EGU2020-12094, updated on 28 Oct 2021
https://doi.org/10.5194/egusphere-egu2020-12094
EGU General Assembly 2020

The seismogenic zones of an M2.0-5.5 earthquakes successfully recovered in deep South African gold mines: the outcomes and the follow-up plan

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This paper reports on the outcomes of the ICDP drilling into seismogenic zones of M2.0-5.5 earthquakes in South African (SA) gold mines (DSeis; 2017-2018), the follow-up work in 2019, and planned post-drilling activity from 2020 onwards.

In deep SA gold mines, seismogenic zones evolve ahead of thin tabular excavations. Normal faulting prevails because mining enhances the vertical maximum principal stress. At 1km depth at the Cooke 4 mine, we elucidated the evolution of the seismogenic zone with a dense acoustic emission network. In 2017, we successfully recovered both the metasedimentary host rock (mainly quartzite ~2.8 Ga) and samples of the seismogenic zone with well-preserved fracture systems using a triple-tube (BQ 1.5m-long). Subsequent laboratory work investigated critical characteristics of rock-rock friction.

In 2014, an M5.5 earthquake, the largest in deep South African gold mining districts, took place. Dense seismic networks, both on the Earth's surface and at 2-3 km depth, showed that this event

was atypical because it was a sinistral event on an unknown geological structure below the mining horizon in West Rand Group strata (~2.9 Ga). Inversion and back-projection of the ground motion showed complicated but unilateral rupture propagation. The densest population of aftershocks shows a sharp upper cut-off and streaks, both dipping to the south. Its centroid lies outside the significant main rupture zone. In 2017, we commenced drilling at a site at 2.9km depth in a tension quadrant of the sinistral faulting, several hundreds of meters above the upper fringe of the M5.5 aftershock plane. During 2017-2018, we drilled holes, of a total length of 1.6 km. With a 1.5m NQ triple-tube for the critical section, we could recover the fault materials and the host rock with the seismic fracture system well preserved. Borehole logging and core curation in SA and laboratory work at international organizations, including Kochi Core Center Japan (KCC), followed during 2017-2019. With the geology data mapped on the mining horizons and the legacy seismic reflection data as additional information, the following picture is emerging: (a) transition of the stress regime from normal-faulting to sinistral-faulting; (b) stress localization; (c) heterogeneity in the aftershock distribution as well as the segregation between the main rupture and aftershocks, potentially correlated with significant heterogeneity in mechanical properties; (d) a role of an altered lamprophyre dike; (e) hypersaline brine with salinity even higher than measurements at other deep gold mines, potentially as old as brine found at Kidd Creek mine, Canada; and (f) abiogenic gas and organic carbon.

These data sets allow us to address questions in earthquake and deep-life sciences raised in the ICDP Science Plan (2014-2019). In 2019, the ICDP Executive Committee described DSeis as a 'successful' project. To integrate and discuss the outcomes in greater depth and plan additional follow-up work, we are planning a post-drilling workshop in November 2020 or January 2021 at KCC before we return the imported critical section of the core to South Africa.

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