DO MESOSIDERITES RESIDE ON 4 VESTA? AN ASSESSMENT BASED ON DAWN GRAND DATA.

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Introduction: Almost a century ago, simple petrographic observations were used to suggest a close genetic link between eucrites and the silicates in mesosiderites [1]. Mesosiderites are composed of roughly equal proportions of silicates that are very similar in mineralogy and texture to howardites, and Fe, Ni metal (Fig. 1) [2]. This similarity has led some to conclude that mesosiderites come from the howardite, eucrite and diogenite (HED) parent asteroid [3, 4]. Subsequent petrologic study demonstrated a number of differences between mesosiderite silicates and HEDs that are more plausibly explained as requiring separate parent asteroids [5]. However, HEDs and mesosiderites are identical in oxygen isotopic composition, and this has been used to argue for a common parent – 4 Vesta [6].

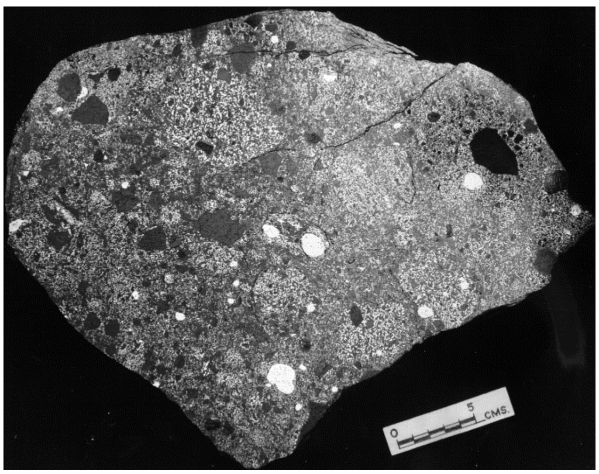

Figure 1. Polished slab of the Mount Padbury mesosiderite showing numerous cm-sized silicate (dark), metal (light) and metal-rich breccia clasts dispersed in a finely divided metal-silicate matrix. (Photograph courtesy of the Smithsonian Institution).

Mesosiderites have had a very distinctive evolutionary history [7-9] that has led to complex models for their formation [*e.g.*, 9-11]. The two main competing models for metal silicate mixing are low-velocity accretion of a naked, molten asteroidal core [10], and high-velocity collisional break-up and reassembly of a differentiated asteroid, mixing core metal with crustal silicates [11]. Concurrent with or subsequent to metal-silicate mixing, a substantial fraction of the silicates were remelted, and the silicates and metal chemically interacted [5, 9]. The metal-silicate breccia was cooled slowly, at $<1°\ Ma^{-1}$ [7, 8]. This evolutionary history is not evident in HEDs. Should mesosiderites hail from Vesta, their complex history would imply that models of the geologic evolution of Vesta are incomplete.

The Dawn mission Framing Camera (FC), Visible and Infrared Mapping Spectrometer (VIR) and gravity constraints are consistent with Vesta being the HED parent asteroid [12]. The Dawn Gamma-Ray and Neutron Detector (GRaND) is uniquely capable of testing the hypothesis that mesosiderites are also part of the lithologic suite on Vesta.

GRaND Measurements: GRaND will determine the elemental composition of Vesta by measuring nuclear emissions from its surface induced by cosmic ray interactions. A prospective study of GRaND at Vesta [13] shows that this instrument is sensitive to variations in eucrite-diogenite mixing ratios in howardites from measurements made in low altitude mapping orbit (LAMO). In LAMO, GRaND will measure and map the abundances of several elements, especially Fe, the macroscopic neutron absorption cross section Σ_a, and derive an average atomic mass $\langle A \rangle$ of the upper few tens of decimeters of the surface. The latter parameters are determined from neutron spectroscopy and are very sensitive to Fe for HED compositions. The presence of Ni in significant abundance would also affect these parameters. With an adjustment of the gain of the bismuth germanate (BGO) scintillator, it may be possible to uniquely determine the abundance of Ni, which produces a high energy capture gamma-ray. Nickel is not present in quantities detectable by GRaND in the HEDs, and models for vestan geologic evolution predict such low values are typical of the crust [*e.g.*, 14]. The detection of Ni would suggest a mesosiderite-bearing (or other metal-rich) terrain on Vesta. Here we show how the four compositional parameters differ between mesosiderites and HEDs.

