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Experimental Measurement of *In Situ* Stress

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The World Stress Map data is determined by stress indicators including earthquake focal mechanisms, *in situ* measurement in mining, oil and gas boreholes as well as the borehole cores, and geologic data. Unfortunately, these measurements are not only infrequent but sometimes infeasible, and do not provide nearly enough data points with high accuracy to correctly infer stress fields in deep mines around the world. Improvements in stress measurements of Earth's crust is fundamental to several industries such as oil and gas, mining, nuclear waste management, and enhanced geothermal systems.

Quantifying the state of stress and the geophysical properties of different rock types is a major complication in geophysical monitoring of deep mines. Most stress measurement techniques involve either the boreholes or their cores, however these measurements usually only give stress along one axis, not the complete stress tensor. The goal of this project is to investigate a new method of acquiring a complete stress tensor of the *in situ* stress in the Earth's crust.

This project is part of a comprehensive, exploration geophysical study in a deep, highly stressed mine located in Sudbury, Ontario, Canada, and focuses on two boreholes located in this mine. These boreholes are approximately 400 m long with NQ diameters and are located at depths of about 1300 - 1600 m and 1700 - 2000 m. Two borehole logging surveys were performed on both boreholes, October 2013 and July 2015, in order to perform a time-lapse analysis of the geophysical changes in the mine. These multi-parameter surveys include caliper, full waveform sonic, televiewer, chargeability (IP), and resistivity. Laboratory experiments have been performed on borehole core samples of varying geologies from each borehole. These experiments have measured the geophysical properties including elastic modulus, bulk modulus, P- and S-wave velocities, and density.

The apparatus' used for this project are geophysical imaging cells capable of hydrostatic stress ($\sigma_1 = \sigma_2 = \sigma_3$), differential stress ($\sigma_1 > \sigma_2 = \sigma_3$), and the unique true triaxial stress ($\sigma_1 > \sigma_2 > \sigma_3$). Velocity surveys can be acquired along all three axes, and therefore the effects of $\sigma_1, \sigma_2, \sigma_3$ on the velocity-stress curve can be obtained. These geophysical cells are being used to reproduce the borehole P- and S-wave velocities by altering the differential stress, allowing for the unique position of determining the stress tensor. Currently, results have been obtained for differential stress ($\sigma_1 > \sigma_2 = \sigma_3$), and true triaxial experiments will determine if σ_3 is the missing factor to reproducing the borehole velocities. This project is the first to combine time - lapse borehole logging data and experimental laboratory data to infer a complete stress tensor.