NOBLE GAS COSMIC RAY EXPOSURE AGES OF FOUR UNUSUAL MARTIAN METEORITES: SHERGOTTITES NWA 4797, NWA 5990, NWA 6342 AND NAKHLITE NWA 5790. L. Huber[1], A. J. Irving[2], C. Maden[1] and R. Wieler[1] [1]Dept. of Earth Sciences ETH Zürich, CH-8092 Zürich, Switzerland (liliane.huber@erdw.ethz.ch), [2]Dept. of Earth and Space Sciences, University of Washington, Seattle, WA, USA.

Introduction: Cosmic-ray exposure ages help to establish relations between different meteorite falls, e. g., by possibly identifying launch-paired meteorites. Here we report ^{3}He-, ^{21}Ne-, and ^{38}Ar-exposure ages of four unusual Martian meteorites and assess uncertainties of cosmic-ray exposure ages.

Samples: NWA 4797 is an unusual ultramafic shergottite with extreme shock features [1, 2]. NWA 5990 is an olivine-bearing diabasic igneous rock related to depleted shergottites with Sm-Nd and Rb-Sr ages of about 400 Ma [3, 4]. NWA 6342 is an unusual ultramafic shergottite with affinities to the "enriched" Martian mantle source [5]. NWA 5790 is a nakhlite with abundant glassy mesostasis (indicating rapid cooling) and a Sm-Nd age of ~1.38 Ga [6, 7].

Analytical Procedures: Fusion-crust-free chips of 49-66 mg of each meteorite, wrapped in Al foil, were pre-heated in the sample storage volume of a UHV furnace at 120°C for 24 h. Noble gases were extraced by heating samples to 1700 °C for 30 minutes. Extracted noble gases were cleaned and analysed according to procedures described in [8]. Blanks were determined by analyzing empty aluminum foil packages and were mostly below 1% of sample gas amounts for the isotopes of main interest here (^{3}He, ^{21,22}Ne) and below 5% for ^{38}Ar. Concentrations of cosmogenic noble gas fractions are estimated to be accurate to ~4%, the $(^{22}Ne/^{21}Ne)_{cos}$ ratio to ~0.5%.

Production Rates of Cosmogenic Noble Gases: Exposure ages of samples can at best be as accurate as adopted production rates. Production rates strongly depend on the position of a sample in the preatmospheric meteoroid and the size of the meteoroid (the "shielding"), as well as the concentrations of major target elements. A further concern is that a sample may have had a complex exposure history, i. e. that not the entire cosmogenic nuclide budget was acquired after ejection of the meteorite from the parent body. Fortunately, for Martian meteorites no complex exposure histories have so far been recognized [9], presumably because they all were ejected from at least a few meters depth below the Martian surface. However, for shergottites an additional complexity arises because many shergottites contain Ne produced by solar cosmic rays (SCR) [10] on top of the galactic cosmic ray-produced Ne (GCR) used to determine exposure ages. The SCR component hampers the use of the ^{22}Ne/^{21}Ne ratio to constrain the shielding of a sample (see below) and hence its production rate of GCR Ne. Also the concentration of $^{21}Ne_{SCR}$ cannot be reliably subtracted from the total $^{21}Ne_{cos}$. We will show below that two of the three shergottites here possibly contain SCR-Ne. The reason why many shergottites contain SCR Ne may be related to a possibly low entry velocity, leading to untypically low atmospheric ablation rates [10].

The above considerations need to be taken into account when discussing exposure ages of meteorites. In the next section we will calculate exposure ages by the widely used procedure proposed by [11, 12], and we will compare these values with results from a physical model of cosmogenic nuclide production [13].

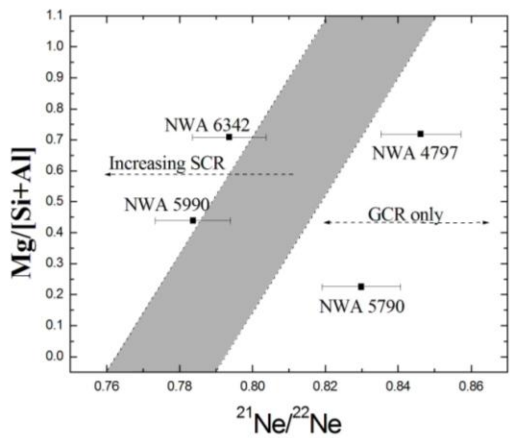

Fig. 1: Adapted from ref. [10], the figure suggests that the two shergottites plotting to the left of the grey band contain solar-cosmic-ray-produced Ne (SCR-Ne).

