NOBLE GASES AND COSMIC RAY EXPOSURE OF SUTTER'S MILL CM CHONDRITE. U. Ott[1,2], S. Herrmann[1], R. Haubold[1], S. Samu[2] and Q.-Z. Yin[3]. [1]Max-Planck-Institut für Chemie, Hahn-Meitner-Weg 1, D-55128 Mainz, Germany; uli.ott@mpic.de. [2]University of West Hungary, H-9700 Szombathely, Hungary. [3]University of California at Davis, Davis, CA 95616, USA..

Introduction: Sutter's Mill is a carbonaceous chondrite regolith breccia that fell in northern California on April 22, 2012 [1]. Among the noteworthy characteristics are exceptionally high entry velocity from a low-inclined, eccentric orbit and exceptionally short cosmic ray exposure (CRE) age. From this and the similar orbital characteristics of the recent (2009) fall Maribo it has been suggested that – although an asteroidal source seems more likely - both may belong to an ~0.1 Ma-old meteoroid stream originating from comet Encke [1]. We have analyzed a small fragment (~ 10 mg) of specimen Sutter Mill's SM51.

Experimental: Noble gases were released by pyrolysis in three temperature steps, and further cleaned, separated and analyzed on a MAP 215 noble gas mass spectrometer using standard procedures [2]. Data have been corrected for extraction blank and interferences. Standardization was relative to intermittently analyzed amounts of calibration gas.

Results: Results are summarized in Tables 1 (He, Ne) as well as Table 2 (Ar, Kr, Xe).

T	^{4}He	$^{3}He/^{4}He$	^{22}Ne	$^{20}Ne/^{22}Ne$	$^{21}Ne/^{22}Ne$
600	2142 ±98	1.55 ±0.07	0.76 ±0.04	9.497 ±0.172	0.0374 ±0.0035
1000	563 ±26	1.55 ±0.10	0.43 ±0.03	7.272 ±0.108	0.0271 ±0.0019
1800	70 ±4	2.03 ±0.51	0.12 ±0.01	10.19 ±0.32	0.0331 ±0.0042
total	2775 ±101	1.56 ±0.06	1.32 ±0.05	8.828 ±0.110	0.0336 ±0.0022

Table 1: He and Ne in stepwise gas release of SM51. Extraction temperatures are in °C, concentrations in units of 10^{-8} cc/g and $^{3}He/^{4}He$ ratios in 10^{-4} units.

Helium and neon. Helium and neon are dominated by trapped components, primarily of the "planetary" type. In particular and as also observed in the analysis by [1], the ratio $^{3}He/^{4}He$ is in the range of planetary compositions such as Q, HL and P3. Trapped $^{20}Ne/^{22}Ne$ is almost identical to that in Maribo [2], which implies a similar mixture of solar and planetary / presolar components (Fig. 1) Concenrations in our SM51 sample are, however only about one third of those in Maribo. Compared to the analyses in [1], concentrations in our SM51 specimen are about 3/4 for ^{4}He and about half for ^{22}Ne, with trapped $^{20}Ne/^{22}Ne$ slightly higher (Fig. 1) and $^{3}He/^{4}He$ lower than observed by these authors. Total Ne isotopic compositions are almost indistinguishable (Fig. 1), but there are differences in the temperature release pattern. Most noteworthy, both here and in [1], is the almost complete absence of cosmogenic ^{21}Ne.

