Geophysical Research Abstracts
Vol. 14, EGU2012-9743, 2012
EGU General Assembly 2012

Middle Holocene landslide cluster in the south-western Alps: Results from cosmic ray exposure dating of numerous large-scale gravitational failures

S. Zerathe (1), T. Lebourg (1), R. Braucher (2), and D. Bourlès (2)

(1) Université de Nice Sophia-Antipolis, Centre National de la Recherche Scientifique (UMR 7329), Observatoire de la Côte d'Azur, Géoazur, 250 av Albert Einstein 06560 Valbonne, France, (zerathe@geoazur.unice.fr), (2) CEREGE CNRS – Univ. Aix – Marseille ; UMR 7330. Plateau d'Arbois BP 80 13545 Aix en Provence Cedex 04

Nowadays, it is formerly assumed that the internal structure of a slope (e.g. lithology and rock mass properties, inherited faults and heterogeneities, etc.) acts as the main preparatory factors for the progressive development of large-scale landslides. However, debates are still ongoing to argue if pointing out some triggering factors, responsible for final slope failures, is possible (amongst them are glacial debuttressing, seismic activities or climatic changes), and especially when considering landslide cluster at an orogen-scale. In the central and eastern Alps, a middle Holocene period ($\sim$4 ka BP) of increased mix-pattern of landslide activity is now identified by many authors (Prager et al, 2008; Sanchez et al, 2009; Borgatti and Soldati, 2010). In this study, we highlight a new spatial and temporally concordant cluster of deep-seated slope failure in the external south-western Alps and we attempt to argue and review the possible causes for such wide-spread slope instabilities at both local and larger scale.

High resolution field mapping coupled with electrical resistivity tomography allow defining the structural model of the deep-seated landslides (DSLs), their depth limit (100 to 200 m depth) and their involved rock volume ($>10^7$ m^3). We show that they developed strictly in the same geostructural context, such as thick mudstone layers overlain by faulted limestone. They followed a block-spread model of deformation that could evolve in rock-collapse events (Zerathe and Lebourg, 2011).

Cosmic Ray Exposure dating, using both ^{36}Cl and ^{10}Be in coexisting limestone and chert, respectively, have been carried out from the main scarps of six DSLs. All the chronological data measured are in the range of 3 to 4.5 ka. They highlighted: (i) mainly single and fast ruptures and (ii) their concomitant initiation with two main peaks of activity at around 3.2 and 4.1 ka.

Because this region was not affected by historical glaciations events, landslide triggering by glacial unloading can be excluded. Our combined data along with field observations preferentially suggest that these failures were climatically driven and where controlled by high pressure changes in the karstic medium. Despite requiring further investigations and discussions, it appears that, based on the numerous dated events during this middle Holocene period, a potential large-scale triggering cannot be excluded in this area.

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