THE GRIMSBY H CHONDRITE: COMBINED NOBLE GAS AND RADIONUCLIDE ANALYSIS J. A. Cartwright[1], G. F. Herzog[2], S. Herrmann[1], N. Shankar[2] P. J. A. McCausland[3] and U. Ott[1]. [1]Abt. Biogeochemie, Max-Planck-Institut für Chemie, Joh.-J.-Becher-Weg 27, 55128 Mainz, Germany. [2]Dept. of Chem. & Chem. Bio., Rutgers Univ., 610 Taylor Road, Piscataway, New Jersey, USA. [3]Dept. of Phys. & Astr., Univ. of Western Ontario, London, Ontario, N6A 3K9, Canada. E-mail: julia.cartwright@mpic.de

Introduction: Following the fall of the Grimsby ordinary chondrite on 25th September 2009, 13 separate fragments were recovered from an area of 8 km^2 in SW Ontario Canada [1]. Whilst initial petrological and observational studies suggested the meteorite was an H5, our preliminary noble gas concentrations and cosmic ray exposure (CRE) ages (21-26 Ma) correlated better with an H6 classification [2]. Furthermore, though observational and infrasound/acoustic studies of the incoming fireball suggested a maximum incoming diameter of 30-40 cm, our cosmogenic noble gas data suggested a minimum of 40-50 cm [2]. Additionally, the very low $^{22}Ne/^{21}Ne_c$ ratio (~1.06) was indicative of heavy shielding [2]. However, this is in the low range, where it is no longer a reliable indicator.

Here we present our latest noble gas results to help better assess Grimsby's classification and history. We have also combined our cosmogenic gas results (^{3}He, ^{21}Ne) with short-lived nuclide analysis (^{10}Be, ^{26}Al) to better assess its CRE age and pre-meteoroid size.

Experimental Procedure: *Noble gases:* At present, two samples from the 46.1g Grimsby "Garchinski" fragment (Grimsby other Garchinski, "GO" and Grimsby pristine Garchinski "GP") have been analysed for noble gases, and samples from a further four Grimsby meteorites (HP-2d, Zbyszek c, PJAM c1 and Alan e1) will be analysed in the coming months. GO is a 29.11 mg subfragment recovered from the Garchinski site 3 weeks after the initial fall. This sample shows clear evidence of oxidation. GP is a 96.54 mg sample taken from the pristine Garchinski fragment that was collected the morning after the initial fall. Noble gases from both GO and GP samples were released using a furnace step-heating technique. The samples were heated in four steps of 600, 1000, 1800 and 1900 ˚C, and the emitted gases were analysed using the noble gas electron source mass spectrometer MAP 215-50 based in Mainz.

Short-lived radionuclides: Samples from two Grimsby fragments (Garchinski Pristine, and HP-1) have been analysed for shortlived radionuclides ^{10}Be and ^{26}Al, whilst analyses of subsamples from a further four fragments (HP-2f, Zbyszek d, PJAM c2, and Alan e2) are underway.

Results and Discussion: Our results from both noble gas and short lived radionuclide analysis are summarised in Table 1, and Figures 1-3.

Trapped gases and chondrite classification: Previous research has shown that different classes of chondrites show different concentrations of trapped ^{36}Ar, ^{84}Kr and ^{132}Xe ([3]; Fig. 1). For Grimsby, our GO data show ^{36}Ar, ^{84}Kr and ^{132}Xe concentrations that lie on the border of H4 and H5 chondrite classes, whilst GP's Kr and Xe concentrations are more consistent with a H5 classification (Table 1, Fig. 1).

Crystallisation Ages: We have calculated nominal K-Ar ages of 3.08 and 3.56 Ga for GO and GP respec-

Table 1: Noble gas and short-lived radionuclide data for GO, GP and HP-1.

