URANIUM-LEAD ISOTOPE EVIDENCE IN THE CHELYABINSK LL5 CHONDRITE METEORITE FOR ANCIENT AND RECENT THERMAL EVENTS. T. J. Lapen[1,2], D. A. Kring[2,3], M.E. Zolensky[2,4], R. Andreasen[1], M. Righter[1], T. D. Swindle[2,5,6] S. P. Beard[2,6], [1]Earth and Atmospheric Sciences Department, University of Houston, Houston TX (tjlapen@uh.edu), [2]Solar System Exploration Research Virtual Institute, [3]Lunar and Planetary Institute, Houston TX, [4]NASA-Johnson Space Center, Houston TX, [5]Geoscience Department, University of Arizona, Tucson AZ, [6]Lunar and Planetary Laboratory, University of Arizona, Tucson AZ

Introduction: The impact histories on chondrite parent bodies can be deduced from thermochronologic analyses of materials and isotope systems with distinct apparent closure temperatures. It is especially critical to better understand the geological histories and physical properties of potenally hazardous near-Earth asteroids.

Chelyabinsk is an LL5 chondrite meteorite that was dispersed over a wide area tens of kilometers south of the town of Chelyabinsk, Russia by an explosion at an altitude of 27 km at 3:22 UT on 15 Feb 2013 [1,2]. The explosion resulted in significant damage to surrounding areas and over 1500 injuries along with meteorite fragments being spread over a wide area [1].

Sample Material: For this study, we analyzed a thick section from a 4.84 g fragment 'C4' [1]. Overall, samples of the Chelyabinsk meteorite consist of ~2/3 light and ~1/3 dark-colored lithologies. The light-colored lithology is composed mainly of clastic material with a chondritic texture often cut by 10-1000 µm wide impact-melt veins [2]. The dark-colored lithology is mainly composed of impact-melt breccia [2]. The sample studied here is from the light-colored lithology with thin (10-20 µm wide) melt veins (Fig. 1).

For U-Pb analyses, phosphate grains were imaged with P, Ca, and Cl X-ray maps of a roughly 1.5 by 2 mm portion of the section surface. Two phosphate minerals are recognized, Cl-apatite and merrillite, and they are randomly distributed across the sample area. The phosphates typically have irregular grain boundaries and range in size from a few microns to over 200 µm in diameter. The grains targeted for analyses are typically > 50 µm in diameter (Fig. 2).

Analytical Methods: *In situ* U-Th-Pb isotope analyses of phosphate were conducted by LA-ICPMS at the University of Houston using a Varian 810 quadrupole ICPMS coupled with a PhotonMachines Analyte.193 excimer laser ablation system. The laser ablation was performed using a 25 µm diameter circular laser spot with a 10 Hz repetition rate. Each analysis included measurement of a 'gas blank' for 20 s followed by 24 s of sample ablation with a fluence of 3 J/cm^2. Common Pb corrections were only applied to the calibration standards; common Pb contents in the samples were below instrument detection.

Internal standards used to correct for instrumental mass and element fractionation are 956 Ma grains from the Bear Lake region of the Bancroft terrane, Canada. Our external calibration standards were from Yates Mine, Otter Lake area, Canada. These were analyzed between every 4 analyses of samples. Results for the external standards yield a 942.8 ± 8.3 Ma U-Pb concordia age which agrees with an *in situ* LA-ICPMS U-Pb age of 933 ± 12 Ma by [3], but is older than a Pb-Pb step leaching age of 913 ± 7 Ma [4]. Data reduction followed methods outlined in [5] and all uncertainties for the calibration standards were propogated into the uncertainties for sample data points. All uncertainties are reported at the 95% confidence interval.

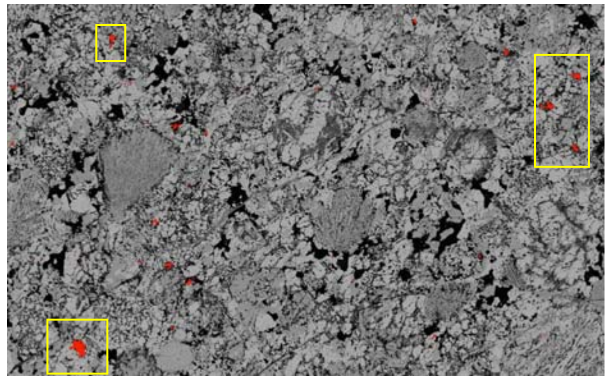

Figure 1. Mg X-ray map (gray) overlain by a P X-ray map (red) of the 'light-colored' chondrite-textured lithology. Image is 2 mm wide by 1.5 mm high. Yellow boxes represent areas shown in Figure 2.

Results and Previous Work: We analyzed 14 spots from 8 phosphate grains. Three of the grains were merrillite, and these did not have high enough U concentrations for age determinations. The remaining 5 grains (grains 1, 3, 4, 6, and 7; Fig. 2), which were Cl-apatite, yielded a discordia line on a U-Pb concordia diagram with upper and lower intercept ages of 4454 ± 67 and 585 ± 390 Ma, respectively (Fig. 3). A weighted average $^{207}Pb/^{206}Pb$ age is 4457 ± 35 Ma (n = 9). The discordia line is not related to residual instrumental elemental fractionation because the lower intercept is not zero and we did not observe residual elemental fractionation in the external standards analyzed with the samples. Thus, we interpret the discordant data to be resulting from partial Pb-loss that happened relatively recently.

