Stress heterogeneity in the source region of the 2014 Orkney earthquake (M5.5), South Africa, estimated by ICDP-DSeis

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The 2014 Orkney earthquake (M5.5) occurred below the Moab Khotsong gold mine in South Africa. The shallowest aftershocks were located only several hundred meters below the deepest level of the mine. Two boreholes (A: 817 m, B: 700 m) were drilled toward the upper margin of the aftershock zone from a specially excavated chamber at 2.9 km depth from the earth surface by the ICDP-DSeis project. Hole A deflected from the aftershock zone, while Hole B intersected it. Hole C (100 m) was branched from Hole B at a distance of 540 m from the hole collar to recover more samples from the aftershock zone. Except for the intersection in Hole B, the drill core recovery rate was ~100%. In-hole geophysical logging, including the surveys of the borehole wall trajectory were carried out along the entire length of Hole A, up to the intersection with the aftershock zone in Hole B (further access in Hole B was restricted due to hole closure in the aftershock zone). Hole C was not logged.

The focal mechanism solutions of mining induced earthquakes shallower than 3 km from the earth surface are usually of the normal faulting type, while those of the Orkney earthquake and its aftershocks deeper than 3.5 km show a strike-slip signature. In this study, we applied the Deformation Rate Analysis (DRA) and the Diametrical Core Deformation Analysis (DCDA) techniques to rock cores recovered from Holes A, B and C, to explore the variation in the stress state with depth that would cause the depth variation in the faulting regime. The DRA consists of cyclic loading on a sample from a drill core to determine the normal stress from hysteresis of the stress-strain curve. The normal stresses were determined in nine directions at each selected depth to determine the principal stress state (3 principal magnitudes and 3 principal directions) respectively. However, because it takes much time for sub-sample preparations and cyclic loadings, we applied this technique at only 3 depths in Hole A. By contrast, the DCDA method measures the differential stress in the plane normal to a borehole. The stresses are evaluated from the ellipsoidal cross-sectional shape of the rock cores. Though only the differential stress can be measured by the DCDA method, it is good for comparative purposes and only takes a few minutes to make the measurements. We evaluated the differential stresses every several meter along Holes A, B and C.

Rock cores of Hole A were oriented by comparing joints and veins identified on the borehole wall optical-televiewer images to the cores. From the comparison, stress orientations were determined in the plane normal to Hole A. The stress orientations were subsequently confirmed by the breakout of borehole wall (identified by the acoustic televiewer). Magnitudes of the maximum and the minimum stresses were estimated by combining the differential stress magnitude evaluated by the DCDA and the width of the breakout.

The differential stresses and the maximum compression directions in the plane normal to Hole A determined by the DRA and the DCDA methods were almost identical to each other. The stress state

along the lengths of Holes A, B and C varied significantly. In few tens of MPa difference was determined within several tens of meters. The paper will discuss the interrelation among the spatial heterogeneities of stresses and physical properties of rocks in the source region of the Orkney earthquake.

Keywords: Principal stress, Drilling into seismogenic fault, Stress measurement by core method

