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Oxygen isotopes and origin of opal in an Antarctic ureilite

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OXYGEN ISOTOPES AND ORIGIN OF OPAL IN AN ANTARCTIC UREILITE H. Downes^{1,2}, Beard A. D.¹, Franchi I. A.³, Greenwood R. C.³. Centre for Planetary Sciences, Department of Earth and Planetary Sciences, Birkbeck University of London, London WC1E 7HX UK h.downes@ucl.ac.uk, ² Department of Earth Sciences, Natural History Museum, London, SW7 5BD, UK), ³ Planetary and Space Sciences, Open University, Milton Keynes, MK7 6AA, UK

Introduction: Fragments of opal ($\text{SiO}_2 \cdot n\text{H}_2\text{O}$) in several internal chips of a single Antarctic polymict ureilite meteorite Elephant Moraine (EET) 83309 have been studied by NanoSIMS to determine their oxygen isotope compositions and hence constrain their origin. The opals occur mainly as clasts up to $300\mu\text{m}$ in longest dimension and often show banding. The bands often terminate at adjacent clasts, suggesting that the opal pre-dates the brecciation and so was not formed in situ. Opal also occurs as thin rims around suessite (Fe_3Si) which is a common mineral in brecciated polymict ureilites, and often contains inclusions of schreibersite ($(\text{Fe},\text{Ni}_3)\text{P}$). It shows no relationship whatsoever with terrestrial weathering veins or rims, although one piece of opal occurs in contact with ureilitic olivine, surrounded by a terrestrial weathering rim. XRD analysis suggests that the opal is of the amorphous variety opal-A, although it appears to be undergoing some degree of recrystallization. The largest opal clast has a composition of approximately 65.5 wt% SiO_2 , 6 wt% FeO and <1 wt% MgO , but compositions vary from 60 to 76 wt% SiO_2 . Analytical totals are always low (67-82 wt%), indicating a substantial quantity of water in the opal. Opal is extremely rare in meteorites. Although it has been reported as a cavity infill in the highly weathered Wolf Creek iron meteorite, it has not been reported as a weathering product in any other meteorite.

Oxygen isotopes: In order to determine the oxygen isotope composition of the opal in the ureilite using the Cameca NanoSIMS 50L at the Open University, an appropriate volcanic opal standard was required. We acquired a piece of unbanded opal hosted in a volcanic rock from the Faeroe Islands (BM 1907,568) from the Natural History Museum mineral collection. Four $\sim 2\text{mg}$ chips, analysed using a laser-assisted fluorination technique, also at the Open University, yielded the following average values: $\delta^{18}\text{O} = 30.06 \pm 0.36 \text{‰}$ (2σ) and $\delta^{17}\text{O} = 15.68 \pm 0.20 \text{‰}$ (2σ).

NanoSIMS measurements were then conducted on the standard and opals using the methods described by [1]. Repeated analyses of the opal standard showed excellent reproducibility with $\delta^{18}\text{O}$ values $\pm 1.0 \text{‰}$ (2σ) and $\delta^{17}\text{O} \pm 1.5 \text{‰}$. Two separate opal clasts were analysed. The results are within error of the Terrestrial Fractionation Line and spread along a line from a point close to the ureilite field towards lower $\delta^{18}\text{O}$ values.

Discussion: Our petrographic observations strongly suggest that the ureilitic opal was formed prior to the brecciation event on the ureilite parent body and prior to terrestrial weathering, and therefore has an extraterrestrial origin. However the oxygen isotope compositions of the ureilite opal all plot within error of the Terrestrial Fractionation line with a mean $\Delta^{17}\text{O}$ value of $0.6 \pm 0.8 \text{‰}$ (2 SE). Opal is known to exchange water readily with the environment. Terrestrial opal has variable, but generally ^{18}O -rich oxygen (~ 19 to 38‰) whereas the ureilitic opal $\delta^{18}\text{O}$ values are more ^{18}O -poor. Antarctic water can have $\delta^{18}\text{O}$ ca. -40 to -50‰ , so it is possible that the trend shown by the ureilite opal may result from interaction with terrestrial water. There is a high abundance of water in the analysed opal, readily facilitating isotopic exchange with the Antarctic environment, even at low temperatures. The equilibrium fractionation factor between water and opal is $\approx 40\%$ at temperatures applicable to Antarctica and therefore the measured values are consistent with a terrestrial origin for the O-isotope signature. The variation in $\delta^{18}\text{O}$ in the ureilitic opal may be the result of partial isotopic exchange between the opal (which initially had a ureilitic oxygen isotope composition) and Antarctic water. Alternatively, the isotopic composition of the Antarctic water may have evolved during interaction with the opal and reaction with the rest of the ureilite meteorite.

Hydrated amorphous silica (i.e. opal) has also been identified in abundance on the surface of Mars where it has been formed at low temperatures (ca 0°C) and by acid alteration of silicate minerals. Opal-A has recently been identified in the ~ 1300 Ma old Martian meteorite Nakhla where it was interpreted as being a product of extraterrestrial aqueous alteration. A similar low temperature hydrothermal asteroidal origin for the fragments of opal in EET83309 cannot be ruled out. Based on the evidence provided, an extraterrestrial origin for the ureilitic opal is more likely than a terrestrial weathering origin. Thus the opal may provide evidence of interaction of asteroidal material and ice, early in the history of the Solar System.

References: [1] Starkey NA et al., 2013. *Geochimica et Cosmochimica Acta* 105, 73-91.