Andic soils and catastrophic mudflows in Italy: Morphological and hydropedological evidences

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Abstract
In Italy rapid landslides are the most frequently occurring natural disasters and, after earthquakes, cause the highest number of victims. In this contribution we attempt to prove that there exists a tight connection between the presence of a specific soil type, namely andic soils, and the occurrence of the main catastrophic mudflows and debris flows occurred in Italy in the last decades. The study was performed by means of an integrated pedological and hydrological analysis on the detachment crowns of some of the most important catastrophic mudflows and debris flows that occurred in Italy in the last decades and involving/evolving surface soils. The results at both regional (Campania) and National (Italy) scale clearly show that despite the large variability of the environmental settings of the studied sites there are indeed some striking homogeneous soil features in the detachment crowns including (i) soil morphology, (ii) andic features ranging from high to moderate, (iii) high water retention throughout a large range of pressure heads. Results seem to reveal clear cause-effect evidences between andic soils and the investigated catastrophic mudflows/debrisflows; this must be related to the unique physical properties of these soils inducing high landslide vulnerability.

Key Words
Landslide, hydropedology, andic soils

Introduction
Due to its relief and its lithological and structural characteristics, Italy is a country where landslides are the most frequently occurring natural disasters and are the cause, after earthquakes, of the highest number of victims. The national landlslide inventory database (IFFI) surveyed 482,272 landslides covering an area of almost 20,500 km^2, which is equivalent to 6.8% of Italy. In such scenario rapid mudflows (and debrisflows) are among the major catastrophic types of landslides occurring in Italy especially in terms of victims and damages. Mudflow is a very rapid to extremely rapid flow (i.e. velocity 0.05–5 m s^{-1}) of saturated plastic materials having a high water content (e.g. Hungr *et al*., 2001). Fast mudflow landslides are grave dangers to people and infrastructures as they can potentially activate large amounts of materials across extended distances in very short time periods. In this contribution we attempt to demonstrate that there is tight connection between the presence of a specific soil type, namely andic soils, and the occurrence of the main catastrophic mudflows and debrisflows occurred in Italy in the last decades and involving/evolving surface soils. In order to perform such study we performed an integrated pedological and hydrological analysis on the detachment crowns of some of the most important catastrophic mudflows and debrisflow occurred in Italy in the last decades and involving/evolving surface soils. We investigated the following landslide sites: Sarno (1998), Salerno (1954), Platì (1951), Versilia (1996) and Albaredo (1987, 2002). A more detailed hydro-pedological study was also performed, using a 2D Richard's based water balance simulation model, in order to address two critical issues for Campanian flow slides susceptibility, namely (i) the presence of discontinuities along the slope (e.g. roads, cliffs, etc.) (ii) the relationship with slope aspect.
It must be emphasised that, a part from the sites of Campania (Sarno and Salerno), no andic soil are reported in the available soil maps referring to the other Italian sites.

Methods
The point based and land based integrated analysis carried out in this study focus on the only catastrophic landslides producing fast mudflows (Table 1). We selected landslides that caused human victims and have suitable technical documentation in the published literature. Landslides occurring before 1841 were not been considered. More than 20 soil profiles from 19 detachment crowns were described and analysed in the field. Only the six most representative sites are given in this contribution attempting to cover a large range of landscapes in terms of geology, geomorphology and latitude. The upper parts of slopes where detachment occurs are generally extremely steep (more than 50-60°). The profiles have been described using the FAO system (1990). Undisturbed soil samples for hydrological analysis were collected from the main horizons