HEDs and Mesosiderites—Compositional Distinctions: Table 1 gives average values of the four compositional parameters in different types of HED meteorites and mesosiderites. Recent work has suggested that only some howardites represent wellmixed, possibly ancient vestan regolith [15]. Most howardites are simple fragmental polymict breccias that did not spend significant time in the actively gardened, uppermost debris layer [15]. Table 1 contains separate entries for these two howardite subtypes, fragmental and regolithic. Chondritic impactor material is present at low levels in many howardites [16]. An exceptional example, PRA 04401, contains up to 70% CM chondrite clasts [17]. CM chondrites are richer in H, Fe and Ni than HEDs [18]. PRA 04401 is included in the table to facilitate comparison between mesosiderites and CM-rich debris on the vestan surface.

There are only minor differences in average atomic mass between members of the HED suite, and this extends to the CM-rich howardite PRA 04401. Mesosiderites by contrast, have ‹A› ~36% greater than that of howardites, and this would readily be detected in the fast neutron signal [19]. The macroscopic neutron absorption cross section (Σ_a) of mesosiderites is 2.5-2.6× that of howardites, and 2× that of PRA 04401. Iron shows a more substantial difference; mesosiderites have 3.4-3.5× the Fe content of howardites, and ~2.5× the Fe content of PRA 04401. Nickel could provide the most sensitive indicator of a mesosiderite terrain on Vesta. Mesosiderites have ~290× the Ni of fragmental howardites, ~74× that of the regolithic howardites, and ~8.5× that of the CM-rich howardite.

Table 1. Average bulk Fe and Ni contents, average atomic masses, and thermal neutron macroscopic absorption cross sections for HED lithologies and mesosiderites, calculated from literature data. Data on CM-chondrite-rich howardite PRA 04401 is from [20]. See [13], for equations for ‹A› and Σ_a.

type	Fe (mg g^{-1})	Ni (mg g^{-1})	‹A›	Σ_a (×10^3)
basaltic eucrite	148	0.009	22.8	7.1
cumulate eucrite	125	0.006	22.4	6.1
polymict eucrite	143	0.11	22.7	7.0
diogenite	131	0.04	22.0	5.8
howardite, fragmental	137	0.14	22.4	6.5
howardite, regolithic	142	0.54	22.6	6.9
PRA 04401	193	4.7	22.9	8.5
mesosiderite	**479**	**40**	**30.5**	**17**
0.1 mes + 0.9 how	171	4.1	23.0	7.5

Rather than a pure mesosiderite terrain, such material may simply be a component mixed into the regolith. As an example, a 10:90 mesosiderite:howardite mix is shown in the table. Such a mix would be more difficult to distinguish from a CM-chondrite-rich regolith in Fe, Ni, ‹A› and Σ_a. CM clasts in howardites contain hydrated phyllosilicates [16, 17]. PRA 04401 likely contains ~3700 µg g^{-1} H, which would impose characteristic decreases in counting rates in the boron-loaded plastic scintillators [13]. Thus, mesosiderite-rich regolith, which should be anhydrous, can be distinguished from exceptionally CM-rich regolith in GRaND data. CM-rich regolith would also be detected by VIR through characteristic absorption features in the infrared spectral region [*e.g.*, 21]. It may be possible to detect metal-rich regions by comparison of VIR spectra with spectra of mesosiderites [22] and by radiative transfer mixing analysis [*e.g.*, 23].

Preliminary Results: Following the commencement of LAMO, GRaND has detected the Fe 7.6 MeV capture gamma ray and strong neutron signals needed to determine the compositional parameters in Table 1 [24]. Additional integration time and analysis is needed in order to determine if regions of anomalously high Fe content are present on Vesta. By LPSC, we should be able to say whether a large-scale Fe anomaly, possibly indicative of a mesosiderite terrain, is present on Vesta. If a significant anomaly is detected, the GRaND team will adjust the gain of the BGO sensor to determine if Ni is present. The spatial scale sampled by GRaND in LAMO is about 300 km. Consequently, spatial-mixing must be considered when interpreting the data. An assessment of detection limits for mesosiderite compositions as a function of spatial scale and compositional mixing will be presented.

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