FOSSIL METEORITES OF SWEDEN: WHAT ARE THEIR COSMIC-RAY EXPOSURE AGES?
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Introduction: More than 80 L-chondritic fossil meteorites were found in Middle Ordovician limestone in the Thorsberg quarry at Kinnekulle in southern Sweden [1, 2]. All meteorite-bearing sediment beds at Thorsberg contain sediment-dispersed extraterrestrial chromite (SEC) grains of L chondrite composition [3]. Similar SEC grains were also found in several correlated sediment beds of other quarries and outcrops in Sweden and in China [3-5]. Detection solar wind noble gases in the SEC grains (**Fig. 1**) has unequivocally and convincingly allowed to identify these grains as micrometeorites which have been generated as dust during the disruption of the L chondrite parent body in the asteroid belt ~470 Ma and arrived on *all* Earth over a timescale of 1-2 Myr [6, 7]. According to [5] "sediment-dispersed EC grains are two orders-of-magnitude more abundant over a part, representing a few million years, of mid-Ordovician strata compared to background levels."

Fossil meteorites. The similar conclusion about increase of L-chondrite flux during the same time onto *all* Earth is represented less proved. Results of precise measurements of the noble gas content in chromite grains of the fossil meteorites have allowed to calculate their cosmic-ray exposure ages [7-9.] All these ages are close to or less than a million years. It is accepted that these ages generally increased according to their position in the sediment column and the difference between the highest and lowest ages is consistent with presumed total deposition time of the sediments of 1-2 Myr. According to [7-9], these data provide evidence of a long-lasting rain of meteorites following the destruction of the L-chondrite parent asteroid ~470 Ma ago.

However, a clear negative correlation between the exposure ages and mass of samples (batches) of chromite grains from fossil meteorites has been found [10-12]. At that, higher exposure ages (T_{21} ~0.6-0.8 Myr) were inherent to the meteorites with chromite grains of bad safety (with preservation states 4 and 5, according to classification [8]), whereas meteorites with well preserved grains (preservation states 1 and 2) had mainly low exposure ages (~0.2-0.3 Myr). These features are shown on **Fig. 2** for meteorites of *non-Ark* (a) and *Ark* (b) groups. Here and below, the T_{21} values of all samples were calculated according to [7-9] for $P_{21}=7.04\times10^{-10}$ cm^3 g^{-1} Myr^{-1}.

It has been assumed that the found negative correlation is caused by underestimation of the nucleogenic $^{21}Ne_{nucl}$ contribution in the chromite grains of small mass (small sizes) [10-12]. However, Meier et al. [6] did not find any ^{21}Ne excess in individual terrestrial chrome spinel grains of the same sediments. Nevertheless, we see clear positive correlation between T_{21} and the ^{20}Ne content in the samples (**Fig. 3**).

At the same time, the badly preserved grains have not only high values of T_{21} but also high ^{20}Ne content. The found regularities can be explained by presence in measured neon of the component enriched by ^{21}Ne, i.e. with ratio of $^{21}Ne/^{20}Ne > ^{21}Ne/^{20}Ne_{atm}=0.00298$. In this case, the more in the sample of ^{20}Ne (**Fig. 3**), the more of unaccounted ^{21}Ne after correction on the trapped ^{21}Ne with use of the ratio of $^{21}Ne/^{20}Ne_{trap}=0.00298$ and, accordingly, the more values of T_{21}.

Verkhovsky et al. [13] revealed isotopic anomalies of Ne – enrichment in ^{21}Ne and ^{22}Ne isotopes relatively to ^{20}Ne in the terrestrial minerals and rocks containing excess Ar and He. The deviation of the $^{21}Ne/^{20}Ne$ isotopic ratio from the atmospheric one reached 900%. The hypothesis about the capture of natural gases with heightened ^{21}Ne content during the process of mineral formation was suggested as being the most probable.

Similar capture of neon enriched in ^{21}Ne could occur during replacing of the minerals in the fossil meteorites by diagenetic pseudomorphs. In this case, presence of the inclusions of these diagenetic pseudomorphs in extracted chromite grains will cause the increase of the content of "cosmogenic" $^{21}Ne_{cos}$. Careful selection and decontamination of terrestrial chromite (OC) grains as well as other genesis of the OC grains have allowed to avoid in [6] the detection of this "foreign" source of ^{21}Ne (**Figs 1b, 2c**).

Brunflo fossil meteorite: The data of four samples of fossil meteorite Brunflo [9] are especially interesting. This meteorite was found in the Gärde quarry at about 500 km distance from Thorsberg quarry. The strata in the Gärde quarry are clearly younger than the meteorite-yielding strata at Kinnekulle; absolute age difference is ~5 Myr [14]. Samples of this meteorite show the same tendency of T_{21} increase with increase in ^{20}Ne content (**Fig. 3**). Minimal value of T_{21} ~0.2 Myr is obtained for the sample with maximal mass, with minimal ^{20}Ne content and apparently with the most preserved chromite grains in this sample.

Conclusions: The obtained data allow assuming that true exposure age of all investigated fossil meteorites does not exceed ~0.2 Myr. The younger age (by ~5 million years) of a strata with Brunflo meteorite with its T_{21}<<5 Myr testifies to a possibility of redeposition of meteorites after their falling in the form of one meteoric shower in ~0.2 Myr or less after destruction of the L-chondrite parent body ~470 Ma. Determination of the content and isotopic composition of Ne in the bulk ("background") samples of the fossil meteorites and in Ordovician limestone could make clear the nature of the found dependences and the history of the fossil meteorites.

