LOW-T THERMOCHRONOLOGY OF ST. SEVERIN LL6 CHONDRITE REVEALED FROM SINGLE-GRAIN PHOSPHATE (U-Th)/He AGES. K. Min[1], P. W. Reiners[2] and D. L. Shuster[3, 4], [1]Department of Geological Sciences, University of Florida, Gainesville, FL 32611, USA (kmin@ufl.edu), [2]Department of Geosciences, University of Arizona, Tucson, AZ 85721, USA (reiners@email.arizona.edu), [3]Berkeley Geochronology Center, 2455 Ridge Road, Berkeley, CA 94709, USA (dshuster@bgc.org), [4]Department of Earth and Planetary Science, University of California, Berkeley, CA 94720, USA.

Introduction: Multiple radiogenic isotope systems and ^{244}Pu fission track data suggest that St. Severin LL6 ordinary chondrite has experienced relatively slow cooling compared to H chondrites. Although the high-T thermal history is well documented from Pb-Pb and ^{49}Ar/^{39}Ar data, the cooling history after the thermal metamorphism in a low temperature range (<200 °C) is poorly understood. The aims of this research are (1) constraining low-T thermal history of St. Severin from (U-Th)/He systematics of phosphates, and (2) deducing general He diffusion properties in merrillite which is the major reservoir of U-Th in many meteorites

Analytical Methods: We performed single-grain (U-Th)/He dating for five chlorapatite and fourteen merrillite aggregates from St. Severin. The textural and chemical features of the individual phosphate aggregates were examined using a scanning electron microscope (SEM) and optical microscopes. To quantify He diffusion kinetics in merrillite and chlorapatite, we produced He isotopes through laboratory proton-irradiation, then performed ^{4}He and ^{3}He diffusion experiments for single grains of merrillite and chlorapatite from the Guarena meteorite. The amount of cosmogenic ^{4}He in each phosphate from St. Severin was calculated based on (1) ^{3}He production rate of 1.61×10^{-8} cc/g-Myr [1], (2) ^{4}He production rate = $5 \times {}^3$He production rate, (3) estimated mass of each aggregates, and (4) exposure age of 14 ± 3 Ma for St. Severin [1]. Although the ratio of the estimated cosmogenic ^{4}He to the measured ^{4}He is less than 0.5 % for most old (>4.0 Ga) samples, some phosphates yield larger ratios requiring complete cosmogenic ^{4}He correction.

(U-Th)/He Data: The Th/U ratios are 7.4 ± 5.0 (average ± standard deviation) and 2.7 ± 3.5 for merrillite and chlorapatite, respectively, being generally consistent with the results of [2]. The Sm contribution to the calculated (U-Th)/He age is more significant for merrillite (2.3 ± 1.2 %) than in apatite (0.4 ± 0.8 %) simply because of the relatively large concentration of Sm in the merrillites, and the old ages of this meteorite. These results imply the importance of analyzing Sm contents to obtain accurate (U-Th)/He ages particularly for old merrillite samples. The ages uncorrected for α-recoil from St. Severin range broadly from 321 ± 12 (2σ) Ma to 4503 ± 270 Ma. The distribution of these ages has a peak at ~ 4.3 Ga and nearly continuous span of younger ages. The weighted mean of the nine oldest samples is 4.272 ± 0.100 Ga with a MSWD of 1.16.

The cross-section dimensions of the phosphates range from ~50 µm to 200 µm. The α recoil correction factor (F_T) based on the morphology of the phosphate yields improbably old ages (>4.6 Ga), suggesting that within the sample aggregates, significant amounts of the α particles ejected from phosphates may have been implanted into the adjacent phases and therefore that this correction may not be appropriate in all cases. The minimum F_T value of 0.95 is calculated based on the peak (U-Th)/He age and ^{40}Ar/^{39}Ar data which provide the upper limit of the α-recoil-corrected (U-Th)/He ages.

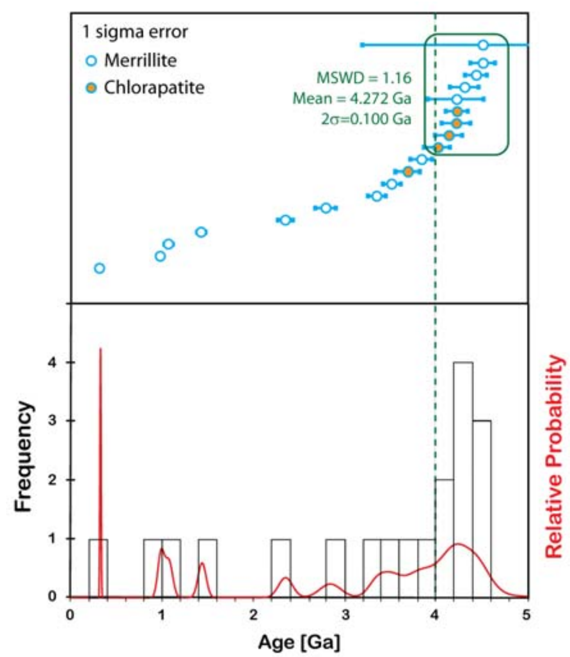

Figure 1: Single grain (U-Th)/He ages of St. Severin merrillite and chlorapatite (top); and frequency diagram and probability density plot (bottom). The peak of the probability density plot overlaps with the weighted mean (4.272 ± 0.100 Ma) of the nine oldest phosphate ages.

