THE GHUBARA (L5) REGOLITH BRECCIA AS A SAMPLE OF THE SOURCE-ROCK OF FOSSIL MICROMETEORITIC CHROMITE FOUND IN ORDOVICIAN SEDIMENTS.

M. M. M. Meier[1], B. Schmitz[1], C. Alwmark[1], C. Maden[2] and R. Wieler[2]. [1]Lund University, Department of Geology, Sölvegatan 12, SE-22362 Lund, Sweden (matthias.meier@geol.lu.se). [2]ETH Zurich, Department of Earth Sciences, CH-8092 Zurich, Switzerland.

Introduction: A large number of fossil meteorites found in a ~4 m thick section of middle Ordovician limestone (deposited over 1-2 Ma) in Sweden have been attributed to a two-orders of magnitude increase in the influx of extraterrestrial matter after the break-up of the L chondrite parent body (LCPB)[1]. Cosmic ray exposure (CRE) ages of relict chromite grains from 9 fossil meteorites reveal that they were delivered rapidly to Earth within <1 Ma [2]. The deposition ages of the fossil meteorites are consistent with Ar-Ar-ages of 470±6 Ma for recent L chondrites [3]. One of the fossil meteorites (Ark 002) is a regolith breccia since its chromite grains contain solar wind (SW) derived He and Ne [2]. The fossil meteorite-rich sediment beds also contain relatively large concentrations of sediment-dispersed extraterrestrial chromite (SEC) grains [4]. These SEC grains have major- and minor element concentrations [4] and an oxygen isotope composition [5] compatible with L chondritic values. Virtually all SEC grains contain He and Ne of SW origin, i.e. once had at least one surface exposed to the SW [6][7]. This implies that they are micrometeoritic dust, produced or released during the LCPB break-up. They picked up at least part of their SW gases in interplanetary space. A significant fraction of these SEC grains, however, have cosmogenic ^{21}Ne (^{21}Ne$_{cos}$) concentrations corresponding to a significantly longer exposure to galactic cosmic rays (GCR) than the <2 Ma transfer time allowed by Poynting-Robertson drag. Exposure ages in a range of typically ~0-40 Ma [7][8] suggest exposure to GCR within the regolith near the surface of the LCPB. The fraction of grains pre-exposed to GCR decreases with time after the break-up, consistent with the LCPB losing most of its regolith in the break-up, but the production of dust from secondary collisions of interior fragments of the LCPB continuing for at least ~2 Ma [8].

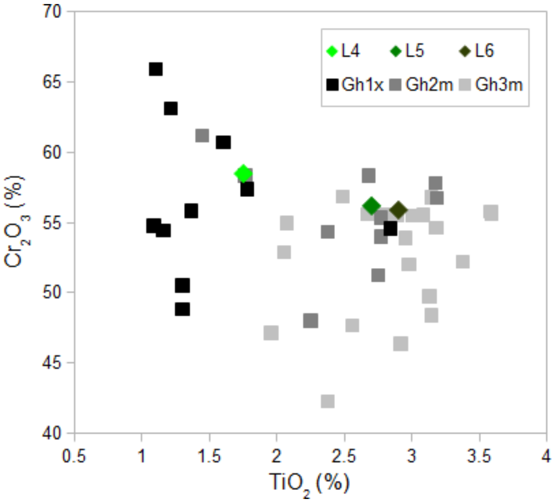

Figure 1: Identification of an L4 inclusion in a L5/6 matrix. Data for average L4, L5, L6 based on [1][13] and references therein. Errors ~10-20% (not shown).

