I-Xe Dating: The time line of chondrule formation and metamorphism in LL chondrites. O. V. Pravdivtseva, C. M. Hohenberg, and A. P. Meshik. McDonnell Center for the Space Sciences and Physics Department, Washington University, CB 1105, One Brookings Drive, Saint Louis, MO 63130, USA (olga@wustl.edu).

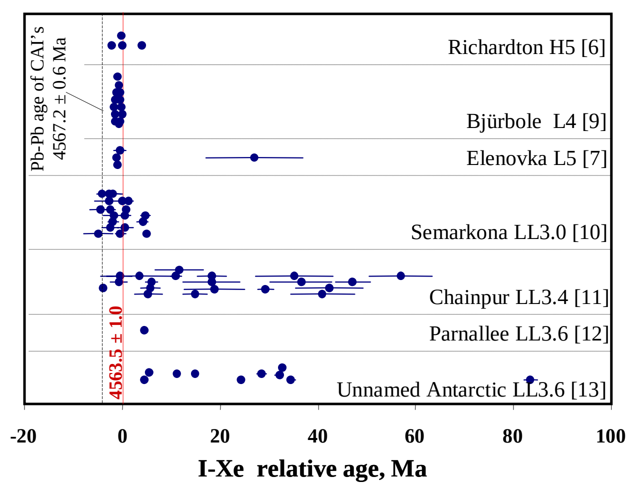
Refractory inclusions, considered to be the oldest solids formed in the solar nebula. (4567.2 ± 0.6 Ma) [1], are common in many carbonaceous and in some ordinary and enstatite chondrites. High-precision Pb-Pb ages for CAI's and chondrules (from different meteorites) suggested that chondrule formation appeared to have started about 2 Ma later than that of CAIs [1]. However, recent $^{26}Al/^{26}Mg$ data suggest simultaneous formation of CAI's and chondrules in Allende [2].

The I-Xe ages of CAI's in Allende are about 2 Ma younger than the I-Xe ages of Allende chondrules [3] but, like all chronometers, the I-Xe system records closure time of its particular host phase. In the case of Allende CAI's, the major iodine-bearing phase is sodalite, a secondary phase presumably formed by aqueous alteration, so I-Xe reflects the post-formational processes in these objects. In chondrules the iodine host phases vary and can reflect formation and/or alteration but, to put chondrule ages on a quantative basis, some problems should first be addressed.

Absolute normalization: The problem with obtaining absolute ages from short-lived chronometers is that it requires intercalibration with long-lived ones. This is best done in the same mineral phases to assure simultaneous closure. We have no assurance of simultaneous closure when the carrier phases are different, or for whole rock samples. Although such comparisions are sometimes necessary, they must be considered in the context of global normalization utilizing many different samples. Such is the case for the absolute age calibration of the I-Xe chronometer.

There are four different determinations of the absolute age of the Shallowater I-Xe reference standard. While not all of them are equally precise, there is no easy way to assign relative uncertainties. Based upon Acapulco apatite, a single-mineral comparison of I-Xe and Pb-Pb, the age of Shallowater enstatite is 4566 ± 2 Ma, where the relatively large uncertainty is due to the uncertainty of the Pb-Pb age [4, 5]. Comparison of the I-Xe and Pb-Pb ages in chondrules from Richardton [6] and Elenovka [7] strongly suggested that the Shallowater absolute age is about 2.9 Ma too old and shold be 4563.1 Ma. In both of these meteorites the I-Xe and Pb-Pb systems probably date the same mineral phase, since there was considerable U-fission Xe in the temperature fractions forming the I-Xe isochron. Gilmour et al. [8], using I-Xe and Pb-Pb age correlations for all available phosphate samples, estimated the absolute age of Shallowater enstatite to be 4562.3, and comparing I-Xe with Mg-Cr (itself calibrated with Pb-Pb by LEW86010), arrived at 4565.1 Ma. Therefore, a zeroth order (equally weighted) estimate gives Shallowater enstatite an absolute age of 4564 +- 1 Ma, about 2 Ma younger than the original age based only upon Acapulco phosphate, a correction in line with our previous observations [6]. A second, perhaps better, estimate is made not considering the Acapulco phosphate Pb-Pb age, which we now know to be too old, and this refines the Shallowater enstatite age to 4563.5 +- 1 Ma. The I-Xe ages of chondrules from various ordinary chondrites are shown in Figure 1, relative to the revised absolute age of Shallowater, along with the Pb-Pb age of CAIs.

