indicates the Ligurian catchment of the Upper Scrivia valley. Neotectonic sketch map (right, modified from Fanucci & alii, 1980). Legend: (1) relative uplift; (2) absolute uplift; (3) differential uplift, the arrow show the lowest area; (4) direct fault and (5) tectonic lineation. Green dashed line indicates the Ligurian catchment of the Upper Scrivia valley.

Piedmont Basin (BTP, *Auctt*) and can be referred to as the Molare Conglomerates and Savignone Conglomerates (APAT, 2008, in press; ISPRA, in press). These polygenic fan-delta conglomerates outcrop in the Vobbia Valley and in the upper Scrivia valley between Mt. Maggio (Savignone) and the Borbera Valley along the right slope (Savignone Conglomerates) and between Mt. Porale and the Lemme Valley along the left slope (Molare Conglomerates) (Figure 3).

The valley's position between the Alps and the Apennines suggests that it was likely involved in both the Alpine and Apennines deformations: at least three alpine deformation phases with ductile behavior occurred with the Cretaceous Flysch involved in the closure of the Ligurian–Piedmontese Ocean (from the Upper Cretaceous to the Eocene). Furthermore, the Oligo-Miocene Units together with the Cretaceous Units, in addition to an alpine deformation phase, underwent the Miocene Apennines deformation phases with ductile–brittle behavior (APAT, 2008, in press; ISPRA, in press).

Shale formations, in particular, were greatly deformed by both Alps and Apennines folding stages as well as the marly-limestone flysch, which is harder and with less ductile rheological characteristics. Conglomerates – which join, at the Oligocene base, the Alpine and Apennines formations of this slope sector – were involved in the Apennines deformations and present a brittle behavior.

Morphotectonics strongly influence the geomorphological evolution of this sector of the Ligurian Apennines (Fanucci & Nosengo, 1979): the area undergoes a general, low-rate uplift with a fault system that gives rise to different blocks with variable responses to regional tilting (Ferraris, Firpo, & Pazzaglia, 2012; Lorenz, 1986).

Several landslides affect the valley, as well as landforms formed by gravity-induced processes and/or related to the action of running water on slopes and on in the river. Large-scale landslides have been mapped in this study. Although the valley is close to the sea, it is characterized by a climate of transition towards continental conditions; pluviometric features depend on weather conditions of the Ligurian central area (the ‘Genoa Low’ atmospheric circulation). A high total amount of precipitation is measured here (Sacchini, Ferraris, Faccini, & Firpo, 2012) with an annual mean rainfall between 1000 mm and more than 2000 mm; temperatures and snowfall are similar to those of the inner Po valleys, with annual mean values between 8°C and 12°C and an average winter minimum of about 0°C, despite the low altitude and proximity to the sea.

3. Material and methods

Field surveys have been extensively carried out throughout the Ligurian area of the Upper Scrivia Valley. To reconstruct the recent geomorphological evolution of the area, aerial photographs from 1954 to 2006 have been analyzed and compared with older photos and historical maps. Final mapping has been performed using a geographical information system (GIS) at 1: 35,000 scale.

All the landslides reported in the IFFI project (ISPRA, 2008) as well as the studies produced by the Po River Authority (Hydrogeological Master Plan) have been considered. Geological data have been derived from published geological maps (APAT, 2008, in press; ISPRA, in press; Servizio Geologico d’Italia, 1969, 1971) and implemented by field observations.

Geomorphological and engineering–geological mapping has been performed following guidelines proposed by the Italian Geological Survey (Servizio Geologico Nazionale, 1994, 2007) and relying on recently published landslides maps (Ardizzone et al., 2012; Ciampalini et al., 2012; Faccini, Piccazzo, Robbiano, & Roccati, 2008; Guerrero et al., 2012; Radbruch-Hall et al., 1982) and susceptibility assessment for planning studies (Melzner, Lotter, Tilch, & Kociu, 2011).

Guidelines consider the representation of the gravity-induced landforms to be summarized in: (i) landslides deposits, (ii) erosion landforms and (iii) DSGSDs.

Large-scale landslides have been sorted following Varnes’ classification as fall, slide (rotational or translational), flow and complex. Furthermore, active forms, that is, landslides that during field survey showed evidence of activity, have been distinguished from non-active forms. Erosional landforms reported on the map were landslide escarpments, steps, counterslopes, closed depressions and trenches.

