IMPACT CHRONOLOGY OF CHELYABISNK.

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Introduction: Chelyabinsk is a metal-rich LL5 chondrite [1] that has light clast-rich and dark melt-rich lithologies [2,3]. Geochronology studies of Chelyabinsk result in multiple ages that have been interpreted to represent at least eight impact events [5]. This work revisits Ar-Ar measurements of Chelyabinsk [6] for the purpose of comparison with other Ar-Ar studies (e.g. [7]) and multiple other ages from other systems to better understand Chelyabinsk's impact history.

Methods: Details of the Ar-Ar measurements for Chelyabinsk can be found in [6]. Literature geochronology results (U-Pb, Pb-Pb, Re-Os, Sm-Nd, Rb-Sr, K-Ar, Ar-Ar, and U-He; see references in [5]) of Chelyabinsk are evaluated for how well they agree with one another as well as the quality of the reported ages. Ages that are based on poor isochrons, determined by K-Ar, or on a mixture of lithologies in the Ar-Ar case, are not considered. If the ages of one method agree independently or are in agreement with multiple methods, this is considered a high probability to represent an impact event.

Results: Figure 1 shows the age distribution from multiple well-determined dating methods of Chelyabinsk, represented as summed Gaussians with a width proportional to the reported uncertainty. This refined impact distribution (compare to [5]) shows impact ages at **~4560 Ma** (Re-Os, Rb-Sr**), ~4450 Ma** (Pb-Pb, U-Pb), **~2800 Ma** (Sm-Nd, Ar-Ar), and **~30 Ma** (Rb-Sr, U-He, U-Pb).

Discussion: Ar-Ar results from [6,7] agree that there is a young age 26 ± 11 Ma, the best defined age from the isotopic dating systems, meaning that many of the systems could have been disturbed by an event at ~30 Ma. They disagree on an older age (~1800 Ma compared to ~2800 Ma), but show very similar behavior. The reason for this discrepancy and how it affects the overall impact distribution is still being worked on, including modeling Ar diffusion [11]. Three studies of Sm-Nd yield four poorly-defined and very different ages; ~300, ~2900, ~3700, ~4452 Ma [2,5,9,5] respectively. The ~300 Ma isochron is consistent with 30 Ma. Two Rb-Sr isochrons yield ages of 150 ± 58 Ma and ~4567 Ma [10]. The ~150 Ma isochron could be representative of the ~30 Ma age found in argon, the difference being an artifact of different shock effects experienced by the different systems [8]. The Pb-Pb age of 4457 ± 35 Ma [12] agrees well with the U-Pb ages of apatite grains that have upper concordia ages of ~4450 Ma (4454 ± 67 Ma, 4452 ± 21 Ma, 4433 ± 110 Ma from [12,1,13] respectively), representing an early post-accretion impact [12]. Apatite has a less constrained lower concordia of 559 ± 180 Ma [12], which might indicate the most recent time lead was lost from the system, and is consistent with ~30 Ma.

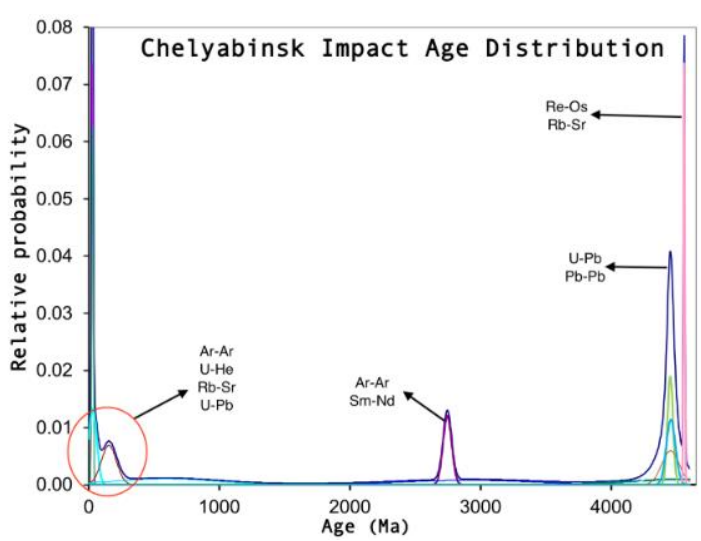

Figure 1. Revised impact age distribution suggested by this work (compare to [5]) suggests a formation age ~ 4560 Ma, an early energetic impact ~ 4450 Ma, an energetic impact not seen in other LL chondrites at ~ 2800 Ma, followed by the most recent impact event ~30 Ma. See text for references.

References: [1] Popova et al. (2013) *Science, 342,* 1069–1073. [2] Galimov et al. (2013) *Sol. Sys. Reas.* 47 255-259. [3] Badykov et al. (2015) *Petrology, 23, 103-115*. [4] Petrova et al. (2016) *MAPS, 51*. [5] Righter et al. (2015) *MAPS, 50, 1790-1819*. [6] Beard et al. (2014) *LPSC XXXXV*, #1807. [7] Trieloff et al. (2018) *MAPS, 53.* [8] Gaffney et al. (2011) *MAPS, 46, 35-52*. [9] Bogomolova et al. (2013) *Doklady Earth Sciences* 452. 1034-1038. [10] Nakamura et al. (2015) *LPSC XXXXV*, #1865. [11] Swindle and Weirich (2017) *LPSC XXXXVIII*, #1265. [12] Lapen et al. (2014) *LPSC XXXXV*, #2561 [13]. Kamioka et al. (2016) Mass Spec Conf., 62.