THE HIGH-TEMPERATURE HISTORY AND PRIMARY STUCTURE OF THE L CHONDRITE PARENT BODY. P. Sprung[1], C. Göpel[2], T. Kleine[3], J. A. Van Orman[4], C. Maden[1], [1]Institute of Geochemistry and Petrology, ETH Zurich, Clausiusstrasse 25, 8092 Zurich, Switzerland (sprung@erdw.ethz.ch), [2]Institut de Physique du Globe de Paris, 4, place Jussieu, 75252 Paris, France, [3]Institut für Planetologie, Westfälische Wilhelms-Universität Münster, Wilhelm-Klemm-Str. 10, 48149 Münster, Germany, [3]Department of Geological Sciences, Case Western Reserve University, 10900 Euclid Ave, Cleveland, Ohio 44106-7216, United States.

Introduction: The thermal history of a planetary body as recorded by multiple meteorite samples from the same body supplies direct constraints on the internal structure, the size range and the differentiation style of a planetary object [e.g., 1-4]. In recent studies, several chronometers including the short-lived Hf-W system were successfully combined to determine the thermal evolution of the acapulcoite-lodranite [2,3] and the H chondrite parent bodies [4]. The latter was shown to have had a concentrically layered internal structure [1,4]. For the L chondrite parent body, a history and internal structure more complex than those of the H chondrite parent body have been proposed based on Pb-Pb phosphate age data (T_c = 480 ±100 °C) that are inconsistent with simple cooling in a concentrically layered body [5]. However, the Pb-Pb data provide limited information on the initial structure of the L chondrite parent body because T_c for the Pb-Pb system in phosphates is much lower than the peak metamorphic temperature reached inside the L chondrite parent asteroid. In contrast, T_c for the Hf-W system in chondrites approximates peak metamorphic temperatures (T_{peak} = 875 ±75 °C, [4]). Hf-W ages thus can constrain the high-temperature evolution and internal structure of meteorite parent bodies. Here we report Hf-W isochrons for eight L chondrites comprising the full range of petrologic types of equilibrated L chondrites (Floyd, L4; Saratov, L4; Elenovka, L5; Homestead, L5; Barwell, L5-6; Bruderheim, L6; Ladder Creek, L6; Marion (Iowa), L6). For most of these samples Pb-Pb ages for phosphates are available [5,6,7,8], permitting a reconstruction of the high-temperature history of the L chondrite parent body through to temperatures of ~450 °C.

Methods: cleaned meteorite chips were gently crushed in an agate mortar. A metal-rich fraction (M) was separated non-magnetic (NM) fractions using a hand magnet. Further purification was acchieved by grinding under ethanol, repeatedly washing off the silicate dust and subsequent leaching in concentrated HF. For 'whole-rock' analyses (WR) complete meteorite chips were ground in an agate mortar. All fractions were dissolved at 120°C in closed Savillex vials using either 6 M HCl - 0.06 M HF (metals) or 5:1 HNO_3-HF followed by several evaporation steps with HNO_3-H_2O_2. Hafnium and W concentrations were obtained by isotope dilution using a mixed ^{180}Hf-^{183}W isotopic tracer added to a ~10% aliquot of the digestion solution. Purification of W and Hf used a slightly modified protocol after [4]. All measurements were conducted on a standard *Nu Plasma* MC-ICPMS at ETH Zurich. Reported W isotope compositions are given in ε^{182}W (i.e., parts per 10 000 deviation) relative to a terrestrial W standard that was analyzed bracketing the sample solutions. External reproducibilities are typically ±30 ppm (2 SD) at ^{182}W signals of approximately 2–2.5 V.

Results: All analyzed L chondrites yield well defined slopes on Hf-W isochron diagrams (e.g., Fig. 1) that demonstrably are not binary mixing lines. Thus, the slopes yield meaningful Hf-W isochron age data ranging from ~2.5 to ~14.2 Myr after CAI (Δt_{CAI}) using the initial ^{182}Hf/^{180}Hf of CAI from [9]. In general, Δt_{CAI} increase with petrologic type (Fig. 2) and initial W isotope composition (~ -3.1 to -2.2 ε^{182}W ; Fig. 3). Only the L4 chondrite Floyd which has a Hf-W age similar to those of L5 chondrites is an exception from this trend.

