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Formation and evolution of ~4.51 Ga mafic crust revealed by coupled U-Pb-Hf-O isotopes of the Jack Hills zircons

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Formation of Earth's primary crust is a critical step for planetary differentiation, dynamic evolution and the emergence of habitable environments, but the timing and nature of Earth's earliest crust remain contentious due to lack of direct geological record. We performed a coupled U-Pb, Lu-Hf and O-OH isotope analyses of a suite of Hadean to Eoarchean (4.37 – 3.75 Ga) zircons from Jack Hills, Western Australia. We filtered the dataset using strict criteria to extract the most reliable ages and Hf-O isotope compositions for these ancient zircons. Our results indicate that the oldest zircons with reliable and reproducible concordia ages formed at ~4.37 Ga. These zircons exhibit subchondritic Hf isotope compositions, and no positive εHf values are found. Importantly, the most pristine and least radiogenic hafnium isotopic compositions indicate an early silicate differentiation event that formed a mafic crust ($^{176}Lu/^{177}Hf = 0.020 \pm 0.002$) at ~4.51 Ga. We interpret this event as a result of rapid solidification of the terrestrial magma ocean following the Moon-forming giant impact, suggesting that the Moon formed at ~4.51 Ga. Oxygen isotopic data suggest that this primary mafic crust extensively interacted with the early hydrosphere, and also likely the CO_2-rich atmosphere, after ~4.2 Ga, whereas the zircon $^{176}Lu/^{177}Hf$ ratios suggest that the altered crust was deeply buried, probably by subsequent magma eruptions. This process promoted crustal differentiation and CO_2 sequestration, facilitating the establishment of habitable conditions on the Hadean Earth.