

**THE H<sub>2</sub>O CONTENT OF AUBRITES.** L. D. Peterson<sup>1\*</sup>, M. E. Newcombe<sup>1</sup>, S. G. Nielsen<sup>2</sup>, C. M. O'D. Alexander<sup>3</sup>, J. Wang<sup>3</sup>, F. Klein<sup>2</sup>. <sup>1</sup>University of Maryland, College Park, MD 20740 USA (\*[ldpete@umd.edu](mailto:ldpete@umd.edu)), <sup>2</sup>NIRVANA laboratories, Woods Hole Oceanographic Institution, Woods Hole, MA 02543, USA, <sup>3</sup>Carnegie Institution for Science, Washington, DC 20015 USA

**Introduction:** It is commonly assumed that Earth accreted the majority of its H<sub>2</sub>O from carbonaceous-chondrite-like (CC) materials and that early-formed planetesimals in the inner solar system were anhydrous. However, the presence of H<sub>2</sub>O has been measured in ordinary [e.g., 1], rumuruti [2], and enstatite chondrites [3], suggesting that non-carbonaceous chondrites could also be a viable source of Earth's water. These discoveries permit the accretion of a portion of Earth's H<sub>2</sub>O budget from its primary feedstock. In order to more fully understand the origin of Earth's water, it is therefore important to provide further constraints on the H<sub>2</sub>O budgets of early-formed inner solar system planetesimals, and the likelihood of H<sub>2</sub>O retention during planetary formation and growth.

Enstatite chondrites and aubrites are the meteorites in the terrestrial collections that most closely resemble the Earth in their O and nucleosynthetic isotopes [4,5], suggesting they may be derived from similar portions of the protoplanetary disk. Recently [3] conducted bulk H<sub>2</sub>O analyses of enstatite chondrites and the Norton County aubrite. [3] report 5300±800 µg/g H<sub>2</sub>O in enstatite separates from Norton County and 3000±2000 µg/g H<sub>2</sub>O in bulk material from Norton County. If correct, this finding implies that aubrite-like material is the wettest achondritic material identified to date [6-8] and that aubrite-like material could account for all H<sub>2</sub>O in the bulk Earth (~700 – 3000 µg/g H<sub>2</sub>O [9]). However, these bulk rock measurements are in stark contrast to *in situ* (secondary ion mass spectrometry; SIMS) measurements of water in ureilites [10], angrites [6], eucrites [7], and several ungrouped achondrites [8], all of which contain very little water (Fig. 1). In light of this apparent difference between the Norton County aubrite and other achondrite meteorites, we have performed *in situ* SIMS measurements of water in a suite of aubrites, to explore the possibility that methodological differences could explain the high H<sub>2</sub>O content of the Norton County aubrite presented by [3], and to more fully constrain the H<sub>2</sub>O content of the aubrite parent body.

In particular, we have conducted *in situ* H<sub>2</sub>O analyses of enstatite, diopside, forsterite, and plagioclase in a suite of main group aubrites (ALH 78113, ALH 84007, LAP 02233, LAR 04316, MIL 13004, and Norton County) and Shallowater. We use our analyses of H<sub>2</sub>O in Norton County enstatite to re-evaluate the Norton County enstatite H<sub>2</sub>O contents reported by [3]. We then take our *in situ* analyses of all

phases in conjunction with published estimates for the modal mineralogy of our samples to provide estimates for the bulk H<sub>2</sub>O content of the aubrites.

**Samples and Methods:** We performed H<sub>2</sub>O analyses of enstatite, diopside, forsterite, and plagioclase using the Cameca nanoSIMS 50L at the Carnegie Earth and Planets Lab. Data collection was spread across three analytical sessions; all Antarctic meteorites were analyzed during the first two sessions, and Norton County and Shallowater were analyzed during the third session. Analyses and data corrections followed existing protocols [10-11]. Well characterized glass [12], orthopyroxene [11], and clinopyroxene [11] reference materials were used to generate calibration curves. Where possible, matrix-matched calibration curves were used. However, the orthopyroxene calibration curve was used for olivine and plagioclase, as these phases have been shown to have similar calibration curves [11,13]. The analytical blank was monitored by repeat analyses of Suprasil 3002 glass and dry synthetic forsterite.

**Results:** Enstatite was measured in all samples and its water content was nearly invariant across the sample set (4±2 µg/g H<sub>2</sub>O) with 3.8±0.2 µg/g H<sub>2</sub>O in Norton County enstatite. Diopside (4.8±0.5 µg/g H<sub>2</sub>O), forsterite (5±3 µg/g H<sub>2</sub>O), and plagioclase (24±3 µg/g H<sub>2</sub>O) were measured in Norton County, MIL 13004, and Shallowater, respectively. We report blanks of <9 µg/g H<sub>2</sub>O for analyses of Antarctic meteorites and <1 µg/g H<sub>2</sub>O for analyses of Norton County and Shallowater.

