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Lower crustal seismicity facilitates strain compatibility between coeval viscous shear zones

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The mechanisms and controls of deep continental seismicity remain poorly understood in comparison to the upper crustal seismogenic zone, especially in intraplate fault zones where earthquakes may be infrequent but nonetheless destructive. Although various mechanisms have been postulated for lower crustal earthquake nucleation, the context of seismicity in dry lower crustal rocks (i.e. granulites) is only just beginning to be explored. The high strength of dry rock is a crucial parameter in determining the deformation behaviour of crustal domains and may allow earthquake nucleation within regimes that are more typically associated with viscous flow. Dry, plagioclase-rich lower crust typically remains strong under high-grade metamorphic conditions and hence could deform by frictional failure at high differential stress, potentially enabling transient seismic behaviour. Here we document the structural context in which seismic failure may occur in the dry lower crust, and derive the associated earthquake source parameters from detailed field observations of the exhumed seismogenic structures.

Interplay between highly localised viscous deformation in mylonitic shear zones and frictional failure of the surrounding rock is observed within exhumed lower crustal anorthosites in Lofoten, northern Norway, where small seismic faults developed in order to maintain strain compatibility. The major mylonitic shear zones localised coevally onto pre-existing planar structures in three major orientations, including larger pseudotachylyte-bearing faults which represented ideal weak precursors for the subsequent solid-state viscous deformation. In the blocks between these major mylonitic shear zones, the anorthosite displays a network of tensile microcracks, but otherwise no pervasive deformation. Locally these internal blocks are cross-cut by networks of pseudotachylyte-bearing faults linking the shear zones which form the boundary to such systems. These pseudotachylytes are dragged into, and therefore were coeval with, the granulite-facies boundary shear zones. Seismic faulting was clearly controlled by these boundary shear zones and represents small-scale seismicity nucleating at lower crustal depths, coeval with viscous deformation. Despite the small magnitudes inferred for these seismic events from standard moment-magnitude scaling (Mw 0.2-1.8), the stress drops implied by slip/length ratios are large, ranging from 0.1 to > 1 GPa, reflecting the high strength of the dry, coarse-grained anorthosite. This system elucidates a mechanism by which spatial clusters of small earthquakes can nucleate within the deep roots of continental fault zones.