Ischia landslides (Italy): A multidisciplinary approach aimed to increase knowledge of soil properties

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Abstract
An integrated approach (chemical, hydrological, mineralogical and micro-tomographic) has been used to study the soils of the landslides occurred in the Ischia island (Italy) on April 2006. The study has been carried out on three soil profiles sampled on representative detachment crowns. The main outcome indicates: (i) presence of volcanic soils, very rich in primary glass, characterised by the presence of poorly ordered kaolinite in all horizons and expandable clay minerals only in the deepest horizons (CBb and Cb), (ii) high values of water content near saturation for all soil horizons, (iii) a relevant vertical discontinuity of soil physical properties. In particular, the deep silty horizon (Cb) retains high amounts of water at low matric potential and shows the lowest value of saturated hydraulic conductivity than the other horizons. This micro-tomographic analysis of this deep horizon indicates a very complex intra-aggregate pore space, which seems an important factor influencing the specific rheological behaviour of this sliding horizon.
In terms of pedogenetic processes, the soils of M. Vezzi northern slope are very different from those described for other catastrophic landslides of the Campania region (Sarno, Quindici, etc.), but they have in common the presence, along the soil profile, of marked physical discontinuities surely contributing to the initiation mechanisms of the landslides.

Key Words
Volcanic soils, hydrological properties, micro-tomography, soil mineralogy, Campania landslides

Introduction
In this paper are presented the preliminary results of a pedological study regarding landslides that occurred on April 30th 2006, on the top of the northern slope of Monte Vezzi, in the Ischia island (South Italy). The type of mechanism occurred during these landslide events is classified as a complex debris slide - debris flow, with an intermediate phase of debris avalanche *(*De Vita *et al.,* 2007). It appeared very similar to phenomena affecting slopes of the Campania calcareous reliefs over many years. In fact, the Campania region has a long history of landslide events. Recent data (years between 1580 and 2002) indicate 453 landslides producing damage to people, leading more than 1300 deaths (SICI, 2007). In spite of the social relevance of these events and, in many cases, the large evidence of the crucial role of the pedological control in these phenomena, soil studies in landslide areas are not so common in Italy, in particular in the Campania region. Since 1999, chemical and physical properties were measured on the soils of the detachment crowns of Sarno and Quindici (Terribile *et al.,* 2000) and 19 other Campania landslides, chosen as catastrophic in terms of human life and damages to infrastructures and occurred in the last century in this region (Terribile *et al.,* 2007). Results showed an important relationship between landslides and Andosol occurrence. Andosol's (WRB, 2006) susceptibility to landslides is known and has been related to some of their physical properties, being the control factors that induce remarkable fragility to ecosystems: i) low adhesion to substrates (Yamanaka, 1964), ii) materials with low inner cohesion (Maeda *et al.,* 1977), iii) high water retention and high saturated hydraulic conductivity (Maeda *et al.,* 1977; Basile *et al.,* 2003). Nevertheless, the volcanic soils of Ischia landslides are younger and seem less weathered than those found on the carbonatic reliefs of the Campania region and, according to a preliminary study (Vingiani and Terribile, 2007), they do not exhibit andic properties, suggesting that not only Andosols slide down in these areas. An integrated approach (chemical, hydrological, mineralogical and micro-tomographic) has been considered to be fundamental in order to better investigate the complexity of these unique volcanic covers in relation to landslide events.

Methods
Three representative soil profiles (according to slope gradient, undisturbed soils, etc.), approximately 250 cm deep, one for each landslide detachment crown, have been described and sampled. Air dried and sieved (less

