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Apatite halogen and hydrogen isotope constraints on the conditions of hydrothermal alteration in carbonaceous chondrites

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Apatite has been widely used for assessing the volatile inventory and hydrothermal fluid compositions of asteroidal and planetary bodies. We measured the OH, F, and Cl abundances, and hydrogen isotope composition, of apatite in the C1-ungrouped Bench Crater meteorite [1] and in the CM1-2 Boriskino chondrite [2]. Apatite in Bench Crater and Boriskino are halogen-poor, close to the hydroxylapatite end-member composition, and characterised by average δD_{SMOW} values of 233±92 ‰ and -226±59 ‰, respectively [3]. Boriskino apatite might exhibit H_2O incorporation with carbonate substitutions [4]. Metamorphism in Bench Crater might have caused H isotope fractionation, by diffusion, of apatite from an initial δD_{SMOW} value of around 130±60 ‰. The matrix in Bench Crater has a δD_{SMOW} value of -16±119 ‰, which represents our best estimate for the H isotope composition of the water accreted by the Bench Crater meteorite parent body. Comparing apatite and water H isotope compositions yields similar apatite-water D/H fractionation of *ca.* 120 - 150 ‰ for both carbonaceous chondrites, suggesting that apatite formed at similar temperatures. However, we cannot estimate further these formation temperatures as there is no study relating temperature and apatite-water D/H fractionation. Combining a lattice strain partitioning model [5] with apatite F and Cl abundances in Boriskino and Bench Crater yields low F and Cl abundances < 300 $\mu g.g^{-1}$ in apatite-forming fluids. The fluid F/Cl ratios are consistent with the bulk F/Cl ratios of other CI and CM chondrites, suggesting that hydrothermal alteration on these meteorite parent bodies took place under closed-system conditions. Based on the calculated OH abundances for the apatite-forming fluids, we estimated the pH values of alteration fluids to be of *ca.* 10 - 13. Such alkaline fluid compositions are consistent with previous modelling and suggest that apatite formed late, towards the end of completion of hydrothermal alteration processes on the Boriskino and Bench Crater parent bodies.

[1] Joy *et al.* (2020), *EPSL* 540, 116265. [2] Verdier-Paoletti *et al.* (2019), *MAPS* 54, 1692–1709. [3] Piralla *et al.* (In press), *MAPS*. [4] Pasteris *et al.* (2014), *Am. Mineral.* 99, 16–27. [5] Kusebauch *et al*. (2015), *GCA* 170, 225–246.