From DSeis to PROTEA - Probing the heart of an earthquake, especially the interaction between metasedimentary rocks and mantle-derived intrusions.

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The ICDP DSeis project accomplished full-core drilling and borehole-logging of the seismogenic zone of the 2014 M5.5 Orkney earthquake, South Africa. Three NQ-holes (total 1.6 km in length), drilled from 2.9 km depth at the Moab Khotsong gold mine, penetrated mostly intact hard rock, including 2.9 Ga meta-sedimentary and altered andesite (Crown) formations dipping ~20°SE. Subparallel altered gabbroic diorite sills intrude the formations.

After the borehole penetrated the Crown Formation and approached the steeply-dipping planar cluster of earthquake aftershocks, it encountered a potassic lamprophyre dyke several meters thick. The lamprophyre was intact close to the dyke contact, with mineral assemblages of augite, actinolite, and biotite. The talc and calcite content and magnetic susceptibility increased towards the centre of the dyke, while the augite and actinolite content decreased. The lamprophyre rock mass then became brecciated, with a substantial fraction of gouge. The Crown Formation adjacent to the dyke contact was also brecciated. Friction tests made on lamprophyre gouge (which contains about 20 wt% talc) yielded very low friction coefficients, similar to the results of previous wet friction experiments (Yabe et al. EGU 2024).

The DSeis drilling also intersected a non-potassic dyke rich in actinolite and chamosite about 300 m east of the potassic lamprophyre dyke. Whilst this dyke hosted no indications for aftershocks, the extracted brine was more hypersaline and older than any brine previously sampled from deep South African gold mines (Nisson et al., 2023). The hypersaline brine was non-meteoric in composition, with dissolved organic carbon concentrations sufficient to support deep life.

Both dykes show significant spatial variation in composition which we attributed to contamination/assimilation and metamorphism, depending on which formations (~20°SE dip) the
dykes cut. We postulate that the localization of aftershocks in ‘streaks’ subparallel to the strata is a result of this compositional heterogeneity.

DSeis has successfully penetrated, sampled, and studied the aftershock sequence on the upper edge of the Orkney earthquake rupture. However, important questions regarding the nucleation and rupture of the earthquake that will only be solved by studying the strong motion source of the mainshock. The proposed PROTEA scientific drilling project aims to probe the Orkney earthquake’s strong motion sources (the heart).

The existing DSeis hole, the new PROTEA hole, and the connecting horizontal tunnels at 2.9 km depth will allow us to deploy a 3D distributed acoustic sensing (DAS) network with a vertical span of several hundreds of meters, and a horizontal span of about 1 km. Using both active and passive seismic sources, we expect to image the 3D structure of the reflectors precisely.

Moab Khotsong has offered the team access to borehole cores that have sampled numerous dykes and sills; as well as access to the database of lithology and geological structure mapped on the mining horizons at 2-3 km depth. These data cover a much broader volume than the DSeis and PROTEA projects, and will significantly extend and enhance the interpretation.

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