THE RELEVANCE OF NOBLE GASES IN IRON METEORITES.

K. Ammon[1], J. Masarik[2], I. Leya[1]
[1]University of Bern, Sidlerstrasse 5, CH-3012 Bern, Switzerland, E-Mail: katja.ammon@space.unibe.ch, [2]Komensky University, Bratislava, Slovakia.

Introduction: Cosmogenic nuclides are produced by interactions of galactic and solar cosmic-ray particles with terrestrial and extraterrestrial matter. The production rates of cosmogenic nuclides depend on the shape of the GCR particle spectra, the total GCR flux, the position within the meteoroid, the size and shape of the meteoroid, and its chemical composition. As a general rule one can say that for iron meteorites the production rates for most cosmogenic nuclides decrease with increasing depth of the sample and size of the body. In addition, for most applications it is safe to assume that the production rates for most cosmogenic nuclides also decrease with increasing mass difference between target element and product nuclide. Consequently, in iron meteorites, S and P, which are present as troilite (FeS) and schreibersite ($(Fe,Ni)_3P$) inclusions, are much better target elements for the production of, e.g., cosmogenic Ne, than the major elements Fe and Ni. In the early 60's Signer and Nier [1,2] postulated a model capable to determine the size of the meteoroid (R), the depth of the sample (d), and the exposure age (T_{exp}) from a single noble gas measurement. Later, Voshage and Feldmann [e.g., 3] recognised that the Signer-Nier model is based only on two independent experimental results, which is not sufficient to obtain three independent pieces of information (R, d, T_{exp}). Consequently, for a proper understanding of exposure histories the exposure ages have to be determined independently. Various approaches are used to determine the cosmic-ray exposure ages of iron meteorites. The two most successful approaches are the ^{41}K-^{40}K and the ^{36}Cl-^{36}Ar system, whereas exposure ages determined via ^{41}K-^{40}K are systematically higher by about 50% compared to those determined via ^{36}Cl-^{36}Ar [e.g., 4]. This finding has usually been interpreted as indicating an increase in the GCR flux in the last few million years. However, it could well be possible that the observed discrepancies are due to an insufficient knowledge of cosmogenic production systematics in iron meteoroids rather than indicating a GCR variation. Here we present new He, Ne, and Ar measurements in samples of the IIIAB iron meteorite Grant and the IID iron meteorite Carbo. Based on the new data we have determined the preatmospheric center location, shape, and radius for both meteorites. By studying the reproducibility of the measurements we demonstrate that troilite and schreibersite inclusions significantly affect the measured Ne concentrations and that such contributions have to be considered. A correction for Ne contributions from S- and P-rich inclusions are performed using cosmogenic ^{21}Ne concentrations and $^{22}Ne/^{21}Ne$ ratios [5]. The results are adopted to the ^{41}K-^{40}K system and new exposure ages are determined for Grant and Carbo.

Preatmospheric shape and radius: We measured 23 and 30 aliquots of Carbo and Grant, respectively. The preatmospheric center locations and the shapes of Grant and Carbo were determined using contour plots of noble gas concentrations and/or elemental ratios (Fig.1).

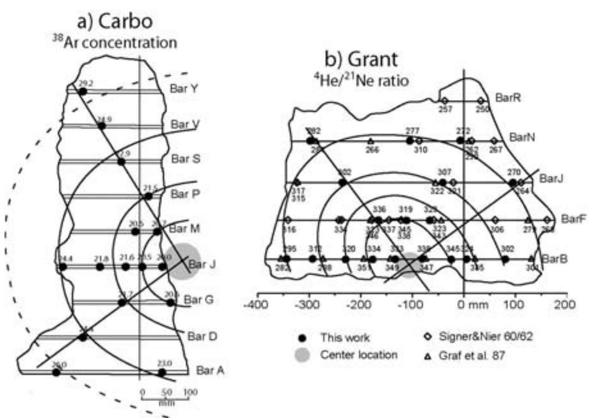

Fig. 1: Preatmospheric center locations (shaded areas) of Carbo and Grant. Black circles are sample positions measured in this work.

The new center location for Carbo agrees well with earlier estimates [6], whereas the new center location for Grant is significantly different [1,2]. The contour plots also indicate that both meteoroids can be approximated as spheres. The radii for Grant and Carbo were determined by adjusting measured and modelled depth profiles for ^{36}Cl. The results, which are shown in Fig. 2, clearly demonstrate that Grant and Carbo were spherical objects with radii of ~38 cm and ~ 75 cm respectively.

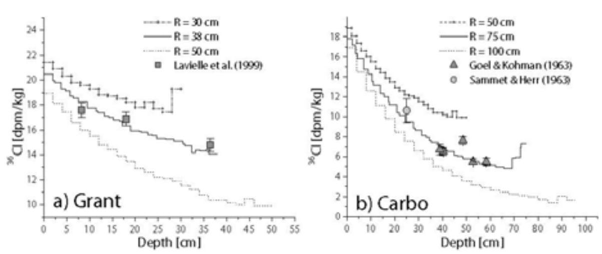

Fig. 2: Determining the preatmospheric radius of Grant and Carbo using measured and modelled ^{36}Cl depth profiles.

