NOBLE GAS ANALYSIS IN THE QUEST TO FIND "REGOLITHIC" HOWARDITES. J. A. Cartwright[1], S. Herrmann[1], J. Herrin[2] D. W. Mittlefehldt[3] and U. Ott[1]. [1]Abteilung Biogeochemie, Max-Planck-Institut für Chemie, Joh.-Joachim-Becher-Weg 27, 55128 Mainz, Germany. [2]ESCG, NASA/Johnson Space Center, Houston, TX, USA, [3]NASA/Johnson Space Center, Houston, TX, USA. E-mail: julia.cartwright@mpic.de

Introduction: The howardite meteorites consist of ~200 polymict breccias of eucrite (basaltic) and diogenite (orthopyroxenitic) material (collectively, the HED group) [1] that originate from the asteroid belt. Infrared reflectance spectroscopy of asteroids and laboratory studies of HEDs have indicated that the asteroid 4-Vesta is the likely parent body [2], and the partially-demolished south pole may be the source region [3]. Asteroid regolith formation processes may be responsible for a number of observed petrological features including impact melt clasts, reworked clasts and mosaisicm. We have identified such features in a study of 30 howardites and polymict eucrites, and developed a regolith grading scheme based on petrology. However, the true regolithic nature of the howardite suite is not well defined, and previous research has suggested correlations between Ni contents of 300-1200 µg/g, a minimal variation in Al_2O_3 content around 8-9 wt% and the presence of solar wind noble gases are key hallmarks of an ancient regolith on Vesta [4]. Through combined petrological, compositional and noble gas research, we aim to better understand howardite petrological diversity, regolith formation processes on parent asteroids, and to establish what defines a truly "regolithic" howardite. Our research will play an integral part in the interpretation of data gathered by the Dawn mission.

Noble gases: Noble gas analysis can help highlight the regolith nature of meteorites by allowing the resolution between solar, "planetary" and cosmogenic components. Solar noble gas components (e.g. solar wind) are implanted into the top few nm of grains on the surfaces of solar system bodies that lack atmospheric and magnetic field protection. These components can be recognized by measured elevations in certain isotopes, in particular ^{20}Ne causing ^{20}Ne/^{22}Ne ratios of ~ 11.2-13.8 [5]. By comparison, cosmogenic noble gas components are produced by high energy galactic cosmic rays (GCR) and low energy solar flare protons (SCR), both of which can penetrate to greater depths (GCR up to ~ 1 m, SCR up to ~2 cm). Both SCR and GCR cause elevations in the ^{21}Ne isotope, though GCR components have higher ^{21}Ne/^{22}Ne ratios due to their higher energies. Planetary components relate to the primary signature of the sample, and can be identified following cosmogenic and solar component resolution. Thus a truly "regolithic" howardite would display evidence of trapped solar wind components (high ^{20}Ne/^{22}Ne, low ^{21}Ne/^{22}Ne), which can mask any influence from SCR or GCR components (low ^{20}Ne/^{22}Ne, mid-high ^{21}Ne/^{22}Ne).

This research: Here we report the preliminary results from our noble gas analyses of four howardites: LEW 85313, EET 99408, MET 96500 and PCA 02066. Bulk major element compositional data have been collected [6], further petrological data for the HED group are reported by our colleagues [7, 8], whilst trace-element analyses are underway. Our work will investigate the extent of whether previously described Ni, Al_2O_3 and noble gas characteristics [4] are in fact indicative of a "regolithic" howardite.

Experimental Procedure:

Sample selection: The first four howardites chosen for noble gas analysis either exhibited "regolithic" Ni and Al_2O_3 contents [4], displayed a number of petrological regolithic features suggesting a high regolithic grade or had both, as summarised in Table 1.

Table 1: Ni, Al_2O_3 and regolithic scale of our howardites.

Howardite	Regolithic Grade	Ni (µg/g)	Al_2O_3 (wt%)
LEW 85313,39	LOW	745	9.2
MET 96500,19	MID	305	8.5
EET 99408,12	HIGH	12	11.5
PCA 02066,8	HIGH	792	8.0

Noble gas analysis: Small fragments of howardites LEW 85313,39 (137.35 mg), MET 96500,19 (94.89 mg), EET 99408,12 (119.86 mg) and PCA 02066,8 (102.77 mg) were loaded into our noble gas electron source mass spectrometer MAP 215-50 and analysed using a furnace step-heating technique in steps of 600, 1000, 1800 and 1900 °C.