with steel cylinders of about 100 and 200 cm^3. Bulk soil samples were also collected from all soil horizons. After air drying, samples were sieved to less than 2 mm and analysed according to USDA (1996) methods: pH in H_2O, organic matter by the Walkley-Black method, Al, Fe and Si in the amorphous oxides/hydroxides and in the organic matter were selectively extracted with ammonium oxalate (Feo, Alo, Sio) treatment at pH=3 (Schwertmann, 1964) and with sodium pyrophospate (Fep, Alp, Sip) (Bascomb,1968), respectively, and their content levels were determined by ICP-AES. Values of Al and Fe extracted with ammonium oxalate were used to calculate the andic property index Alo+0.5Feo. Allophane and imogolite quantities were estimated using the Parfitt (1990) method, based on selective extractions. On undisturbed soil samples the saturated hydraulic conductivity was measured applying the constant head method (Klute and Dirksen, 1986). Following an evaporation process, the method of Wind for determining water retention and hydraulic conductivity was applied (Tamari *et al*., 1993) on larger samples (200 cm^3). The soil water retention curves ($\theta(h)$) of smaller samples (100 cm^3) were determined through use of the tension table (Dane and Hopmans, 2002). The water retention and hydraulic conductivity experimental data were parameterised according to the Mualem-van Genuchten relationship (van Genuchten, 1980). Constitutive hydraulic functions where applied in a 2D simulation model (Hydrus 2D, Simunek *et al*., 1999). This model enable us to simulate the soil water balance of slope assuming a defined length and soil depth, and an infinite width. Runs were performed on the same soil simulating the water balance in presence and absence of roads or cliffs. This was obtained changing the boundary conditions: (i) free drainage in case of pedo-continuity and (ii) a seepage face in case of pedo-discontinuity due to roads or cliffs. Runs were also performed to compare soil water balance on two soils on North and South slope (Basile *et al*., 2003).

Results

The main features of the investigated sites where the catastrophic landslides occurred are given in Table 1. Almost all the sites refer to very steep mountain environments having different aspects and geologies. All sites have a forest land use, generally chestnut. The landslides have generally occurred in a very large number and with different rainfall intensity. The number of victims and damages are typically related to the presence of urban settings along the flows rather than to the landslide magnitude.

Table 1. Main features of landslides and detachment crowns (det.=detachment; (l)= data obtained from literature).

Location	Date (l)	Landslide type (l)	Elevation range of det. crown (m asl)	Slope range of det. crowns	Main aspect	Main land use	Main bedrock	Number of land-slides (l)	Rain peak (l)	Vic-tims (l)
Albaredo (Lombardia)	16/11/02	Soil slip-debris flows	1000-1100	41°-50°	W	Grassland with chestnut	Metamorphic rocks	50	230mm /60h	0
Versilia (Toscana)	19/6/96	Soil slip-debris flows	300-900	31°-45°	NE	Chestnut forest	Metamorphic arenaceous rocks & Phyllitic schist	647	400mm /6h	14
Salerno (Campania)	26/10/54	Soil slip-mud flows	200-800	40°-50°	N	Chestnut forest	Limestone	NA	504mm /24h	> 300
Sarno (Campania)	5/5/98	Soil slip-debris/earth flow	700-950	33°-55°	SW	Chestnut forest	Limestone	100	173mm /48h	159
Platì (Calabria)	16/10/51	Soil slip-debris flows	700-1100	40°-50°	SE	Mixed forest (Chestnut - Oak)	Metamorphic rocks	NA	1495mm /72h	19
Giffone (Calabria)	29/6/05	Soil slip	500-1000	38-45°	NW	Chestnut forest	Granite	NA	NA	NA

The most important morphological and chemical features of these soils are given in table 2. All soils are rather deep, they frequently have some kind of vertical discontinuities (e.g. buried soils) and have a dominant sandy loam texture. The soil structure of surface horizons is always granular with a rather high organic C content. pH ranges from acid to neutral, and most importantly all soils show striking andic features ranging from high (Alo+0,5Feo>2%) to moderate ((Alo+0,5Feo:1-2%). The andic features range from silandic in southern sites to aluandic in Northern sites but some of these andic soils do not fulfil WRB requirements for Andosols. In fig. 1 some water retention curves referring to the most important soil horizons of the investigated sites are reported. The curves show a striking homogeneous behaviour with a very high water retention over all pressure heads but especially near saturation. In fact water content at saturation is comprised between a minimum of 0.52 $cm^3\ cm^{-3}$ till a maximum of 0.78 $cm^3\ cm^{-3}$. Moreover, these are very permeable soils according to their very high saturated hydraulic conductivity (data not shown).

