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# Effects of loading–unloading and wetting–drying cycles on geomechanical behaviors of mudrocks in the Colombian Andes

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ABSTRACT

The mudrocks in the Colombian Andes, particularly those exhibiting low cementation (bonding), are susceptible to degradation when the environmental conditions change, which are challenging issues for engineering works. In this paper, the changes in physico-mechanical properties of mudrocks were monitored in laboratory, and some influential factors on the mechanical competence of geomaterials were studied. The geotechnical characteristics and experimental designs were developed from physical, chemical, mechanical and compositional points of view. In the tests, the techniques such as vapor equilibrium technique (VET) were employed to apply wetting–drying cycles and to control relative humidity (suction-controlled) and loading–unloading cycles through ultrasonic wave velocities technique. The results show that the main failure mechanisms for the laminated mudrocks start on the microscopic scale by fissures coalescence, exhibiting physico-chemical degradation as well; the global geomechanical behavior presents a state between a ductile, like rock, and a fragile, like soil. The obtained results can provide engineering values according to monitoring laboratory set, when compared with in situ conditions.



## 1. Introduction

The mechanical behaviors, in particular the degradation of geomaterials, have traditionally been met with suitable ways of scaling effects of environmental factors, which determine the behaviors and responses of samples representative of the physical environments.

In fact, the behavior of a sample in laboratory could be substantially different from that of in situ rock mass. It would be very important to compare the structures of these two scales, attempting to incorporate, in the experimental program, all the environmental factors that influence the response of a rock mass of a clayey nature, especially of a laminated structure.

The studied material in this context is sedimentary rock composed of microscopic particles (diameter less than 75 μm) of clayey nature, in addition to the characteristics of degradability associated with its chemical–mineralogical composition. Although the material is "over-consolidated" clay in geological times, it presents a goal-stable character in most cases by finely laminated structure, whose resistance is mainly due to time that has withstood the weight of sediments above confining, and, to some extent, to the formation of "contacts" between particles or any minor amounts of any type of agent binder that may be present (bonding).

Digenetic consolidation processes experienced by the geomaterials are associated with events involving movements of the earth's crust, including tectonic and massive erosion. Without considering the surface modeling due to engineering practices such as the construction of underground and shallow works, the mechanical properties of the material at the "beginning" of their training (stress–strain history) may have been affected. Therefore, the geomaterial develops different degrees of susceptibility to new processes, which arouses the interest in dealing with the present investigation (Fig. 1).

This work is based on a given susceptibility state of geomaterial and discusses the mechanisms that control the loss of mechanical behavior of sedimentary mudrocks, which are responsible for many stability problems in engineering works, such as underground and shallow excavations, foundations and fillings for various engineering structures. It is considered that within the

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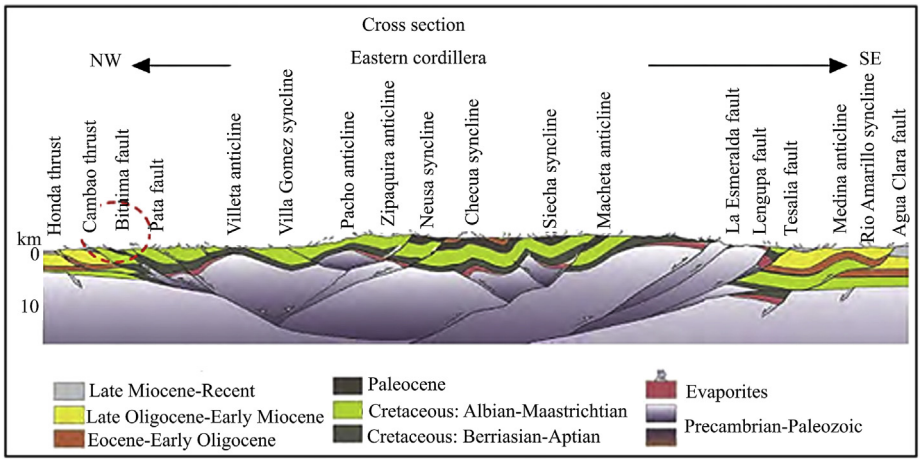


**Fig. 1.** Cross-section of the Eastern Cordillera of Colombia. From Hydrocarbon National Agency – HNA (Barrero, 2007).

mechanisms influencing the deterioration of the mechanical properties of these geomaterials, these are wetting–drying (w–d) cycles and unloading, usually associated with loading–unloading (l–u) cycles.