On the basis of geomorphological constraints, several DSGSDs were also mapped; according to their main dynamical behavior, they were distinguished in sackungen and lateral spreads. Lastly, DSGSD distribution and their relative surface were analyzed within a GIS.

A high-resolution digital elevation model (DEM) (5 m), distributed by Regione Liguria, has been used as a topographic base and analyzed in Esri ArcGIS for the subsequent shadow relief representation and slope map. The shadow relief is an ideal base for geomorphologic maps, thanks to its clear rendering of valley floors and relief forms. The slope map is particularly useful for the study of landslides and deep-seated gravitational slopes movements.

Anthropic landforms have been excluded from the base map in order to avoid intense overlapping between geomorphological deposits and other topographic forms; the main inhabited centers and their respective elevation have been mapped instead.

4. Large-scale landslides and DSGSDs map

Several faults and the ongoing uplift of the entire area provide evidence for Pliocene and Quaternary tectonics (Figure 3) (Fanucci, Pintus, Tedeschi, & Vignolo, 1980; Ferraris et al., 2012). Recent tectonic forcing is also confirmed by river terraces at various altitudes, embanked meanders and drainage capture, in addition to general slope rejuvenation. All of these contributing factors strongly influence valley slope evolution.

4.1. *Landform deposits*

On the Main Map, we represented a Landslides Index related to landslide frequency on each lithotype. The Landslides Index is calculated for each bedrock type and is the ratio between the landslide area and the total area. Conglomerates cover less than 50 sqkm within the basin, with 11% covered by landslides; marly limestones, cover 190 sqkm, with a Landslide Index of 10%; shaly flysch and marls cover more than 60 sqkm, with 8% covered by landslides. Slope analysis shows that 40% of landslides develop on gradient values around 50%.

The majority of geomorphological features highlighted on the map consist of gravity-induced processes and running water-related landforms and deposits. Landslides, debris cover, alluvial fans and deposits (highlighted by the DEM-derived cartographic base) are the most typical landforms of the Scrivia valley. This is also characterized by a limited hydrographic network, which frequently develops along tectonic lineations, as well as by incised sectors with high relief energy (Biancotti & Cortemiglia, 1982). All the most relevant geomorphological landforms and processes appear to be linked to the presence of large-scale landslides and DSGSDs.

Landslides are distributed all over the valley and characterize every rock mass type (see statistics), as reported in the geo-lithological sketch map (Figure 4). They are for the most part complex landslides (almost 200) followed by rock falls, flows (around 150) and slides (more than 100). In addition, a number of DSGSDs (more than 50) were mapped. Performing an analysis of the extent, we observed that DSGSDs cover over 25 sqkm while the sum of all other kinds of landslides covers about 30 sqkm (figures top center). Almost half of DSGSDs cover an area of more than 1 sqkm each (figure and tables bottom center); there are more sackung-like movements (32) than lateral spreads (17), but the latter cover on average a larger area (0.696 vs. 0.452 sqkm). The majority of landslides develops within DSGSDs and present slow movements, with the exception of smaller ones, often characterized by falls along the valleys slopes and in the vicinity of road cuts. Many small villages rise up in areas covered by landslides, some of those required expensive safety measures even if mostly characterized by few movements. The main ones are the landslides of Arezzo (Vobbia), Savignone, Bastia (Busalla), Casabianca (Torriglia), Vallegge (Crocefieschi), Pietrafraccia (Ronco Scrivia) and Monte Porale (see Main Map). Some villages present unstable escarpments with fast fall phenomena, for example, around Monte Maggio and Rocca della Cappelletta (Crocefieschi). Other photographic examples of landslides and morphotectonic elements are reported in Figure 5.

4.2. *Erosion landforms*

Among the erosion landforms, some active fall escarpments are notable. They form predominantly on conglomerates, especially where these come in contact with more ductile lithotypes such as clayey flysch; good examples are in the area of Monte Maggio and around Monte Porale and Bric Castellazzo.

