NOBLE GASES IN INDIVIDUAL SEDIMENT-DISPERSED CHROMITE GRAINS – MICROMETEORITES FROM AN ORDOVICIAN ASTEROID COLLISION M.M.M. Meier[1], B. Schmitz[2], P. R. Heck[3], H. Baur[1], R. Wieler[1], [1]ETH Zürich, Isotope Geology, NW C84, CH-8092 Zürich, Switzerland, meier@erdw.ethz.ch, [2]University of Lund, Dept. of Geology, Sölvegatan 12, SE-22362 Lund, Sweden, [3] Dept. of Geology & Geophysics, University of Wisconsin, 1215 W. Dayton St., Madison, WI 53706, USA.

Introduction: The Thorsberg quarry in southern Sweden is known for its high concentration of fossil meteorites in mid-Ordovician marine limestone [1]. The same sediment beds contain up to 3 sediment-dispersed extraterrestrial chromite (SEC) grains per kilogram of limestone dissolved in HF and HCl [2]. Both fossil meteorites and SEC were produced in the break-up of the L chondrite parent asteroid ~470 Myr ago. In [3], batches of 5 to 6 SEC were analysed for He and Ne. Large amounts of trapped noble gases of (fractionated) solar wind (SW) composition were found, indicating that a significant fraction of the SEC must be micrometeorites directly exposed to SW. While the fossil meteorites were delivered by close-by orbital resonances in the asteroid belt [4], SEC were presumably additionally delivered by Poynting-Robertson drag [3]. The cosmic-ray exposure (CRE) ages of the fossil meteorites correlate inversely with sediment deposition age and indicate very rapid transport from the asteroid belt [4]. Since at least a substantial fraction of the chemically highly resistant SEC kept their noble gas inventory to the present day, and since SEC are much more abundant than fossil meteorites, CRE ages of SEC offer the potential to study the Ordovician asteroid collision and its terrestrial impact in more detail and over longer timescales than fossil meteorites.

The aim of this work is to determine He and Ne amount and composition of *individual* SEC grains. This may allow us to draw conclusions on 1) how many of the SEC are in fact micrometeorites vs. fragments of larger meteorites and 2) how long they travelled in interplanetary space, based on putative ^{21}Ne excesses from which CRE ages may be calculated.

Samples and Methods: 16 SEC grains from the upper and middle "Sextummen" bed from the Thorsberg quarry were analysed. The fossil meteorites from the same bed have CRE ages of 0.41 to 0.62 Myrs [4]. Due to the small size (63 - ~180 μm diameter, 0.6 – 13.7 μg) of the SEC grains, any excess of cosmic-ray induced ^{21}Ne can be expected to be very small. Therefore, we used an ultra-high-sensitivity mass spectrometer and a low-blank extraction line. The mass spectrometer concentrates gases almost quantitatively into the ion source by a molecular drag pump (compressor) [5]. Detection limit for ^{21}Ne was ~(4 – 8) x 10^{-16} cm^3 STP. Grain mass was measured on a micro-balance to ~10%. For 8 grains, the concentrations of Mg, Al, V, Ti, Fe, and Cr were measured to determine grain-specific cosmic-ray production rates for ^{21}Ne based on [4] for galactic cosmic rays (GCR) and [6] for solar cosmic rays (SCR). GCR production rates were adjusted for 4π exposure. SCR production rates were adjusted for 4π exposure at a weighted-average heliocentric distance of 1.5 AU, taking into account irradiation intensity and Poynting-Robertson transfer times to Earth from an initial heliocentric distance of 2.2 AU (~semi-major axis of asteroid 8 Flora, largest remnant of the Ordovician asteroid collision [7]).