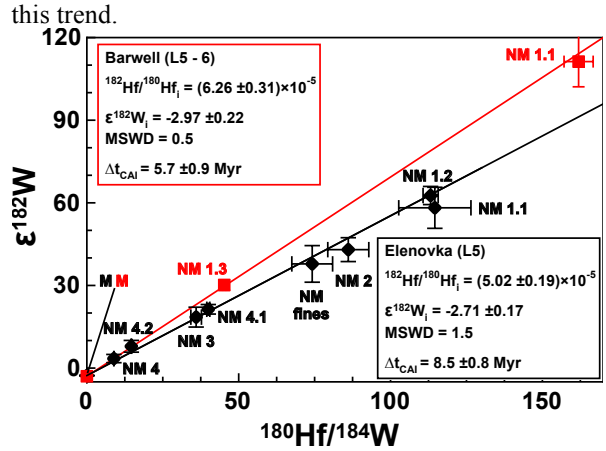

Fig. 1: Hf-W isochrons for Barwell (L5-6, red) and Elenovka (L5, black).

Discussion: Irrespective of petrologic type, shock state or degree of weathering and in keeping with results of a previous study on H chondrites [4], the presented Hf-W isochron age data provide the oldest of all available age data for each individual L chondrite. This demonstrates the great robustness and high resistance of the Hf-W system to any later disturbance. The Hf-W age of Saratov (L4; Δt_{CAI}: 2.5 ±0.9 Myr) overlaps with that of St. Marguerite (H4, Δt_{CAI}: 1.7±0.7 Myr, [4]) and is indistinguishable from Al-Mg ages for chondrules from primitive L chondrites [10]. Thus, it may date

chondrule formation, consistent with the observation that its metamorphic peak temperature probably was below the closure temperature of the Hf-W system [11]. Floyd, the other L4 chondrite investigated for this study, has a Hf-W age significantly younger than Al-Mg ages for L chondrite chondrules, indicating that the Hf-W ages of at least some type 4 chondrites were reset during parent body heating and metamorphism.

The general increase in Δt_{CAI} with petrologic type suggests a more rapid cooling and lower metamorphic peak temperatures in those regions of the L chondrite parent body that comprised the lower petrologic types. This is fully consistent with a primary, concentrically layered structure of the L chondrite parent body that resulted from thermal metamorphism driven by an internal heat source (i.e., radioactive decay of short-lived nuclides). Initial structure and early high-temperature thermal history thus appear to have been similar for the L and H chondrite parent bodies.

In contrast, Pb-Pb age data from the literature for phosphate fractions from the same meteorites [5,6,7,8] do not show a clear progression with petrologic type (Fig. 1). Saratov (L4) and Homestead (L5) have Pb-Pb phosphate ages that are too young for undisturbed cooling from peak metamorphic temperatures in an internally heated, concentrically layered asteroid (Fig. 1). These two L chondrites thus derive from regions that were strongly affected during modifications of the ordered primary structure of their parent body, most likely by impacts. Such impacts may have buried some material deeper inside the asteroid, causing slower cooling, and may have caused some local temperature excursions. In this regard the history of the L chondrite parent body differed from that of the H chondrite parent body, which at least in some areas escaped later impact-related disturbance [1,4].

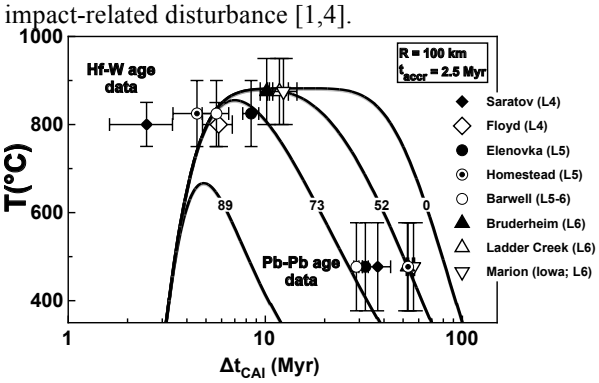

Fig 2: Cooling curves for L chondrites. Hf-W ages from this study, Hf-W closure temperatures from [4], Pb-Pb data from [5,6,7,8]. Solid lines depict temperature evolution paths at different depths (indicated by numbers in km distance from the centre) in a spherical body of 100 km radius that was internally heated by ^{26}Al decay (for details see [4]).