Other fall escarpments border those areas undergoing active landslides. The majority of instability phenomena develop in the ridge–slope–valley floor system (Hutchinson, 1988; Jaboyedoff, 2011); these phenomena can be related to DSGSDs that are highlighted by specific erosion landforms, such as closed depressions often featuring swampy deposits, trenches at metric scales (Monte Cravì and Monte Porale), steps affecting the whole slope (Monte Maggio), para-karst landforms (Monte Porale Isola del Cantone), reverse scarps (Monte Porale

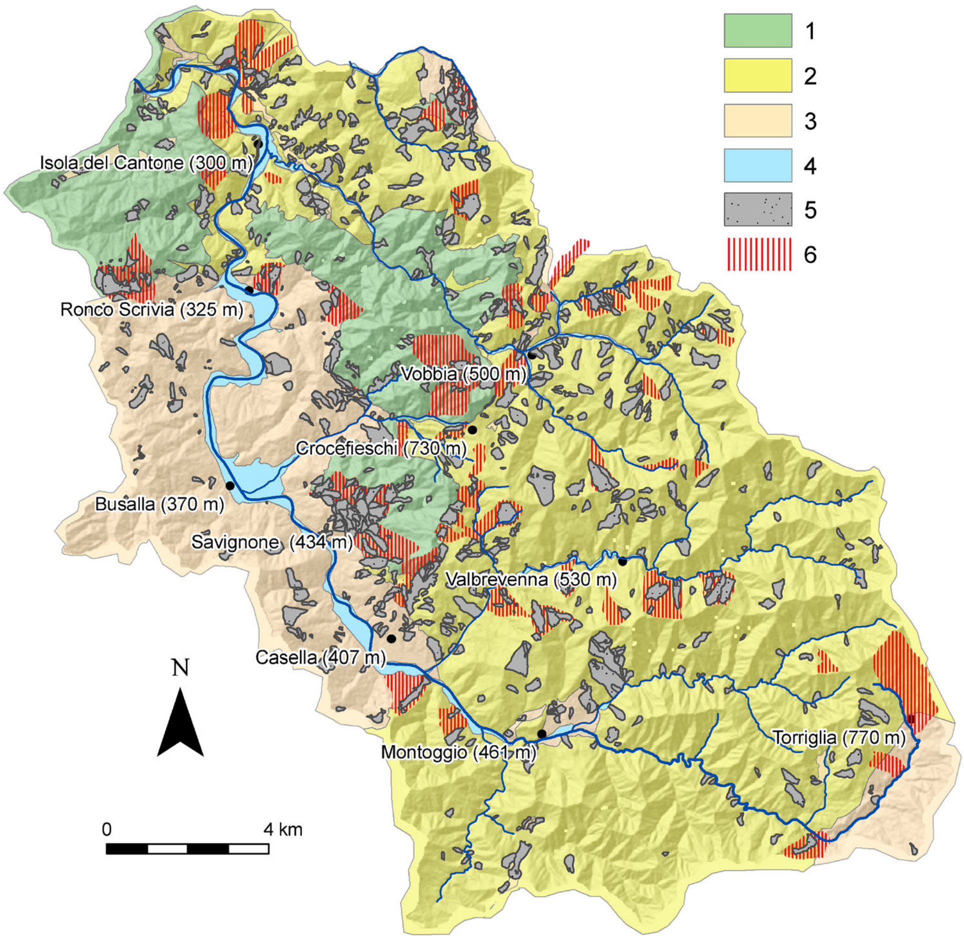

Figure 4. Geo-lithological sketch map of Upper Scrivia valley with semi-quantitative petro-physical parameters. Legend: (1) conglomerates (good quality rock masses); (2) marly limestone (fair quality rock masses); (3) shales, sandy shales and marls (poor quality rock masses); (4) alluvial deposits; (5) large-scale landslide and (6) DSGSD.

and Torriglia), low ridges, collapsed or zigzagged watershed (Arezzo di Vobbia and Monte Buio) and double ridges (Rocche del Reopasso) (Figure 6).

4.3. *DSGSDs*

DSGSDs are related to slope movements such as rock flows, deep rock slides (classified as sackung) and lateral spreads, which occasionally develop into rock avalanches at a paroxysmic stage (for example at Sorrivi, between the towns of Savignone and Valbrevenna). Despite sackung-like mass movements prevailing in number (Arezzo di Vobbia and Isola del Cantone), the largest DSGSDs consist of lateral spreads (Monte Maggio, Monte Porale and Rocche del Reopasso), probably thanks to their dynamics.

