Catena 171 (2018) 199–211

Contents lists available at ScienceDirect

Catena

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

Compositional characterization of fine sediments and circulating waters of landslides in the southern Apennines – Italy

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ARTICLE INFO

Keywords:
Landslides
Fine sediments
Circulating water
Physical-mechanical properties

ABSTRACT

Several studies in the last several years have shown that slope stability and the physical–mechanical properties of sediments can be influenced by their granulometrical, chemical and mineralogical characters and circulating water chemistry, which highlights the importance of studying these processes using a multidisciplinary approach. Two landslides, in a well-known geological area in the Southern Apennines impacted by many landslides, were studied to integrate geological and geomorphological surveys and geotechnical tests with the compositional characterization of the sediments and circulating waters and through a careful definition of the tipology and intensity of the weathering processes.

Pliocene clays and Oligocene slates affected by the studied landslides were characterized for mineralogical, chemical and grain-size composition and these compositional characters were compared with their physical (Atterberg limits, plasticity, activity) and mechanical (friction angle, cohesion, residual shear strength) properties. These properties were determined using distilled water, waters circulating in the landslide sediments and saline solutions that amplify seasonal chemical variations. The compositional and physical-mechanical properties of the sediments were compared with the slip and low deformation zone positions, detected *in situ* from inclinometer measurements, in order to identify any anomalies in the weak zones along the stratigraphic column.

The results showed some correlations between the compositional characters of sediments (grain size, mineralogy and geochemistry) and the slip zone position, and highlighted that the chemistry of the circulating waters can modify certain physical-mechanical behaviours. However, the magnitude and modalities of such influences depends strongly on the geological history and lithotypes involved in the sliding. The Pliocene clay landslide was found to have several slope instability risk factors, such as kaolinite content and water salinity, while the physical-mechanical properties of the Oligocene slates were demonstrated to be less sensitive to sediment and water compositional characters.

Finally, significant correlations were detected between the position of the slip zone and the degree of sediment chemical alteration using a new weathering index specifically designed for the sediments studied.

These results demonstrate that the study of landslides must not ignore the compositional characterization of the sediments and waters, as certain chemical or mineralogical features can represent important risk factors contributing to the worsening of the slope stability and the triggering of the slip.

1. Introduction

Landslide and erosion processes are regarded as very important hazards to anthropogenic environments, causing serious socio-economic damage including the loss of human life. These processes are usually studied using geomorphological and hydrological approaches, supported by geotechnical characterization of sediments. These approaches consider the most common movement triggers, such as slope steepness, pluviometry, infiltration, surface runoff and the intrinsic physical-mechanical properties of the sediments which are all important in the kinematic identification of landslides, their classification and the definition of slip surface depth and geometry.

Reference has been made to the analysis of residual shear strength of fine sediments by Terzaghi (1936), Hvorslev (1939) and Skempton

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https://doi.org/10.1016/j.catena.2018.07.009
Received 20 September 2016; Received in revised form 2 July 2018; Accepted 12 July 2018

(1948), and several reviews (Lupini et al., 1981; Skempton, 1985) have dealt with the issue of shearing mechanisms, primarily in laboratory tests. Residual shear strength is widely considered a very important parameter in the analysis of slope stability, particularly where sliding phenomena occur in correlation with pre-existing discontinuity surfaces (Skempton, 1985; Stark and Eid, 1994; Mesri and Shahien, 2003; Lo Presti and Froio, 2004). Meanwhile, further research developments have shown that some compositional characters of sediments can influence the residual shear strength. Skempton (1964) first highlighted that residual shear strength increases as clay content increases, and Kenney (1967, 1977) noted the influence of montmorillonite and kaolinite quantities on the mechanical behaviour of clays. Correlations between the residual friction angle and clay minerals such as kaolinite, illite and montmorillonite were also highlighted by Mesri and Cepeda-Diaz (1986). Furthermore, several authors observed that changes in the pore water chemistry can also influence the residual shear strength of the sediments with important implications being reported for the seasonal reactivation of landslides and the role of the weathering processes on slope instability (Chandler, 1969). In particular, Ramiah (1970) highlighted the effects of pore water chemistry on the residual friction angle, Steward and Cripps (1983) showed the influence of weathering on the engineering properties of pyritic shales, Moore (1991) demonstrated that shear strength can be modified by pore water chemistry, clay mineral weathering and cation exchangeable capability. The accumulation of salt, especially in coastal areas, precipitation of carbonates and iron compounds and the exchange of different valence cations were indicated as further processes able to modify the shear strength of the shear zones (Hutchinson, 1969, 1970; Hawkins and McDonald, 1992; Anson and Hawkins, 1998; Tiwari et al., 2005; Mesri and Huvaj-Sahrihan, 2012).

Further studies have confirmed that several physical–mechanical properties of sediments can be influenced by their granulometrical, chemical and mineralogical characters and circulating water chemistry (Di Maio, 1996; Martinez-Nistal et al., 1999; Torrance, 1999; Cafaro and Cotecchia, 2001; Sridhran, 2001; Cotecchia, 2003; Loroueil and Hight, 2003; Bogaard et al., 2007; Summa et al., 2010, 2015). As a result, the interest in this topic has increased and has highlighted the importance of studying these processes using a multidisciplinary approach, integrating geological and geomorphological surveys and geotechnical tests with detailed compositional characterization of the sediments and circulating waters and a careful definition of the weathering process typology and intensity.

