Infiltration of volatile-rich mafic melt in lower crustal peridotites provokes deep earthquakes, initiates km scale shearzones and volatile transfer from the lower crust to the atmosphere

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We provide here in situ evidence from a network of well-preserved extensional shear zones cutting a rift related lower crustal Reinfjord Ultramafic Complex, Seiland Igneous Province, that formed in the late Ediacaran. Our results can explain seismic events well below the seismic zone of continental rifts and associated CO₂ emissions. Processes leading to catastrophic failure of the weakened rocks led to extremely high strain rates and the formation of pseudotachylites can be traced from a network of mm-m scale steeply dipping transtensional shearzones associated with gabbroanitic dykes to a 2km long low angle extensional shearzone. Deformation, initiated through a priming of the dyke-host rock interface by magmatic fluids, exploits subgrains and microfractures in olivine, with reactive CO₂-bearing fluids leading to volume expanding reactions such as olivine + diopside + CO₂ = Dolomite + enstatite, enhancing olivine grain fracturing. Fragmentation of the olivine grains and addition of weaker phases facilitated strain localization and local increases in strain rate by two orders of magnitude. Catastrophic failure of the weakened rocks led to extremely high strain rates and the formation of pseudotachylites in several cyclic events. The frictional heat raised the temperature above the dolomite forming reaction, causing release of CO₂ and H₂O along the fault, but also in the surrounding mafic-ultramafic rocks, forming veins around the shearzone. Fluid-rock interaction surrounding shear zones is highly variable and depends on bulk rock compositions. Thermodynamic modelling demonstrates that mineral reactions involving hydration and carbonation differ between dunitic rocks and the pyroxenitic dykes which intersect them. Alteration of dunitic rocks results in the formation of dominantly magnesite-anthophyllite-talc and talc-magnesite assemblages causing approximately 12% volume expansion, resulting in a sharp reaction front contacts with the host rock. When the alteration zones cross the dunite-pyroxenite boundary the associated alteration has a more gradual boundary towards the unaltered rock and the alteration zone widens by approximately 40%. In contrast to the simpler dunite alteration assemblage, the pyroxenitic dykes are altered to a complex mixture of cummingtonite-anthophyllite, magnetite and chlorite. Additionally, orthopyroxene is completely pseudomorphed by a mixture of cummingtonite and magnetite, whereas olivine xenocrysts are partly preserved and surrounded by a magnesite-anthophyllite assemblage. Other, open cavity-like areas are filled by chlorite, amphibole, and Mg-MgCa carbonates, indicating volume reduction during alteration of the pyroxene. Accordingly, dunite alteration effectuates a significant volume expansion, and are therefore only altered locally during
seismic creep events. The pyroxenites are near volume neutral throughout interaction with the same fluids, and are thus more homogeneously altered. The formation of chlorite in hybrid compositions, such as the dykes in the lower crust, may create weak permeable zones that are consequently exploited as pathways for fertile mantle fluids and will hence also be the locus of ore bearing fluids moving to the upper crust. We conclude that catastrophic failure along shear zones in lower crustal continental rifts is possible without remote stress events in the presence of pre-existing heterogeneities and volatiles. These zones also acted and transport conduits for volatiles from the lower crust to atmosphere.