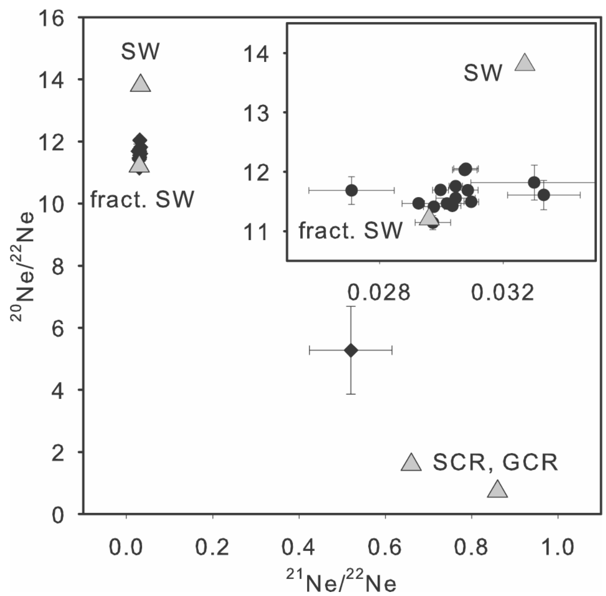

Figure 1: Ne three isotope plot: Measured values (diamonds and dots) and Ne components (triangles). One grain shows a clearly resolvable ^{21}Ne excess over solar composition, while others show a measurably resolvable excess. Errors are 1-σ and include analytical uncertainities.

Results and Discussion: At least 15 of the 16 grains contained Ne and He of SW composition, one data point in Fig. 1 falls on a mixing line between the SCR/GCR endpoints and a trapped component that could either be (fractionated) SW or air (see Fig. 1). One grain with SW Ne has a non-solar ^{3}He/^{4}He ratio (~2.59 x 10^{-5}), possibly due to radiogenic ^{4}He, as this is the largest of all grains (13.8 μg).

Since only ~3% of all L chondrites falling today are asteroidal regolith breccias containing SW gases [8], and since only the topmost few nanometers of a meteoroid are exposed to SW, the fact that all measured grains (with one possible exception) contained solar He and Ne implies that the SEC truly are (parts of) very small (<1 mm) micrometeorites, rather than fragments of larger meteorites disintegrated by terrestrial weathering. This is not unexpected, as the flux of extraterrestrial material today is dominated by micrometeorites [9]. During the first million years after the large collision, the relative contribution of dust to the overall flux of extraterrestrial material may be expected to have been even larger.

Fig 2. shows a correlation between noble gas concentration and grain mass. 10 of the 16 grains show increasing concentrations with decreasing mass/size, compatible with surface correlated ^{20}Ne. However, 6 of the 16 (including the two largest) grains show very small concentrations of ^{20}Ne, independent of grain mass. For the 8 grains where ^{4}He concentration was measured, a similar trend is observed.

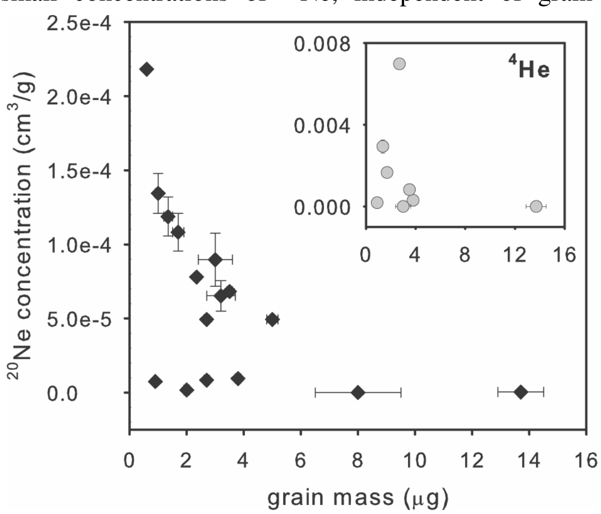

Figure 2: 10 of the 16 grains show a correlation between ^{20}Ne concentration and mass that implies surface-implantation. 6 grains contain only very little trapped Ne of SW composition. ^{4}He (inset) shows a similar correlation.

