Estimate of the stress state in the source region of Mw 2.2 earthquake in a South African deep gold mine

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Introduction:
During 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, to better understand the earthquake generation, it is important to investigate a temporal variation in stresses around the fault. Many attempts have been made to measure the stresses around faults by deep drillings. A variety of techniques are proposed to measure the stresses in the borehole or by using the core samples. However, techniques that can be applied to large depths (> 1km) are limited.
An earthquake of Mw 2.2 (mainshock, hereafter) occurred at 3.3km depth in Mponeng mine, a deep gold mine in South Africa, on December 27, 2007. The rupture plane of the mainshock diagonally cut a 30-m-thick gabbroic dyke. Yabe et al. (2013) drilled a borehole penetrating the source fault of the mainshock ~1.5 years after the mainshock. They evaluated the stress state in the source region based on the borehole breakout and the core discing. However, they could constrain only bounds of stress magnitudes, as well as the direction of principal stresses. That is, their resolution of stress magnitudes is very low.
In this study, we estimate the differential stress in a plane perpendicular to the borehole axis with a higher resolution by applying the DCDA (Diametrical Core Deformation Analysis, Funato and Ito, 2013) to core samples recovered from the above-mentioned borehole. Stress measurement by DRA (Deformation Rate Analysis) is also performed.

Method:
DCDA estimates the differential stress in the plane normal to the borehole axis from the azimuthal variation in diameter of a core sample which was induced by stress relief associated with drilling. Circumferential profile lines are set every ~2 cm on each core sample to measure diameter every 2 degree. DRA measures the axial stress parallel to the uniaxial loading to a sub-sample based on a non-linearity of its stress-strain curve.

Result:
When the azimuthal variations in diameter were incoherent among the profile lines on a single core sample, we regarded that the core sample was scraped during drilling and did not use data of such cores. Differential stresses were about 20 MPa in the host rock (quartzite) and in the dyke (gabbro) near the contact. On the other hand, it was ~100 MPa at the central portion of the dyke. These results fell between the upper and the lower limit estimated by Yabe et al. (2013). We determined the principal stress in a plane normal to the borehole axis by DRA. The maximum and the minimum compressive stresses were ~110 MPa and ~30 MPa at footwall-dyke region, respectively. The differential stress at same region is,

then, calculated to be ~80 MPa, being consistent with the estimation by DCDA.

Discussion:
Considering its geological conditions, we divided the study region into three; quartzite, footwall-dyke and hanging-wall-dyke regions. Under the assumption that the stress state is uniform within each region, we conducted grid-search to find the principal stress in each region that satisfies the differential stress measured by DCDA and criteria of borehole breakout and core discing. We could constrain principal stress directions very well except for footwall-dyke region where no borehole breakout or core discing were observed.

Conclusion:
By applying the DCDA to drilling core samples recovered from a close vicinity of the source fault of Mw 2.2 earthquake occurred at ~3.3 km below surface in a South African deep gold mine, we successfully obtained a new constraint on the stress state in the source region of the Mw 2.2 earthquake, where only rough estimation has been made by Yabe et al. (2013). To improve the estimation in the footwall-dyke, we apply DRA.

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