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Mapping the redox state of the young Solar System using ytterbium valence state

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Rare-earth elements (REE, restricted here to the lanthanides) usually form 3+ cations in terrestrial rocks, although Eu^{2+} and Ce^{4+} are often found. In enstatite chondrite (EC), elemental anomalies in Eu and Yb have been reported in calcium sulfide (oldhamite) [1-3] and in leaching experiments on whole rocks [4]. The presence of Yb^{2+} in sulfides synthesized experimentally in highly reduced conditions corresponding to those of EC formation has been identified by X-ray absorption near-edge spectroscopy (XANES) [5]. In order to gain further insight on the redox formation conditions of Solar System objects, we have determined the valence state of Yb in a collection of meteorites covering 4 to 5 orders of magnitude in oxygen fugacity (fO_2) by XANES at sector 13 of the Advanced Photon Source. In the studied meteorite minerals, Yb abundance ranges from 1 to 30 ppm. The data were collected on merrillite grains from two equilibrated ordinary chondrites (H6 and LL6), oldhamite grains from three EH (EH3 to EH5) and four EL (EL3 to EL6) EC, one merrilite grain and one stanfieldite grain in a pallasite (Seymchan), on merrillite grains from a eucrite, and phosphates of an ungrouped primitive achondrite (NWA 11119). The obtained Yb XANES spectra were compared to those measured in terrestrial apatites (containing 17 to 79 ppm Yb) and in synthetic materials (metallic Yb, YbS, Yb_2S_3, Yb_2O_3). In terrestrial apatites as well as in ordinary chondrites, the eucrite, the ungrouped achondrite, and the pallasite, Yb is present as Yb^{3+} only. In EC, about half of the Yb is in the Yb^{2+} form. The absence of detectable difference in Yb redox state between EH and EL chondrites suggests that the observed difference in Yb anomalies found between EH and EL REE patterns [3] is not due to oxygen fugacity prevailing during condensation and parent-body equilibration but rather to fractionation due to element volatility.

[1] Crozaz G & Lundberg LL (1995) GCA 59; [2] Gannoun et al. (2011) GCA 75; [3] Hammouda et al. (2022) PEPS 9; [4] Barrat et al. GCA 265 ; [5] Ingrao et al. Geochim Cosmochim Acta 265.