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Review Article

An introductory review on gravitational-deformation induced structures, fabrics and modeling

Michel Jaboyedoff [a,*], Ivanna Penna [a], Andrea Pedrazzini [b], Ivo Baroň [c], Giovanni B. Crosta [d]

[a] Research Centre for Terrestrial Environment — CRET, University of Lausanne, Geopolis 3793, CH-1015 Lausanne, Switzerland
[b] Office de l'environnement du canton du Jura, 2, Chemin du Bel Oiseau, 2806 Saint Ursanne, Switzerland
[c] Geological Survey of Austria, Dep. of Geophysics, Neulinggasse 38, 1030 Vienna, Austria
[d] Dept. of Earth and Environmental Sciences, Università degli Studi di Milano Bicocca, Milano, Italy

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A B S T R A C T

Recent studies have pointed out a similarity between tectonics and slope tectonic-induced structures. Numerous studies have demonstrated that structures and fabrics previously interpreted as of purely geodynamical origin are instead the result of large slope deformation, and this led in the past to erroneous interpretations. Nevertheless, their limit seems not clearly defined, but it is somehow transitional. Some studies point out continuity between failures developing at surface with upper crust movements.

In this contribution, the main studies which examine the link between rock structures and slope movements are reviewed. The aspects regarding model and scale of observation are discussed together with the role of pre-existing weaknesses in the rock mass. As slope failures can develop through progressive failure, structures and their changes in time and space can be recognized. Furthermore, recognition of the origin of these structures can help in avoiding misinterpretations of regional geology. This also suggests the importance of integrating different slope movement classifications based on distribution and pattern of deformation and the application of structural geology techniques. A structural geology approach in the landslide community is a tool that can greatly support the hazard quantification and related risks, because most of the physical parameters, which are used for landslide modeling, are derived from geotechnical tests or the emerging geophysical approaches.

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1. Introduction

Geological structures and fabrics (i.e., spatial and geometric configuration or pattern of main constituent features), originated by gravitational slope failures, have been frequently omitted/underestimated by

* Corresponding author. Tel.: +41 79 752 35 15.
E-mail address: michel.jaboyedoff@unil.ch (M. Jaboyedoff).

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field geologists, and the recent literature presents a variety of such examples. PS-DInSAR analyses demonstrated that Alpine valleys are significantly affected by gravitational movements (e.g., Ambrosi and Crosta, 2011). Some studies suggest that commonly more than 5% of alpine slopes are affected by deep-seated gravitational slope deformations (e.g., Agliardi et al., 2009a, 2012, 2013; Pedrazzini et al., 2011). From these observations the following questions arise: what are the similarities between tectonics and slope tectonics at a local and at regional scale? Does a real limit between processes exist? In fact, very similar patterns can be found depending on the material involved, the size and type of slope instability, and the scale of observation (Fig. 1). Numerous studies demonstrated that folds or faults in a slope can be generated by large slope deformations, which have been confused with pure tectonics. Early works by Oulianoff and Badoux (1922), Zischinsky (1969), Nemčok et al. (1972), and Záruba and Mencl (1982) have shown that deformation of rocks can result from gravitational spreading of a valley slope. In addition, deformation within soft rocks (e.g., clay, marl) shows behaviors very similar to classical tectonics (Hutchinson, 1988). Gomberg et al. (1995) noted that the landslide slip surfaces and tectonic faults are analogues. Baroň et al. (2004) mapped folds within active, deep-seated rotational landslides in the flysch belt of Outer West Carpathians, which originated due to compression along active landslide blocks. The blocks had relatively well preserved original geological structure whereas the zones of compression underwent deformation analogous to tectonic nappes. Ortner (2007) and Alsop and Marco (2012) pointed out that the orientation of the fold axis in the case of gravity driven movements, is parallel to the strike of the slope, making sometimes possible to distinguish between tectonics or slope tectonic-driven structures. Slope tectonics is the result of the interaction between rock-mass properties, type of failure mechanism and factors driving to slope destabilization. External factors influence the behavior of any slope and are often connected to the recent history of the slope. Relief controls the stress level in the slope and this is required in order to generate a potential instability, but it is clear that rock mass strength and pre-existing structures can play a major role on slope instabilities (Ambrosi and Crosta, 2006, 2011). The origin of discontinuities affecting rock masses is diverse, and can owe to stratification, foliation, faults and fractures induced by tectonic deformation, exhumation, topographic stress, loading history, valley erosion, debuttresing and consequent release of valley slopes due to glacial retreat. Nevertheless, the rock can be damaged by tectonics or gravity induced stresses, with or without the support of water pressure reducing the effective stress, or by high differential stresses. According to Selby (1982), assuming a perfectly sound granitic rock (unit weight: 25KN/m^3; uniaxial compressive strength: 200 MPa) with no discontinuity, the critical height of a vertical cliff would be 9 km, a value never observed in nature. Since the early works of Heim (1932), Ampferer (1939), Stini (1941), and Terzaghi (1963), many studies have analyzed the impact of type of slope deformation on hillslope processes. However, and except by a few exceptions (Agliardi et al., 2001, 2009a; Chigira, 1992; Hutchinson, 1988; Mahr and Nemčok, 1977; Nemčok et al., 1972), only some works have addressed this issue in the broad sense. The objective of this paper is to summarize the state of the art regarding the classification of slope movements with emphasis on slope scale rock instabilities, the main gravitational deformation-induced structures and fabrics that can be found in gravitational slope failures, as well as the numerical models and their limitation to reproduce such structures.

