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Rock strength and time dependent deformation of borehole breakouts in the ICDP Outokumpu deep borehole

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While the mechanical properties of plate boundaries are relatively well known and characterized by earthquake occurrence, intraplate regions are still largely *"terra incognita"*, especially in cratonic shields where only seldom and very few data related to the state of the stress field are available. The only way to detect such data and understand the geological and physical processes responsible for the present stress field in an intraplate area is to carry out in-situ measurements of stress-induced deformation in a borehole over time. We had a unique and extraordinary opportunity to measure and investigate the time-dependent deformation in an aseismic area directly in-situ inside the 2500 m Outokumpu open borehole in eastern Finland. The stress data acquired in 2006 and 2011 have been analysed and show that a slow but continued deformation of the upper part of the Earth's crust, albeit unexpected, is still ongoing. The continuous formation and development of stress-induced borehole enlargements in a tectonically very stable and almost aseismic area is unforeseen and raises questions of global importance. For this, two complementary approaches were conducted: identification of breakout zones and rock physics measurements on selected drill cores. We compared the two datasets to study the changes of breakout geometry and to quantify the growth of the breakouts in this time span from differences in width, length and depth. For the second method, UCS experiments were conducted providing unconfined compressive strength on specimens collected from above, middle and below breakout zones, and rough estimates of the static Young's modulus based on the initial length and axial travel of the load frame. The sample height-diameter (H:D) ratio of available drill cores was less than required in testing standards (ASTM D7012, 2014, ISRM 1999). The relatively small grain size of drill cores allowed drilling of smaller-diameter subcores that in most cases fulfilled or exceeded the minimum H:D ratio (1.7<H:D<2.3). We realized that also along the same lithology some zones are affected by enlargements and other remain undamaged. Therefore, we performed the geomechanical analyses on specimens from the same lithology but not affected by failures. Fifty-one uniaxial compressive tests were conducted on specimens belonging to four main rock types at different depths: biotite gneiss, diopside tremolite skarn, micaschist and serpentinite. Results from geomechanical test show UCS values range from 27 to 245 MPa with an average of 102 MPa and a standard deviation of 42, while the elastic Youngs modulus range from 3 to 20 GPa with an average of 7.3 GPa and a standard deviation of 2.8. Most samples collected within breakout zones have UCS values from 40 to 170 MPa and H:D ratio from 1.8 to 2.0, less that required by the

standards. The samples outside of the breakout zones show UCS values from 27 to 186 MPa, and H:D ratio from 1.7 to 2.3. The hypothesis for testing was that borehole breakouts were formed in weaker rocks. Our results does not confirm this hypothesis, but the observed time-dependent deformation in Outokumpu borehole is interesting and calls for further studies.