THE COMPOSITION OF THE FLUX OF MICROMETEORITES AFTER THE L-CHONDRITE PARENT BODY BREAKUP ~470 MA AGO: ≤1% H CHONDRITIC, ≥99% L CHONDRITIC.

P. R. Heck[1,2,3], B. Schmitz[1,4], S. S. Rout[1,2], T. Tenner[5], K. Villalon[1,2,3], A. Cronholm[4], F. Terfelt[4], and N. T. Kita[5], [1]Robert A. Pritzker Center for Meteoritics and Polar Studies, Field Museum of Nat. Hist., 1400 S Lake Shore Dr, Chicago, IL 60605, USA. E-mail: prheck@fieldmuseum.org. [2]Chicago Center for Cosmochemistry, [3]Dept. of Geophysical Sciences, Univ. of Chicago, 5734 S Ellis Ave, Chicago, IL 60637, USA. [4]Astrogeobiology Laboratory, Dept. of Physics, Lund Univ., P.O. Box 118, SE-221 00 Lund, Sweden. [5]WiscSIMS, Dept. of Geoscience, Univ. of Wisconsin-Madison, 1215 W Dayton St, Madison, WI 53706-1692, USA.

Introduction: The motivation for the present study was to find H-chondritic material in ~470 Ma old mid-Ordovician limestone that contains highly abundant L-chondritic material. The latter has been identified as debris from the L-chondrite parent body breakup (LCPB) in the asteroid belt ~470 Ma ago and the flux of L chondrites to Earth has been estimated as ~100× higher than today [1]. This L-chondritic debris, ranging from micrometeorites (MMs) and meteorites, to larger fragments that formed impact craters, dominated the extraterrestrial material that arrived on Earth over a period of more than 1 Ma after the LCPB [1]. This is very different from today, where H and L chondrites fall at about the same rate (H/L meteorite fall ratio is ~0.9; [2]. It is intriguing to search for the small fraction of other chondritic material to determine what other chromite-bearing extraterrestrial material arrived on Earth during a time that was dominated by L chondrites. The mineralogy of MMs and meteorites had been altered during the ~470-Ma-long residence in the sediments and the objects became fossilized. Only chromite and chrome-spinel have retained their original compositions. Average elemental concentrations of a large number of samples are used for classification, e.g., [3]. For individual grains elemental analysis is combined with oxygen isotopic analysis of single grains by SIMS [4]. Out of the 101 recovered fossil meteorites only one is not L chondritic and was classified as winonaite-like [5]. Fossil MMs are more abundant than fossil meteorites and are found as sediment-dispersed extraterrestrial chromite and chrome-spinel (SEC) grains. Elemental averages of hundreds of SECs from mid-Ordovician sediments from Sweden, China and Russia are consistent with L-chondritic composition, e.g., [3,6–8]. An L-chondritic origin of 24 individual SECs from Sweden and Russia was found [4].

Here, we expand the sample base to 120 SEC grains for elemental and oxygen isotopic analysis to search for non-L-chondritic grains.

Samples and Methods: Because of their abundance, SECs can be more readily recovered than fossil meteorites and are well suited for the present study. We randomly selected a total of 120 SECs (63-120 µm in diameter): 83 SECs from three sediment beds from the Thorsberg quarry in Sweden, and 37 SECs from correlated sediments at the Lynna River section in Russia. The grains were extracted from limestone by acid dissolution and sieving and identified with SEM/EDS [8]. Flat-polished epoxy grain mounts were prepared with centrally mounted chromite standard UWCr-3 [4] and imaged by SEM.

Grains on gold-coated mounts were analyzed with a Cameca IMS-1280 SIMS for three oxygen isotopes with conditions and procedures according to [4]. This includes monitoring and correction for the hydride tailing interference on $^{17}O^-$.

