VARIATIONS IN THE ABUNDANCE OF REGOLITH DERIVED MICROMETEORITES WITH TIME, FOLLOWING THE L-CHONDRITE PARENT BODY DISRUPTION AT 470 MA

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Introduction: The largest documented asteroid breakup event in the history of our solar system occurred at ~470 Ma, when an L-chondrite parent body disrupted in the asteroid belt [1]. The break-up resulted in a large increase in the delivery of extraterrestrial material to Earth. The finding of more than 80 fossil L-chondritic meteorites in Middle Ordovician limestone in the Thorsberg quarry in southern Sweden shows that the meteorite flux was enhanced by two orders of magnitude for at least a few million years after the disruption event [2, 3]. This enhancement was further corroborated by the finding of anomalously high quantities of sediment-dispersed extraterrestrial chromite (SEC) grains of L-chondritic composition in Swedish, Chinese, Scottish and Russian contemporary limestones [4-6].

A recent study [7] on SEC grains from the fossil-meteorite-bearing limestone from the Thorsberg quarry revealed that the vast majority of the grains were delivered to Earth as micrometeorites, as they contain He and Ne of solar wind composition. Furthermore, ~25% of the grains showed cosmic-ray exposure (CRE) ages >3 Ma, implying that these grains have been pre-exposed prior to transfer to Earth, most likely in an asteroidal regolith. The aim of this study is to extend the previous work both geographically and in time, by noble gas analyses of L-chondritic SEC grains from two Chinese limestone beds ca. one and two Myrs, respectively, younger than the one in [7] and from one Swedish limestone bed ~300 Kyrs older than that of [7].

Samples and Methods: A total of 61 SEC grains; 15 grains from the ~2 Myrs younger bed (P1), 20 from the ~1 Myrs younger bed (Y10), both from the Puxi River section in China [4], and 26 SEC grains from the ~300 kyrs older Swedish limestone bed Arkeologen (Ark) were analyzed for Ne isotopes. In addition, six terrestrial chromite (OC) grains, two from each bed, where analyzed, to control for a possible contribution of nucleogenic ^{21}Ne from the surrounding sediments. The grains were weighed and the elemental composition for each grain was determined, this in order to allow for the calculation of grain-specific cosmic-ray production rates. Because of the small size of the SEC grains, typically with a diameter of ~100 µm and a mass of ~1-2 µg, only low amounts of cosmic-ray induced ^{21}Ne were expected. Therefore, we used a low-blank extraction line and an ultra-high-sensitivity mass spectrometer for the noble gas analysis [8]. Detection limit for ^{21}Ne was ~4 x 10^{-16} cm^3 STP. Cosmic-ray production rates for ^{21}Ne are based on [9].

Results: All of the 61 SEC grains contained large amounts of trapped Ne of solar wind composition. They all plot near the line connecting the unfractionated solar wind component (SW; ^{20}Ne/^{22}Ne = 13.8, ^{21}Ne/^{22}Ne = 0.0327) with the fractionated solar wind component (fSW; ^{20}Ne/^{22}Ne = 11.2, ^{21}Ne/^{22}Ne = 0.0296; Fig 1) in the Ne three-isotope diagram. About 70% of the SEC grains plot significantly (more than 1 σ) to the right of the line connecting the SW with the fSW, i.e. towards the galactic cosmic ray (GCR) component, indicating an excess of cosmogenic ^{21}Ne. The rest of the grains encompass the line within their respective error bars, but with data points still falling predominantly to the right of the line. From the excess of cosmogenic ^{21}Ne a CRE age can be calculated (for details regarding the method of calculation, see [7]). The calculations reveal that 24 of the 61 SEC grains (~39%) have a CRE age >5 Ma, indicating that these grains have been pre-exposed prior to the break-up event. The six OC grains showed no or very low ^{21}Ne-excesses, below detection limit, demonstrating that the acquisition of nucleogenic ^{21}Ne is insignificant in the sediment beds considered here.

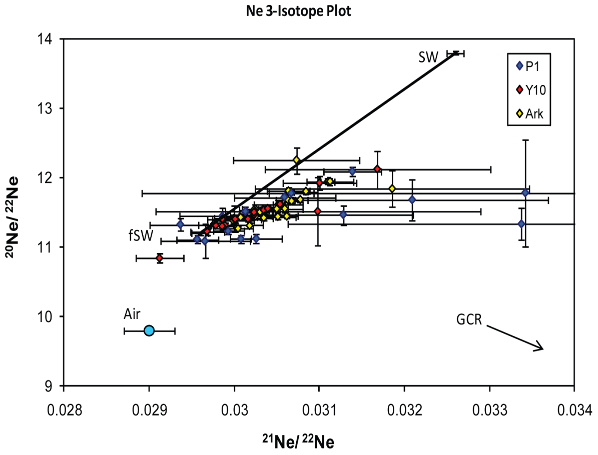

Fig. 1. Three-isotope diagram for Neon for all individual SEC grains of the three sediment beds. All grains plot near the line connecting the fractionated solar wind (fSW) with the solar wind component (SW). The galactic cosmic ray component (GCR) plots outside of the graph (^{20}Ne/^{22}Ne ≈ 0.95 ^{21}Ne/^{22}Ne ≈ 0.85). Three SEC grains are not plotted because of their low gas concentrations, close to the detection limit, resulting in very large error bars. All error bars are 1 σ.