Results and Discussion: Noble gas concentrations and ratios are displayed in Table 2, whilst Figure 1 is a plot of ^{20}Ne/^{22}Ne vs. ^{21}Ne/^{22}Ne ratios for our samples.

Crystallisation ages: As the howardites are polymict breccias, it is difficult to calculate true crystallisation ages. Whilst we have calculated nominal K-Ar ages of 3.39 ± 0.04, 4.63 ± 0.05, 3.90 ± 0.05 and 2.30 ± 0.18 Ga for LEW 85313, MET 96500, EET 99408, and PCA 02066 respectively, these values likely represent an average Ar retention age. MET 96500 may contain the oldest brecciated materials dating from the time of solar system formation.

Cosmic ray exposure (CRE) ages: We obtained CRE ^{3}He (T_3), ^{21}Ne (T_{21}), and ^{38}Ar (T_{38}) ages for all four howardites using the ^{22}Ne/^{21}Ne-corrected production rate equations of [9]. EET 99408,12 had ages of 6.9, 13.9, 16.4 Ma; MET 96500,19 had 16.9, 24.3, 21.0 Ma; PCA 02066,8 had 13.6, 21.6, 20.3 Ma. For these samples, the ^{3}He CRE ages are lower than associated

^{21}Ne and ^{38}Ar ages, which may be indicative of He loss from eucritic material within our samples. For LEW 85313, average howardite production rates were used (due to masking by trapped Ne) to give ages of 29.3, 18.9, 15.0 Ma. The older ^{3}He age may relate to high $^{3}He/^{21}Ne$ and associated $^{22}Ne/^{21}Ne$ ratios introducing uncertainty that we cannot properly correct, as our data do not yield reliable $(^{22}Ne/^{21}Ne)_c$.

Noble gas concentrations: Overall, LEW 85313 displays the highest noble gas concentrations compared to the remaining three howardites (Table 2). This may be indicative of a higher contribution from trapped noble gas components, including solar gases.

Cosmogenic vs. solar noble gas components: Despite analysing three howardites with apparently “regolithic” Ni and Al_2O_3 contents [4], only LEW 85313 shows clear evidence for implanted solar wind, with elevated $^{20}Ne/^{22}Ne$ ratios up to ~10.3 and low $^{21}Ne/^{22}Ne$ ratios down to ~0.1 (600 ºC step, Fig. 1). The trapped composition may be similar to that of SEP-Ne. Concentrations observed here are within the range observed for “regolithic” howardites as summarised in [12]. By comparison EET 99408 and MET 96500 have $^{21}Ne/^{22}Ne$ ratios similar to GCR (~0.8-0.9), and PCA 02066 shows only slightly elevated $^{20}Ne/^{22}Ne$ up to ~1.5 (1800 ºC, Fig.1 inset). Surprisingly, LEW 85313 displays our lowest regolithic grade as deduced from petrography, whilst solar wind-poor EET 99408 and PCA 02066 have our highest grade.

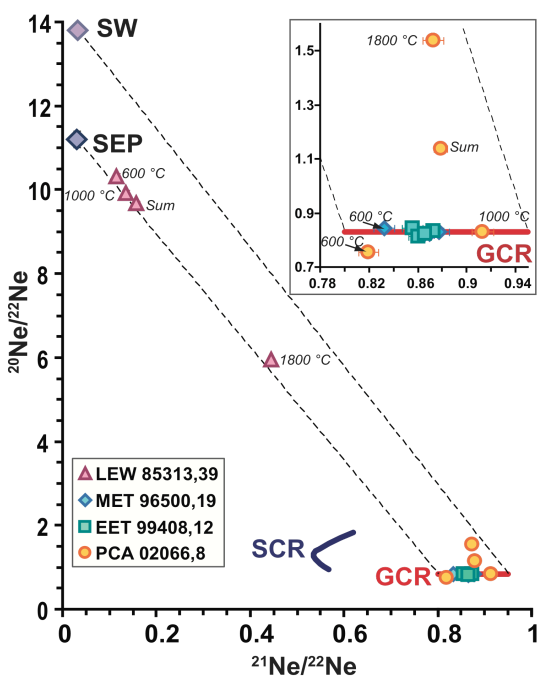

Figure 1: Plot of $^{21}Ne/^{20}Ne$ vs. $^{20}Ne/^{22}Ne$ with endmembers of solar wind (SW), solar energetic particles (SEP) [6], GCR [10], SCR [11] and our howardite data. Temperature steps are shown where distinguishable. 1900 ºC steps are omitted due to low Ne concentrations.