2. Classifications

In contrast to several classifications proposed to categorize and describe slope movements (Cruden and Varnes, 1996; Heim, 1932; Hutchinson, 1988; Varnes, 1978) based on different criteria, a consistent classification of the structure and fabric, produced by those processes, is still missing. A general agreement has been found around the classification proposed by Cruden and Varnes (1996), which is based on the type of movement (i.e., falls, topples, slides, lateral spread, flow and complex/compound) and of the material involved (i.e. rock, coarse- or fine-grained soils). However, this classification does not allow a precise description of large (slope scale) rock instabilities. Hungr and Evans (2004) proposed a specific classification for those movements based on the role of the rock structure (failure mechanism) and the mechanical properties of the rock mass.

Classifications of slope mass movements are mainly based on materials and mechanisms, whereas deformational features common

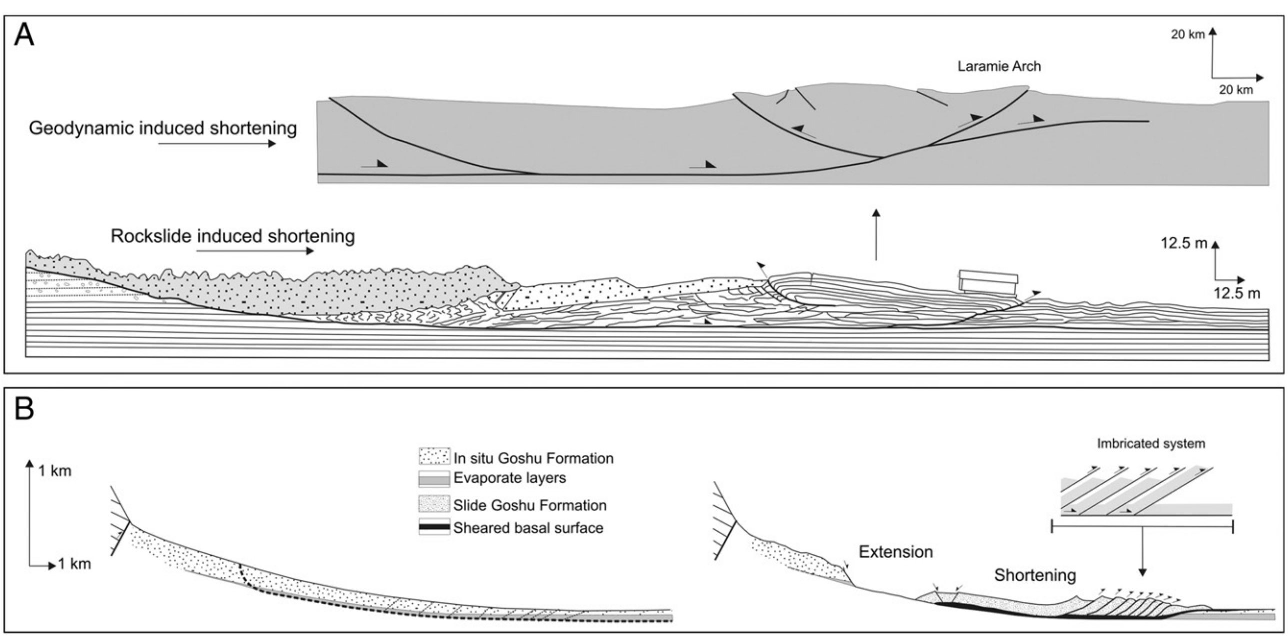

Fig. 1. A) Cross section of Pre-Cambrian basement surface in Wyoming (from Erslev, 1993) and cross section of Arvel rockslide (after Choffat, 1929). Note the analogy between crustal-scale structures induced by tectonic deformation and rockslide induced structures within lacustrine sediments. B) Cross section from Baga Bogd landslide (Mongolia, after Philip and Ritz, 1999) showing deformation due to slope collapse and analogy with imbricated structures from thrust tectonics (after McClay, 1992).