EVIDENCE OF NEBULAR WATER IN RECENT ORDINARY CHONDRITE FALLS CHELYABINSK AND BENENITRA. Z. Jin[1*] and M. Bose[1], [1]Center for Isotope Analysis, School of Earth and Space Exploration, Arizona State University, Tempe, AZ 85287-6004. *Ziliang.jin@asu.edu

Introduction: We reported D/H ratios and water contents of nominal anhydrous minerals (NAMs) in several ordinary chondrites with petrologic types of 4–6 [1-2]. We found that NAMs in these ordinary chondrite Antarctic *finds* are not completely dry and water contents can be as high as 1500 ppm. Their D/H ratios range from -123‰ to 106‰. Although we followed strict protocols to prepare, mount, and measure the samples, we cannot completely avoid the effect of the stone's residence in Antarctic ice. Thus, to resolve effects of terrestrial alteration, measurements of recent ordinary chondrite *falls* is necessary.

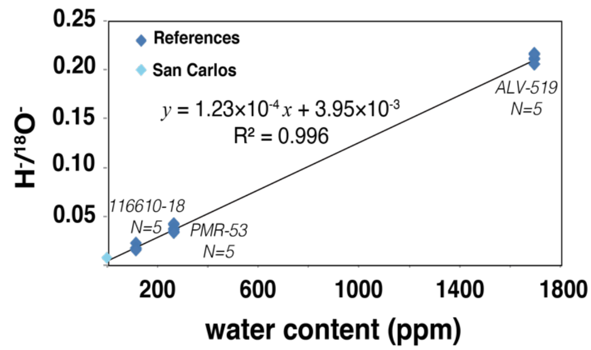
In this study, we measured D/H ratios and water contents in NAMs from two recent ordinary chondrite falls Chelyabinsk and Benenitra. These analytical results were used to constrain the volatile content in ordinary chondrite parent bodies.

Samples: Two fresh falls selected for the study are LL5 Chelyabinsk and L6 Benenitra. Chelyabinsk fell in Russia in 2013 while Benenitra was recovered from Madagascar in 2018. The fragments of both meteorites were collected immediately after the fall.

Fresh chips from the Field Museum were polished without using any hydrogen-bearing lubricants. The dry-polished chips were then mounted in indium metal and coated with a 35nm-film of gold. The pyroxene minerals were identified by elemental mapping of the mounted samples performed by the wavelength-dispersive spectroscopy. Afterwards, the mounts were stored under 45ºC in the oven for 1 week before they were introduced into the ultra-high vacuum of the analysis chamber in the NanoSIMS 50L at Arizona State University.

Analytical methods: The D/H ratios and H_2O concentrations of pyroxenes from LL5 Chelyabinsk and L6 Benenitra were measured. A Cs^+ primary beam of ~320 pA was rastered on a 20×20 µm area on the silicate surface. $^{1}H^-$, $^{2}D^-$, $^{12}C^-$ and $^{18}O^-$ secondary ions were detected in the multicollection mode. The electron gun (~100 nA) was used to compensate for the charging of the sample surface. The entrance slit (ES1) was used to obtain a flat-top mass peak for hydrogen. Prior to data collection, the target area was presputtered for 20 minutes. Each measurement consisted of 150 frames with a counting time of 500 µs/pixel. The secondary ion signal from the internal 70% of the rastered area was collected using electronic gating. The vacuum in the analysis chamber was constant at ~1.5–1.6 × 10^{-10} torr. Three terrestrial standards, namely, ALV-519 (H_2O=1700 ppm), PMR-53 (H_2O=268 ppm), and 116610-18 (H_2O=118 ppm) were employed to calibrate the water contents and D/H ratios. The anhydrous San Carlos was used as the blank to monitor the background water content. The background was estimated to be <35 ppm (Fig. 1). D/H ratios of references ALV-519 (~1.557 × 10^{-4}) and PMR-53 (~1.375 × 10^{-4}) are used to calculate the true D/H ratios of the measured pyroxene minerals, which were then normalized to standard mean ocean water (SMOW).

Fig. 1*. H/O ratio vs. H_2O content for the standards*



used for calibration. The background water content is <35 ppm, shown by San Carlos olivine (light blue diamonds).

Results: Water contents and hydrogen isotope compositions normalized to SMOW (δD_{SMOW}) of the pyroxenes from Chelyabinsk and Benenitra are plotted in Fig. 2.

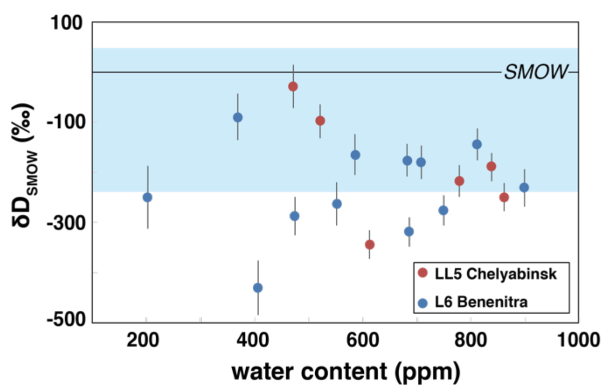


Fig. 2. *Water contents (ppm) and δD_{SMOW} values (‰) of pyroxenes from LL5 Chelyabinsk and L6 Benenitra. δD_{SMOW} range in terrestrial samples is shaded in blue.*

In LL5 Chelyabinsk, the δD_{SMOW} of 6 measured pyroxene grains are from -343‰ to -29‰ (Median = -203 ± 114‰, 2 standard error of the median or 2SM). Their water contents range from 471 ppm to 861 ppm

(Median = 696 ± 172 ppm, 2SM). The δD_{SMOW} of 12 pyroxene grains from L6 Benenitra vary from -431‰ to -90‰, with a median δD_{SMOW} = -240 ± 66‰ (2SM). These pyroxenes contain between 202–899 ppm water, with a median value of 634 ± 146 ppm (2SM). These numbers have been corrected for solar wind and galactic cosmic ray spallation.