Fig.1.

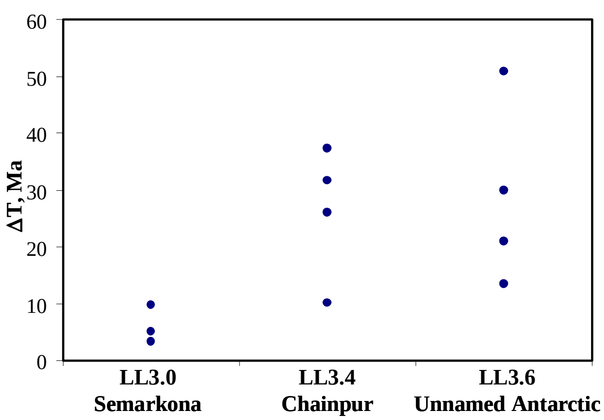


The spread of I-Xe ages for chondrules from the LL chondrites increases with increasing metamorphic grade, consistent with the more extensive alteration and/or longer equilibration times implied. For the unnamed Antarctic meteorite, Herd et al. [14] suggested a long equilibration time based on six U-Pb and Rb-Sr analyses of fragments from 5 chondrules. The young isochron ages based on Pb-Pb and Rb-Sr, 4489 ± 43 and 4385 ± 40 Ma respectively, support the conclusion that this meteorite had a more complex thermal history than is indicated by texture and mineral analyses alone.

Chondrules are known to have multiple mineral phases that can potentially carry iodine and thus provide I-Xe ages. If these have distinct thermal properties, and thus release radiogenic Xe at different temperatures, step-wise heating may resolve the age information contained in different phases. Indeed, all ordinary chondrites, discussed here have chondrules with dual I-Xe structures (low and high temperature isochrons), except for the single measurement from Parnalee (Figure 1).

Longer equilibration times for the higher-grade ordinary chondrites probably mean that more time ΔT elapsed between closures of the I-Xe system in the high- and low-temperature host phases from the same chondrule. In Figure 2 we see a clear correlation between ΔT and the metamorphic grade of chondrules from LL meteorites.

Fig.2. For chondrules with low and high temperature isochrons, the time interval ΔT between closure of the I-Xe system in the high- and low-temperature host phases increases with metamorphic grade in LL chondrites.



With the revised absolute age of the Shallowater reference, the oldest Semarkona chondrules now seem to have formed nearly simultaneously with the CAIs (4567.2 ± 0.6 Ma, or perhaps shortly thereafter since the uncertainties for the old Semarkona chondrule ages are rather high). That the older I-Xe ages from Semarkona chondrules may reflect the time of actual chondrule formation was first suggested by Swindle et al. [10]. Younger I-Xe ages are established during the ongoing post-formational alteration. Krot et al. [15] argue that the entire range of I-Xe ages in the type 3 ordinary chondrites reflects the long duration of aqueous alteration on the LL parent body. While I-Xe ages of chondrules from Parnallee, the unnamed Antarctic meteorite, and most of the Chainpur chondrules may indeed reflect the extended duration of alteration on the parent body, formation time may still be preserved in chondrules from the more primitive Semarkona.

Chondrules from ordinary chondrites of higher metamorphic grade, Richardton, Bjurbole, and Elenovka, have I-Xe ages that cluster tightly about 2 Ma after CAI formation (Figure 1).

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