

**NOBLE GASES IN TWO METEORITES THAT FELL IN DENMARK AND SLOVENIA IN 2009.** U. Ott<sup>1</sup>, S. Herrmann<sup>1</sup>, H. Haack<sup>2</sup> and T. Grau, <sup>1</sup>Max-Planck-Institut für Chemie, Joh.-J.-Becher-Weg 27, D-55128 Mainz, Germany (uli.ott@mpic.de), <sup>2</sup>Natural History Museum of Denmark, University of Copenhagen, Øster Voldgade 5-7, DK-1350 Copenhagen K, Denmark, <sup>3</sup>ERFM, Puschkinstr. 23, D-16321 Bernau b. Berlin, Germany.

**Introduction:** We report results for noble gases in samples of two meteorites that fell in Europe in the first half of 2009: a) Maribo (Denmark) fell on January 17, 2009. It was observed by surveillance video cameras in Sweden and an all-sky camera in the Netherlands [1] and reports were received by the Danish fireball network from some 550 eyewitnesses; b) a meteorite that fell near Jesenice in Slovenia on April 9, 2009. Material was collected by one of us (T.G.).

**Samples and Experimental:** Maribo has been classified as a carbonaceous chondrite of type CM2 [1], whereas the Slovenian meteorite should be classified as an ordinary chondrite of type L6 [2]. Noble gases were analyzed by standard analytical techniques (e.g., [3]) in two fragments from each of the two meteorites (~41 mg each for Maribo and ~100 mg fragments for the ordinary chondrite). Gas extraction was in three temperature steps (600, 1000, 1800 °C), except for Maribo #2, which was analyzed using 200 °C heating intervals from 400 °C to 1800 °C.

**Results:** Data for He and Ne are summarized in Table 1, those for Ar, Kr and Xe in Table 2.

	<sup>3</sup> He	<sup>4</sup> He	<sup>22</sup> Ne	<sup>20</sup> Ne/ <sup>22</sup> Ne	<sup>21</sup> Ne/ <sup>22</sup> Ne
M 1	1.66 ±0.03	8531 ±147	4.28 ±0.09	8.598 ±0.096	0.06855 ±0.00053
M 2	1.58 ±0.02	8430 ±121	4.24 ±0.07	8.631 ±0.023	0.06613 ±0.00030
J 1	5.80 ±0.07	979 ±20	1.710 ±0.014	0.8317 ±0.0030	0.9285 ±0.0042
J 2	5.75 ±0.07	566 ±12	1.664 ±0.013	0.8337 ±0.0030	0.9283 ±0.0042

Table 1. He and Ne results (abundances in 10<sup>-8</sup> cc/g). M = Maribo; J = OC fall near Jesenice.

	<sup>36</sup> Ar	<sup>38</sup> Ar/ <sup>36</sup> Ar	<sup>40</sup> Ar	<sup>84</sup> Kr	<sup>132</sup> Xe
M 1	81.2 ±1.8	0.1872 ±0.0012	228 ±7	0.844 ±0.028	1.008 ±0.037
M 2	84.0 ±1.4	0.1875 ±0.0008	296 ±6	0.846 ±0.020	1.015 ±0.027
J 1	0.963 ±0.022	0.2448 ±0.0083	3056 ±83	0.0056 ±0.0002	0.0056 ±0.0001
J 2	0.690 ±0.032	0.3686 ±0.0250	3516 ±89	0.0063 ±0.0002	0.0061 ±0.0002

Table 2. Ar, Kr and Xe results (abundances in 10<sup>-8</sup> cc/g). M = Maribo; J = OC fall near Jesenice.

**Maribo:** Except for the abundance of <sup>40</sup>Ar, totals for the two fragments are identical (Tables 1, 2) and show patterns typical for CM2 meteorites.

**Helium and neon.** With evidence for some solar neon released at the lowest temperatures, Ne (and probably also <sup>4</sup>He) are dominated by the HL component carried by presolar diamond [4, 5], as shown in the Ne 3-isotope plot of Fig. 1. Evident is also the presence of presolar SiC, indicated by the dip in <sup>20</sup>Ne/<sup>22</sup>Ne [5, 6] at 1800 °C for Maribo 1 and at 1200 °C in the high-resolution analysis of Maribo 2.