Previous chronologic studies of this meteorite include Pb-Pb step-leaching experiments of the dark

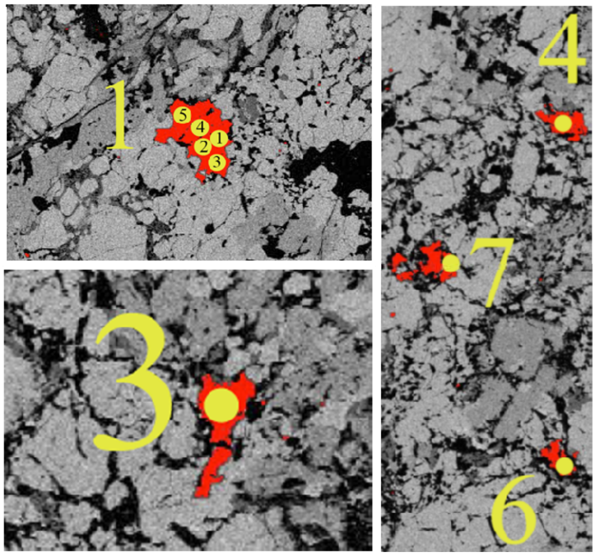

Figure 2. Higher magnification images from the areas marked by yellow boxes in Fig. 1. The Cl-apatite grains (red) are shown with the 25 µm laser spot locations (yellow) which are shown to scale. Phosphate grain labeled #1 (lower left box in Fig. 1) was large enough to accommodate 5 analyses and the other 4 grains had only one analysis each. All of the data for these grains are shown in Fig. 3.

impact-melt breccia lithology that yielded an age of 4538.3 ± 2.1 Ma [6], which is one of the oldest ages determined for this meteorite. *In situ* SIMS U-Pb analyses of phosphates from the melt breccia lithology yielded an upper intercept on a concordia diagram of 4452 ± 21 Ma [1] (Fig. 3), identical to that of our study. The data of [1], however, do not show evidence of substantial Pb-loss as seen in this study. Sm-Nd isotope investigations yielded a poorly constrained age of ~290 Ma which is indicative of severe late disturbance of the Sm-Nd system [2]. Ar-Ar data from both impact-melt and chondrite-textured lithologies indicate a period of recent disturbance [7]. Ar-Ar data from the chondrite-textured lithology yields a well constrained Ar degassing event at 28.6 ± 3.3 Ma that is likely related to an impact event [7]; this age is younger than any Ar-Ar age from ordinary chondrites. Ar-Ar data for the impact-melt rich lithology has been partially degassed, but not as thoroughly, in a late Ar degassing event [7].

Discussion: The combined U-Pb data from this study and those of [1] yield an upper intercept age of 4456 ± 18 Ma for both the chondrite and impact-melt breccia lithologies. As noted by [1], these ages are younger than phosphate ages from other ordinary chondrites. This age is also too young to be the timing of type 5 textural development. This age is also younger than the Pb-Pb step leaching age from [6], but it is difficult to compare these data because the in situ technique targets single phases whereas the step-leaching technique analyzes mixtures of phases and their leachates. The upper intercept age of Fig. 3 most likely represents an early event that essentially reset the U-Pb isotope systematics of apatite and likely represents the timing of formation for the impact-melt breccia lithology.

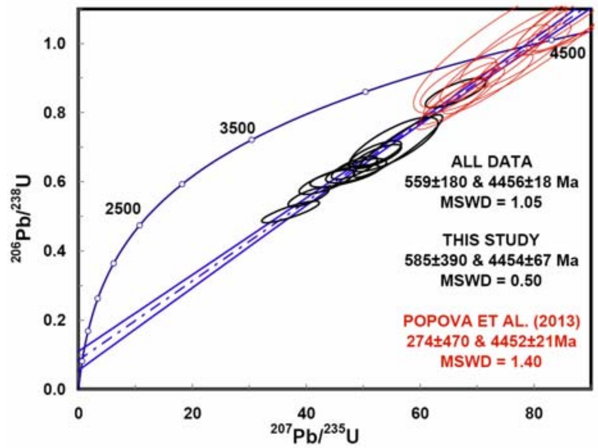

Figure 3. U-Pb concordia diagram for data obtained in this study (black) and data from [1] (red). The blue solid lines represent the error envelope for the discordia line. The combined data yield the best estimates for the upper and lower intercept ages shown as 'All Data' above.

The lower intercept age of 559 ± 180 Ma likely represents a late thermal event that is also seen in the Sm-Nd and Ar-Ar isotope systematics. The Sm-Nd 'age' of ~290 Ma is consistent with our lower intercept age and may be a function of re-distribution of REE by phosphate mineral recrystallization/reaction during the late shock/heating event. The Ar-Ar age of 28.6 ± 3.3 Ma for the chondrite-textured lithology is likely the best estimate for the age of this late event [7], but it doesn't preclude a heating event around 500 Ma followed by another at 29 Ma that caused significant Ar degassing and perhaps additional Pb-loss from the phosphates. Finally, these thermal events do not seem to have as significantly affected the U-Th/He isotope systematics of the LL6 chondrite St. Severin, which give phosphate ages that are similar to our upper intercept age [8]. Thus, the relatively recent impact-related heating events may be restricted to fragments of the original parent body.

References:[1] Popova O. et al. (2013) Science 342, 1069-1073. [2] Galimov E. et al. (2013) Geochem. Int. 51, 522-539. [3] Chew D. et al. (2011) Chem. Geol. 280. 200-216. [4] Barfod G. et al., GCA, 69, 1847-1859. [5] Shaulis B. et al. (2010) G3, 11, Q0AA11 . [6] Bouvier, A. (2013) LPI Contribution 1737, p.3087. [7] Beard S. et al. (this meeting). [8] Min et al. (2013) GCA 100, 282-296.