Results and Discussion: Fig. 1 is adapted from ref. [10]. Data points to the left of the grey band strongly suggest the presence of SCR Ne, which has a lower ^{22}Ne/^{21}Ne ratio than GCR Ne. According to this figure, shergottites NWA 5990 and NWA 6342 possibly contain SCR Ne, whereas shergottite NWA 4797 likely is free of SCR Ne. Neither does nakhlite NWA 5790 show signs of SCR Ne, which is not surprising as no nakhlite has been reported to contain this component. Fig. 1 therefore suggests that for NWA 5790 and NWA 4797 shielding-corrected ^{3}He and ^{21}Ne production rates according to [11, 12] can be calculated, based on the shielding-dependent ratio ^{22}Ne/^{21}Ne. As recommended by [12], we adopt for shergottites the shielding formula for eucrites given by [11], while for the nakhlite we adopt an average of the shielding terms for eucrites and howardites. Major element concentrations are from refs. [1, 3, 5, 14]. Production rates of ^{38}Ar for all four meteorites are calculated according to equ. 10 in ref. [11] and do assume "average" shielding; i. e. they take into account only the major element concentrations of the samples but no shielding correction. The possible presence of SCR-Ne inhibits an explicit shielding correction based on $^{22}Ne/^{21}Ne$ for the two shergottites NWA5990 and NWA 6342. Nevertheless, the SCR-Ne indicates that the two samples came from close to the preatmospheric surface of presumably small meteoroids. In the framework of the formalism of [11, 12] we thus assume, somewhat arbitrarily, that the pure GCR component of these two meteorites had a $^{22}Ne/^{21}Ne$ ratio of 0.83. We do not correct for a concentration of putatively SCR-produced ^{21}Ne (or SCR ^{3}He or ^{38}Ar).

Table 1 shows preliminary exposure ages calculated as described in the previous paragraph.

	T(^{3}He)	T(^{21}Ne)	T(^{38}Ar)
NWA 4797	4.0	**3.7**	5.2
NWA 5990	2.8	**2.7**	2.1
NWA 6342	4.5	**3.8**	2.6
NWA 5790	6.5	**9.6**	7.3

Table 1: Exposure ages (in million years) of three shergottites and one nakhlite, based on cosmogenic ^{3}He, ^{21}Ne and ^{38}Ar, respectively. See text for uncertainties.

We note a more or less reasonable agreement between the three different ages for each meteorite, although there are also a few quite substantial differences. Usually, ^{21}Ne ages are considered to be more reliable than either ^{3}He or ^{38}Ar ages, because the latter are not shielding-corrected and may suffer from inhomogeneous Ca concentrations in <100 mg sized samples, while the former may be affected by losses of cosmogenic ^{3}He. The ^{21}Ne ages are therefore in bold face and we mainly concentrate on these numbers.

The preferred age of nakhlite NWA 5790 of 9.6 Ma falls essentially into the exposure age peak at ~10-12 Ma observed for all nakhlites dated so far [9, 12]. It seems that this meteorite lost some of its cosmogenic ^{3}He while the relatively low ^{38}Ar age might be due to an untypically low Ca concentration of our sample. It appears thus that the mesostasis-rich nakhlite 5790 is launch-paired with the other nakhlites.

The three shergottites studied here seem to have exposure ages between roughly 3 and 4 Ma. Again, we prefer the ^{21}Ne ages over the ^{38}Ar ages because of possibly inhomogeneous Ca concentrations. We note that our preferred age of 3.7 Ma for NWA 4797 (and even more so our ^{38}Ar age of 5.2 Ma) is considerably higher than the Ar exposure age of 2.2 Ma reported by ref. [15]. Many similar shergottites have exposure ages in the 3 – 4 Ma range [12], hence some of the samples measured here could in principle be launch-paired with them. However, the three shergottite samples belong to three distinct categories based on their trace element characterisitics, and thus may not be spatially (or genetically) associated on Mars. In detail, ultramafic shergottites may exhibit an exposure age peak at ~4-5 Ma, different from the ~2-3 Ma peak for basaltic shergottites [11, 12]. Given the uncertainties of the ages reported here (see also next paragraph) it seems premature to identify NWA 5990 with the latter peak and NWA 4797 and NWA 6342 with the former peak.

Apart from the exposure ages given in Table 1, we also estimate ages based on production rates predicted by the model by Leya and Masarik [13]. Although the relation between a production rate and $^{22}Ne/^{21}Ne$ is in general by far not unique in this model, the rather high $^{22}Ne/^{21}Ne$ values of the two non-SCR-affected meteorites indicate meteoroid sizes not larger than r = 10 cm and sample depths not larger than 2 cm. For reasons given above we adopt the same shielding conditions also for the other two shergottites. The corresponding production rates yield the following ^{21}Ne exposure ages: NWA 4797 = 5.3 Ma, NWA 5990 = 3.4 Ma; NWA 6342 = 5.1 Ma; NWA 5790 = 10.0 Ma. The agreement with Table 1 is good for nakhlite NWA 5790, indicating that the conclusion that this and all other studied nakhlites presumably are launch-paired is quite robust. However, the sizeable differences for the three shergottites between the ^{21}Ne ages obtained with the same data but two different calculation methods indicate once again that absolute uncertainties of cosmic ray exposure ages are often considerably larger than formal uncertainties.

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