DSGSDs have been found along the entire valley, mainly on conglomerates and on marly-limestone flysch, particularly where they come in contact with shaly flysch. The DSGSD trend depends on lithotechnical and tectonic factors, since they are located at contacts between

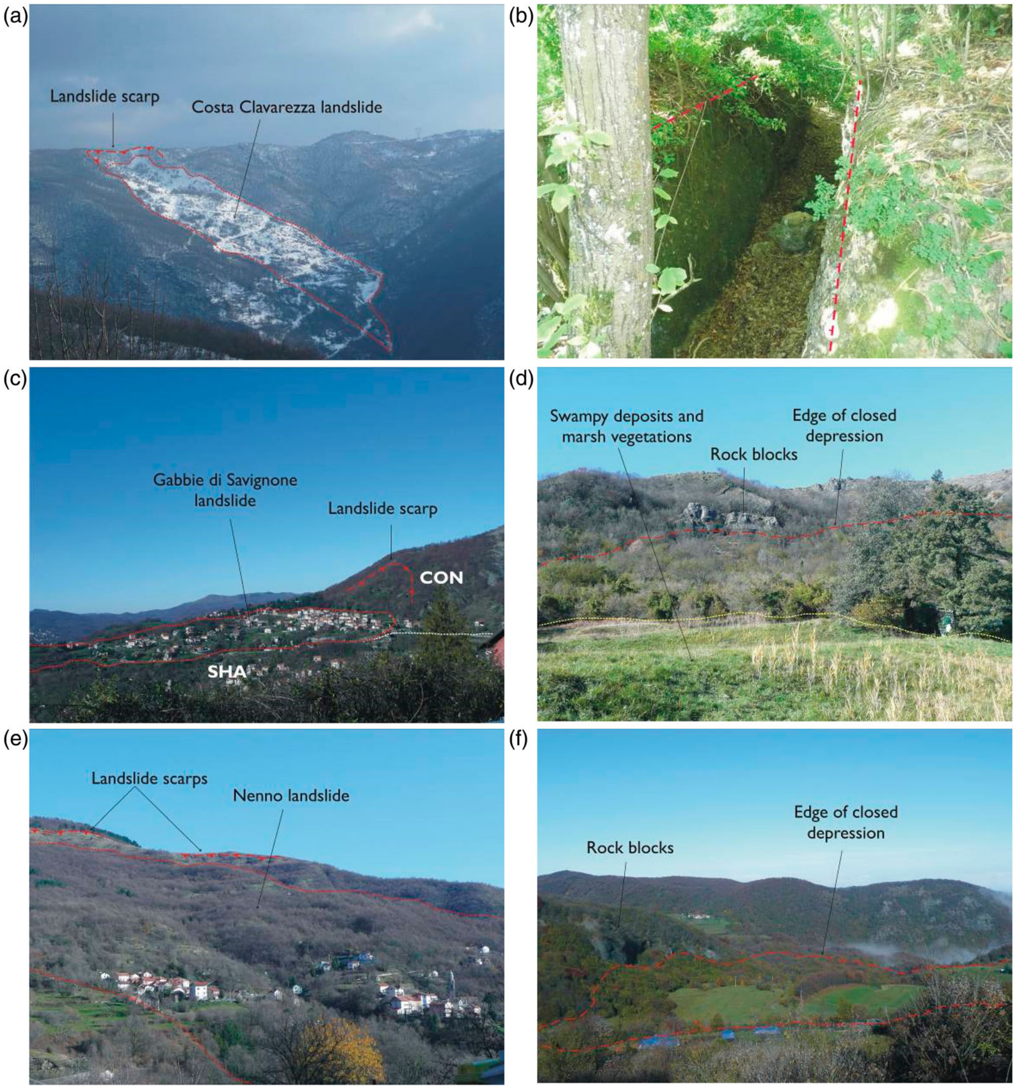

Figure 5. Large-scale landslides types and morphotectonic elements. (a) Costa Clavarezza complex landslide (Vobbia valley) highlighted by snow cover; (b) Trench in a slope near Crocefieschi (Vobbia river valley); (c) Savignone village on landslide deposits downslope of a conglomerate escarpment; (d) counterslope bordering a closed depression with swampy deposits and marsh vegetation close to Mt. Porale; (e) Nenno village complex landslide downslope of scarps in marly limestone and (f) lower part of the Case Tanadorso lateral spread above the contact between clays and conglomerates.

lithotypes with different geomechanical behavior and within the Mt. Antola Flysch, generally characterized by heterogeneous rock masses (Hoek, Marinos, & Marinos, 2005). A crucial condition seems to be the contrast between brittle and rigid rocks overlying ductile rocks (Poisel & Eppensteiner, 1988) such as conglomerates on flysch, or marly limestone on argillite or on shaly flyschs (hard on soft rocks). Possible influences from an acquifer–aquiclude system suggested from the rock succession and water springs distribution have not been considered because of the lack of available data.

