Frictional properties of the fault hosting aftershocks of the 2014 Orkney earthquake (M5.5), South Africa, and proposal of a new drilling project PROTEA to probe the heart of the earthquake

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The ICDP-DSeis (Drilling into Seismogenic zones of M2.0 – M5.5 earthquakes in deep South African gold mines) project recovered rock samples from a fracture zone that hosted the aftershocks of the 2014 Orkney earthquake (M5.5). The fracture zone was formed in an altered lamprophyre dike (Lamprophyre, hereafter) intruded into the Crown Formation (local name of altered basaltic andesite). One of the DSeis holes intersected another dike (named the Onstott dike) ~300 m east of the Lamprophyre. A fissure containing ancient (1.2 Ga) hypersaline brine rich in DOC (dissolved organic carbon) was found in the Onstott dike. The formation and metamorphism of these dikes are discussed in Ogasawara et al. (EGU24). This study describes the frictional properties of Lamprophyre that motivated us to propose a new drilling project PROTEA.

The southern shallowest section of the fault intersected by the DSeis hole did not slip significantly during the Orkney earthquake mainshock, but hosted high aftershock activity. This implies that the fault intersected by the DSeis hole was stable frictionally and decelerated coseismic slip to halt the dynamic propagation of the mainshock rupture. Thereafter, the fault transitioned to an unstable state and produced aftershocks. The recovered rocks revealed the Lamprophyre did not contain any quartz and was rich in talc, biotite, amphibole, and calcite. Loss of drilling water into the fault zone suggested that the pore pressure in the fault zone was low (<6 MPa, water head pressure in the borehole). Consequently, sliding-rate step tests were conducted under wet (saturated, but without pore pressure) condition using the powdered samples to investigate evolution of the frictional property with increasing sliding distance.

The friction coefficient of Lamprophyre was ~0.3, much lower than that of the Crown Formation (~0.7). The friction coefficients of both lithologies were almost independent of sliding distances. Lamprophyre showed rate-strengthening behavior irrespective of sliding distance. Acoustic emission (AE) activity, which mimics aftershock activity, in the Lamprophyre gouge became higher with increasing sliding distance. This implies a hierarchical evolution of frictional property of Lamprophyre. These experimental results explain the spatial coincidence of the mainshock rupture termination and high aftershock activity.
The weakness of Lamprophyre may enable the formation of a fault in Lamprophyre. However, its rate-strengthening behavior would prevent the nucleation and spontaneous propagation of the rupture on a fault in Lamprophyre. Frictional properties, the stress state, the pore pressure, and/or lithology around the hypocenter should differ from those in the aftershock zone. Therefore, we propose a new drilling project PROTEA (Probing the heart of an earthquake and life in the deep subsurface) to drill a hole targeting the hypocenter and the strong motion source of the Orkney earthquake. It will explore the frictional properties, stress state, pore pressure, and lithology that enabled the nucleation and the initiation of the dynamic rupture, as well as the radiation mechanism of strong motions. PROTEA will drill multiple holes intersecting the Onstott dike, not only to elucidate locality and universality of ecosystems that exist in the fissure brine, but also to investigate the interaction between seismicity and microbial activity.