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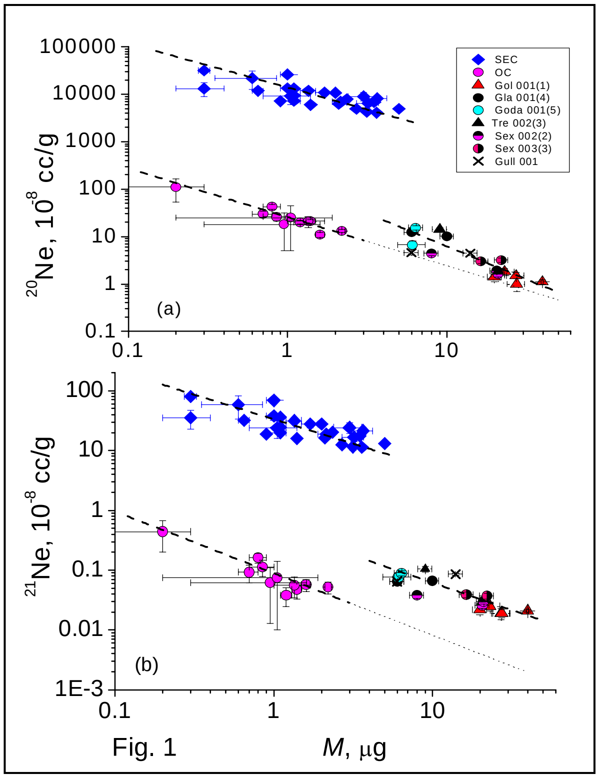

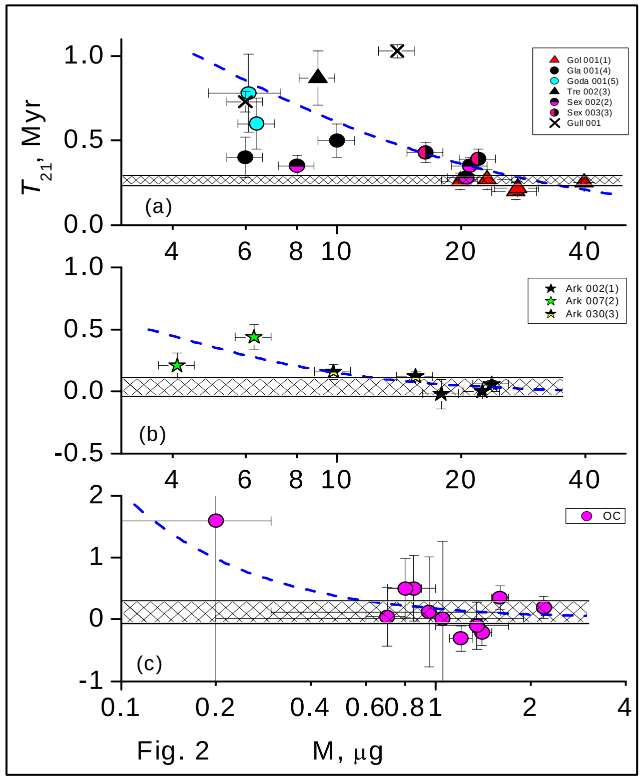

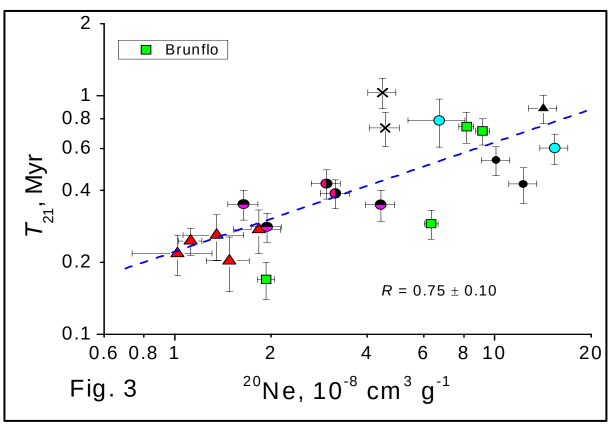

Fig. 1. ^{20}Ne (a) and ^{21}Ne (b) contents vs. sample mass (M) for sediment-dispersed extraterrestrial chromite (SEC) grains with ^{20}Ne>2×10^{-5} cm^{3}g^{-1}, terrestrial chrome spinel (OC) grains and batches of chromite grains from "*non-Ark*" fossil meteorites. The grain preservation states are given in parentheses. Here and below: the dotted lines are regression lines. (According to data [6-8].)

Fig. 2. Positive correlation between cosmic-ray exposure ages (T_{21}) and mass (M) of batches of chromite grains from fossil meteorites of "*non-Ark*" (a) and "*Ark*" (b) groups. (c) Values of "T_{21}" vs. M of individual OC grains. Shaded areas are ±2σ of: (a) T_{21} average value for fossil meteorites of Gol 001 and Sex 002 (preservation states are 1 and 2 respectively), 0.26 ± 0.03 Myr; (b) the same for Ark 001, 0.04 ± 0.08 Myr; (c) average value of T_{21} for OC with σ(T_{21})≤30%, 0.16 ± 0.23 Myr. (According to data [6-8].)

Fig. 3. Positive correlation between cosmic-ray exposure ages (T_{21}) and ^{20}Ne contents for batches of chromite grains from the fossil meteorites. (According to data [7-9].)

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