One goal of this project is to check whether pre-exposure to GCR as inferred for SEC grains can also be observed in chromite grains from recent L chondritic regolith breccias. Of these, Ghubara (L5) is a well studied example (e.g. [3][9][10]). Since it has an Ar-Ar age of ~470 Ma [3], we can virtually be certain that it was part of the LCPB whose break-up delivered the fossil meteorites and SEC grains. Furthermore, Ghubara is of particular interest because it is a two-generation regolith breccia, where the inclusions themselves are fragments of an earlier compacted regolith, even containing higher concentrations of SW derived noble gases than the matrix [10]. Here we study chromite grains from the matrix and one large (~4 x 2 cm) light-colored inclusion (type X1 according to [10]), in order to compare them with the SEC grains in major element composition, size distribution, He, Ne concentrations and isotopic compositions, and ^{21}Ne exposure ages. We also compare the Ghubara chromite grains with their counterparts in Ark 002.

Methods: We dissolved two pieces (8.6 g and 7.7 g) of dark Ghubara matrix (Gh2m and Gh3m) and one piece (4.8 g) of light-gray inclusion (Gh1x) in 11.3 M hydrofluoric acid for one week. After neutralization and sieving, the >63 µm fraction was searched for chromite grains under the microscope. All identified grains (18, 23 and 39 for Gh1x, Gh2m and Gh3m, respectively) were transferred to a carbon tape sample-holder using a fine brush. The grains were then imaged in a Scanning Electron Microscope (SEM, Hitachi S-3400N), and analyzed for their composition in Cr, Fe, Mg, Al, V, Ti, Mn and Zn, using energy dispersive spectrometry (EDS, Oxford Instruments INCAx-sight) on unpolished grain surfaces. 30 chromite and 5 chrome-spinel grains were then analyzed at ETH Zurich for their He and Ne using a high-sensitivity, custom-built compressor source noble gas mass spectrometer [11]. The mass of each grain was measured on a micro-balance. For a more detailed description of the noble gas analysis, see [7].

Results & Discussion: Chromite grains >63 µm have been identifed in equal abundance in matrix and inclusion (3-5 grains/g). However, except for a single very large (~400 µm) chromite grain from the inclusion, grains from the matrix are significantly larger (average diameters ~160 μm vs. ~80 μm). Since both the mean and maximum diameter of chromite grains increase with petrographic type [12], this suggests type L5/L6 for the matrix and type L4 for the inclusion. This view is corroborated by Cr_2O_3 / TiO_2 concentrations (Figure 1), which are similar to L4 chromite values for inclusion grains, and L5/6 values for matrix grains. No other compositional differences (in Fe, Mg, Al, V, Mn and Zn) between matrix and inclusion were apparent.

The most striking difference between SEC grains and the chromites from Ghubara and Ark 002 are the very low amounts of SW derived He, Ne in the latter two populations. The maximum concentration of SW ^{20}Ne in any Ghubara chromite grain is $2.9 * 10^{-6}$ ccSTP/g, a factor of ~100 lower than observed in the SEC grains with the highest CRE ages [7][8]. The chromite grains from Ark 002 are similarly poor in SW ^{20}Ne [7]. The regolith portion from which Ghubara and Ark 002 are derived was thus either less mature than the average LCPB regolith sampled by the SEC grains, or it has lost a large fraction (>99%) of its SW gases as a consequence of heating during the break-up event, or regolith compaction, or both.

The most notable difference between the chromite grains from Ark 002 and Ghubara is the range of concentrations of $^{21}Ne_{cos}$. Ark 002 has an average $^{21}Ne_{cos}$ of $5.8 * 10^{-11}$ ccSTP/g, resulting in an extremely low CRE age of <0.1 Ma [2]. The average $^{21}Ne_{cos}$ concentration in all Ghubara chromite grains is $\sim 1.2*10^{-8}$ ccSTP/g. With a production rate for ^{21}Ne for chromite in moderately sized meteorites of $7.04*10^{-10}$ ccSTP/g [6], this yields an apparent CRE age of ~17 Ma, in good agreement with the age of 15-20 Ma reported for bulk Ghubara by [10] (Figure 2). However, our analysis based on individual grains reveals a different picture. Some grains from the inclusion show $^{21}Ne_{cos}$ concentrations significantly higher than the average. The highest measured $^{21}Ne_{cos}$ concentration of $7.4*10^{-8}$ ccSTP/g would correspond to a (4π) exposure to GCR for up to 105 Ma. These chromite grains have probably been pre-exposed to GCR within the regolith of the LCPB, prior to the break-up. We can conclude that the range of pre-exposure ages in Ghubara chromite grains (from the inclusion) is similar to the one proposed for SEC grains. This is a strong additional support for the previous interpretation of the high $^{21}Ne_{cos}$ concentrations observed in some SEC grains being the result of regolith pre-exposure on the LCPB [7][8].