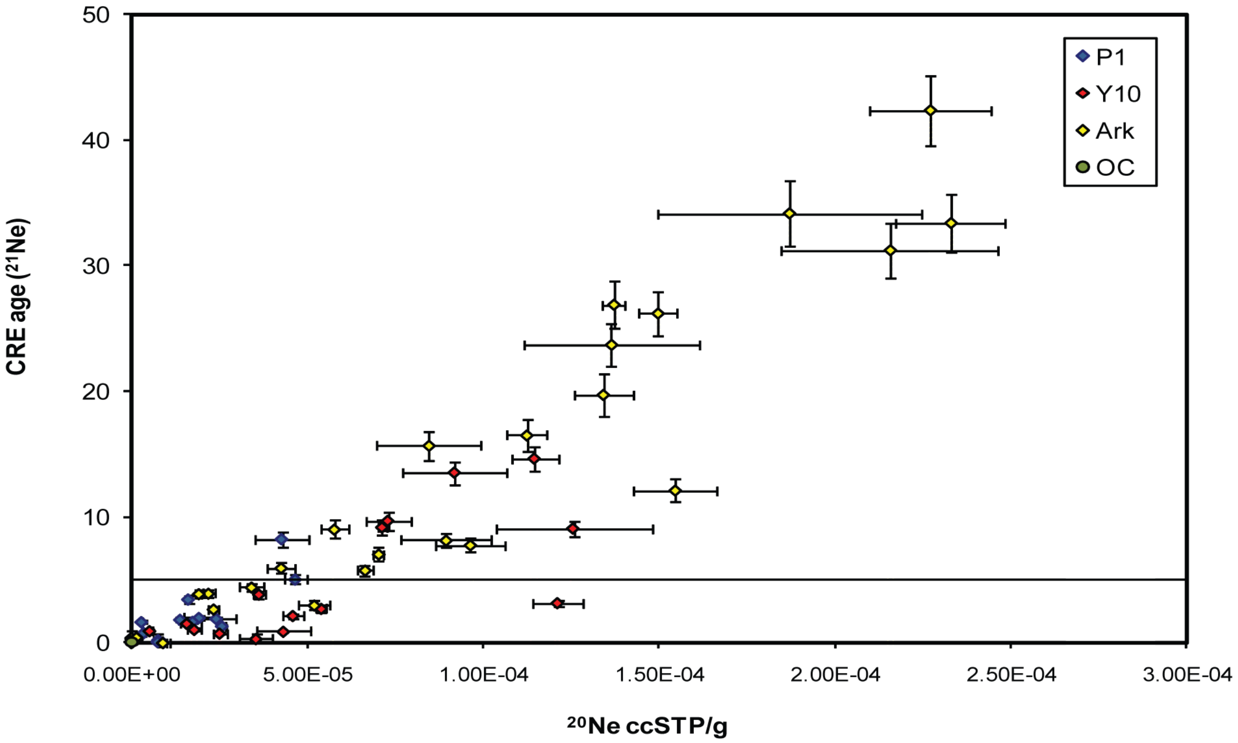

Fig. 2. Ne-21 based cosmic ray exposure age (Myrs) vs. concentration of ^{20}Ne for both SEC and OC grains. The horizontal line at 5 myrs marks the estimated upper limit for grains without a clear pre-exposure signature. The ^{20}Ne in the samples is predominantly solar, as shown in Fig.1. Note the correlation between high exposure ages and high concentrations of solar Ne, indicating that the production of cosmogenic ^{21}Ne is related to the pick-up of solar wind, as would be expected in an asteroidal regolith environment [8]. Also note that all OC grains plot at or near zero. All error bars are 1 σ.

Discussion and Conclusion: All of the SEC grains from the three Ordovician limestone beds contain Ne of solar wind composition. Since only ~3% of all L chondrites falling today are asteroidal regolith breccias containing SW gases [10], and since only the topmost few nm of a meteoroid are exposed to SW, this implies that, as in the case of the SEC grains from the previous study [7], they were delivered to Earth as micrometeorites or parts thereof.

The number of grains with high CRE ages vary between the different beds (Fig 2), with Ark having 65% pre-exposed SEC grains and higher exposure ages on average, whereas the SEC grains from the two younger Chinese beds generally show lower CRE ages with 25% pre-exposed grains in the 1.3 Myrs younger Y10 bed and only 13% in the 2.3 Myrs younger P1 bed. Furthermore, as can be seen in Fig 2, the SEC grains with high CRE ages also have high amounts of ^{20}Ne. Since ^{20}Ne is predominantly solar, this means that grains with high GCR exposure ages also have been exposed for a long time to the solar wind. As has been observed in a previous study [11], this condition is best met in an asteroidal regolith. Thus, it seems like the percentage of pre-exposed SEC grains, derived from the L-chondrite parent body regolith, decreases with time of delivery to Earth, following the disruption event. This could be explained by a scenario where most of the regolith was shed in the initial break-up of the L-chondrite parent body, thus reaching Earth within the first few 100 kyrs. In the younger sediment layers most of the regolith derived grains with high pre-exposure ages are gone and non-regolithic SEC grains from secondary collisions dominate.

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