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Melt-triggering fluids forming Earth's earliest primitive crust came from the mantle

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By the end of the Archean Eon, a significant portion of Earth's continental crust had formed through partial melting of hydrated mafic rocks, producing sodic granitoids of the tonalite-trondhjemite-granodiorite (TTG) suite. While extensive research has focused on the geodynamic environments of Archean crustal formation, the mechanisms and sources of water required for TTG generation at mid- to low- crustal depths remain poorly understood. To address this, petrography, bulk-rock geochemistry, in-situ O and Hf isotopes, and zircon petrochronology from TTG gneisses of the Lewisian Gneiss Complex (LGC), NW Scotland, are used to identify two compositionally distinct groups of TTGs—hornblende- (hbl-TTGs) and biotite-bearing (bt-TTGs)— and constrain the origin of the water involved in their formation.

In-situ U–Pb geochronology of magmatic zircon cores from both hbl- and bt-TTG yields crystallization ages between 2.7 and 2.9 Ga, coinciding with a major phase of crustal growth in the LGC at ca. 2.8 Ga. Hbl-TTGs are primitive, sodic (K_2O/N_2O 0.26) tonalitic magmas derived from partial melting of low-K mafic rocks, with characteristic Nb/Ta   20, Zr/Sm   85, Gd/Yb   4 and Sr/Y   121. Hbl-TTGs between 2.94 to 2.83 Ga show εHf values between +3 and −3, while zircon $\delta^{18}O$ values (5.4–6.4‰) suggest interaction with a predominantly mantle-derived water source and a subordinate contribution from isotopically fractionated supracrustal fluids. In contrast, bt-TTGs are less sodic (K_2O/N_2O 0.48) and more evolved, derived from partial melting of low-K mafic and tonalitic sources, with lower Nb/Ta   12, Zr/Sm   65, and higher Gd/Yb   5 and Sr/Y   164, compared to the hbl-TTGs. Zircon εHf (+4 to −6) and mantle-like $\delta^{18}O$ values (5.2–6.0‰) from 2.7 to 2.8 Ga bt-TTGs indicate addition of juvenile material to reworked crust.

Petrography and geochemistry identify two distinct TTG groups with different source characteristics. Hbl-TTGs are primitive magmas that originated from the interaction of a mafic source with a dominantly mantle-derived fluid. In contrast, the slightly younger bt-TTGs formed by partial melting of a more evolved source that interacted with juvenile material and reworking of older crust. These findings suggest that the water required for crustal formation processes was likely already present and bound within the mafic crust in the early Earth.