As is evident from the distinct correlation lines of $\varepsilon^{182}W_i$ with decreasing $^{182}Hf/^{180}Hf_i$ for L and H chondrites (Fig. 2), the L chondrite parent body evolved with a bulk Hf/W of ~1.2; a factor of ~2 higher than that of the H chondrite and acapulcoite-lodranite parent bodies and indistinguishable from that of carbonaceous chondrites [12]. L chondrites also have higher Si/Fe than H chondrites, a feature commonly attributed to the higher metal content of the latter [13]. As such the different Hf/W ratios of the L and H chondrites may be interpreted to reflect the lower metal content of the L chondrites. However, carbonaceous and H chondrites have similar Si/Fe but different Hf/W, indicating that the W budget of chondrites is not exclusively controlled by variable proportions of Fe metal. The distinct Hf/W ratios may instead reflect variable contributions from Fe-poor, highly refractory metal condensates to different chondrite classes. Such an interpretation would be in accordance with recent high-precision HSE data for ordinary chondrites [14,15] that also call upon the presence of at least two different HSE carriers in chondrites.

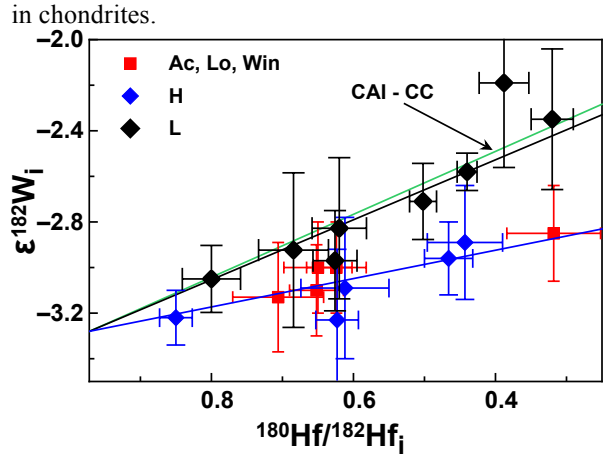

Figure 3: $\varepsilon^{182}W_i$ vs. $^{182}Hf/^{180}Hf_i$ for L and H chondrites as well as for Acapulcoites (Ac), Lodranites (Lo) [2,3], and Winonaites (Win) [3]. Solid lines are regression lines through the average composition of carbonaceous chondrites [12] (green), L (black), and H (blue) chondrite data points and the initial composition of CAI after [9].

References: [1] Trieloff M. et al. (2003) Nature 422, 502-506. [2] Touboul M. et al. (2009) *EPSL, 284,* 168-178. [3] Schulz T. et al. (2010) *GCA, 74*, 1706-1718. [4] Kleine T. et al. (2008) *EPSL, 270,* 106-118 . [5] Göpel C. et al. (1994) *EPSL, 121,* 153-171. [6] Sprung P. et al. (2010) *41st LPSC,* #1921. [7] Amelin Y. (2000) *31st LPSC,* #1201. [8] Rotenberg E. Amelin Y. (2001) *32nd LPSC,* #1675. [9] Burkhardt C. et al. (2008) *GCA, 72,* 6177-6197. [10] Rudraswami N.G. & Goswami J.N. (2007) *EPSL, 257,* 231-244. [11] Kessel R. et al. (2007) *GCA, 71*, 1855-1881. [12] Kleine T. et al. (2009) *GCA, 73,* 5150-5188. [13] Palme H. & Jones A. (2003) *Treatise on geochemistry, 1.03*. 41-61. [14] Fischer-Gödde M. et al. (2010) *GCA, 74*, 356-379. [15] Horan M. et al. (2009) GCA 73, 6984-6997.