A total of 519 analyses were performed on the SECs and the standards. After SIMS analysis major and minor elemental compositions were determined quantitatively with SEM/EDS and grains were imaged again by SEM [10]. All elemental concentrations in SECs were compared to ranges observed in modern meteorites. Of all elements Ti and V are most inert to diagenetic alteration in SECs. Although there is overlap in TiO_2 and V_2O_3 contents among chromites and chrome-spinels from the different ordinary chondrite groups, the overlap is smaller for TiO_2.

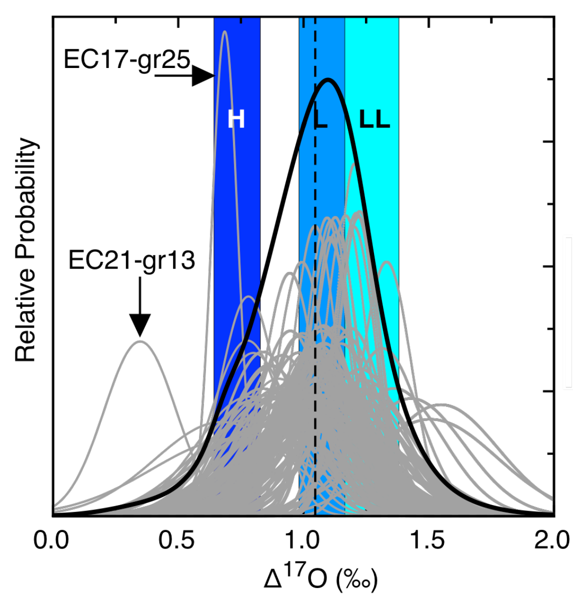

Fig. 1. Each grey curve represents the probability density for a $\Delta^{17}O$ value of a SEC grain. The bold black curve is the sum of all probabilities. Shaded fields are group averages±SD for bulk meteorites reported by [9].

Thus, TiO_2 is more useful to distinguish between the different groups, e.g., [3]. $\Delta^{17}O$ values ($=\delta^{17}O-0.52\times\delta^{18}O$) of the SEC grains were calculated and compared together with TiO_2 contents to values of known ordinary chondrites.

Results and Discussion: 113 out of 120 SECs have $\Delta^{17}O$ values (0.8‰ to 1.5‰; average 1.05‰±0.16‰) and TiO_2 contents (1.7 to 3.6 wt%; average 3.0±0.3 wt%) that match equilibrated L-chondritic composition (Figs. 1,2). Within error, some of the data falls into the natural overlap of L and LL chondrites. Although for those samples we cannot unambiguously distinguish between the L and LL chondritic, we think an LL chondritic composition is unlikely because the grains with the highest $\Delta^{17}O$ values that fall into the LL and L ranges have lower TiO_2 contents than grains with lower $\Delta^{17}O$ values, not higher TiO_2 as would be expected for LL chondrites. Five further grains have lower $\Delta^{17}O$ values (0.7‰ to 0.8‰) consistent with the H-chondritic range but their errors reach into the L-chondritic field and their TiO_2 contents are best matched with L-chondritic values (Figs. 1,2). Thus, based on the data an H-chondritic origin is difficult to support for any of these SECs.

In contrast, one additional grain from Thorsberg (EC17-gr25) is possibly H chondritic as its $\Delta^{17}O$ value within its error (0.7‰±0.1‰) is H chondritic (Fig. 1) and its TiO_2 content (2.5±0.1 wt%) is also consistent with H chondritic (Fig. 2). There is one grain (EC21-gr13) whose origin we cannot explain as its $\Delta^{17}O$ value (0.3±0.1‰) falls between H-chondritic and terrestrial values and its TiO_2 content (2.6±0.2%) falls into the range of H and L chondrites (Fig. 1). We cannot fully exclude that we sampled a crack filled with epoxy or with a terrestrial alteration phase that resulted in a mixed signal. There is a very low probability that the low $\Delta^{17}O$ values in this and the previously discussed grain are from chondrules of any ordinary chondrite group. It is unlikely that any of the SECs are from chondrules because chromites in chondrules are usually much smaller than the SECs studied here and coarse chromite is very rare in chondrules (<0.1% [11]).

