MINERALS FROM ASTEROID REGOLITH AND METEORITES REVEAL EARLY-STAGE PROCESSES IN SOLAR SYSTEM HISTORY. Maitrayee Bose[1] and Ziliang Jin[1], [1]Arizona State University, School of Earth and Space Exploration, 550 E. Tyler Mall, Building PSF, Room 686, Tempe, AZ 85287 (Maitrayee.bose@asu.edu).

Introduction: Proto-Earth formed quickly in the first few millions years in a hot and dry environment, close to Sun. It's surface was possibly molten owing to planetesimal impacts, and therefore must have naturally lost its water and destroyed labile organic biomolecules. It has been proposed that proto-Earth received additional water, later in its accretionary history, via accretion of hydrous carbonaceous asteroids [e.g., 1, 2]. These carbonaceous asteroids are proposed to have been introduced into the inner solar system chaotically, during formation and migration of giant planets, and delivered materials rich in water and other organic materials including amino acids. Alternative models have been suggested where Earth could have acquired its water directly from the solar nebula [e.g, 3–6]. We explored a combination of these scenarios to understand how water was incorporated into the Earth−Moon system both during planetary accretion and impacts from chondritic asteroids. Impacts are particularly important for deep delivery of hydrogen into the magma. We tested this scenario by studying samples never investigated before, namely regolith grains from asteroid 25143 Itokawa and meteorite analogs belonging to the L/LL class of ordinary chondrites.

Results and Discussion:

Itokawa. The hydrogen isotopic composition (δD) of the measured pyroxene grains from Itokawa is −79 to −53‰, strikingly similar to Earth's mantle water [7]. These minerals contain water contents of 698 to 988 parts per million (ppm) weight, which corresponds to a water content of 160 to 510 ppm for Bulk Silicate Itokawa parent body [7]. We also estimated that asteroids like Itokawa that formed interior to the snow line could have provided up to 0.5 Earth's oceans during the formation of Earth and other terrestrial planets. This implies that migration from the outer solar system may not be required to explain the high water on Earth and other terrestrial planets. Incorporation of the water into mineral structure in the solar nebula and accretion of ordinary chondrite parent bodies should be able to explain the water in our oceans.

The striking similarity of the D/H ratio of the Itokawa grains to that of Earth's mantle provides corroborating evidence for a common liquid heritage for Inner solar system bodies. Itokawa had a complex history of thermal metamorphism and collision, reaching temperatures at least as high as 900°C. But our thermal-diffusion models predict that less than 10% of the water in the grains would be lost, as a result of these processes.

Meteorite analogs. The water contents and D/H ratios in pyroxenes from several metamorphosed ordinary chondrites were measured [8]. The δD values vary from -123 to 106 ‰ similar to Itokawa pyroxenes, while the water contents in the grains are between 458 and 1807 ppm. We had chosen meteorites belonging to both L and LL class, and petrologic types 4–6 in order to look for correlations between petrologic type and volatile contents or D/H ratios but no relationships were ascertained. The most surprising component of these studies is the high water contents on these nominally anhydrous phases.

Mechanism of hydrogen incorporation into microscopic particles in the early solar nebula. We revisited the issue of incorporation of hydrogen into the minerals in the low-pressure environment in the early solar system. A process of incorporating water from the nebula directly into the mineral structure of early-formed solids is chemi-adsorption [9], which is not efficient in the hot, rarified environment in the inner solar system.

We have identified and modeled a more dominant process - implantation of H^+ - that operated in the early sun's history and is capable of introducing vast amounts of hydrogen into the freshly formed minerals [10]. The dusty ionized plasma, rich in H^+ moving at few keV energies can be efficiently implanted into the top surface of the grains, which then diffuses inward to saturate the bulk of small 50-500 μm particles. A density of ionized hydrogen of about 2×10^5 cm^{-3} results in an estimated flux to be $\sim2\times10^{11}$ cm^{-2} s^{-1}. This flux is considerably larger than the proton flux attributed to the solar wind and galactic cosmic rays. Assuming a high-retention coefficient (>10%) of the implanted hydrogen, up to 1000 ppm of water can be produced in particles of enstatite composition within a year. Thus, we propose that this process of H^+ implantation, followed by diffusion is the driver for incorporating water into the first-formed solids in our solar system.

Preparing for Bennu and Ryugu samples. C-type asteroids Bennu and Ryugu are expected to contain abundant organic or hydrated minerals, compared to Itokawa, that need to be investigated for their volatile contents and D/H ratios to constrain the chemistry occurring in these bodies. Our lab at Arizona State University (ASU) is preparing for analyses on Bennu and

Ryugu samples. Measurements of tiny amounts of hydrogen and deuterium have become possible because of the ASU NanoSIMS that can achieve small beam sizes, relevant for studying small particles and its high sensitivity for measuring trace amounts (<15 ppm) of hydrogen. We have developed the protocols that will allow us to measure the tiny regolith minerals at high lateral resolution and desired precision.

Because olivine is the largest mineral component in the Itokawa collection, we estimate that it will be for Bennu and Ryugu as well. Hence, we are synthesizing matrix-matched olivine standards for hydrogen isotope analyses to share with the community. We have also measured metal in a few Fe-Ni meteorites for volatiles (*unpublished work*), which becomes particularly important considering that magnetite was found on Bennu [11]. Finally, the thermal-diffusion models used on Itokawa, can be used to predict how Bennu and Ryugu may have lost volatiles as a result of nebular and parent body processes.

Conclusions: Through our work, we have shown how cosmochemical constraints on water contents and D/H ratios in small bodies can provide important input to dynamical models attempting to explain the provenance of water in planets. Our investigations have augmented an understanding of processes that produce water loss (via impacts, thermal metamorphism) and can inform models about water delivery to the terrestrial planets by hydrated planetesimals and water partitioning into the core of planets during differentiation.

I will talk about our work on Itokawa and ordinary chondrites in the meeting, including the consequences of high- vs low-velocity collisions of planetesimals and the impact of fast cooling rates of materials post-impact that drive volatile losses on small bodies.

References: [1] Hallis L. J. et al. (2015) *Science* 350, 795-797. [2] Sarafian A. et al. (2014) *Science*, 346, 623-626. [3] Ikoma M. and Genda H. (2006) *The Astrophysical Journal* 648, 696-706. [4] Hirschmann M. and Kohlstedt D. (2012) *Physics Today* 65, 40-45. [5] Sharp Z. (2017) *Chemical Geology* 448, 137-150. [6] Wu J. et al. (2018) *Journal of Geophysical Research: Planets* 123, 2691-2712. [7] Jin Z. and Bose M. (2019) *Science Advances* 5, eaav8106. [8] Jin Z. and Bose M. (2019) *50th Lunar and Planetary Science Conference* (Abstract#2132). [9] Asaduzzaman A. (2015) *Icarus*, 304, 74-82. [10] Jin Z. and Bose M. *In prep. for ApJ*. [11] Lauretta D. et al. (2019) *Nature* 568, 55-60.