Mineral inclusions and their influence on cosmogenic production rates: The production of cosmogenic Ne is very sensitive to S- and P-rich inclusions. For example, the production rate of cosmogenic Ne from S is about ten times higher compared to production from Fe and/or Ni [e.g., 7]. SEM images of Grant and Carbo clearly demonstrate that there are troilite and schreibersite inclusions of only a few hundred microns which makes a separation of pure metal impossible. However, such small inclusions are nevertheless big enough to significantly increase the production rates of cosmogenic Ne and a reliable correction is necessary. The correction performed by us is based on the observation that the ^{22}Ne/^{21}Ne ratios and ^{21}Ne concentrations in outliers correlate. Such a correlation is expected as the ^{22}Ne/^{21}Ne ratios from S and P are distinctly higher than ^{22}Ne/^{21}Ne ratios from Fe and Ni. Consequently, large contributions of Ne produced from S and P are accompanied with higher ^{22}Ne/^{21}Ne ratios. This finding enables a precise and consistent method for quantifying such contributions [5]. Some results are shown in Fig. 3.

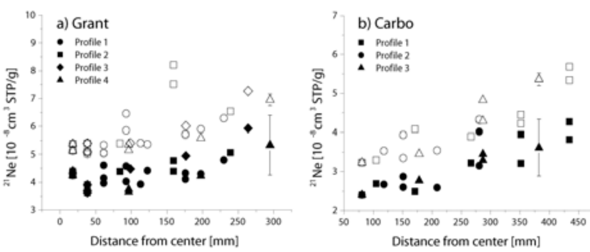

Fig. 3: Corrected (full symbols) and uncorrected (open symbols) ^{21}Ne depth profiles for Grant and Carbo. The 1σ error bar of 20% is valid for all corrections.

Contributions of S and/or P of only about 2-3% increase the cosmogenic ^{21}Ne concentration by up to 20%. However, after correction, the depth profiles are significantly more consistent and outliers are efficiently reduced.

The influence of the ^{21}Ne correction on the ^{41}K/^{40}K-^{4}He/^{21}Ne exposure ages: The ^{41}K-^{40}K method for calculating cosmic-ray exposure ages is based on measured ^{4}He/^{21}Ne ratios. Since such ratios are affected by S- and/or P-rich inclusions, the question is whether the basic assumptions of the ^{41}K-^{40}K dating method has to be re-evaluated. The ^{41}K-^{40}K system is developed by Voshage and co-workers and is based on the follwing equation [8]:

$$\frac{\lambda T_K}{(1 - e^{-\lambda T_K})} = \frac{M}{N} \qquad (1)$$

whereas the M-value contains only measured K concentrations and N is a parameter for the production rate ratios of K. Since the production rates for K isotopes are not known, N is approximated as a function of the shielding parameter ^{4}He/^{21}Ne. Remember, ^{21}Ne is affected by S- and P-rich inclusions, which was not considered so far for the ^{41}K-^{40}K dating system. Correcting the ^{4}He/^{21}Ne ratios for contributions from mineral inclusions always lowers the exposure age. For Grant the corrected exposure age is 535 ± 119 Ma instead of 695 Ma calculated by Voshage and Feldmann [8]. The corrected age agrees now with the ^{36}Cl-^{36}Ar age of 447 ± 9 Ma [9]. The corrected T_K of 707 ± 157 Ma for Carbo is also lower than the uncorrected one (850 Ma) [8]. Unfortunately no reliable ^{36}Cl-^{36}Ar ages for Carbo can be found in literature.

Conclusion: We demonstrate that the production of cosmogenic Ne in iron meteorites is significantly influenced by small troilite and schreibersite inclusions. Only based on ^{22}Ne/^{21}Ne ratios for Fe, Ni, S, and P a correction procedure was developed to reliably quantify such contributions [5]. After correction, the ^{21}Ne depth profiles for Grant and Carbo are consistent and the scatter is significantly reduced. Based on corrected ^{4}He/^{21}Ne ratios new ^{41}K-^{40}K cosmic-ray exposure ages are calculated for both meteorites. The new ages are significantly lower than those determined earlier, based on incorrect ^{4}He/^{21}Ne ratios. Now the corrected ages agree well with other age systems, i.e., ^{36}Cl-^{36}Ar, ^{10}Be-^{21}Ne, and ^{26}Al-^{21}Ne. Consequently, the systematic discrepancies between the ^{41}K-^{40}K ages and the ^{36}Cl-^{36}Ar ages, usually attributed as long-term GCR variations [e.g., 4, 9, 10] can most probably be explained by our insufficient knowledge of reaction systematics in iron meteorites.

References: [1] Signer P. and A.O. Nier (1960) *JGR, 65* 2947-2964. [2] Signer P. and A.O. Nier (1962) *Res. on Meteorites*, C.B. Moore, 7-35. [3] Voshage H. and H. Feldmann, (1978) *Earth & Planet. Sci. Let., 39*, 25-36. [4] Voshage H. (1978) Earth *& Planet. Sci. Let., 40*, 83-90. [5] Ammon K. et al. (2007), in prep. [6] Hoffman, J.H. and A.O. Nier (1959), *Geochem. et Cosmochem. Acta, 17*, 32-36[7] Leya I. et al. (2004) *Meteoritics & Planet. Sci.*, 39, 367-386. [8] Voshage H. and H. Feldmann (1979) *Earth & Planet. Sci. Let., 45*, 293-308. [9] Lavielle B. et al. *Earth & Planet. Sci. Let., 170*, 93-104. [10] Voshage H. (1984) *Earth & Planet. Sci. Let., 71*, 181-194.