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Present-day stress state in the Outokumpu deep drill hole, Finland

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This study aims to investigate the present-day stress field in the Outokumpu area, eastern Finland, using interpretation of borehole failure on acoustic image logs in a 2516 m deep hole. Two main objectives of this study are: i. to constrain the orientation of maximum horizontal stress by mapping the occurrence of stress-induced deformation features using two sets of borehole televiewer data, which were collected in 2006 and 2011; and ii. to investigate whether any time dependent deformation of the borehole wall has occurred (creep). The Outokumpu deep hole was drilled during 2004-2005 to study deep structures and seismic reflectors within the Outokumpu formation and conducted within the International Continental Scientific Drilling Program (ICDP). The hole was continuously core-drilled into Paleoproterozoic formation of metasediments, ophiolite-derived altered ultrabasic rocks and pegmatitic granite. In 2006 and 2011 two downhole logging campaigns were performed by the Operational Support Group of ICDP to acquire a set of geophysical data. Here we focus on a specific downhole logging measurement, the acoustic borehole televiewer (BHTV), to determine the present-day stress field in the Outokumpu area. We constrain the orientation and magnitude of in situ stress tensor based on borehole wall failures detected along a 2516 m deep hole. Horizontal stress orientation was determined by interpreting borehole breakouts (BBs) and drilling-induced tensile fractures (DIFs) from BHTV logs. BBs are stress-induced enlargements of the borehole cross section and occur in two opposite zones at angles around the borehole where the wellbore stress concentration (hoop stress) exceeds the value required to cause compressive failure of intact rock. DIFs are caused by tensile failure of the borehole wall and form at two opposite spots on the borehole where the stress concentration is lower than the tensile strength of the rock. This occurs at angles 90° apart from the center of the breakout zone. Acoustic imaging logs provide a high-resolution oriented picture of the borehole wall that allows for the direct observation of BBs, which appear as two almost vertical swaths on the borehole image separated by 180°. BBs show poor sonic reflectivity and long travel times due to the many small brittle fractures and the resulting spalling. DIFs appear as two narrow stripes of low reflectivity separated by 180º and typically sub-parallel or slightly inclined to the borehole axis. The analysis of these images shows a distinct compressive failure area consistent with major geological and tectonic lineaments of the area. Deviations from this trend reflect local structural perturbations. Additionally, the 2006 and 2011 dataset are used to compare the changes of breakout geometry and to quantify the growth of the breakouts in this time span from differences in width, length and depth to estimate the magnitude of the horizontal stress tensors. Our study contributes to understand the structure of the shallow crust in the Outokumpu area by defining the current stress field. Furthermore, a detailed understanding of the regional stress field is a fundamental contribution in several research areas such as exploration and exploitation of underground resources, and geothermal reservoir studies.