Figure 6. Pictures of six case studies; (a) Gabbie di Savignone: lateral spread phenomena Conglomerate/Shales contact; (b) Prarolo (Isola del Cantone): blind valley on the right along a slope characterized by para-karst forms (sinkholes); the profile simulates a valley trend determined by the core of an anticline where the weak Montoggio Shales outcrop; (c) Cipollina (Ronco Scrivia): wide reverse slope and closed depression at Case Porale with marsh vegetation; (d) Sorrivi: scarp/counterscarp slope around the Conglomerate and marly-limestone contact. The conglomerate block is tilted and the slope below the village is characterized by massive presence of rock blocks; (e) Arezzo di Vobbia: note the low ridge and stepped profile. The village lies on an active landslide and (f) Bric Castellazzo at Montessoro (Isola del Cantone): low ridge simulates a syncline strata bedding. Note the complex landslide scarp.

On the Main Map, we report indices related to bedrock underlying DSGSDs: the majority of DSGSDs (30%) develop among marly limestones (the prevailing lithotype within the study area); 28% develop at the contact between marly limestones and shales; 17% at the contact between conglomerates and shales; 10% of DSGSDs develop on conglomerates and another 10% develop at the contact between conglomerates and marly limestones.

Of particular interest is the location of DSGSDs at the contact among conglomerates, limestones and shales. This is infrequent in the valley but always linked to slope instability (Sorrivi, Mt. Cravì).

Statistics related to slope gradient highlight a prevailing presence of DSGSDs on gradient values ranging from 16% to 45%, lower values in comparison to average values obtained for large landslides.

The scheme in Figure 7 displays the main morphological characteristics of different types of DSGSDs. The geomorphological cross-sections show various gravity- and tectonic-induced slope dynamics such as sackung (rock mass flow and rock mass slide) at Prarolo, Nenno and Arezzo di Vobbia, lateral spread nearby Gabbie di Savignone and Sorrivi, double-sided compound sagging and spreading at Tanadorso–Cipollina and Montessoro.

Cross-sections correspond to six different DSGSD types, chosen on the basis of geologic and geomechanic features. Each one presents specific geomorphological characteristics, slope dynamics and landslide types.

1. DSGSDs on the Mt. Antola Formation, made up of marly limestone with thin clayey shale interlayers (MLS).
2. Case studies at the contact between the Savignone Conglomerates and Montoggio Shales (CON–SHA).
3. Case studies at the contact between the Molare Conglomerates and Montanesi argillitic flysch (CON–SHA).
4. DSGSDs at the contact between the marly-limestone flysch of Mt. Antola and the base complex of the Montoggio Shales (MLS–SHA).
5. DSGSDs at the contact between the Savignone conglomerates and marly limestones (CON–MLS).
6. Complex situations at the contact between the Savignone Conglomerates, marly-limestone flysch and the base of the Montoggio Shales (CON–MLS–SHA).

The 'MLS' DSGSD type can be observed in the section at Arezzo di Vobbia, Nenno, Pratolungo di Montoggio and Piani-Frassineto. This is determined by dynamics such as deep rock flow or deep rock slide, in particular on an unfavorable structural setting with prevailing clay shale interlayers at the valley floor; it is often linked to landforms such as scarps and counterscarps, zigzagged or collapsed watersheds, para- and pseudokarstic landforms and a wide diffusion of complex or flow landslides.

The 'CON–SHA' type outcrops around Gabbie and Savignone (as shown in the section), close to Mt. Maggio, at Minceto (Ronco Scrivia) and at Bastia (Busalla). It is mainly associated with lateral spreading; it shows landforms such as spread rock blocks, closed depressions, trenches, scarps and counterscarps, para- and pseudokarstic forms and a wide diffusion of flow landslides.

Another 'CON–SHA' type with different conglomerates and shales formations is found on the Mt. Porale area at Ronco Scrivia and it is mainly associated with deep phenomena such as lateral spreading and double ridges. It shows mechanisms of the 'double-sided compound sagging' (Hutchinson, 1988) type with closed depressions, scarps, counterscarps, trenches and a number of flow landslides.