than 2 mm) soil samples have been analysed chemically, according to the Official Methods of Soil Analysis (Page *et al*., 1982). Due to the volcanic context, specific chemical analysis for Andosol classification have been carried out: phosphate retention (Blackemore *et al.,* 1987), ammonium oxalate (Schwertmann, 1964) and Na-pyrophosphate (Bascomb, 1968) selective extractions. Particle size measurements were performed by means of laser diffraction technique (LD) using a Malvern Mastersizer 2000 system®, after soil dispersion by Na- hexametaphosphate. This dispersant agent is efficient in the case of absence or scarce andic properties. Mineralogical analysis, by means of X-ray diffractometry (XRD), has been carried out on sand, silt and calcium saturated clay fractions and patterns have been acquired by a Rigaku Geigerflex D/Max IIIC®, with Ni filtered CuKa radiation at 35 kW and 35 mA. Undisturbed soil samples approximately 400 cm^3 in volume were collected in each pedological horizon to determine the hydrological properties. The saturated hydraulic conductivity, *Ks,* was measured by means of a constant head permeameter (Klute and Dirksen, 1986). Both $\theta(h)$ relationship, between water content θ and water pressure head *h,* and $K(\theta)$ relationship, between hydraulic conductivity *K* and water content, were determined applying the evaporation method (Wind, 1968; Tamari *et al*., 1993). During a 1-dimensional transient upward flow due to the evaporation process, an automated system acquired weights of the soil samples and pressure head data from pressure transducers connected to three tensiometers for each sample. To determine the points of the $\theta(h)$ curve for higher values of *h* a pressure apparatus was used. X-ray micro-tomographic scanning has been performed on 30 mm^3 of soil aggregates, obtained by sieving the bulk soil at 2 mm, using the SKYSCAN 1172 desktop system (www.skyscan.be) based on a microfocus cone beam source. The intra-aggregate three-dimensional pore structure has been reconstructed at 3 microns pixel resolution using an optimised inverse Radon transform (Kak and Slaney, 1988). Intra-aggregate pores have been visualized using Image ProPlus software (www.mediacy.com) and analyzed using the "opening" algorithm to calculate the pore size distribution (Serra 1982) and the procedure of Lantuejoul and Maisonneuve (1984) to calculate the percolation curves in order to evaluate the connectivity of the pore space.

Results

All soils are characterised by thin (5 cm) very dark brown (10YR 2/2) organ-mineral topsoils, with abundant (40%) small (2-5 mm) coarse fragments. The subsoil, from dark yellowish to olive brown (10YR 4/4 - 2.5Y 4/3), is increasingly moist with depth, and skeletic (more than 50% of coarse fragments), till the depth of 170 cm, where greyish brown (2.5Y 5/2), not massive, ashy horizons, with few (less than 4%) coarse fragments, occurs (CBb and Cb horizons). As follow, only results of the more representative soil profile (P2) are presented and discussed. Some chemical and physical properties of the P2 soil profile are reported in table 1.

Table 1. Some chemical and physical properties of the P2 profile.

Horizon	Depth (cm)	OC	pH		PR	Alo +0.5 Feo	*Ks*
		g kg^{-1}	H_2O	KCl	%	%	cm h^{-1}
A	0-5	71.3	6.7	6	31.6	0.47	n.d.
Bw1	5-50	5.9	7.1	5.7	22.1	0.43	102.9
Bw2	50-90/110	5.5	7.3	5.7	21.4	0.45	144.7
ABb	110-130/140	4.7	7.1	5.1	17.2	0.26	n.d.
Bb	140-170	2.7	7.3	5.4	14.6	0.21	24.5
CBb	170-215	1.3	7.2	5.0	7.8	0.10	31.9
Cb	215-220+	1.2	7.3	4.8	3.5	0.07	5.7

PR= phosphate retention; Ks= saturated hydraulic conductivity; n.d. = not determined

The results of the particle size distribution analysis evidenced a main bimodal distribution of soil particles, from the top of the profile to 170 cm, while a general unimodal distribution below 170 cm (CBb and Cb horizons), confirm the presence of a marked textural discontinuity at that depth, not only in terms of coarse fragments (Figures 1a and 1b).

Mineralogical analysis indicates the presence of K and Na feldspars and mica, in both sand and silt fractions, while analcime has been detected mainly in the silt fraction. The clay fraction analysis evidenced presence of kaolinite in all the soil horizons, while expandable clay minerals have been found only in the C horizons (CBb and Cb). Some of the measured water retention curves are plotted in figure 2. They show high values of water content near saturation (more than 0.6 cm^3/cm^3) and also along the whole range of pressure heads.