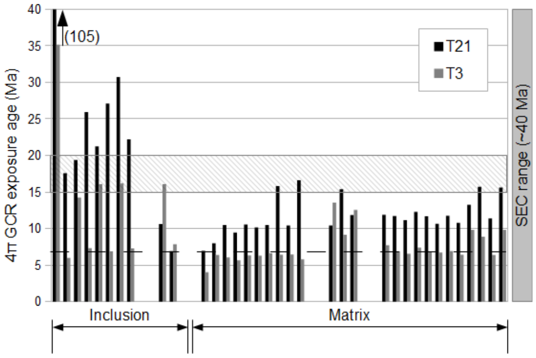

Figure 2: CRE ages for ^{3}He (T3) and ^{21}Ne (T21) for chromite from inclusion and matrix. Hatched area corresponds to published CRE age [10], long-dashed line to CRE age of ~7 Ma. The gray area to the right encompasses the CRE age range seen in SEC grains [7][8]. Errors ~10% (not shown).

For inclusion grains, the CRE ages based on cosmogenic ^{3}He ($^{3}He_{cos}$) and the ^{3}He production rate for chromite [6] are systematically smaller than the CRE ages from $^{21}Ne_{cos}$, indicating loss of $^{3}He_{cos}$ at some point after first-generation ("inclusion-era") regolith exposure. In contrast, for grains from the matrix a correlation between T3 and T21 is evident, with corresponding ($^{3}He_{cos}$-loss-corrected) CRE ages from ~7 to ~15 Ma. This correlation is incompatible with a last-stage GCR exposure of Ghubara for 15-20 Ma. It is best explained by a GCR exposure of matrix grains in a well-mixed (second-generation, "matrix-era") regolith, either without significant pickup of SW noble gases, or subsequent loss of these gases, followed by a 4π GCR exposure of ~7 Ma. No grain has a corrected CRE <5 Ma, consistent with the observation that cosmogenic radionuclides like ^{10}Be are in saturation [10]. As second conclusion of this project, we therefore propose that the last-stage irradiation of Ghubara, i.e. its transfer from the most recent parent asteroid to Earth, is only ~7 Ma, within error coincident with a small ~5-6 Ma peak in the CRE history diagram for L5/6 chondrites with low radiogenic ^{40}Ar concentrations [14].

References: [1] Schmitz B. et al. (2001) *EPSL* 194, 1-15.[2] Heck P.R. et al. (2004) *Nature* 430, 323-325.[3] Korochantseva E.V. et al. (2007) *Met. & Planet. Sci.* 42, 113-130.[4] Schmitz B. et al. (2003) *Science* 400, 961-964.[5] Greenwood R.C. et al. (2007) *EPSL* 262, 204-213.[6] Heck P.R. et al. (2008) *Met. & Planet. Sci* 43, 517-528.[7] Meier M.M.M. et al. (2010) *EPSL* 290, 54-63.[8] Alwmark C. et al. (2011) *LPSC* 42, Abstract #2004.[9] Binns R.A. (1968) *GCA* 32, 299-317.[10] Ferko T.E. et al. (2002) *Met. & Planet. Sci.* 37, 311-327.[11] Baur H. (1999) *EOS Trans. AGU 46,* F1118.[12] Bridges et al. (2007) *Met. & Planet. Sci.* 42, 1781-1789.[13] Alwmark C. & Schmitz B. (2009) *Met. & Planet. Sci.* 44, 95-106. [14] Graf T. & Marti K. (1992) *Ann. Rev. Earth Planet. Sci.* 20, 221-243.