Noble Gas (cc/g)	GO	GP
^{3}He (10^{-8})	34.1 ± 0.4	30.3 ± 0.4
^{4}He (10^{-6})	12.8 ± 0.3	12.7 ± 0.3
$^{21}Ne_c$ (10^{-8})	9.7 ± 0.1	9.6 ± 0.3
^{22}Ne (10^{-8})	10.3 ± 0.1	10.1 ± 0.3
$^{20}Ne/^{22}Ne$	0.828 ± 0.003	0.826 ± 0.04
$^{21}Ne/^{22}Ne$	0.944 ± 0.007	0.946 ± 0.007
$^{22}Ne/^{21}Ne_c$	1.060 ± 0.008	1.057 ± 0.009
$^{36}Ar_t$ (10^{-8})	2.4 ± 0.1	-*
$^{38}Ar_c$ (10^{-8})	1.3 ± 0.1	-*
^{40}Ar (10^{-6})	31.6 ± 2.8	43.3 ± 2.5
$^{84}Kr_t$ (10^{-10})	2.9 ± 0.1	1.7 ± 0.1
$^{132}Xe_t$ (10^{-10})	3.4 ± 0.2	2.2 ± 0.1
Nuclide (dpm/kg)	**HP-1**	**GP**
^{10}Be	13.8 ± 0.8	15.8 ± 0.6
^{26}Al	43.6 ± 1.0	46.6 ± 1.3

t = trapped, c = cosmogenic
**data reduction for Ar in GP is not yet complete.*

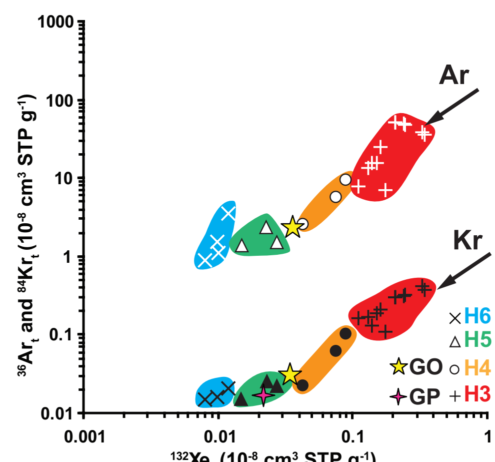

Figure 1: Noble gas concentrations $^{132}Xe_t$ against $^{36}Ar_t$ and $^{84}Kr_t$ for chondrite classes with data for GO and GP (Table 1). Chondrite data from [3-6], t = trapped.

tively, based on the ^{40}Ar concentration (Table 1) and a K content of 0.099 wt% [7]. The corresponding U/Th-He ages are 3.18 and 3.22 Ga for GO and GP respectively, based on an average U concentration for H chondrites of 12 ppm [8].

Cosmogenic Gases: Our initial CRE ages of 21-26 Ma for GO reported in [2], were based solely on cosmogenic noble gas data (using the $^{22}Ne/^{21}Ne$-corrected production rate equations of [9], with the ^{38}Ar production rate modified according to [10]) and average H chondrite composition [8]. Using the HP-1 Grimsby composition [7], we obtained CRE ^{3}He (T_3), ^{21}Ne (T_{21}), and ^{38}Ar (T_{38}) ages of 21.0, 23.4, 26.5 Ma for GO. For GP we obtain ^{3}He (T_3) and ^{21}Ne (T_{21}) ages of 18.6 and 22.6 Ma. Because of the uncertain (but heavy) shielding, we also calculated CRE ages using the production rate ratios $P(^{21}Ne)/P(^{10}Be)$ and $P(^{21}Ne)/P(^{26}Al)$ given in [11, 12], assuming the radionuclides to be in saturation. For the two ^{10}Be activities listed in Table 1, this gives us CRE ages of 43 and 49 Ma for GP, and 44 and 49 Ma for GO. Using the ^{26}Al activities (Table 1), we have 42 and 44 Ma for both GO and GP samples. In a third approach, we used the production rates of [13] for a combined fit to our ^{10}Be, ^{26}Al and ^{21}Ne data. We excluded $^{3}He_c$ and $^{38}Ar_c$ from the fit because of possible losses, which are suggested by the low U-Th/He and K/Ar ages. The best fits correspond to a CRE age of ~ 35 Ma. Overall, the calculated ages of 42-49 Ma do not correlate with the common H-chondrite peaks of ~ 7 or ~ 33 Ma observed previously [11], whilst the age of ~ 35 Ma may be consistent with the 33 Ma peak.