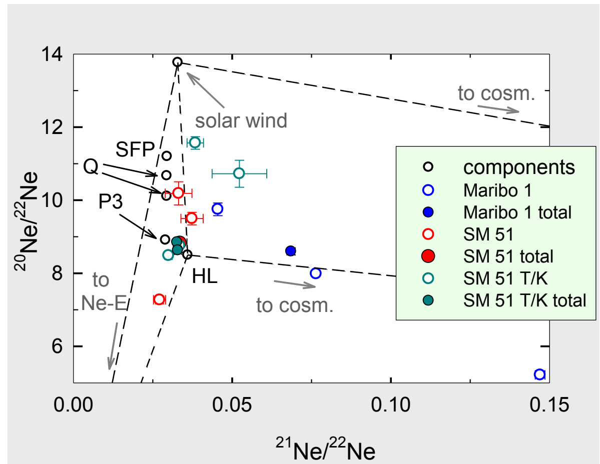

Fig. 1: Three-isotope plot for neon. Besides our SM51 data, the Tokyo / Kyushu ("T/K") data from [1] are shown as well as data for Maribo from [2]. The dashed lines show mixing lines between some of the endmembers (solar wind, Ne-E, Ne-HL, cosmogenic; for references see text).

Argon, krypton, xenon. As in the case of the light trapped gases, ^{36}Ar, ^{84}Kr, and ^{132}Xe are somewhat lower (at ~80%) than those found in [1].

T	^{36}Ar	$^{40}Ar/^{36}Ar$	^{84}Kr	^{132}Xe
600	15.7 ±0.5	51.3 ±1.3	0.19 ±0.01	0.22 ±0.01
1000	18.9 ±0.6	6.1 ±0.2	0.21 ±0.01	0.29 ±0.02
1800	18.1 ±0.5	1.0 ±0.3	0.17 ±0.01	0.22 ±0.01
total	52.6 ±0.9	17.9 ±0.5	0.57 ±0.02	0.73 ±0.03

Table 2: Ar, Kr and Xe in stepwise gas release of SM51. Extraction temperatures are in °C, concentrations in units of 10^{-8} cc/g.

The isotopic composition of Xe is mostly Q-like [3], with some evidence for radiogenic ^{129}Xe in the 1000 °C extraction step. Enhanced ^{136}Xe is seen in the first release step and indicates the presence of Xe-HL [3]. Similar excursions are observed in the Tokyo /

Kyushu analysis of SM51 at 900 °C and in the 1000 °C release of Maribo (Fig. 2; [1, 2]).

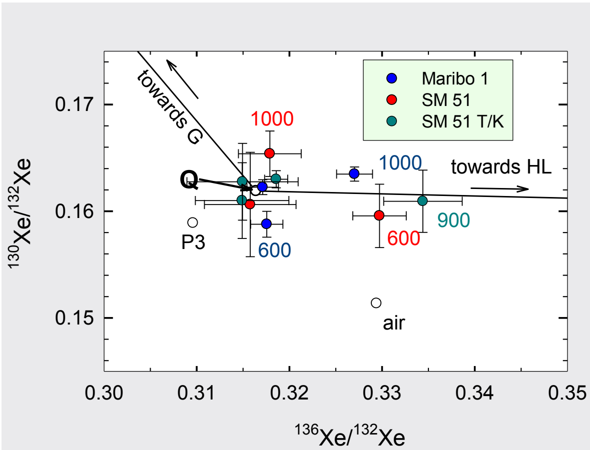

Fig. 2: Three-isotope plot of $^{130}Xe/^{132}Xe$ vs. $^{136}Xe/^{132}Xe$ (stepwise release data). Besides our SM51 data, the Tokyo / Kyushu ("T/K") data from [1] are shown as well as data for Maribo from [2]. For references and discussion see text.

Discussion, presolar minerals: The abundance in SM51 of presolar diamond can be estimated from the excursion towards Xe-HL in the 600 °C step. Assuming a mixture of Q and HL with $^{136}Xe/^{132}Xe$ as given in [3], the ^{132}Xe-HL abundance for this step is ~7.5x10^{-11} cc/g, which – for a concentration in diamond from primitive meteorites of typically ~1.6x10^{-7} cc/g [4] – implies a diamond abundance of 471 (±106) ppm. Naturally this is a lower limit, since besides Xe-Q also Xe-P3 may be present with lower $^{136}Xe/^{132}Xe$ and in addition more of Xe-HL may be "hidden" in the other steps. This is slightly lower than a corresponding lower limit estimate for Maribo 1 based on its 1000 °C release (Fig. 2), which results in 627 (±120) ppm. A strict upper limit of ~1460 ppm – similar to the abundance determined for the most primitive meteorites [5] - is obtained by assuming *all* of ^{22}Ne to be Ne-HL.

