VARIABLE COSMOGENIC ARGON IN L/LL5 CHONDRITE KNYAHINYA.

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Introduction: The study of stable and radiogenic cosmogenic nuclides, as the duration a rock was exposed to cosmic rays, is an important tool in meteoritics. It helps to determine impact events on meteorite parent bodies, typically in the asteroid belt, but also on the Moon or Mars [e.g., 1-3]. Such events also directly affect the Earth, as documented by the discovery of fossil remains of the catastrophic impact that disrupted the L chondrite parent body ~480 Ma ago [4]. In addition, cosmogenic nuclides help to confirm or exclude pairing of meteorites of the same chemical class, or –if differently determined cosmic ray exposure (CRE) ages disagree– can give hints at (i) complex exposure histories such as the exposure of a meteorite in two periods, e.g. on a parent body and later in space, (ii) the residence time on Earth or (iii) heating experienced on the surface of a parent body, during transfer to Earth or atmospheric entry.

Cosmogenic (cosm) noble gases such as ^{3}He, ^{21}Ne and ^{38}Ar are often used because their measurement requires little sample mass and preparation, and per experiment several cosmogenic nuclide concentrations can be determined, leading to a set of CRE ages that can be compared. However, discrepancies are frequently observed, and their origin is often unknown. Here we study the effect of chemical, i.e. target mineral heterogeneity on cosmogenic noble gas concentrations in the well-studied [5,6] LL/L5 chondrite Knyahinya.

We will show that in ~20 mg aliquots of ordinary chondrites, typical for our noble gas examinations, the chemical composition of the major target elements varies significantly from sample to sample. Particularly the concentrations of Ca, K and Fe, essential for the production of ^{38}Ar$_{cosm}$, should be determined in the same split aliquots. Otherwise, errors in the ^{38}Ar CRE age of up to almost a factor of two can occur.

Experimental: 15 samples of ~20-40 mg were taken from a single 0.55 g fusion crust-free fragment of Knyahinya (ETH collection) and powdered. The 15 powders were each split for the determination of noble gas (8-24 mg) and major element (2-17 mg) concentrations. Noble gases were measured with the "Albatros" mass spectrometer at ETH [see 3 for details]. We used 45 eV electron acceleration and ^{84}Kr and ^{129,132}Xe were measured together with Ar. Blank corrections were significant ($\leq$1% for ^{4}He, 19-79% for ^{36}Ar, 5-21% for ^{40}Ar) but much smaller for cosmogenic ^{3}He (<0.02%), ^{21}Ne (<0.2%) and ^{38}Ar (6-21%). The elements Na, Mg, Al, P, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Ni, and Co were determined by ICP mass spectrometry using a Thermo Scientific Element XR. Reproducibility was assessed by repeated analysis (4-6 times) of a representative sample aliquot, and was 3-8% (2 RSD; relative standard deviation) for the various elements.

Results and Discussion: All results are broadly consistent with each other and literature data [5,6]. ^{3}He, ^{21}Ne and ^{38}Ar are entirely cosmogenic. However, ^{38}Ar$_{cosm}$ concentrations vary by 66%, while ^{21}Ne$_{cosm}$ and ^{3}He$_{cosm}$ vary by only 37% and 25%, respectively. In contrast, the essential ratio $(^{22}\text{Ne}/^{21}\text{Ne})_{cosm}$, which constrains the shielding conditions of the sample against cosmic rays varies by only <2%. ^{38}Ar$_{cosm}$ correlates with Ca, its major target element (r^2 ~0.87), which shows a spread of more than a factor of two. All major target elements show significant scatter, well beyond analytical uncertainty, suggesting that Knyahinya's minerals are relatively coarse-grained and heterogeneously distributed at the 10-20 mg scale. The three important target elements for ^{38}Ar$_{cosm}$, Ca, Fe and K (together producing ~93% [7,8]) show the largest scatter: RSD for Ca and Fe concentrations in the aliquots are 25% and 18%, respectively, whereas the major targets for the production of ^{21}Ne$_{cosm}$, Mg, Al and Na, only show 9-12% each. ^{3}He is produced by a larger number of target elements (O, Mg, Al, Si, Fe, Ni) and in similar rates and is, hence, more robust against element variations. We also note here that the purely physical model that we commonly use to predict cosmogenic nuclide production rates for ordinary chondrites, depending on the shielding and chemical composition [9], does not include K. Hence, based on formulas for ^{38}Ar$_{cosm}$ [7,8] and the chemistry of our Knyahinya samples, we may underestimate the ^{38}Ar$_{cosm}$ production by ~15%.

In summary, the determination of CRE ages with ^{38}Ar$_{cosm}$ in a 10-20 mg sample of ordinary chondrite requires caution, and preferably the determination of the target element concentrations of Ca, Fe (and K) in an aliquot of the same sample. In unfavourable cases, the age can otherwise be wrong by up to a factor of two, due to heterogeneously distributed main carrier minerals. The production of ^{21}Ne$_{cosm}$ from Mg, Al and Na shows much less variation (~10%), well within the assumed uncertainty for *ab initio* modelled production rates of perhaps 20%.

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