Obviously, these mechanisms are also developed in different scales and affect the material in a variety of ways. It is recognized that the physico-chemical degradation is the main agent to the structure of materials, little detectable by starting at the micro-structural level sometimes. In addition, the hydro-thermo-physico-chemical factors should be involved with mechanical effects of geomaterials.

In summary, it is a process of "accelerated" weathering, in comparison with that experienced by strongly cemented and consolidated geomaterials, such as the igneous and metamorphic rocks. These processes are significantly complex in characterization and even more in modeling, and also arise in different scales of observations, in which an experimental program is required to attend this wide diversity of processes and phenomena associated with properly delimited control variables.

This paper aims to elucidate part of phenomena of degradation of laminated mudrocks in the Colombian Andes, which is proposed:

(1) To explore and identify the main morph-structural features of rock formations in field, where laminated mudrocks predominate.
(2) To characterize the studied material, both in field and laboratory, from the physical, chemical and mineralogical points of view, and to determine its composition and relationships with its mechanical behaviors.
(3) To determine the main effects of degrading actions such as w–d and l–u cycles on the mechanical behaviors of geomaterials through implementing advanced laboratory techniques.
(4) To suggest models of mechanical behaviors which can properly describe the degradation phenomena through modeling laboratory tests.
(5) To propose practical technologies aiming at the characterization of mudrocks and the physico-mechanical behaviors during the construction of engineering works.

In the context, it is important to recognize the principal properties of the geomaterial as shown in Table 1.

## 2. Geo-engineering characterization of laminated mudrocks in the Colombian Andes

As the mudrocks are the geomaterials of sedimentary in nature, and particularly in this case with laminated structure, they have low void cementation and even little digenetic consolidation. Basically, they are formed in Andean tropics, regional environments of tectonic strongly active in mountainous region. Thus a careful process of identification and characterization of their constituent elements (Fig. 2) is required, for instance the scanning electronic microscopy (SEM) from the National University of Colombia, Bogota head in 2007.

### 2.1. Introduction to the characterization of mudrocks

In a broad sense, the characterization of a geomaterial must include determination of chemico-mineralogical composition, physical properties and indices, and basic aspects of their mechanical responses to normal loads, usually related to site-specific construction. Furthermore, the mechanical behavior of material in question is complex in its forecast, since it cannot be simulated by conventional models or features of goal-stable structure, thus some additional elements are required for engineering purposes.

Characterization activities of a geomaterial should not be performed by a standard or just as a simple fulfillment of requirements set out in standards or building codes. The adopted method must meet the specific needs of the project and especially the uncertainties associated with the lack of knowledge of the intrinsic characteristics of the material about the eventual response to actions during its useful lifespan. Therefore, non-destructive techniques are suitable in the initial stages of the characterization.

Many landslides and mass movements have taken place in dealing with argillaceous rock formations, even more when these are unavailable little or no cemented laminar, where the ground movements are initiated soon after certain excavation activities or simple exposure of the geomaterial to environmental changes.

The characterization of rocks presented here is part of the approach of the scales of observation, i.e. micro-, macro- and mega-structure, since it is found that various processes of damage or structural defects of geomaterials take place equally in different spatio-temporal scales (Torres and Alarcon, 2007), and consequently the geomaterial characterization must obey the real behaviors expected on the scale (Fig. 3).

This method includes the characterization of the material in terms of its mineral components, chemical processes and