A similar approach can be used to derive a lower limit for the abundance of presolar silicon carbide. Assuming Ne released at 1000 °C to be a mixture of Ne-HL and Ne-E(H) [3, 6], yields a Ne-E(H) abundance of ~6.3x10^{-10} cc/g, which for an concentration in presolar SiC of 1.65x10^{-4} cc/g [5] corresponds to 3.8 (±0.4) ppm of SiC, roughly half of what has been estimated for Maribo [2].

Discussion, cosmic ray exposure history: The cosmic ray exposure age of Sutter' Mill is extremely short, with a CRE age of 0.051 ± 0.006 Ma reported by [1]. Like in [1], our data do not provide information from He and Ar because of the predominance of trapped components. Our Ne results are even more extreme than those of [1]: if errors are taken into account, none of our observed compositions fall outside the triangle spanned by solar wind, Ne-HL and Ne-E, thus there is no unequivocal evidence for the presence of *any* cosmic ray produced Ne in our analysis.

It is possible, nevertheless, to do some educated guesswork, based on estimates for the dominant trapped components released at given extraction temperatures. As an exercise we have assumed the trapped Ne released at 600 °C to be predominantly a mixture of solar fractionated Ne (SFP; Fig. 1) and Ne-P3, that released at 1000 °C to be a mixture of Ne-HL and Ne-E(H), and the one released at 1800 °C to be predominantly Ne-HL and SFP-Ne (compositions taken from [3, 6, 7]. For the calculation we assumed in addition a 5% uncertainty in the composition of Ne-E(H), and for the cosmogenic component $^{22}Ne/^{21}Ne = 1.11$, $^{20}Ne/^{22}Ne = 0.83$, also with 5% uncertainties. Only the first (600 °C step) delivers a positive result outside error of 0.65 (± 0.31)x10^{-10} cc/g of cosmogenic ^{21}Ne, the nominal total being (0.47±1.10) x10^{-10} cc/g. This is only about half that reported in [1]. However these authors considered only trapped Ne-P3 from presolar diamond [1] and ignored the unavoidable presence Ne-HL, with distinctly higher $^{21}Ne/^{22}Ne$ (Fig. 1). Note that in the 900 °C step where the bulk of the inferred cosmogenic Ne was released, the authors clearly observed the release of the HL component in Xe (Fig. 2) and that Ne-HL in diamond is considerably more abundant than Ne-P3 (e.g., >5x in CM Murray [4]). As a consequence, the true abundance of cosmogenic ^{21}Ne in SM51 must be considerably less than reported in [1]. Using our nominal value given above (unfortunately with large error) and a production rate of 2x10^{-9} cc/(g Ma) as in [1], a nominal CRE age is ~0.019 Ma.

Conclusions: In terms of trapped noble gases, Sutter's Mill is a typical CM chondrite. Abundances of presolar diamond and silicon carbide estimated from noble gases are similar to those found in other CMs. The cosmic ray exposure age is exceedingly short, at least an order of magnitude shorter than for Maribo [2]. The longer CRE age of Maribo does not lend support to the suggestion by [1] that both are part of an old ~0.1 Ma meteoroid stream.

References: [1] Jenniskens P. et al. (2012) *Science, 338,* 1583-1587. [2] Haack H. et al. (2012) *Meteoritics & Planet. Sci., 47,* 30-50. [3] Ott U. (2002) *Reviews in Mineralogy and Geochemistry, 47,* 71–100. [4] Huss G. R. and Lewis R. S. (1994) *Meteoritics 29*, 811-829. [5] Huss G. R. et al. (2003) *Geochim. Cosmochim. Acta 67*, 4823-4848. [6] Heck P. R. et al. (2009), *Astrophysical Journal 698,* 1155-1164. [7] Wieler R. (2002) *Reviews in Mineralogy and Geochemistry, 47,* 21–70.