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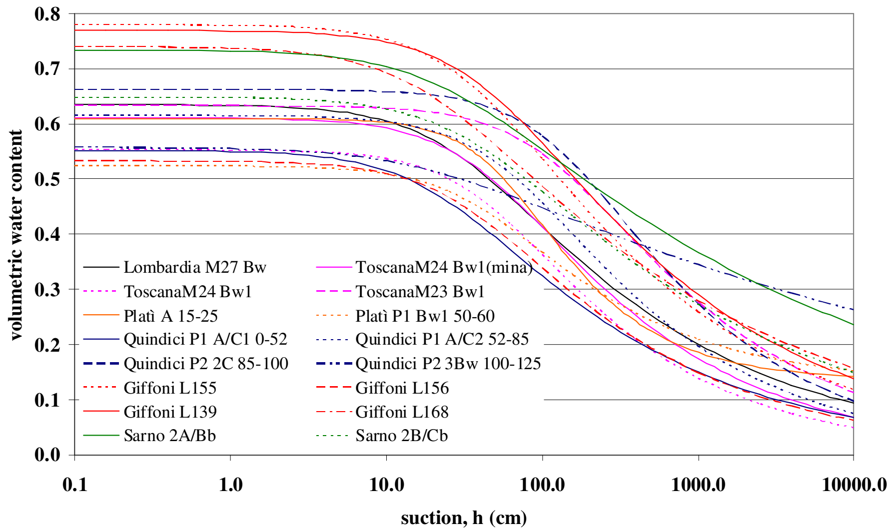

Figure 1. Water retention curves of representative soil horizons of the investigated sites.

At more local scale, discontinuities in the soil cover (i.e. abrupt slope change, road cut) were also modelled and the resulting effects were shown in Fig.2 where the time evolution of soil water storage in the profile (2 m) is reported, both for pedo-continuity (P-C) and pedo-discontinuity (P-DC) simulations. The results refer to the same vertical section located at 100 m from the up slope position. The increase in water storage due to the boundary effects ranges from 30% in the rainy days till 45% in the dryer period. This increases the soil weight and reduces the effective stress inside the soil: therefore, the P-DC condition will increase the risk of instability of the pyroclastic slope cover.

Table 2. Most important features (FAO, 1990) of the soils in the detachment crowns of the investigated landslides. Abbr.S: sandy; Si: silty; L:loam; G: granular, SB subangular blocky, m: medium, c: coarse,wd :weakly developed; md: moderately developed; sd: strongly developed

