Investigating the Thermal Cracking Process of Granitic Rocks Using Digital Image Correlation (DIC)

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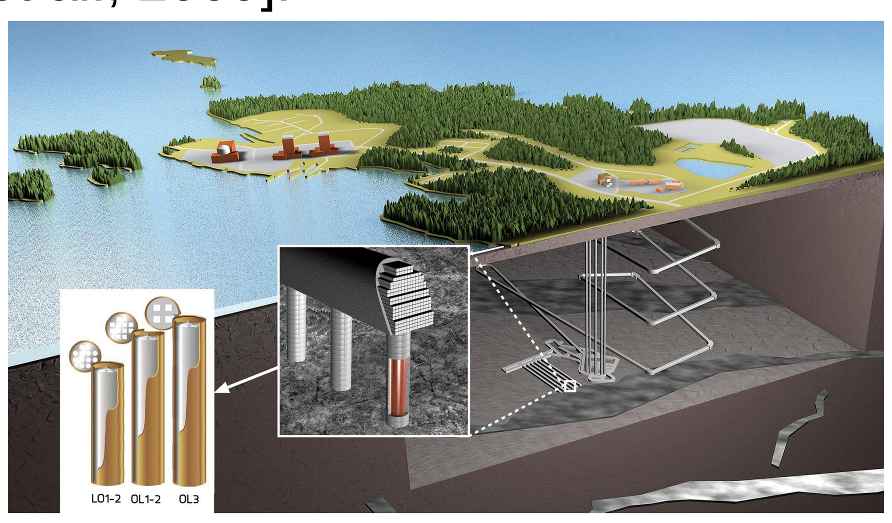
BACKGROUND

Granitic formations host many geothermal reservoirs and nuclear waste repositories, such as the one in Onkalo, Finland. These operations expose the host rock to temperature changes - production of hot fluids or injection of cold fluids in geothermal reservoirs, or the decay of spent nuclear waste in nuclear waste repositories – which result in thermo-elastic stresses that could potentially initiate cracks. Experimental investigations of the thermal cracking of granitic rocks have indicated that the mechanical properties of heat-treated rocks are highly dependent on the temperature the granitic rocks have been exposed to [Bauer and Handin, 1983]. In addition, lab work on the rate of formation of thermal cracks indicated that cracking increased when the sample temperature reached 573 ˚C [Nasseri et al., 2009].



The Onkalo spent nuclear fuel repository in Eurajoki, Finland [NEA, 2020].

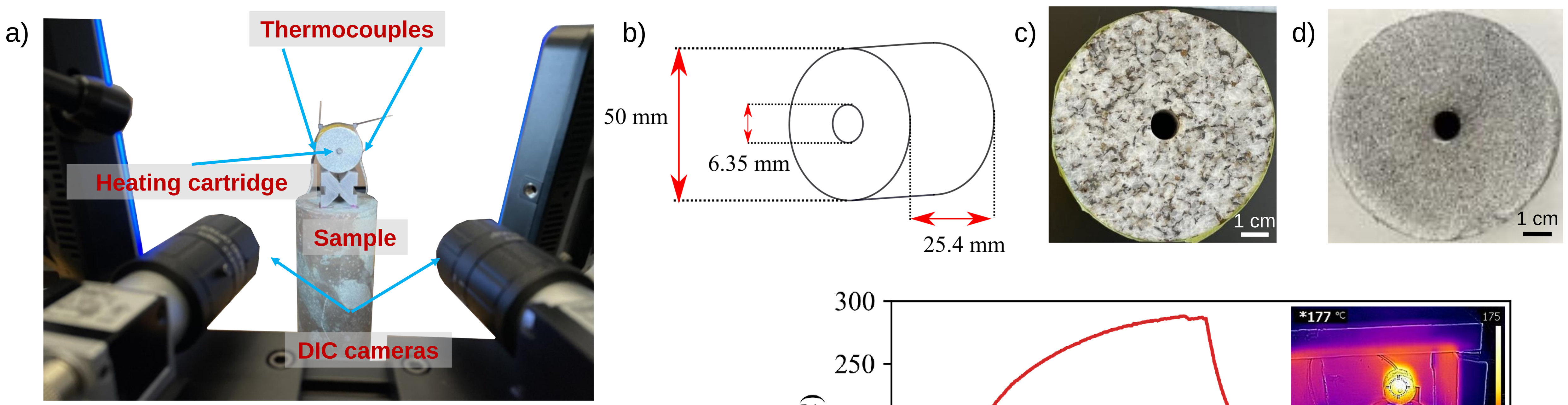
WHY / PURPOSE

Understanding the thermal cracking of granitic rocks is crucial for many underground applications. Thermal cracking has been investigated using methods such as acoustic emission (AE) monitoring, petrographic analysis, and numerical modeling [Aboayanah et al., 2022; Meredith et al., 2001]. In this work, we adopted a robust measurement technique, the stereo (3D) digital image correlation (DIC), to investigate thermal cracking behavior of Stanstead granite, which is a fine-grained granite found in Eastern Canada. DIC technique can provide full-field displacement and strain at meso- and macro-scopic scales. This provides more in-depth insight into the processes of crack initiation and propagation, and in this case, into those thermally induced.

