Previous work on the chemical composition of inclusions in Phalaborwa baddeleyite (ZrO₂) xenocrysts showed that inclusions were a result of the physical alteration of the baddeleyite crystal and the subsequent filling of the cracks by the magma at the end of an emplacement process. Wavelength dispersive X-ray spectroscopy (WDS) analysis of these secondary inclusions and the baddeleyite matrix did not provide any evidence for the presence of U. Previous work for determining the U-Pb-Th isotope ratios in Phalaborwa baddeleyite for geochronology applications using SIMS (SHRIMP technique) and LA-ICP-MS analysis (spatial resolution of 25-50 μm), reported on extremely variable concentrations of uranium (51-2124 ppm). However, no evidence for the presence of U inclusions in natural baddeleyite has previously been reported. In this paper we will describe the characterization of small (~1 μm) uranium oxide (UO₂) primary inclusions in baddeleyite.

Sections of approximately 2 mm thickness were cut from a Phalaborwa baddeleyite xenocryst using a diamond wire saw and polished to a 0.25 μm finish. FIB lamella were prepared from U containing inclusions which were identified using back-scattered electron (BSE) imaging in an FEI Helios NANOLAB. The FIB lamellae were imaged and analysed using a JEOL ARM 200F TEM with an attached SDD energy dispersive X-ray spectrometer (EDS).

BSE imaging of the baddeleyite matrix revealed small uranium inclusions (~1 μm) intersecting the surface. No U-inclusions were associated with any physical alteration such as crack formation in the zirconia matrix. The HAADF STEM image of a uranium oxide inclusion (bright) in the baddeleyite (dark) is shown in Figure 1 (left) together with the corresponding BF image in Figure 1 (right). Figure 2 shows an SAD acquired over the interface of the inclusion and the surrounding matrix indicating an epitaxial relationship between two crystals. EDS line scans across the boundaries of the inclusion did not provide any evidence for inter-diffusion between U and Zr. These results possibly explain the large variation for U concentrations obtained by previous workers. It is also suggests that UO₂ form primary inclusions which were incorporated in the baddeleyite matrix via the initial crystallization process in the earth’s mantle where an immiscible UO₂ droplet crystalizes upon cooling of a ZrO₂-UO₂ melt, followed by the epitaxial growth of ZrO₂ on the UO₂ nucleation kernels upon further cooling.

References
Fig. 1: HAADF STEM (left) micrograph of a UO inclusion (bright) in ZrO$_2$ with the corresponding BF micrograph on the right.

Fig. 2: Partially indexed SAD taken over the UO$_2$-ZrO$_2$ interface.