Petrogenesis of the 4.02 Ga Idiwhaa tonalitic gneiss and implications for crust formation on the early Earth

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The Acasta Gneiss Complex dominantly comprises meta-igneous rocks that record magmatic U-Pb zircon ages between 4.02–3.4 Ga [1–4]. Of particular significance is the 4.02 Ga Idiwhaa tonalitic gneiss (ITG), a mappable, relatively well-preserved tonalitic suite that contains abundant primary igneous 4.02 Ga zircons. This suite represents the world's oldest known zircon-bearing igneous rock unit, allowing for combined isotopic analysis of zircons in the context of their parental whole rock [5].

Unlike typical Archean tonalite-trondhjemite-granodiorite magmatic rocks, the well-preserved meta-igneous ITG is characterized by chemical features that indicate evolution dominated by shallow-level fractionation processes involving plagioclase. Zircons from the ITG document primary crystallization at 4.019 ± 1.8 Ma and occur as two chemically distinct phases of igneous growth with a marked decrease in $\delta^{18}O$ from +5.6 ‰ to +4.7 ‰. This drop in $\delta^{18}O$ can be explained by late-stage assimilation of hydrothermally altered crust [5]. Despite the difference in $\delta^{18}O$ values, Hf-isotope compositions of these two phases of zircon are indistiguishable, with initial εHf values (normalized to chondrite at 4020 Ma) of approximately -2.

Flat chondrite-normalized rare-earth-element patterns within the Idiwhaa unit suggest the low $\delta^{18}O$ assimilant was not Hadean TTG-like crust, while the -2 εHf value in both phases of zircon growth indicates interaction with an early-formed enriched reservoir, potentially ancient mafic crust. Ongoing measurements of whole-rock radioisotope tracer signals ($^{142-143}Nd$, $^{207-206}Pb$, ^{87}Sr) will help define the source of the ITG and its significance for the evolution of the early Earth.

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