TOWARDS A UNIFIED REGOLITH INDEX FOR HOWARDITES. A. S. Peter[1] , P. Nakarmi[2], T. Mewes[2] , and J.A Cartwright[1] [1]Department of Geological Sciences, The University of Alabama, Tuscaloosa, AL 35487, Alabama, USA. [2]Department of Physics and Astronomy, The University of Alabama, Tuscaloosa, AL 35487. Email: aspeter@crimson.ua.edu

Introduction: The loose, unconsolidated layer of debris that covers the surfaces of planetary bodies is generally termed "regolith". While the regolith on the Earth's surface is extensively studied due to its proximity, for the Moon, the Apollo and Luna missions allowed us to characterize the nature of these regolith materials [1] in combination with studies of lunar meteorites, e.g. [2]. For other bodies within our solar system without returned samples, we can best characterize their respective regoliths through indirect means like remote sensing or in-situ observation of meteorite samples that originate from them.

Earlier studies of the lunar regolith used particle size distribution of the grains, solar wind noble gases, ferromagnetic resonance spectroscopy (FMR) [3], petrography, and optical spectroscopy to characterize both their chemical and physical properties, e.g. [4]. FMR can be used to quantify the magnetization dynamics of rock materials. In addition, FMR analysis formed the basis of an indexing system to define regolith sample maturation i.e. exposure time on the surface of the Moon [5]. The intensity of their characteristic resonance (I_s) to total iron content (FeO) i.e. I_s / FeO was used to classify the regolith into three major maturity groups – immature (I_s / FeO < 30), submature (I_s / FeO between 30 - 60) and mature (I_s / FeO > 60) [3,5]. FMR was further correlated with solar wind gases, petrographic agglutinates, and mean grain sizes to better understand the trend in the maturity of the lunar regolith [3].

Of particular interest in this work is to perform a comparison study with HED (howardite, eucrite, and diogenite) meteorites to devise a similar regolith indicator scale that can be used to characterize regolith formation on asteroid 4-Vesta. It has been suggested that Vesta receives a low solar flux and there are lower impact velocities compared to the Moon [6], therefore, processes that change the surfaces of these bodies differ due to their solar position. Howardites are surface breccia composed of both eucrite and diogenite [7]. Some are regolithic whereas others are fragmental [8,9]. The fragmental or non-regolithic howardites are solar wind noble gases poor [8,9] and have been suggested to be analogous to Vestan megaregolith [10] whereas the regolith howardites are solar wind noble gases rich and are the likely analogs of Vesta regolith [8,9]. A high level of siderophile content has also been found correlated with regolith howardites[11].

Both solar winds and siderophile contents of Vesta regolith have been used as markers to better characterize these loose surface materials [8,9,11]. Here, broadband ferromagnetic resonance (FMR) spectroscopy will be further used to define properties that make the howardites regolithic. Importantly, we will use similar aliquots of howardites analyzed previously [8,9] to help correlate noble gases with FMR. Recent refinement to this technique can allow us to carry out characterization over a broad range of frequencies [12] for the howardites. Using a similar approach to the lunar samples, we will be comparing noble gas data for regolithic and non-regolithic howardites with FMR. Therefore, we hope to more accurately work towards a classification scheme for determining the regolith grade for the HEDs.

Methods: For our investigation, we will obtain the FMR spectra of 15 howardite samples using a custom built FMR instrument at the University of Alabama (UA). The samples are EET 87513; GRO 95535; GRO 95602; LEW 85313; MET 00423; CRE 01400; EET 83376; EET 87518; EET 99400; EET 99408; MET 96500; QUE 94200; QUE 97002; PCA 02066; SAN 03472. All of the howardite samples are from different locations in Antarctica - GRO = Grosvenor mountains; EET = Elephant Moraine; MET = Meteorite Hills; LEW = Lewis Cliff ;CRE = Mount Crean ; QUE = Queen Alexandra Range; PCA = Pecora Escarpment; SAN = Sandford Cliffs

Small chips ranging in masses from ≈ 2.6 to 21mg made up of cylindrical to flaky shaped samples with sizes between 1-3mm in diameter will be analyzed. Broadband FMR measurements are a non-destructive method to probe the magnetization dynamics over a wide frequency range, 1 – 64GHz. A field swept measurement of the sample response to a microwave driving field is recorded.

