Zircon evidence for eclogite facies metamorphism at 3.9 Ga

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Models describing the earliest crustal evolution on Earth increasingly feature the operation of subduction during the first 500 Myr after accretion, either in modern-style settings [1], or as a meteorite impact-triggered process that may have initiated global crustal overturn [2]. However, no direct evidence of early subduction has been reported. Here we present geochemical data for a detrital zircon from the Jack Hills (Western Australia) that records the existence of a high-pressure eclogite-facies rock, uniquely generated by recrystallization of deeply buried crust at 3.9 Ga. We show that isotopic ($\delta^{18}O$, U-Pb, εHf), trace element (REE, Li, Ti) and microstructural observations (CL, EBSD) are consistent with zircon formation due to burial and metamorphism of a quartz-rich, low-Al metasedimentary rock at eclogite facies conditions. The zircon records crystallization in primordial magma extracted from the mantle at 4.3 Ga. The igneous host rock was ultimately exhumed to the surface and eroded, transfering the zircon to a high $\delta^{18}O$ supracrustal rock as a detrital grain. The zircon recrystallized during burial and eclogite facies metamorphism at 3.9 Ga. This produced fir-tree sector zoning, $\delta^{18}O$ of 10.2 ‰ (highest of any Archean/Hadean zircon), low T_{Ti} (630 °C), and a Eu/Eu* value of 0.92, indicating conditions where plagioclase is not stable. Non-depleted HREE [$(Yb/Gd)_N$ = 67] indicates garnet was not present. The distinctive geochemical features indicate the metamorphic host rock is best explained as a high $\delta^{18}O$, low-Al, detrital zircon-bearing metasedimentary rock, such as quartzite. Formation of a thin overgrowth during a 3.75 Ga event records part of its exhumation path to the surface. By 3.0 Ga, the zircon had eroded and was deposited in the Jack Hills metasedimentary rocks. Eclogite facies metamorphism provides evidence for lithospheric thickness >60 km by 3.9 Ga, and is the first direct evidence supporting models that propose operation of a tectonic regime involving subduction on the early Earth. An overturn of early crust is also consistent with initiation of mantle depletion after 3.9 Ga [3].

[1] Hopkins et al. 2008 Nat. [2] O'Neil et al. 2017 Nat. Geosci. [3] Fisher and Vervoort 2018 EPSL.