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Nb-Ta paradox and the redox state of Earth's primordial magma ocean

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The bulk silicate Earth (BSE), and all its sampleable reservoirs, have a subchondritic niobium to tantalum ratio (Nb/Ta). Because both elements are refractory, and Nb/Ta is fairly constant across chondrite groups, this can only be explained by a preferential sequestration of Nb relative to Ta in a hidden (unsampled) reservoir. Experiments have shown that Nb becomes more siderophile than Ta under very reducing conditions, leading the way for the accepted hypothesis that Earth’s core could have stripped sufficient amounts of Nb during its formation to account for the subchondritic signature of the BSE. Consequently, this suggestion has been used as an argument that the Earth accreted and differentiated, for most of its history, under very reducing conditions. Here, we present the first series of metal-silicate partitioning experiments of Nb and Ta in a laser-heated diamond anvil cell, at P and T conditions directly comparable to those of core formation; we find that Nb is more siderophile than Ta under any conditions relevant to a deep magma ocean, confirming that BSE’s missing Nb is in the core. However, multi-stage core formation modeling only allows for moderately reducing or oxidizing accretionary conditions, ruling out the need for very reducing conditions, which lead to an over depletion of Nb from the mantle (and a low Nb/Ta ratio) that is incompatible with geochemical observations. Earth’s primordial magma ocean cannot have contained less than 2% or more than 18% FeO since the onset of core formation.