He diffusion Experiments: The radiogenic ^{4}He and proton-induced ^{3}He diffusion experiments yield two well-defined linear trends in Arrhenius plot for chlorapatite (r = 43 μm) and merrillite (r = 59 μm) grains. The linear regression of ^{3}He data for chlorapatite yields E_a = 128.1 ± 2.4 kJ/mol, and $\ln(D_o/a^2)$ = 11.6 ± 0.5 $\ln(s^{-1})$ which is consistent with the terrestrial apatite and meteoritic Acapulco apatite. Linear regression to the merrillite data corresponds to E_a = 135.1 ± 2.5 kJ/mol, and $\ln(D_o/a^2)$ = 5.73 ± 0.37 $\ln(s^{-1})$. Assuming these results also apply to St. Severin and that crystal dimensions define the limiting diffusive length-scale, the closure temperatures of merrillite and chlorapatite in St. Severin are estimated to be 104 °C and 43 °C, respectively, for a cooling rate of 2 °C/Ma. The new data indicate that diffusive retentivity of He within merrillite is significantly higher than that of chlorapatite, which has implications for quantitative interpretation of He ages measured in meteoritic phosphates.

Cooling History of St. Severin: Among the nine oldest ages from St. Severin, five ages from merrillite yield a weighted mean of 4413 ± 150 Ma (MSWD = 0.33). If the next oldest merrillite age (3842 ± 119 Ma; SA2-7a) is included, the weighted mean becomes 4250 ± 310 Ma although the resulting MSWD is 3.6. The representative merrillite age is likely to be bounded by the two weighted means, one with too small (< 1) MSWD and the other one with too large (> 1) MSWD. Out of the nine oldest ages, the four apatite ages generate a weighted mean of 4152 ± 140 Ma (MSWD = 0.48). With the next oldest apatite age (3688 ± 131 Ma; SB1-4a), the weighted mean becomes 4052 ± 280 Ma (MSWD = 2.8). Similarly to the case of merrillite, it is expected that the representative apatite age is within these two weighted mean values. The systematically older ages of merrillite than apatite are consistent with the results obtained from the diffusion experiments ($T_c^{Merrillite} > T_c^{Chlorapatite}$). With the estimated closure temperatures and the representative ages, the low-T thermal history of St. Severin is inferred (Figure 2). The estimated cooling curve is consistent with existing isotopic ages as well as Pu fission track data [3] when anchored to the Pb-Pb ages.

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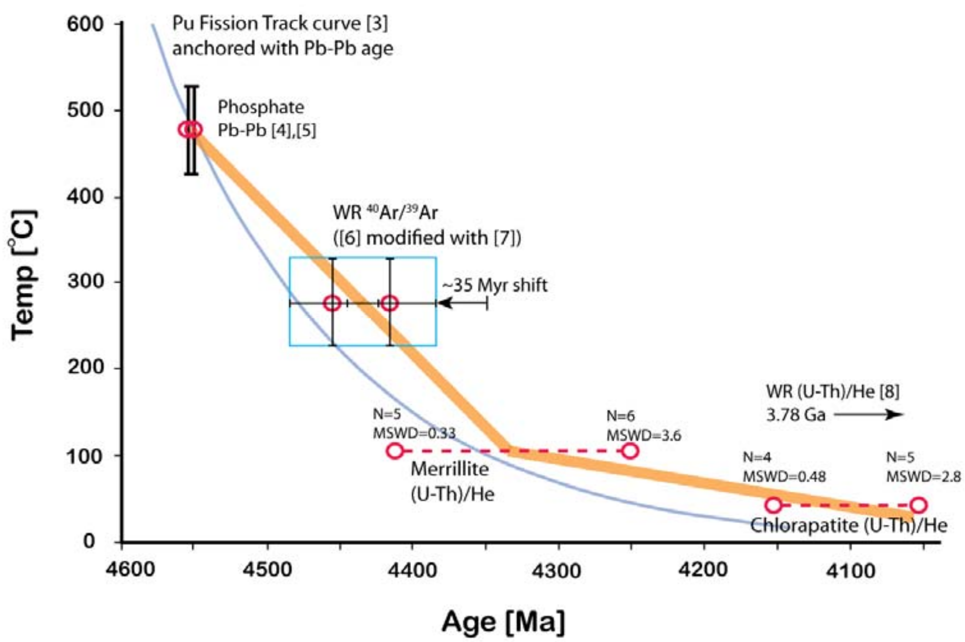

Figure 2: Cooling history of St. Severin inferred from various isotopic systems and Pu fission tracks. Low-T part of the cooling curve is constrained from the merrillite and chlorapatite (U-Th)/He ages and closure temperatures determined from Guarena chondrite phosphates.