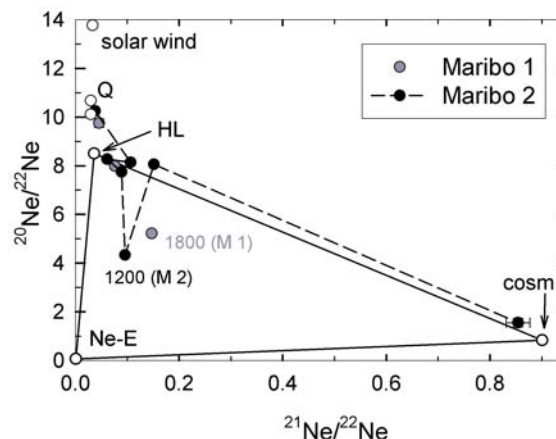


Fig. 1. Neon 3-isotope type plot for Maribo. The solid line spans the triangle defined by Ne-E, Ne-HL and a typical composition for cosmogenic Ne. The dashed line traces the high-resolution stepped analysis of Maribo 2.

**Argon, krypton, xenon.** Ar, Kr and Xe are dominated by Q-gases [5, 7]. As shown in Fig. 2, a small contribution from adsorbed air is evident in the first release steps, while HL-Xe carried by presolar nano-diamond [4, 5] is apparent at intermediate temperature (800, 1000 °C.) Due to the large abundance of trapped Xe there is only marginal evidence for the presence of radiogenic <sup>129</sup>Xe.

**Abundance of presolar phases.** The isotopic excursions in Ne (Fig. 1) and Xe (Fig. 2) allow an estimate of the abundances of presolar diamond and SiC. Using the approach of [8, 9] with a “constant” Ne-E concentration of SiC, from both the 1800 °C data point for Maribo 1 and the 1200 °C for Maribo an abundance of ~10 ppm is inferred. A similar estimate for presolar diamond, assuming a Xe-HL abundance typical for diamonds from CM2 meteorites [9] gives ~500 ppm.

These are lower limits, of course, since more may be hidden in the isotopically more “normal” steps.

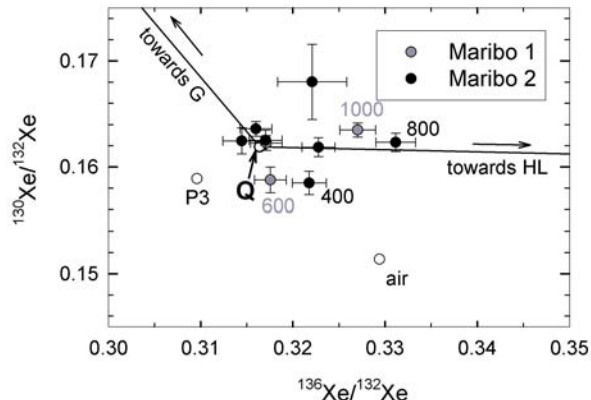


Fig. 2. Xenon 3-isotope plot of  $^{130}\text{Xe}/^{132}\text{Xe}$  vs.  $^{136}\text{Xe}/^{132}\text{Xe}$  for Maribo. The lines are mixing lines between Xe-Q and a) HL-Xe carried by presolar diamond off scale to the right and b) Xe-G carried by presolar SiC towards the upper left.

**Ages.** With a significant contribution to  $^4\text{He}$  from trapped He, it is not possible to calculate a U/Th-He age. Nominal K-Ar ages, based on the  $^{40}\text{Ar}$  abundances in Table 2 (probably containing a significant air contribution) and a K abundance of 372 ppm [10] are 1.14 and 1.37 Ga.

Cosmic ray exposure (CRE) ages that we have calculated following [11] suffer from the problem that the abundance of trapped Ne is too high for a reliable determination of the shielding parameter  $(^{22}\text{Ne}/^{21}\text{Ne})_{\text{cos}}$ . Assuming “average shielding (shielding parameter = 1.11) leads to CRE ages of 0.69 Ma (Maribo 1) and 0.63 Ma (Maribo 2). Corresponding ages based on  $^3\text{He}$  are higher at 1.03 and 0.98 Ma; He and Ne ages can be made to agree at  $\sim 1.04 (\pm 0.05)$  Ma, if very little shielding (parameter  $\sim 1.24$ ) is assumed.