The 'MLS–SHA' type is found at Isola del Cantone, Montoggio and Torriglia and shows phenomena of both deep rock flow and lateral spreading with counterscarps, para and pseudokarstic landforms, trenches, rock block collapses and a wide diffusion of complex landslide, mainly due to the slides and flows.

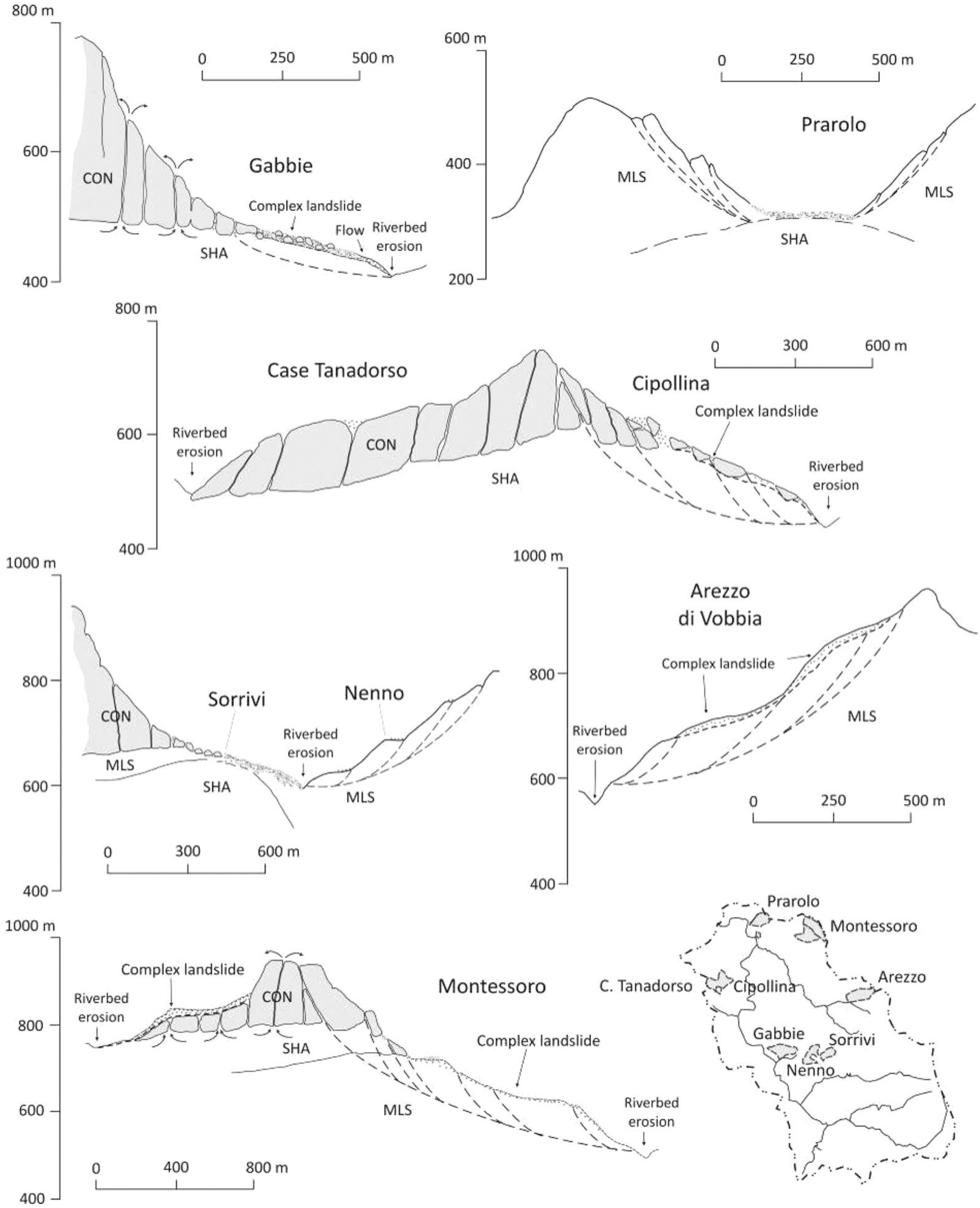

Figure 7. Geomorphological cross-sections of six different case studies (Gabbie di Savignone, Prarolo, Case Tanadorso e Cipollina, Sorrivi e Nenno, Arezzo di Vobbia, Bric Castellazzo e Montessoro) of large-scale landslides and DSGSDs. MLS: marly limestone with shale interlayers, CON: Conglomerate, SHA: mainly shales.