#### **Discussion:**

*Re-evaluation of the H<sub>2</sub>O content of Norton County:* Prior bulk analyses of enstatite separates by [3] yielded 5300±800 µg/g H<sub>2</sub>O in Norton County enstatite. Our *in situ* analyses of Norton County enstatite yielded 3.8±0.2 µg/g H<sub>2</sub>O, over 3 orders of magnitude lower than the value reported by [3]. We attribute the difference in reported H<sub>2</sub>O concentrations primarily to terrestrial contamination. Notably, bulk methods, as employed by [3], have been demonstrated to overestimate the H<sub>2</sub>O contents of nominally anhydrous minerals due to terrestrial contamination, even after preheating samples to 125°C [14]. Additionally, if Norton County enstatite contains ~4 µg/g H<sub>2</sub>O, as suggested by our *in situ* analyses, then analyses of Norton County enstatite should be unresolvable from the 500 µg/g H<sub>2</sub>O blank reported by [3]. However, this is not the case, suggesting that the analyses of Norton County enstatite separates from [3] reflect significant terrestrial contamination.

Considering that analyses of Norton County enstatite separates by [3] reflect significant terrestrial contamination, we also re-evaluate the bulk Norton County H<sub>2</sub>O content of 3000±2000 µg/g H<sub>2</sub>O reported by [3]. Modal mineralogy of the Norton County aliquots were not reported in [3], and were described as “dark” and “grey” lithologies. We use published modal mineralogy [15], our measured mineral H<sub>2</sub>O concentrations, and published partition coefficients [16-17] to estimate a bulk Norton County H<sub>2</sub>O content of < 10 µg/g H<sub>2</sub>O. We suggest the difference between our estimated H<sub>2</sub>O contents and the bulk H<sub>2</sub>O content of Norton County reported by [3] predominantly reflect terrestrial contamination and alteration, similar to analyses of enstatite separates. Notably, inclusion of <3 vol. % of terrestrial alteration phases common to enstatite chondrites and aubrites (e.g., portlandite, bassanite, and smectites [18]) can account for the total H<sub>2</sub>O content reported by [3]. We performed the same exercise, as for Norton County, to estimate the bulk H<sub>2</sub>O content of Shallowater and our Antarctic meteorites which yielded a bulk H<sub>2</sub>O content of <10 µg/g H<sub>2</sub>O for all samples.

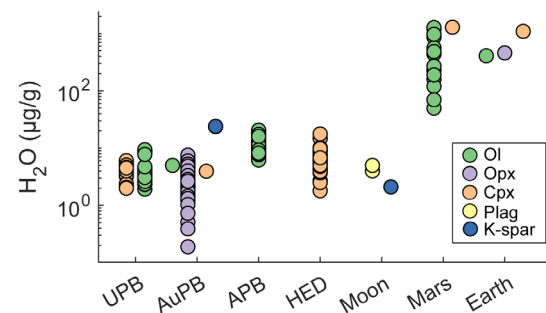
*Water content of the main group Aubrite parent body:* Aubrite petrogenesis is complex and is thought to be the result of several heating and melting events [19]. Therefore, we do not attempt to calculate a bulk parent body water content using simple melting models. Instead, we assume that the material analyzed herein is broadly representative of the majority of material on the aubrite parent body. This would likely imply a bulk parent body with, at most, 10's to 100's of µg/g H<sub>2</sub>O. We note that our *in situ* analyses of aubrite minerals overlap with other published analyses of primitive achondrites and achondrites (Fig. 1).

*Implications for inner solar system parent bodies:* Our results support the efficient desiccation of planetesimals as a result of heating and melting [8,10], which implies that H<sub>2</sub>O was delivered to the terrestrial planets by parent bodies that experienced limited thermal processing (i.e., chondrites). Similarly, we suggest that aubrite-like material is not a viable source of H<sub>2</sub>O to the Earth as implied by the results of [3]. Furthermore, if our results for Norton County extend to the enstatite chondrite analyses conducted by [3], then enstatite chondrite-like material may not be a primary source of H<sub>2</sub>O to the Earth. Further work targeting enstatite chondrites will need to be done to evaluate this hypothesis [20].

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**Fig. 1** Grain volatile contents for olivine (Ol), orthopyroxene (Opx), clinopyroxene (Cpx), plagioclase (Plag), and potassium feldspar (K-spar) from the ureilite parent body (UPB; [11]), aubrite parent body (AuPB; this study), angrite parent body (APB; [5,21]), eucrite parent body (HED; [6,22]), the Moon [23-24], Mars [25-26], and the Earth [27]. Note, for clarity, only upper bounds are plotted for the Earth. From left to right, parent bodies are ordered by approximate degree of melting (ureilites are primitive achondrites) and then by estimates of parent body size.