This approach was performed in this study, where two pilot areas affected by landslides were studied in the Basilicata region in order to determine stratigraphic, compositional and physical-mechanical properties of the sediments and to compare the compositional features of the slip zones with the no-slip zones. The pilot areas are located in the Southern Apennines where landslides (recorded in the national GIS-based archive http://webmap.irpi.cnr.it/) frequently occur when fine-grained sediments are abundant (Del Prete et al., 1989; Summa et al., 2010, 2015). The two landslides are distinguished by different terrains: Pliocene fine grained sediments with low or early deformations and Oligocene slates that have a history of complex deformation. These sediments were chosen to highlight compositional similarities or differences and the potential effects on slip mechanisms.

To keep to natural conditions most faithfully and to reproduce realistic conditions, the laboratory tests were performed using samples collected from boreholes, whilst also considering the chemical characters of the waters circulating in the landslide areas and their strong seasonal changes. In fact, Atterberg Limits and residual shear strength were determined using distilled water, waters circulating in the landslide sediments (in order to evaluate the effects on the sediment mechanical behaviour of the rock-water interaction processes occurring *in situ*) and saline solutions (to amplify the effect of water chemical variability). The results of such conventional and innovative laboratory tests have been described in terms of plasticity and residual shear strength of the sediments. The experimental work aims to investigate how the slope stability can be influenced by grain-size, chemical and mineralogical characters of the sediments and by the salinity of natural solutions.

2. Geological setting

The southern Apennines are an east-verging accretionary wedge originating from the deformation of the African passive margin, occurring during Neogene times and involving different paleogeographic domains of platform and basin. This wedge is represented from west to east by the Liguride-Sicilide basinal domain, Apennine carbonate platform, Lagonegro basin and Apulian carbonate platform (Knott, 1987; Monaco and Tortorici, 1995; Cavalcante et al., 2007).

Older fine-grained sedimentary rocks (Cretaceous - Oligocene), also affected by mass degradation processes, represent deep-sea and piggy back basin deposits involved in the successive accretion processes related to the collision between the European and Apulian margins (Knott, 1987, 1994; Patacca and Scandone, 2007; Tortorici et al., 2009).

The areas studied are located in two different sectors of the southern Apennines (Fig. 1).

The Tricarico landslide is situated in the Bradano Valley, at the eastern boundary of the Apennines, where Pliocene clays, clayey silts, sandstones and limestones outcrop. These sedimentary units were deposited in piggy-back basins or on the margins of marine domains (Ori and Friend, 1984; Sabato and Marino, 1994) and were ascribed to two different sedimentary cycles, the middle-lower Pliocene Ariano cycle and the upper Pliocene Atessa cycle (Maggiore and Walsh, 1975; Caldara et al., 1993; Sabato and Marino, 1994). The Atessa cycle deposits are composed of a lower unit (sandy limestone), constituting the structural horst on which the ancient centre of Tricarico is located, and an upper, mainly silty and clayey unit. This second unit outcrops in the area of the studied landslide is in a small valley depressed by a normal fault with respect to the calcareous horst (Fig. 2).

The second landslide studied is in the village of Latronico, where the weakly metamorphic Frido Unit (Ligurian Complex) widely outcrops together with the no-metamorphic Crete Nere Formation (Fig. 3). The Frido Unit is a poly-deformed and poly-metamorphosed sequence composed by calc-schists and blackish or greyish slates, with intercalations of quartzites, phyllites and marls, also involving serpentinites, garnet-rich gneiss and lenticular metabasites (Bonardi et al., 1988; Monaco et al., 1995; Cavalcante et al., 2009). The Crete Nere Formation (Selli, 1962) shows characters of broken formation and overlies the Frido Unit with a tectonic contact (Bousquet, 1971, 1973; Scandone, 1972; Amodio Morelli et al., 1976; Spadea, 1976). This formation is mainly composed of quartzites, grey clays and black slates with calcareous intercalations (Vezzani, 1969; Bonardi et al., 1988; Cavalcante et al., 2009).

The historic part of the village is situated on the Pleistocene deposits of the S·Arcangelo Basin (Vezzani, 1967), interpreted as a satellite basin founded on active thrust sheets during the Pliocene – Pleistocene apeninnic compression phase (Hyppolite et al., 1994; Pieri et al., 1994) or as a pull-apart basin (Turco et al., 1990). These deposits are represented by polygenic cemented conglomerates of the Castronuovo Conglomerates Formation (Vezzani, 1967; Patacca and Scandone, 2001).

3. Materials and methods

Macroscopic observations of geognostic cores taken from boreholes (S10 and S11 in Tricarico, S5 and S6 in Latronico, made by Basilicata University during previous studies) provided stratigraphic characterization of the sediments affected by landslides (Figs. 2 and 3). The S10 and S11 Tricarico boreholes are located at the foot and the middle of the landslide in correspondence with the areas with more evident superficial deformations. The S5 and S6 Latronico boreholes are located at