A situation similar to the second type of 'CON−SHA' can be observed near the contact between the Savignone Conglomerates and a marly-shaly facies of the Mt. Antola Flysch (CON−MLS) at Bric Castellazzo on both slopes of the Spinti Valley and Bovegna Stream (at Montessoro, near Isola del Cantone): this presents double-sided compound sagging, closed depressions, trenches and slides.

The Mt. Antola Formation generally shows a brittle behavior although locally, where ductile lithotypes outcrop (mainly argillitic facies of the marly-limestones formation and its Paleocene covers), it exhibits a greater deformability.

The last type is the most complex one and is located at the contact between formations with different rock deformability (CON–MLS–SHA). It mainly occurs at Sorrivi (Savignone) and Mt. Cravì (Vobbia). Saddles and valley bulging, trenches and rock block collapses, para and pseudo-karstic landforms, scarps and counterscarps, closed depressions, a wide diffusion of fall and topple landslides uphill and slide/flow landslides downhill can be found; an ancient rock avalanche at Sorrivi can also be observed.

The same cross-section shows on the opposite slope an example of an 'MLS' type near the village of Nenno.

5. Discussion and conclusion

All the mapped large-scale landslides and DSGSDs are ancient phenomena probably triggered during both the Pleistocene and the last great climate change in the Pleistocene–Holocene transition, when instability increased due to Pleistocene uplift, base-level fluctuations and periglacial evolution effects (Crescenti, Dramis, Prestininzi, & Sorriso-Valvo, 1994). Neotectonics, different geomechanical behavior of rock formations and Quaternary climate change played an important role in valley dynamics, with large water amounts and debris volumes as a consequence of the base-level variations (Dramis & Sorriso-Valvo, 1994; Faccini, Piccazzo, & Robbiano, 2009). Alternation of interglacial and glacial climatic periods in the Quaternary triggered deep-seated gravitational phenomena, occasionally of large size, frequently reactivated by both valley system evolution and seismicity, currently with lower intensity than in the Plio–Pleistocene age.

Recent studies identified several examples of Plio–Pleistocene drainage capture along the Po–ligurian divide (Ferraris et al., 2012). In particular, for the Scrivia valley, we suppose a Quaternary displacement of the divide caused a renewing of instability along the Po slope. This may represent a fundamental triggering factor for DSGDs in the Ligurian Apennines, considering the lack of the glacial instability that affected the Alpine sector instead (Crosta & Clague, 2009).

In this morphostructural scenario, exogenic processes developed – also due to high relief energy – associated with lithotype alteration, running water and gravity-induced action that caused slope instability and landslides. Being typical features of DSGSDs linked to stresses in the ridges for neotectonic activity, geomorphological conditions, structural and rock mechanics (Agliardi, Crosta, & Zanchi, 2001; Dramis & Sorriso-Valvo, 1994) were primary factors; abundant precipitation seems not to be directly related to DSGSD triggering. On the contrary, rainfall is a prominent cause of the current slope condition, superimposed both on large landslides and deep-seated deformations.

The Upper Scrivia Valley landslides are scattered over the entire study area. The main map shows that gravitational processes and landforms deeply characterize geomorphological dynamics of the valley. The gravitational process distribution highlights that the most prominent factor is the widespread presence of DSGSDs. These huge, ancient gravitational phenomena are correlated to several factors such as lithology, contacts between different formations, tectonics and orography. Extent and volumes of these movements play a key role in the field of geological survey and have an important application also in the field of both land planning and monitoring of hazardous situations taking into account climate change on landslide activity (Coe & Godt, 2012; Crozier, 2010; Jakob & Lambert, 2009). The possible building of other infrastructure, roads, bridges and tunnels should take into account the massive DSGSDs distribution. Volumes of slope movements have a greater extent than landslides: the formers involve values at least one size higher than the latter. An integrated monitoring program is needed in order to control the dynamics of these phenomena through the combination of conventional methods with either satellite observations, GPS and topographic and geodetic lines, which accurately represent the deep slope movement.

Software

The geological section and the data set of the map, including the symbols of the geomorphological legend, have been digitized and managed using AutoCAD 2010. The Digital Terrain Model was produced using Esri ArcGIS 9.2.

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