Our finding of one H-chondritic SEC out of 119 L-chondritic SECs is in agreement with the following estimate that is independent of our data: For the sake of this argument we assume the present-day fraction of H chondrites among ordinary chondrite falls (~42%; [2]) for the background flux not related to the LCPB ~470 Ma ago. We also assume that the H/L-chondritic abundance ratio of micrometeorites is similar to the ratio of macroscopic meteorites. We discuss this in [10] based on data from recent ordinary chondritic micrometeorites, e.g., [12,13]. We then use the previous estimate of a 100× higher flux of L-chondritic material to Earth and find that only one H-chondritic sample (0.9%) out of 119 samples would be expected.

Conclusions: Our study strengthens conclusions from previous studies that L-chondritic material dominated the flux of extraterrestrial matter to Earth after the LCPB event. We conclude that the upper limit for the fraction of H-chondritic micrometeorites in post-LCPB sediments is 1%. With this upper limit we predict that a fossil H chondrite will be discovered in the Swedish Thorsberg quarry within the next decade at current fossil meteorite discovery rates. In our discussion we illustrate the usefulness of the combined approach of using $\Delta^{17}O$ and TiO_2 for classifying SECs. Although there are limitations due to natural overlap of compositions, none of the indicators alone would be sufficient to classify an individual SEC.

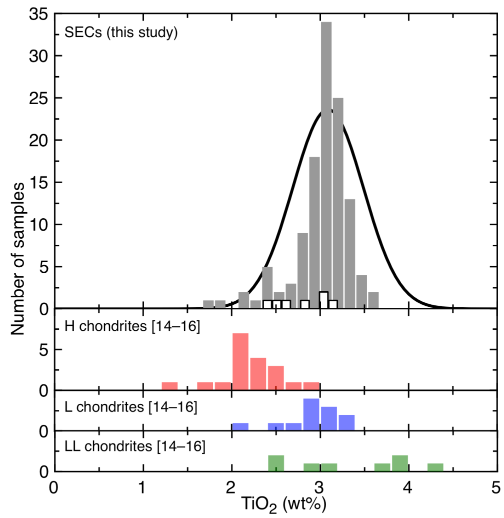

Fig. 2. TiO_2 of studied SECs compared with chromites from equilibrated ordinary chondrites. SECs with low $\Delta^{17}O$ are shown as a white histogram in the top panel.

References: [1] Schmitz B. (2013) *Chemie der Erde 73*, 117–145. [2] Meteor. Bull. Database (2015), http://www.lpi.usra.edu/meteor. [3] Schmitz B. and Häggström T. (2006) *MAPS 41*, 455–466. [4] Heck P. R. et al. (2010) *GCA 74*, 497–509. [5] Schmitz B. et al. (2014) *EPSL 400*, 145–152. [6] Schmitz B. et al. (2008) *Nat. Geosci. 1*, 49–53. [7] Lindskog A. et al. (2012) *MAPS 47*, 1274–1290. [8] Schmitz B. et al. (2003) *Science 300*, 961–964. [9] Clayton R. N. et al. (1991) *GCA 55*, 2317–2337. [10] Heck P. R. et al. (2016) *GCA* (in press). [11] Krot A. N. and Rubin A. E. (1993) *LPS 24*, 827–828. [12] Van Ginneken M. et al. (2012). *MAPS 47*, 228–247. [13] Prasad M. S. et al. (2015) *MAPS 50*, 1013–1031. [14] Snetsinger K. G. et al. (1967) *Am. Min. 52*, 1322–1331. [15] Bunch T. E. et al. (1967) *GCA 31*, 569–1582. [16] Wlotzka F. (2005). *MAPS 40*, 1673–1702.