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Bridging the gap between micro- and lab-scale measurements using automated micrograph analysis for constrained micromechanical modelling

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Microcracks can affect the mechanical and physical properties of rocks, including their stiffness and strength. To provide a link between the micro-scale attributes and the mechanical behaviour of rock, micromechanical models consider parameters that form a quantitative description (geometry and density) of the microcracks within the material. To provide values for these parameters, that typically are poorly constrained, we characterised the microcracks in a set of fine-grained granite samples that have undergone varying amounts of thermal stressing. To achieve this goal, we developed a segmentation algorithm to automatically extract the microcracks from optical micrographs of thin sections, thereby permitting the calculation of the crack length and number of microcracks per unit area (and therefore average microcrack density). The algorithm allows us to work with large image sets to produce heat maps showing the spatial distribution of the average microcrack length and number density over large areas. The results from our image analysis method are in very good agreement with those from widely-used stereological techniques, and we show that it can be applied to other natural materials containing microcracks. In the laboratory, we measured the stiffness and strength of thermally microcracked granite samples under uniaxial compression. We first applied an upscaling approach by comparing the measured rock strength with that predicted by Ashby and Sammis' (1990) sliding wing crack model (using the microcrack characteristics measured from our automated micrograph analysis). We find good agreement between the model and the experimental data for granite heated to temperatures below the alpha-beta transition of quartz ($\sim$573 °C). For temperatures of 600 °C and above, rock strength is overestimated by the model, possibly due to variations in fracture toughness and aperture which are not taken in to account by our modelling. Finally, we follow a downscaling approach by using the sliding crack model of David et al. (2012) to infer average microcrack density and aperture from the stiffness of the thermally microcracked samples during cyclic stressing. We show a good agreement between macro- and micro-scales if a scaling factor is introduced in the crack density estimate. The experiments and modelling presented herein therefore demonstrate how the micro-scale can inform on mechanical properties on the laboratory-scale, and vice-versa. A detailed understanding of up- and downscaling is important for uniting microstructural observations with laboratory-scale measurements.