THE CONTINUING QUEST FOR "REGOLITHIC" HOWARDITES. J. A. Cartwright[1], D. W. Mittlefehldt[2], J. E. Quinn[3] and U. Ott[1]. [1]Max Planck Institut für Chemie, Johann-Joachim-Becherweg 27, 55128 Mainz, Germany. [2]NASA/Johnson Space Center, Houston, TX, USA. [3]Jacobs Technology ESCG, Houston, TX, USA; current: PANalytical, Inc., Westborough, MA, USA. E-mail: julia.cartwright@mpic.de

Introduction: The howardite, eucrite and diogenite (HED) meteorites likely originate from asteroid 4-Vesta [1], the first of two asteroids targeted by NASA's Dawn mission [2]. Howardites are polymict breccias dominantly composed of basaltic (eucrite) and orthopyroxenitic (diogenite) material [3]. They are believed to originate from the surface of Vesta, and may represent the regolithic surface layer. Many howardites contain "regolith"-like features including fragmental breccias clasts, carbonaceous chondrite fragments and melt clasts (impact and volcanic). Though such features may relate to asteroid regolith formation processes, the exact regolithic nature of the howardite suite is not well defined.

Finding regolith: True regolithic nature can be established using noble gas analysis, where Solar Wind (SW) is implanted into grains at the upper-most surfaces of solar system bodies that lack a protective atmosphere or magnetic field. We would therefore expect clear evidence for SW in truly regolithic howardites. Additional regolith indicators were suggested by [4], who cite the presence of melt glasses (spheroid) and high siderophile element contents - specifically Ni of >300 µg/g. In addition, they noted that the more "regolithic" howardites had an Al_2O_3 range of 8-9 wt%, which alongside a eucrite/diogenite (E/D) ratio of 2:1, are potential limits for a well-mixed regolith. However, we found no obvious correlation between these parameters and SW in our first ten howardite noble gas analyses [5-7]: though the SW-rich samples had similar Ni and Al_2O_3 abundances as suggested by [4], so did a number of non SW-rich samples. Nor did we find a strong correlation between apparent regolithic grade (based on our petrological observations, e.g. [5,8]) and SW content. We also observed that significant proportions of carbonaceous chondrite (CC) fragments observed within a few of our howardites introduce a planetary component (e.g. [9]) that may overprint or be mixed with latent SW or fractionated solar wind (FSW, e.g. [10]), producing SW-like noble gas ratios up to $^{20}Ne/^{22}Ne$ ~6, $^{21}Ne/^{22}Ne$ ~0.5 [6-7]. As CC fragments have been observed in the previously assigned "regolithic" howardites and their presence has not been taken into effect, the parameters described by [4] may show some bias [7].

This research: Here, we continue our search for regolithic howardites, reporting preliminary noble gas data for CRE 01400, EET 87513, EET 99400 and SAN 03472. Additional samples will be analysed in time for LPSC. By comparing our results with bulk and trace element data, petrographic observations, and our previous howardite results, we hope to better define the features of a "regolithic" howardite.

Table 1: Total noble gas concentrations, ratios, Ni and Al_2O_3 contents, E/D ratio and est. regolithic grade for our latest howardite analyses.

Noble gas	CRE 01400	EET 87513	SAN 03472	EET 99400
^{3}He	0.384(12)	0.363(10)	0.495(14)	0.235(9)
^{4}He	27.4(3)	57.1(7)	48.8(6)	20.1(3)
$^{20}Ne_t$	-	38.28(1.81)	-	-
$^{21}Ne_c$	7.71(22)	7.12(17)	9.66(23)	6.83(20)
^{22}Ne	8.78(21)	11.50(22)	11.76(24)	7.94(19)
$^{20}Ne/^{22}Ne$	0.839(3)	3.945(22)	0.828(3)	0.841(3)
$^{21}Ne/^{22}Ne$	0.879(14)	0.627(8)	0.821(10)	0.860(13)
$(^{22}Ne/^{21}Ne)_c$	1.133(18)	1.196(17)	1.214(15)	1.158(18)
$^{36}Ar_t$	0.962(68)	3.227(164)	0.523(90)	1.058(94)
$^{38}Ar_c$	1.754(89)	3.073(153)	4.297(216)	3.150(169)
^{40}Ar	5.11(34)	14.61(99)	14.83(1.01)	10.72(75)
Ni	34.0	156.5	26.3	16.1
Al_2O_3	5.06	9.12	10.24	10.16
E/D	35/65	68/32	78/22	79/21
Reg. Grade	LOW	MED	LOW	MED

^{3-4}He, ^{40}Ar in 10^{-6} ccSTP/g, $^{20-22}Ne$, $^{36-40}Ar$ in 10^{-8} ccSTP/g. Ni in µg/g. Al_2O_3 in wt% [11]. t = trapped, c = cosmogenic. $^{21}Ne_c$ and $^{20}Ne_t$ obtained assuming a SW-like trapped component [12] (only EET 87513) or Earth atmospheric (EA) composition [13] & $(^{20}Ne/^{22}Ne)_c$ 0.80 [14]. $^{38}Ar_c$ and $^{36}Ar_t$, obtained assuming EA composition [15] & $(^{38}Ar/^{36}Ar)_c$ of 1.5 [16].

Experimental Procedure: Noble gas analysis was performed on an MAP 215-50 noble gas mass spectrometer (Mainz). Fragments of CRE 01400 (74.23 mg), EET 87513 (71.44 mg), EET 99400 (82.62 mg) and SAN 03472 (89.51 mg) were analysed in temperature steps of 600, 1000, 1800 and 1900 °C.