Our cosmogenic data can also help determine the initial size of the Grimsby meteorite. First, the low $(^{21}Ne/^{22}Ne)_c$ ratios, which range between 1.057-1.060,

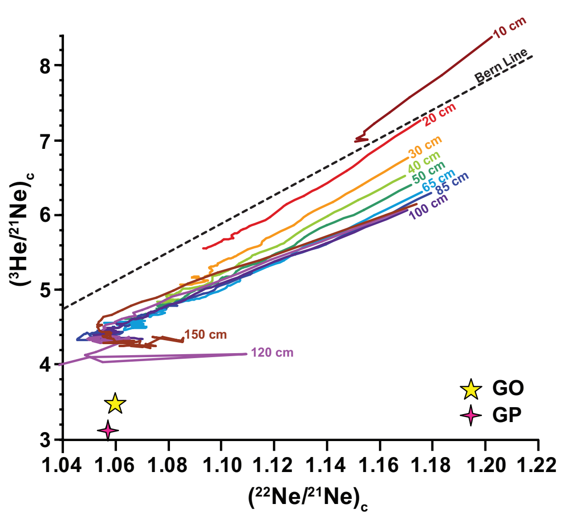

Figure 2: Plot of $(^{22}Ne/^{21}Ne)_c$ vs. $(^{3}He/^{21}Ne)_c$ ratios modeled by [13] for H-chondrites, with our GO and GP data (Table 1). Also plotted is the "Bern line" [14]

indicate heavy shielding, implying that Grimsby was a large body during most of the time that the noble gases accumulated. According to [13], $(^{21}Ne/^{22}Ne)_c$ ratios this low are achieved only in meteoroids with a minimum radius of ~ 100 cm (Fig. 2). Assuming a single-stage exposure, the ^{10}Be and ^{26}Al activities narrow the range of possible meteoroid depths as shown in Figure 3. Given our measured CRE ages and the fact that Grimsby is a fall, these low activities cannot relate to short (one-stage) exposure nor an old terrestrial age.

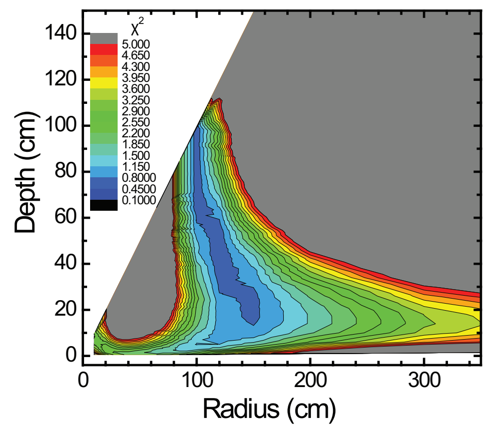

Figure 3: Best fits (lowest χ^2) for radius and depth of incoming meteoroid, based on ^{10}Be, ^{26}Al, ^{21}Ne.

Conclusions: Our latest data suggest that Grimsby is likely a H5 class chondrite, with an initial meteoroid diameter of at least 100 cm. As this size does not agree with the 30-40 cm from infrasound/acoustic studies and with evidence of both He and Ar loss, this may suggest that the Grimsby meteoroid though once large, has had a complex history, probably including a late break-up. For example, as the radionuclide activities are low, and since such systems only "observe" the last few halflives, this may require a breakup in the last 1 Ma or so.

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