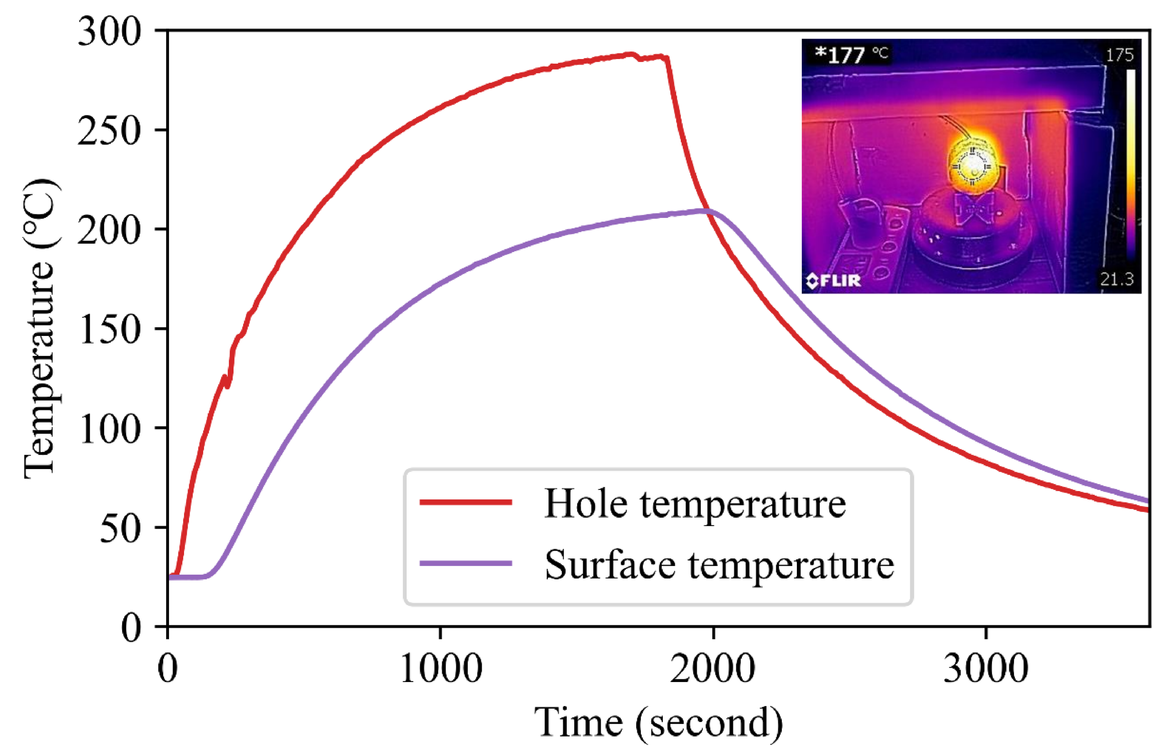
METHODOLOGY

To investigate the initiation and propagation of thermal cracks in Stanstead granite, we used the DIC system with a heating and cooling regime on cylindrical samples. The samples were cut from a 50 mm diameter core, surface polished, and a 6.35 mm hole drilled in center of the sample. A speckle pattern was then applied on the surface of the cylinders using spray paint. During the experiment, using a sequence of digital images from the painted sample surface, the DIC algorithm tracks the coordinate changes in the speckle pattern to determine the deformation and strain of the surface.

a) Experimental setup, b) sample schematic, c) sample before the application of speckle pattern, d) sample after painted with speckle pattern for the deformation field visualization using DIC.

