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Long-term evolution and variations of maturation of deep-seated slope failures, insights from the "La Marbrière" slope (Southern Alps, France).

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Deep-seated and large-scale gravitational slope deformations have been now found in most of mountains range. They correspond to complex gravitational movements of a whole slope, related to rock-creep at depth, at a slow rate of deformation. These processes can lead to individualized deep-seated landslide (DSL) and potentially to catastrophic collapses which constitute major issue in the landslide and rockfall prevention. Time of maturation and potential long term evolution of the DSL process remains poorly analyzed, especially due to their location. Indeed the DSL currently evolves in high mountainous areas and are submitted to strong erosion factors as fluvial or glacial denudation which doesn't allow a long preservation of landforms and structures.

The study area is located at the front of the Southern subalpine chain and more specifically along the slope of "La Marbrière", situated under the city of Grasse (SE France). A geological framework is associated with a thick and tamped Triassic substratum (clays and gypsum) overlained by highly fractured and faulted Jurassic limestone (producing a mechanical contrast between layers).

The aim of the study is 1) to define the structural model of the DSL and especially the depth boundary of the deformation and 2) to characterize the different stages of evolution of the deep-seated slope failure and their ages in order to attempt a kinematic reconstruction of the DSL for a better understanding of the process. A multidisciplinary methodology was applied, combining high resolution geological/structural/geomorphological field mapping with deep electrical resistivity tomography and cosmic ray exposure dating of the gravitational scarps. We also integrated dating results of speleothems by U/Th series obtained by a previous archaeological study (Gassin et al, 1997)).

Field investigations show a total length of 3 km for overall DSL, involving 110E6 m3 of rock material. The spatial correlation between morpho-structures (scarps and trenches) and inherited brittle tectonic features clearly exhibit a control of the deformation by two systems of pervasive vertical faults N40° and N160°. Moreover, electrical resistivity tomographies reveal gravitational vertical offset on the faults at 150m deep and suggest a location of the basal rupture around 200m deep. From geomorphological evidences and a specific repartition of the morpho-structures according to their typologies, we identify, at least, three areas reaching different states of the gravitational process evolution. Particularly: (i) a mature/eroded post-collapse area characterized by a first general slope-failure older than 400 ka (U/Th) and post residual movements dated to 76 ka (10Be and 36Cl), (ii) a younger post-collapsed area, typified by highly evolved morpho-structures (scarps and trenches), pervasive deformation and a collapse-event dated to 13 ka (10Be and 36Cl), and finally (iii) a pre-collapse and active area which shows toppling, scarps and trenches in evolution. These different maturation stages may reflect a non linear evolution of the slope degradation depending on its tectonic/morphologic heritage and the internal controls. It also suggests the importance of considering long time scale (potentially over 400 Ka) in the development of such processes.

Considering a relative homogeneous geological structure of the slope, we compare each zone offering us a good insight of the different evolution stages of the DSL and we propose a kinematic interpretation of the overall DSL. At the beginning of the process, the soft substratum, added to the inherited persistent anisotropies, represent key factors for the initiation of the DSL. Slow outflow of clays under the lithostatic pressure of individualized limestone compartments produces the general slope subsidence. Subsequently, progressive toppling of the landslide mass leads to a catastrophic rock collapse by translational slip along bedding plane. From a regional stand point, new cosmic ray exposure dating (10Be and 36Cl) of surrounding large scale failures provide ages about 13 ka and suggest a potential triggering by water over-pressure linked to the last deglaciation.