Colloids and Surfaces A: Physicochem. Eng. Aspects 466 (2015) 57–65

Contents lists available at ScienceDirect

Colloids and Surfaces A: Physicochemical and Engineering Aspects

journal homepage: www.elsevier.com/locate/colsurfa

Rheology of natural slurries involved in a rapid mudflow with different soil organic carbon content

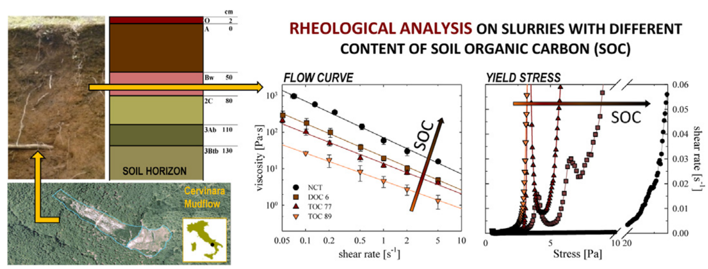
Claudia Carotenuto[a,*], Maria C. Merola[a], Marta Álvarez-Romero[b,1], Elio Coppola[b], Mario Minale[a]

[a] Dipartimento di Ingegneria Industriale e dell'Informazione, Seconda Università di Napoli, Via Roma 21, 81031 Aversa (Caserta), Italy
[b] Dipartimento di Scienze e Tecnologie Ambientali Biologiche e Farmaceutiche, Seconda Università di Napoli, Via Vivaldi 43, 81100 Caserta, Italy

HIGHLIGHTS

- We study slurries involved in mudflow with various soil organic carbon (SOC) content.
- Various quality and quantity of the original SOC are selectively chemically removed.
- We test SOC effect on viscosity and yield stress, both clearly decrease by reducing SOC.
- As in dry and wet soil, SOC has a "stabilizing" role in natural slurry rheology.
- Dissolved organic carbon is the key SOC fraction stabilizing slurries microstructure.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 8 August 2014
Received in revised form 13 October 2014
Accepted 21 October 2014
Available online 5 November 2014

Keywords:
Soil organic carbon
Natural hazards
Viscosity
Yield stress
Slurry
Suspensions

ABSTRACT

This work deals with the study of the effect of the soil organic carbon (SOC) content on the rheology of a concentrated natural slurry made with soil collected from a site involved in a catastrophic rapid mudflow. We considered the soil with all the original SOC and with various fractions of it, selectively removed with specific chemical treatments. In this way, we obtained samples with different quantities of SOC having different solubilities and degrees of complexation with the soil mineral matrix.

Flow curves and yield stresses of slurries, with a soil volume fraction of 40%, are experimentally determined. Flow curves show a marked shear-thinning behaviour and, at each imposed shear rate, the viscosity decreases by reducing the content of SOC. Similarly, the yield stress decreases while reducing SOC. Our findings highlight the stabilizing effect of SOC in the investigated liquid slurries and, furthermore, they suggest that the organic carbon quality, more than its quantity, plays a crucial role in slurry rheology. In particular, the dissolved organic carbon is the fundamental organic fraction stabilizing the slurry microstructure.

* Corresponding author. Tel.: +390815010410; fax: +39 0815010204.
E-mail addresses: claudia.carotenuto@unina2.it (C. Carotenuto), mariaconsiglia.merola@unina2.it (M.C. Merola), a82alvro@uco.es (M. Álvarez-Romero), elio.coppola@unina2.it (E. Coppola), mario.minale@unina2.it (M. Minale).
[1] Current address: Department of Agricultural Chemistry and Pedology, Faculty of Science, Agrifood Campus of International Excellence—ceiA3, University of Cordoba, 14071 Cordoba, Spain.

http://dx.doi.org/10.1016/j.colsurfa.2014.10.037
0927-7757/

1. Introduction

Mud and debris flows are natural, concentrated mixtures of soil and water that, upon gravitational instability, become mobiles and flow down slope [1]. They are considered serious geological hazards since they may reach long distances and high velocities becoming dangerous and/or destructive in mountain area throughout the world [2,3]. Many experimental, numerical and theoretical investigations have been performed to characterize the phenomenon [4,5], so to achieve efficient early warning systems and practicable mitigation strategies (*e.g.* [1,6]). Trigger and evolution of a mudflow are influenced by many factors acting on different length scales: (i) the morphological characteristics of the site and its vegetation cover, at macro-*scale*; (ii) the geopedological and hydraulic properties of the soil, at meso-*scale*; (iii) the soil grain shape, size distribution, mineralogy and soil-water mixture properties (concentration of the solid phase, salinity, pH), at micro-*scale*. Among the soil properties, the soil organic carbon (SOC) content can play a role and, to our knowledge, its effect in mudflow triggering and evolution has never been systematically investigated.

SOC originates from plants, animals and microorganisms, and their exudates. Since 1948 [7], it is known that it increases the soil stability, defined by Haynes and Swift [8] as the capacity to resist the slacking and the dispersive actions of water in order to maintain the soil porous structure intact. When SOC is lost, soils tend to become hard and compact (clayey soils) or loose and friable (sandy soils). The frequent addition of easily decomposable organic residues leads to the synthesis of complex organic compounds that bind soil particles into structural units called aggregates. These aggregates help to maintain a loose, open, granular condition. SOC that stabilizes microaggregates is incorporated in the small pore spaces, is protected from further microbial attack, and persistes for long time. Conversely, SOC that stabilizes the larger aggregates is constantly renewed by crop growth and is readily accessible to microbial attack [9]. Hierarchical theory of aggregation thus proposes that larger aggregates are composed by more stable microaggregates [10].

