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Characterization of the deformation and thermal behavior of granitic exfoliation sheets with LiDAR and infrared thermography (Yosemite Valley, USA)

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Yosemite Valley is a long (11 km) and deep (∼1 km) glacier-carved valley, bounded by steep granitic cliffs cutting the western slope of the central Sierra Nevada mountain range (California, USA). These cliffs produce numerous rockfalls every year (925 events reported between 1857 and 2011) and this rockfall activity is often linked to the presence of sheeting joints (Stock et al., 2013), also called exfoliation joints, formed in response to stress changes associated with changes in the topography (Martel, 2011). Furthermore, the historical rockfall inventory indicates that many events occurred without recognized triggers (Austin et al., 2014), in summer time, and on sunny days in particular. This suggests that thermal stress changes are involved in triggering of rockfalls (Collins and Stock, 2016).

To further characterize the relationship between thermal stresses and rock face deformation, we carried out three experiments in Yosemite Valley during October 2015: (i) monitoring of a sub-vertical granodiorite exfoliation sheet on the Rhombus Wall for 24 consecutive hours (from 8:00 p.m. to 8:00 p.m.) using terrestrial LiDAR, crackmeters and infrared thermal sensors; (ii) monitoring the El Capitan rockwall composed of tens of exfoliation sheets for 8 consecutive hours (from 5:30 p.m. to 1:30 a.m.) with terrestrial LiDAR and thermal imaging; (iii) collecting several sequences of thermal GigaPan panoramas during periods of rock cooling on both cliffs (Rhombus Wall and El Capitan).

In parallel to these experiments, we also developed a method for calibrating and correcting the raw apparent temperature measured by our thermal imager (a FLIR T660 infrared camera) from thermoresistances, reflective and black papers and by using some information given by the LiDAR point clouds (range, dip and dip direction).

LiDAR monitoring of experiments (i) and (ii) allowed us to detect millimetric deformations for the exfoliations sheets whose crack aperture is persistent, deep and greater than 9 cm, confirming the results of Collins and Stock (2016). Then, the LiDAR – infrared thermography coupling allowed us to establish a link between the contraction – expansion cycles observed and daily thermal variations: the cycles of contraction (crack closure) occur between 3:00 p.m. and 8:00 a.m. and are associated with cooling, whereas the opposite is true for the expansion cycles (crack opening). In addition, in the case of experiment (i), we observe a delay of about 40 minutes between the time when surface temperatures are minimum and the maximum closure of the crack (-5.33 +/- 0.01 mm), which occurs a little before 8:00 a.m.

Concerning the thermal behavior of the exfoliation sheets, the experiments (i) and (ii) show that the exfoliation sheets are almost always colder than surrounding stable areas, except during the hottest hours of the day when the temperatures are similar. At the end of the night, the temperature deviation between an exfoliation sheet and a stable part can reach 5 to 6 Celsius degrees (values valid for October) and this thermal contrast makes it possible to remotely detect the presence of exfoliation sheets in a rockwall. This result was then confirmed by the experiment (iii) which shows that a whole series of exfoliation sheets could be detected at a distance of 1 km, by means of thermal comparisons. Coupled to the LiDAR, infrared thermography can thus be useful for drawing a 3D map of exfoliation sheets in a cliff of several hundred meters high.