Discussion: One should be cautious about terrestrial weathering, when studying highly volatile elements, such as hydrogen in Antarctic finds because hydrogen can be easily exchanged [e.g., 3]. Compared to the previously reported water contents of the NAMs in the type 3–6 ordinary chondrites (300–1500 ppm, [2]), the water contents of the minerals measured in this study have lower upper limits (<900 ppm) and smaller variation (200–900 ppm). Therefore, the choice of recent chondritic falls and using ideal sample preparation and measurement protocols are critical to minimize terrestrial contamination.

The other events that could have modified the contents of water in the measured minerals include thermal metamorphism and impacts on the parent body. The studied chondrites belong to the petrologic types 5 and 6 and thus have experienced high-temperature events (up to 1050–1300 K) in their parent bodies [4]. These high temperatures occur due to the presence of radiogenic elements, e.g., ^{26}Al, that produce heat. Based on the parent body model proposed by [6], type 6 materials are suggested to occur in the most interior area (0-67 km) of a 85 km-in-radius parent body, while type 5 materials occur in the area with a distance of 67––78 km from the core. By using our previous thermal-diffusion model [2] and taking the peak temperatures and durations of the thermal metamorphism into account, the water loss of both types 5 and 6 materials in the parent body is less than 1%. In addition, high post-shock temperatures during impact events barely caused dehydration of the minerals because of the high cooling rate (200–600ºC/hour, [7]). It is important to note that both these dehydration processes are inadequate in releasing vast quantities of water in planetesimals once they have formed by accretion of NAMs. Hence, the water measured in the ordinary chondrite NAMs were most likely incorporated from the primordial solar nebula, when the silicates condensed.

Gas giants, Jupiter, Saturn, Uranus, and Neptune, formed early in the solar system history and are characterized by very low δD_{SMOW} values (-600 – -800‰) [9-11]. The measured silicates in ordinary chondrites in this study are also characterized by negative δD_{SMOW} values (Fig. 3), inspite of losing volatiles during thermal metamorphism. We propose that the observed low δD_{SMOW} values in Chelyabinsk and Benenitra can be explained by a scenario where ionized solar nebular hydrogen is implanted in the early formed silicates and changing their hydrogen isotopic characteristics [8]. We argue that the range in δD_{SMOW} values in the NAMs likely indicates a deuteration process of the solar nebular gas in the early history of the inner solar system.

The deuterium-poor signatures recorded in the NAMs dominates in planetesimals, and subsequently introduced into the terrestrial planets, e.g., Earth, during the accretion process. Because water on Earth now has higher D/H ratios than those of ordinary chondrites, it could reflect subsequent changes brought about during differentiation or accretion of additional chondritic sources (e.g., enstatite chondrites) within the frost line. Future studies of water in various chondritic falls are thus needed to provide useful constraints.

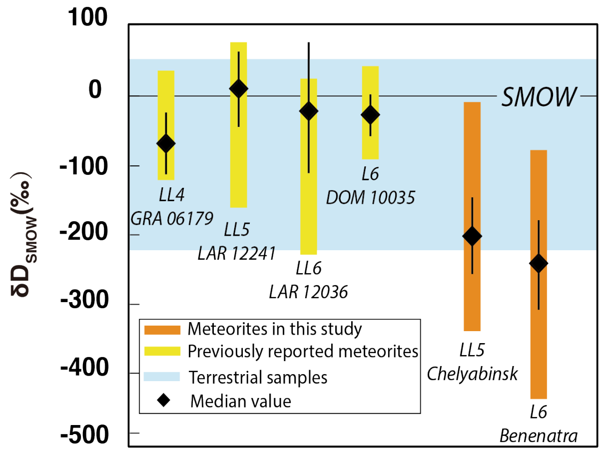


Fig. 3. δD_{SMOW} (‰) of pyroxenes in ordinary chondrites and terrestrial minerals. The black diamonds indicate the median δD_{SMOW} of each group. The errors are 2SM.

Acknowledgements: We thank Philipp Heck and the Field Museum in Chicago for providing the samples.

References: [1] Jin and Bose (2019) *LPS L, Abstract,* #1576. [2] Jin and Bose (2019) *Sci. Adv.* 5:eaav8106. [3] Stephant et al. (2002) *Sci. Rep. 8:12385*. [4] Bennett III and McSween Jr. (1996) *Meteorit. Planet. Sci.* 31, 783-792. [5] Huss et al. (2006) *MESS II*, 567-586. [6]Yurimoto et al. (2011) *Science*, *333*, 1116-1118. [5] Asaduzzaman, A. (2015) *ICARUS, 304,* 74-82. [6] Miyamoto et al. (1982) *LPS XIII*, 12, 1145-1152. [7] Ganguly et al. (2016), *Geochim. Cosmochim. Acta* 192, 135-148. [8] Jin Z. and Bose M. (2020) *LPS LI, Abstract,* #1250. [9] Geiss and Gloeckler (1998), *Space Sci. Rev.* 84, 239–250. [10]Feuchtgruber et al. (1999), *Astron. Astrophys*. 341, 17–21. [11] Lellouch et al. (2001), *Astron. Astrophys*. 670, 610-622.