Estimate of the stress state in earthquake source region in South African deep gold mine by DCDA

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In the earthquake preparation process, the strength of a fault and the stress state around the fault evolve by interacting with each other through the fault slip. Therefore, many attempts have been done to measure the stresses around faults by deep drillings. However, techniques that are applicable to a large depth (> 1km) are limited. An earthquake of Mw2.2 (mainshock, hereafter) occurred at 3.3km depth in Mponeng mine, a deep gold mine in South Africa. The rupture plane of the mainshock diagonally cut a 30-m-thick gabbroic dike. Yabe et al. (2013) drilled a borehole passing the source fault of mainshock ~1.5 yrs afterward. They constrained possible ranges of the stress magnitudes, as well as the principal directions, based on the criteria of the borehole breakout and the core disking. In this study, we estimate the differential stress in a plane normal to the borehole axis with a higher resolution by Diametrical Core Deformation Analysis (DCDA, Funato and Ito, 2013) to the cores recovered from the borehole. DCDA is applied also to the cores of another borehole drilled ~7 mo before the mainshock in the same area. We also discuss applicability of DCDA to estimate stress at great depths.
DCDA estimates the differential stress from azimuthal variation in diameter (differential strain) of a core induced by stress relief associated with drilling. We collected seven core samples, ~30 cm long, from each borehole. The diameter was measured along circumferential profile lines set every ~2 cm on each core. Results: Coherent azimuthal variations in diameter were seen on three and five of seven core samples collected from the borehole drilled before and after the mainshock, respectively. Since core samples with incoherent diameter variations are considered to be damaged during drilling, we exclude them from the discussion below.
The pre-mainshock differential stresses were estimated to be ~100 MPa along the borehole from the central part of the dike to the host rock (quartzite) in west. The post-mainshock ones were about 20 MPa in the western host rock and near the west contact. On the other hand, it was ~70 MPa at the central part of the dike. The post-mainshock differential stresses obtained in this study fell in the range estimated by Yabe et al. (2013), while they were two times or more greater than their optimal values.
In DCDA, it is assumed that the core expansion induced by the stress relief by drilling is purely elastic. However, the core samples in this study were taken at a depth of ~3.3 km from the surface. The overburden pressure is as high as ~80 MPa. When such a high stress as ~80 MPa is unloaded, the inelastic deformation may occur, resulting in overestimation of the differential stress. In order to evaluate the effect of the inelasticity on the estimation, we carried out uniaxial creep tests of the dike. The ratio of the inelastic deformations to the elastic deformations was less than 10%. Just before the yielding under the uniaxial compression test or the uniaxial tensile (Brazilian) test, the inelastic strains were not larger than 30 % of the elastic strains. Therefore, the larger magnitudes of the differential stresses estimated in this study than those by Yabe et al. (2013) are not apparent by the inelasticity of the dike. There is a significant difference between the pre- and the post-mainshock differential stresses. However, because of different inclinations of the two boreholes, the pre- and the post-mainshock differential stresses cannot directly be

compared with each other. We grid-searched a stress state that can reproduce both differential stresses. The principal directions of stress were fixed to those by Yabe et al. (2013). The maximum magnitude of the principal stresses was 300 MPa. No stress state was found to simultaneously reproduce both of the pre- and the post-mainshock differential stresses, suggesting that DCDA can detect a temporal change in the stress state.

Keywords: South African deep gold mine, Diametrical Core Deformation Analysis