Five samples of howardites were chosen for the preliminary analysis to measure the inherent magnetization dynamics of the metallic ferromagnetic minerals within the howardites. These aliquots are GRO 95535, EET 99408, LEW 85313, SAN 03472, and QUE 94200. Of these samples, GRO 95535 and LEW 85313 showed solar wind noble gases while others were dominated by cosmogenic noble gases [8,9].

Also, 2 mesosiderite and 2 iron meteorites were run through the instrument to provide reference spectra for analysis. The mesosiderites are two Bondoc aliquot

(A1 and A2) and Vaca Muerta aliquot. The iron meteorites are Soledade and Sikhote Alin.

To determine the FMR index of the samples, it is first necessary to find the intensity of the characteristic resonance (Is) which is obtained using the expression $(\Delta H)^2 A/m$, where ΔH is the peak to peak line -width, A is the amplitude and m is the mass of the sample. ***FMR index*** = Is/ total FeO content of the sample

Results and Interpretation: A sample with distinct resonance spectra will allow us to determine the intensity of the resonance (Is). Using this value, we can thereby classify the regolith into their distinct categories of maturity. Also, we can correlate the magnetic susceptibility data with those of the noble gases for their patterns and trends.

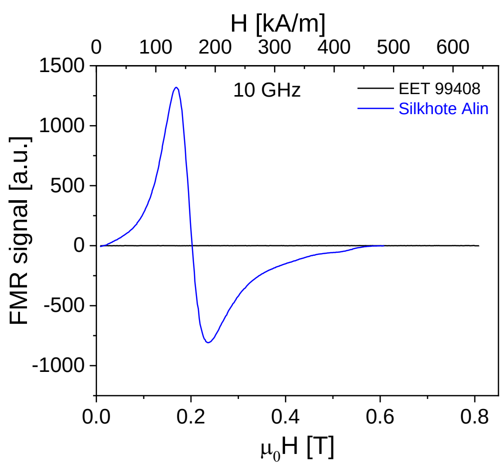

Fig. 1: FMR spectra of iron meteorite Sikhote Alin and howardite EET 99408. Sikhote Alin shows a typical resonance to the magnetic field applied, while EET 99408 shows no signal.

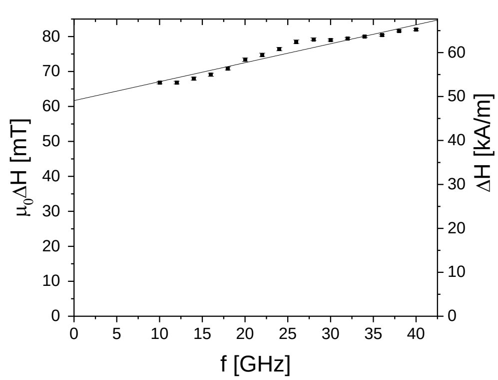

Fig. 2: Linewidth plot of Sikhote Alin. From this plot, we derived the $\mu_0\Delta H_0 = 62 \pm 1$[mT]

Figure 1 is a plot showing the response of Sikhote Alin, an iron meteorite, and EET 99408, a howardite, to microwave excitation in the FMR instrument.

From the plot, it is clear that there is no signal for the EET 99408 (black horizontal line) whereas the iron meteorite, Sikhote Alin (blue line), which showed strong spectra. The EET 99408 spectra typify the other four howardites samples analyzed using the technique. Therefore, we cannot plot the line width of this sample, and hence, the intensity of the resonance (Is) cannot be determined.

Overall, both iron meteorites showed a response to this technique, while the howardites and mesosiderites did not show a discernable FMR signal. This was surprising given the high siderophile content of the howardites [11]. Also, solar wind noble gases show a high abundance within this sample [8][9] just like the lunar regolith [3].

Conclusion: For the spectra obtained from the preliminary investigation there are different reasons as to why no signal was obtained from this analysis. Howardites may not contain a significant amount of nanophase iron detected within the lunar regolith due to the nature of the space weathering on Vesta [13]. This implies that there might be a significant magnetic field shielding the surface of Vesta from solar winds [14] but this does not correspond with the high abundance of solar wind gases found within the howardites [8,9].

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