In Fig. 1, almost all data points are found near a line connecting the unfractionated SW component (^{20}Ne/^{22}Ne = 13.8, ^{21}Ne/^{22}Ne = 0.0327) with the "fractionated SW" (former "SEP") component (^{20}Ne/^{22}Ne = 11.2, ^{21}Ne/^{22}Ne = 0.0296). Considering 1-σ errors, 6 of the grains plot significantly to the right of the line, indicating cosmogenic ^{21}Ne, 2 are found left of the line and the rest encompass the line within their respective error bars (but with data points still falling predominantly to the right of the line). Considering 2-σ errors, only 3 grains would show ^{21}Ne excess (see Fig. 1). From these small ^{21}Ne excesses, a CRE age can be calculated. These ages nessecarily have large uncertainties, on the one hand due to analytical errors (2- σ ~ 60-90%, but on the other hand also because for these micrometeorites we also need to consider Ne production by solar cosmic rays, which depends strongly on heliocentric distance. Only ages of the 8 grains with known elemental composition are considered reliable. The calculated ages range from 0.046 to 9.6 Myrs, if GCR and SCR are taken into account (Fig. 3). If only GCR would be considered, the ages would be ~50-70% larger. Most of the grains are within 2-σ errors consistent with the range of CRE ages of the fossil meteorites in the same sediment bed (grey area in Fig. 3). One grain is significantly younger than the others and may have been formed in a secondary collision. Two grains seem to be much older, but also have large error bars. As noted, it is difficult to better constrain these ages without knowing more about the transfer / exposure history of the individual grains. The best ages are measured with large but gas-poor grains, so this is where follow-up measurements will take us.

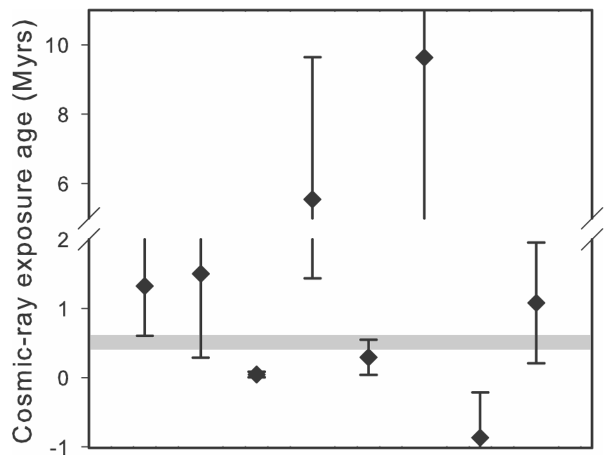

Figure 3: CRE ages (SCR + GCR) for 8 of the grains (2-σ-errors). The grey area denotes the exposure age range of fossil meteorites from the "Sextummen" bed [4].

Conclusion: At least 15 of 16 sediment-dispersed chromite grains from the upper and middle "Sextummen" bed of Ordovician limestone in southern Sweden contain surface-implanted He and Ne of SW composition, implying that these grains were once micrometeorites, rather than fragments of weathered meteorites. Small ^{21}Ne excesses can be used to calculate very rough CRE ages.

References: [1] Schmitz B. et al. (1996), *EPSL.* 145, 31–48. [2] Schmitz B. and Häggström T. (2003), *MAPS.* 41, 455–466. [3] Heck P.R. et al. (2008) *MAPS*, in press. [4] Heck P.R. et al. (2004) *Nature* 430, 323–325 [5] Baur H. (1999) *EOS Trans. AGU* 46, F1118 [6] Hohenberg C. et al., *LPSC IX*, Vol 2, p. 2311-2344, [7] Nesvorny D. et al. (2007) *Icarus* 188, 400-413, [8] Bischoff A. and Schultz L. *MAPS.* 39, 5118 [9] Peucker-Ehrenbrink B. (1996) *GCA* 60, 3187-3196