**Slovenian meteorite:** Measured abundances of “trapped” Ar, Kr and Xe are about two orders of magnitude lower than in Maribo, consistent with a classification as type 6 ordinary chondrite [12]. The abundance ratios  $^{36}\text{Ar}_{\text{trapped}}/^{84}\text{Kr}/^{132}\text{Xe}$  of 164/1.00/1 (P1) and 98/1.06/1 (P2) are not indicative of significant terrestrial contamination [13], as expected for a fresh fall, but the Xe isotopic ratios suggest otherwise. Radiogenic  $^{129}\text{Xe}$  is present at a level of  $\sim 5 \times 10^{-12}$  cc/g. With  $^{129}\text{Xe}/^{132}\text{Xe}$  ratios (1.09 and 1.07, respectively) not significantly enhanced, the exact amounts depend sensitively on the choice of “trapped”  $^{129}\text{Xe}/^{132}\text{Xe}$ , however.

**Ages.** Cosmogenic He and Ne are identical in the two analyzed fragments, while there are differences in the radiogenic isotopes  $^4\text{He}$  (higher in P1) and  $^{40}\text{Ar}$  (higher in P2). Assuming average L chondrite abun-

dances of K, U and Th [14], K-Ar ages for P1 and P2 are 3.02 Ga and 3.53 Ga, while corresponding U/Th-He ages are 2.7 and 1.7 Ga.

Neon in the Slovenian fall is purely cosmogenic. The well-determined cosmic ray shielding parameter  $(^{22}\text{Ne}/^{21}\text{Ne})_{\text{cos}}$  of  $1.077 (\pm 0.006)$  for both samples indicates that they were exposed to cosmic rays in a well shielded position. According to the predictions of the latest model by [15], for meteoroids of L chondrite chemical composition such a low value can be achieved only for radii more than 30 cm. Using the empirical formulae of [11] and again using average L chondrite composition, inferred  $^{21}\text{Ne}$  cosmic ray exposure ages for P1 and P2 are 4.06 and 3.95 Ma. CRE ages based on  $^3\text{He}$  are slightly lower (3.57 and 3.53 Ma), while those based on  $^{38}\text{Ar}$  (calculated according to [11], with the modification by [16]) are slightly lower for P2 (3.2 Ma) and significantly lower for P1 (1.4 Ma).

**References:** [1] Weisberg M. K. et al. (2009) *Meteoritics & Planet. Sci.*, 44, 1355-1397. [2] Bischoff A. (2009) pers. comm. [3] Schwenzer S. P. et al. (2007) *Meteoritics & Planet. Sci.*, 42, 387-412. [4] Lewis R. S. (1987) *Nature*, 326, 160-162. [5] Ott U. (2002) in *Reviews in Mineralogy & Geochemistry Vol. 47*, 71-100. [6] Tang M. et al. (1988) *Geochim. Cosmochim. Acta*, 52, 1235-1244. [7] Lewis R. S. et al. (1975) *Science*, 190, 1251-1262. [8] Huss G. R. et al. (1995) *Geochim. Cosmochim. Acta*, 59, 115-160. [9] Huss G. R. et al. (2003) *Geochim. Cosmochim. Acta*, 67, 4823-4848. [10] Palme H. (2009), pers. comm. [11] Eugster O. (1988) *Geochim. Cosmochim. Acta*, 52, 1649-1662. [12] Marti K. (1967) *Earth Planet. Sci. Lett.*, 2, 191-196. [13] Scherer P. and Schultz L. (1994) in *Noble Gas Geochemistry and Cosmochemistry* (ed. J. Matsuda), 43-53. TERRAPUB, Tokyo. [14] Wasson J. and Kallemeyn G.W. (1988) *Phil. Trans. R. Soc. Lond. A*, 535-544. [15] Leya I. and Masarik J. (2009) *Meteoritics & Planet. Sci.*, 44, 1061-1086. Details available at [www.noble-gas.unibe.ch](http://www.noble-gas.unibe.ch). [16] Schultz L. et al. (1991) *Geochim. Cosmochim. Acta*, 55, 59-66.