Results and Discussion: Noble gas concentrations and Ne isotopic ratios are displayed in Table 1, with Ni and Al_2O_3 contents and the proportion of E/D calculated from major element data [11]. Fig. 1 is a plot of $^{20}Ne/^{22}Ne$ vs. $^{21}Ne/^{22}Ne$ ratios.

CRE ages: We obtained CRE ^{3}He (T_3), ^{21}Ne (T_{21}), and ^{38}Ar (T_{38}) ages for our howardites using the $(^{22}Ne/^{21}Ne)_c$-corrected production rate equations of [15] and element abundances measured by LA-ICP-MS (this work) and XRF [11]. CRE 01400 had ages of 23.3 ± 0.7, 27.8 ± 1.6, 24.8 ± 1.3 Ma, EET 87513 had 21.6 ± 0.6, 36.7 ± 1.7, 27.2 ± 1.4 Ma, SAN 03472 had 30.7 ± 0.9, 55.1 ± 2.4, 33.6 ± 1.7 and EET 99400 had 14.4 ± 0.6. 34.4 ± 2.0 and 25.1 ± 1.4 Ma. For all samples, the ^{3}He CRE ages are lower than associated ^{21}Ne and ^{38}Ar ages, which indicates He loss from the samples.

Regolithic SW?: Though we analysed samples with a range of Ni and Al_2O_3 contents and suitable E/D ratios, only one – EET 87513 – shows evidence for a SW-like component, with ^{20}Ne/^{22}Ne ratios up to ~6.1 and low ^{21}Ne/^{22}Ne ratios of ~0.5 (1000 ºC step, Fig. 1). These data are compatible with a contribution from trapped FSW, yet compared to our previous data, the Ne ratios and the release pattern show a strong similarity to our CM-dominant howardites (e.g. PRA 04401, highest ^{20}Ne/^{22}Ne of ~6.1 at 1000 ºC) rather than our two SW-dominant samples LEW 85313 and MET 00423 (e.g. MET 00423, highest ^{20}Ne/^{22}Ne of ~11.1 at 600 ºC) [5-7]. Despite us having found no CC fragments during petrological examinations nor during sample preparation for noble gas analysis, this trend suggests that EET 87513 may contain significant CC material, contributing a significant planetary noble gas component that may have been mixed with a separate trapped FSW-Ne component. This hypothesis is supported by the observations of [22], who reported on a CM2 clast separated from EET 87513. These contrasting observations may hint at alternate hosts for planetary components within howardites. Whilst our previous emphasis has been on the presence of CC-fragments, cryptic CC contributions to the matrix (dispersed fine-grained material) may act as an important additional host of planetary components. With Kr and Xe data, we will shed further light on the extent of trapped SW/FSW, planetary components and potential mixing.

The remaining howardites CRE 01400, SAN 03472 and EET 99400 show strong contributions from regular GCR-Ne, augmented by production on Na, and show increasing ^{21}Ne/^{22}Ne with temperature (Fig. 1), as observed in our previous analyses [5-7].

Conclusions: Our results have a number of implications. Firstly, we continue to observe no clear correlation between Ni contents of >300 µg/g, Al_2O_3 of 8-9 wt% and SW noble gases, though most samples with SW and planetary components do show some elevation in Ni. Secondly, a correlation between our petrologically estimated regolithic grade and SW gases is not observed, further supporting the notion that regolithic processes on Vesta are complex and difficult to identify using lunar models as a guide (e.g. [5-8]). Finally, the role of CC material within howardites is an important factor contributing planetary components that can masquerade as SW-Ne or be mixed with trapped SW-Ne components. Fine-grained CC contribution to a howardite matrix may also supply sufficient planetary gases to dominate the release. The release patterns for truly SW-rich and CC-rich samples are different – SW is released at low temperature, planetary at mid temperature – allowing us to better distinguish between these two SW-like trends.

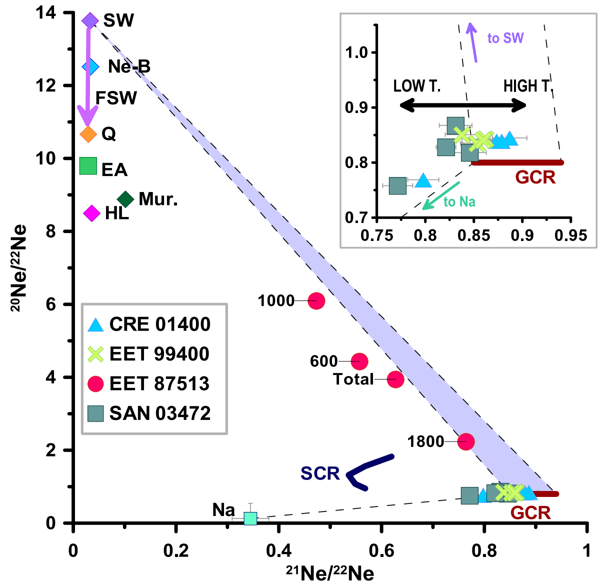

Fig. 1: Three isotope plot of ^{20}Ne/^{22}Ne vs. ^{21}Ne/^{22}Ne for our latest howardites. Other components plotted: SW [17], FSW [10], Ne-B [18], EA [13], GCR ((^{20}Ne/^{22}Ne)$_c$ from [14]; (^{21}Ne/^{22}Ne)$_c$ calculated using [19] (0-150 cm) for average howardite composition [3]), SCR (0.5-10 g/cm2, R0 = 70 MV) [20], contribution from Na [21]. Dashed lines represent mixing between GCR and SW, or GCR and Na.

Future work: By continuing our noble gas analysis of polymict eucrite and howardite samples, and combining our data with that of the Dawn mission, we hope to observe clearer parameters pertaining to a "regolithic" origin.

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