The large majority of the works dealing with the role of SOC is related to the study of soil structure and its alteration due to land use and soil/crop management practices [10,11] and, thus, principally refers to dry or wet samples [12–15]. The SOC stabilizing effect tends to increases from dry to wet samples. The case of larger water contents, *i.e.* of *liquid* soil slurries, is less investigated, but this is the typical condition encountered in mudflows, reached after long and/or intensive rainfall.

Aim of this paper is to investigate the effect of the organic carbon on slurry rheology. This can be achieved by either artificially adding organic carbon to the soil, or somehow removing from it different amounts of its original SOC. Since the stabilizing effect of organic carbon depends also on the matching among soil superficial properties and organic compounds, as proven by, *e.g.*, Chenu and Guérif [16] who observed that scleroglucan (a fungal polysaccharide) is more active with pure montmorillonite than with pure kaolinite, or by Barré et al. [17] who showed that scleroglucan largely stabilizes a clay loam soil, while polygalacturonic acid (PGA, a root mucilage analogue) has only little impact, we followed the second approach.

Rheology has been recognized as an important tool to study fast landslides [4,18–21] and, recently, has been also used to investigate the stabilizing effect of SOC in soils [14,17,22,23]. In this work, we then rheologically investigate if SOC can potentially play a role in the initiation and evolution of a mudflow. To this end, we perform different rheological tests on concentrated natural slurries made with a soil, taken from a site involved in a catastrophic fast landslide (Cervinara, Avellino, South Italy), containing different fractions of the original SOC, that is indeed removed, in different amounts, with adequate chemical treatments. We considered slurries with a soil volume fraction equal to 40%. Rheological tests here performed aim at obtaining, for each level of SOC content, the yield stress and the flow curve of slurries. Yield stress may be put in relation with the triggering conditions of a landslide, while flow curve with its subsequent evolution.

2. Materials and experiments

2.1. Soil

The soil was collected from a slope affected by a catastrophic landslide in 1999 [24], in Cervinara site (Avellino, South Italy), Fig. 1a. The soil evolved on a slope covered by pyroclastic deposits pumice-cineritic affected by erosion, landslide, accumulation of material and burial of the oldest surfaces. In particular, the sample was taken from a specific pedological profile (Fig. 1b), which shows the horizons succession O-A-Bw-2C-3Ab-3Btb (Fig. 1c), defined according to the system of soil classification proposed by the USDA-NRCS (United States Department of Agriculture-Natural Resources Conservation Service) [25]; the profile is classified as an Andic Humudepts, mesic, ashy-pumiceous. In the horizon classification, capital letters represent the master horizons and layers of soils and in particular: (O) horizons dominated by organic soil materials, (A) mineral horizons formed below an O horizon, (B) horizons formed below an *A* horizon that are dominated by the obliteration of all or of the majority of the original parent material structure (ashes and pumices), (C) horizons little affected by pedogenic processes. The numbers before the capital letters indicate granulometry discontinuities and lowercase letters designate subordinate distinctions within master horizons: (w) distinctive colour or

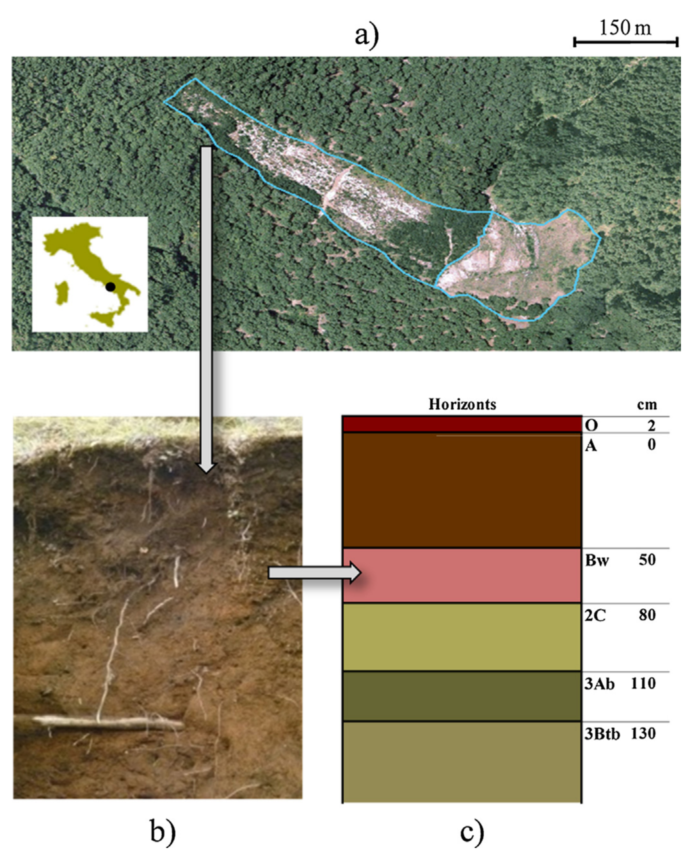


Fig. 1. (a) Sky view of Cervinara (Avellino, South Italy) site with the landslide area highlighted; (b) picture of the soil profile vertical section; (c) scheme of the horizons of the profile. Arrows indicate the sample collection points.