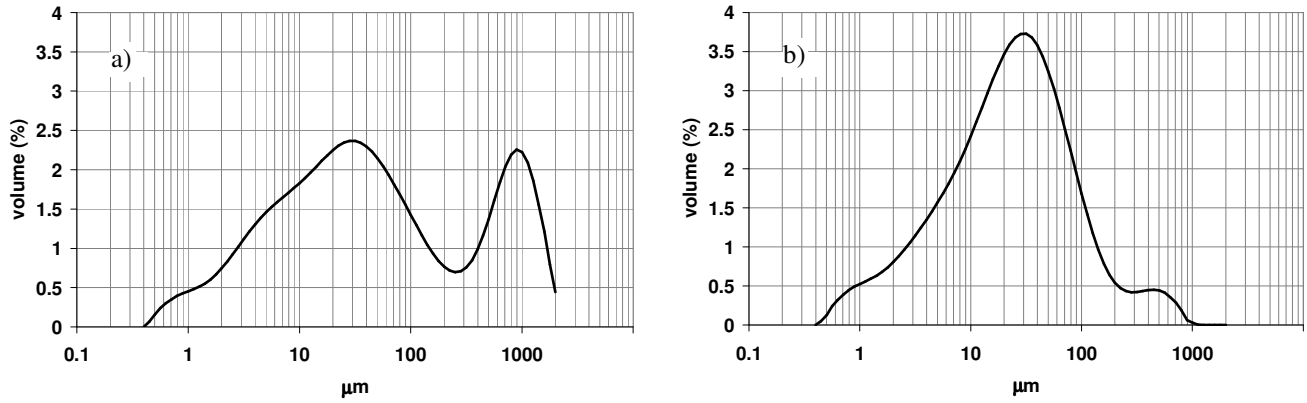

Figure 1. Particle size distribution of the ABb (a) and Cb (b) horizons.

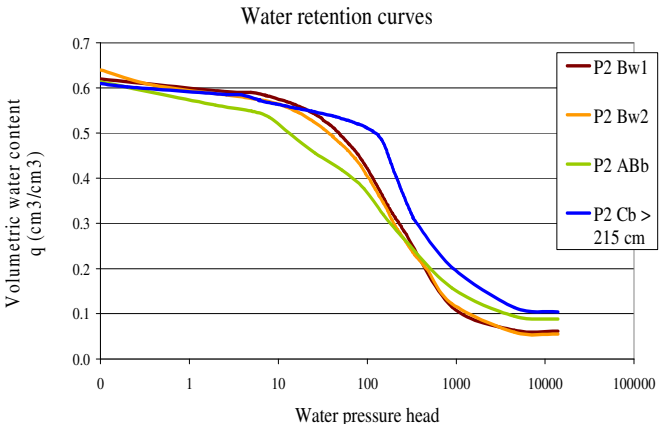

Figure 2. Water retention curves of some P2 soil horizons.

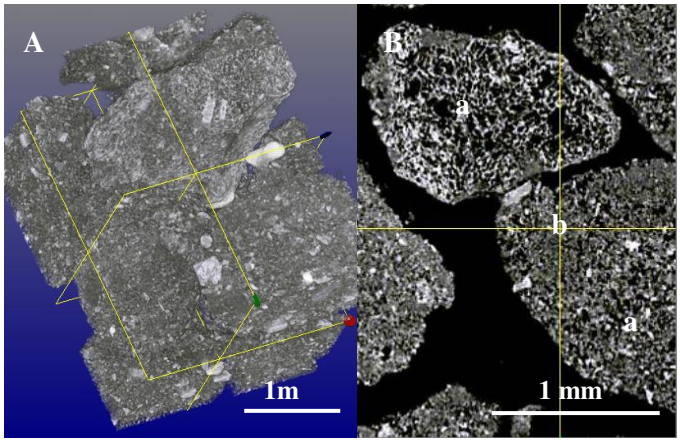

Figure 3. µCT-generated (A) three and (B) two-dimensional images of soil aggregates from the Cb horizon.

In particular, the Cb horizon, compared to the more structured upper horizons, shows high values of water retention for high values of tension and a drastic change of the slope of the retention curve for a tension value of about 130 cm. In table 2 are shown some of the *Ks* values determined by laboratory measurements. The values are high, in agreement with the well drained soil profile characteristics, but there is an important decrease of the saturated hydraulic conductivity in the deepest horizon Cb.
The three-dimensional visualisation of the Cb horizon intra-aggregate space (Figure 3) shows two different arrangements: the first (Figure 3B-b) is relative to large pumice grains and the second (Figure 3B-a) to smaller particles (generally of the silt size) constituting the soil matrix. The quantification of the intra-aggregate pore architectures by 3D image analysis (data not given in this paper) confirms the presence of larger pores (30 µm estimated mean diameter) in the pumice structure, as compared to the soil matrix consisting of smaller particle (10 µm estimated mean diameter) arrangements. Both pore systems showed an overall isotropic fully connected porosity. Results of the micro-tomographic analysis (not yet completed) seem coherent with data on the hydraulic properties.

Conclusions

This work led to a first knowledge about the soil properties of the M. Vezzi northern slope, in the Ischia island, through the use of a multidisciplinary (chemical, mineralogical, hydrological and micro-tomographic) approach. Results evidenced, along the soil profile, the presence of a marked discontinuity in terms of clay mineralogy, particle size distribution and hydraulic properties corresponding to a deep horizon (170 cm), whose upper limit is considered the sliding surface of the soil materials involved in the landslides. First data on the complex intra-aggregate pore space of this deep horizon showed the presence of a fully connected porosity, whose ongoing analysis is expected to give a contribution to the knowledge of the causes of water drainage reduction in the soil profiles, considered to be a primary cause of landslides.

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