Profile	Horizon	Boundaries	Texture	Structure	Carbonates	pH	Organic C	Alo+0,5Feo	Alp/Alo
Sarno-P1 (Campania)	A	0 - 20	SL	G m, wd	none	7,3	98,5	4,99	0,25
	Bw	20 - 38	SL	SB m, wd	none	7,5	10,7	2,46	0,05
	Bc	38 - 71	LS	SB c, wd	none		4,2	5,68	0,00
	C	71 - 100			none	7,5			
	2A/Bwb	100 - 140	SL	SB c, wd	none		10,5	2,05	0,06
Salerno -M25 (Campania)	A	0 - 9	SL	G c, sd	none	7,3	58,0	4,47	0,04
	Bw1	9 - 28	SiL	SB m, sd	none	7,4	24,3	4,95	0,03
	Bw2	28 - 48	SiL	SB m, md	none	7,6	15,60	5,47	0,02
	Bw3	48 - 70	SiL	SB m, md	none	7,8	9,60	3,49	0,05
Versilia M24 (Toscana)	OA	0-2	S	G c, sd	none	4,1	178,80	0,24	1,00
	Bw1	2-65	SL	SB c, md	none	4,8	12,92	0,50	1,00
	Bw2	65-150	SL	SB m, md	none	4,6	9,55	1,03	0,64
Albaredo-M27_3 (Lombardia)	A	0-40	S	SB m, md	none	5,1	32,00	1,35	0,73
	Bw	40-110	SL	SB m, md	none	5,3	11,03	1,82	0,19
Platì (Calabria)	A	0-45	L	G c, md	none	5,1		1,35	1,08
	Bw1	45-90	CL	SB m, md	none	5,1	24,97	1,53	0,48
	Bw2	90-120			none	5,2	18,90	1,26	0,54
	BC	> 120				6,0	19,80	0,85	0,39
Giffone (Calabria)	A1	0-15	SL	G m, sd	none	5,1	51,40	1,53	<0,5
	A2	15-30	SL	SB m, md	none	5,0	49,41	2,26	<0,5
	Bw1	30-50	SL	SB m, md	none	5,3	30,95	2,37	<0,5
	Bw2	50-80	SL	SB m, md	none	5,6	25,65	1,60	
	2Ab	80-110	SL	SB m, md	none	5,5	30,11	2,24	
	3Bw1	110-150	SL	SB c, md	none	5,6	16,98	1,83	
	3Bw2	150-200	SL	SB c, md	none	6,0	1,76	0,72	

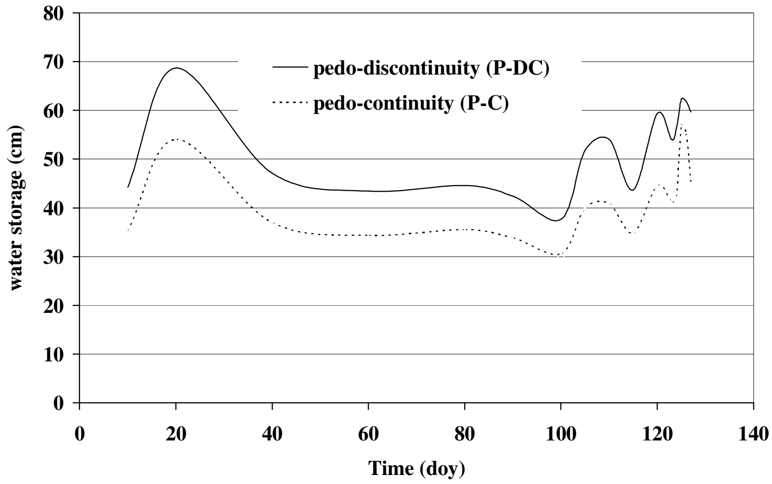

Figure 2. Effects of pedo-continuity (undisturbed slope) and pedo-discontinuity (seepage face) on soil water storage.

Conclusions

The study of soils in the detachment crown of the investigated catastrophic landslides in Italy clearly shows that despite the large differences in geological and climatic settings soils are rather similar and show similar morphology and both andic features and high water retention features. Overall the results at the Italian scale seem to reveal an evident cause-effect between andic soils and the investigated catastrophic mudflows/debrisflow. This is important considering that non-andic non-sliding soils are very much reported in the available soil maps of the investigated landscapes. We believe that andic soils, because of the unique physical properties (hydrological properties, high susceptibility to liquefaction, etc.) induce high landslide vulnerability. We also believe that hydropedology should be added to classical approaches to ameliorate the understanding and the risk assessment of these complex phenomena.

These findings are of primary importance and prove the need of using soil information for classifying zones of different landslide hazard risk (landslide hazard assessment). We also believe that our findings are important also in stimulating similar studies in other areas of the world, especially but not exclusively volcanic, where this type of landslides occur.

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