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In situ strain detection of stress-strain relationships and their controls on progressive damage in marble and quartzite by neutron diffraction experiments

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The application of data derived from rock mechanical experiments to large spatial and temporal scales required to assess rock slope stability and landscape evolution is complicated, as these processes of rocks are affected by its lithology, tectonic heritage and rheological behavior under the contemporary stress field. Interpretations of experiments and field sites are restricted to surficial, pre and post state observations of deformations, under almost always subcritical near surface stress fields. We set up an novel experiment to quantify a) the level of inherited residual elastic strains, b) the effect of subcritical low magnitude load steps, c) load magnitudes at which deformation become permanent and further strains are induced and d) differences of rheological behavior due to lithology.

In order to gain greater insight into the stress-strain relationships and their control on progressive damage we employed in situ neutron diffraction techniques to observe crystal lattice strains in pure marble (Carrara marble, > 98 vol% $CaCO_3$) and quartzite (Dalsland quartzite, > 98 vol% SiO_2) samples during stepped Brazilian tests. We measure a gauge volume of ~42 mm3 in the center of cylindrical samples (Ø= 30 mm, l= 22 mm quartzite, l = 26 mm marble) using the EPSILON neutron time-of-flight (TOF) strain diffractometer in Dubna, Russia. Surface-mounted strain gauges provide macroscopic strain data, and acoustic emission sensors are used to detect microcrack initiation. Initial states are measured without load to determine the load-free lattice parameters. Load is increased in three to four stages of approximately 15%, 33%, 66%, and 75-80% of the ultimate intact rock strength ($\sigma 1$ max), and maintained during diffraction measurements (up to 12 hours each). Each load step is followed by a load-free state. Deviatoric strain in both major principal compressive ($\sigma 1$) and minor principal in plane ($\sigma 3$) direction, as well as residual strain, with reference to a strain-free state of powdered samples are calculated for whole diffraction patterns. We obtained initial residual contractional strains of $\sim$ -150 μstrain for Carrara marble and of $\sim$ -50 μstrain for the Dalsland quartzite samples. Already during the first load step of $\sim$10-15% $\sigma 1$ max superposition of the residual strain state is observed and strains partially remain during unloading step. Increased stress magnitudes of the load steps enable us to identify strains as a function of external load and subsequent unloading, indicating, in both rocks, that upon unloading from former loads to less than 75% $\sigma 1$ max, the material remains partially extensionally strained.