Table 2: Noble gas concentrations and ratios of our selected howardites. t = trapped, c = cosmogenic.

Noble Gas (cc/g)	LEW	MET	EET	PCA
^{3}He	48.4	11.3	27.9	22.5
(10^{-8})	± 1.4	± 0.4	± 0.9	± 0.6
^{4}He	986.1	23.1	29.4	16.7
(10^{-6})	± 33.9	± 0.8	± 0.9	± 0.4
$^{20}Ne_t$	354.6	< 0.01	< 0.01	2.3
(10^{-8})	± 15.7			± 0.2
$^{21}Ne_c$	4.7	3.0	4.6	5.7
(10^{-8})	± 0.1	± 0.1	± 0.1	± 0.1
^{22}Ne	36.7	3.5	5.3	6.5
(10^{-8})	± 0.8	± 0.1	± 0.1	± 0.1
$^{20}Ne/^{22}Ne$	9.682	0.823	0.822	1.139
	± 0.036	± 0.003	± 0.003	± 0.005
$^{21}Ne/^{22}Ne$	0.157	0.870	0.866	0.879
	± 0.001	± 0.006	± 0.006	± 0.005
$(^{22}Ne/^{21}Ne)_c$	≡1.14*	1.150	1.156	1.100
		± 0.008	± 0.008	± 0.007
$^{36}Ar_t$	111.8	1.1	6.4	3.6
(10^{-9})	± 2.7	± 0.3	± 0.5	± 0.4
$^{38}Ar_c$	13.8	17.0	26.7	19.8
(10^{-9})	± 0.5	± 0.6	± 0.8	± 0.6
^{40}Ar	8.6	16.0	12.9	3.6
(10^{-6})	± 0.2	± 0.5	± 0.4	± 0.1
$^{84}Kr_t$	36.0	2.0	8.5	2.0
(10^{-11})	± 1.1	± 0.1	± 0.4	± 0.1
$^{132}Xe_t$	20.5	1.1	3.7	1.3
(10^{-11})	± 0.5	± 0.1	± 0.1	± 0.1

**Sample was dominated by trapped Ne, so $(^{22}Ne/^{21}Ne)_c$ could not be resolved. Value here is average for Howardites [9].*

These preliminary results have a number of implications. Firstly, as we do not observe any correlation between Ni contents of 300-1200 µg/g, Al_2O_3 of 8-9 wt% and solar noble gases, this may suggest that the “regolithic’ howardite bulk chemical parameters reported by [4] are imperfect predictors of length of time spent in an active regolith. Secondly, as we do not observe a correlation between our regolithic petrological features and solar noble gases, this could indicate that the mechanisms causing howardite formation and their associated asteroid regolithic processes are complex. With further noble gas analysis of the remaining polymict eucrite and howardite samples combined with future data from the Dawn mission, we may observe clearer parameters pertaining to a “regolithic” origin.

References: [1] Mittlefehldt, D.W. *et al.* (1998) *Rev. Min.* 36: 4.1-4.195. [2] Drake M.J. (2001) *MAPS* 36:501-513. [3] Thomas P. C. *et al.* (1997) Science 277:1492-1495. [4] Warren, P.H. *et al.* (2009) *GCA* 73:5918-5943. [5] Benkert J.-P., *et al.* (1993) *JGR* 98(E7), 13147-13162. [6] Mittlefehldt D.W. *et al.* (2010) LPS *XLI,* Abstract #2655. [7] Mittlefehldt D. W. et al. (2011) *LPS XLII,* this conf. [8] Johnson K. N. *et al.* (2011) *LPS XLII,* this conf. [9] Eugster O. and Michel T. (1995) *GCA* 59(1), 177-199. [10] Garrison, D.H. *et al.* (1995) *Meteoritics* 30:738-747. [11] Reedy, R.C. (1992) *LPS XXIII*, 1133-1134. [12] Schultz, L. and Franke, L. (2004) *MAPS* 39:1889-1890.