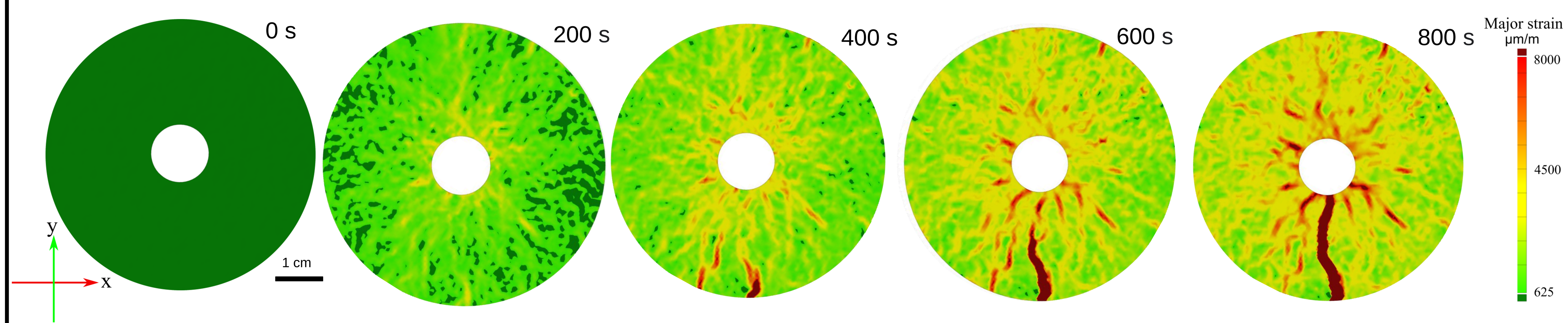


The experiment presented in this work lasted for one hour and consisted of both heating and cooling phases, 30 minutes each. To heat the Stanstead granite samples, a heating cartridge was inserted in the drilled hole. Thermocouples were applied close to the hole and the outside of the cylindrical samples to monitor the temperature change over time.



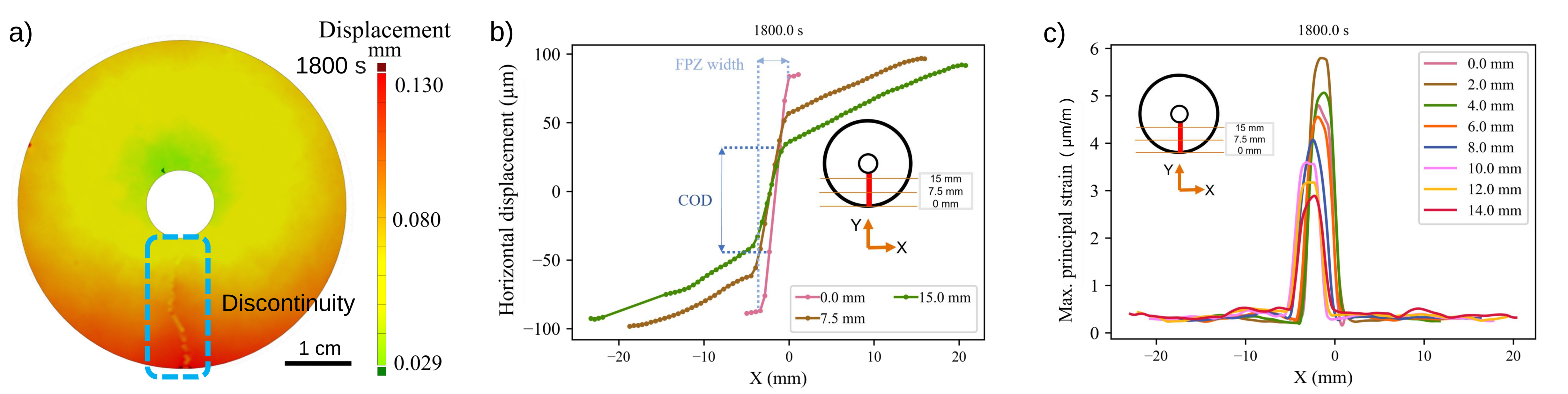
Temperature variation with time for the heating and cooling half-cycle and thermal imaging of the sample during the heating cycle at 177 ˚C.

RESULTS



Major principal strain distribution and macroscopic crack propagation during the heating half-cycle (until 800s).

The DIC major strain analysis showed that the macroscopic crack initiated from the outer boundary of the sample (i.e., colder end) due to tensile stresses exerted by the expansion of the sample's interior (i.e., hotter end). The displacement field results also showed the discontinuity of the displacement field across the crack. The clear jump in the horizontal displacement across the crack can be used to calculate the crack opening displacement (COD) and the width of the fracture process zone (FPZ). The DIC analysis also showed strain localization around the macroscopic cracks. The DIC has proven to be a very useful experimental tool for investigating the thermal cracking of granitic rocks and the development of the FPZ during crack propagation.



(a) Resultant-displacement field at the end of the 30 minutes heating half-cycle, (b) definition of the crack opening displacement (COD) and width of fracture process zone (FPZ), (c) maximum principal strain across the crack.

DIC is a useful experimental tool for investigating the crack propagation process of crystalline rocks during heating and cooling cycles that simulate thermal treatment in underground applications such as hydraulic stimulation of geothermal reservoirs.

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