K/TH IN ACHONDRITES AND INTERPRETATION OF GRAND DATA FOR THE DAWN MISSION. T. Usui[1], H. Y. McSween, Jr.[1], D. W. Mittlefehldt[2] and T. H. Prettyman[3], [1]Dept. of Earth Planet. Sci., University of Tennessee, Knoxville, TN 37996 (tusui@utk.edu), [2]Astromaterials Research Office, NASA Johnson Space Center, Houston, TX 77058, [3]Los Alamos National Laboratory, Los Alamos, NM 87545.

Introduction: The Dawn mission will explore 4 Vesta [1], a highly differentiated asteroid believed to be the parent body of the howardite, eucrite and diogenite (HED) meteorite suite [e.g. 2]. The Dawn spacecraft is equipped with a gamma-ray and neutron detector (GRaND), which will enable measurement and mapping of elemental abundances on Vesta's surface [3]. Drawing on HED geochemistry, Usui and McSween [4] proposed a linear mixing model for interpretation of GRaND data. However, the HED suite is not the only achondrite suite representing asteroidal basaltic crusts; others include the mesosiderites, angrites, NWA 011, and possibly Ibitira, each of which is thought to have a distinct parental asteroid [5]. Here we critically examine the variability of GRaND-analyzed elements, K and Th, in HED meteorites, and propose a method based on the K-Th systematics to distinguish between HED and the other differentiated achondrites. Maps of these elements might also recognize incompatible element enriched areas such as mapped locally on the Moon (KREEP) [6], and variations in K/Th ratios might indicate impact volatilization of K. We also propose a new mixing model using elements that will be most reliably measured by GRaND, including K.

K-Th systematics: Combinations of volatile and refractory elements (e.g. K and La) that both behave incompatibly during igneous processes have been used to characterize various planets [e.g. 7], because ratios (e.g. K/La) reflect initial chemical compositions that are not changed significantly by later magmatic processes. The moderately volatile element K and refractory element Th are used in this study, because GRaND can accurately determine the abundances of these radioactive elements [6].

A purpose of this study is to establish a reference K/Th ratio of the HED suite for comparison with that of Vesta's surface which will be obtained by Dawn. However, whole-rock trace element chemistries in some meteorites reflect sample heterogeneity (especially for coarse grained samples), and K values in particular are sometimes disturbed by terrestrial alteration [8]. Thus, we selected unaltered HED meteorites for which K and Th abundances were reported in more than 3 analyses, and employed mean values with relative standard deviations (1σ) less than 30%. The se-

lected K-Th data show a strong positive correlation, providing a K/Th ratio of 1.0×10^3 ($R^2 = 0.7$) (Fig. 1a).
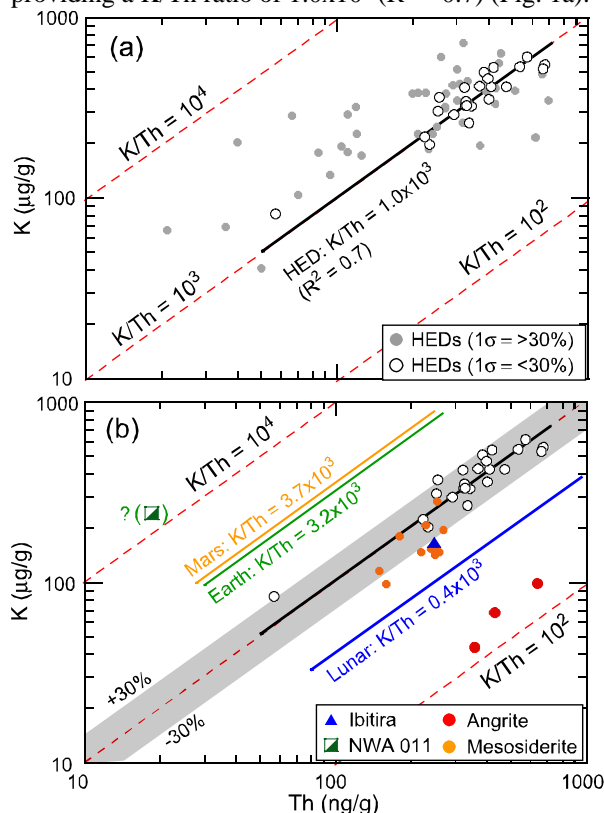

Fig. 1: (a) Whole-rock K versus Th plot for HED meteorites (mean values from the literature). The mean K and Th data with relative standard deviation (1σ%) <30%, are selected to obtain a regression line. (b) Whole-rock K versus Th plot for differentiated meteorites: Ibitira, angrites, NWA 011 and mesosiderites, along with the selected HED meteorites. A shaded area indicates ±30% from the regression line in (a). K/Th ratios for Earth (MORB and average continental crust), Mars (Martian meteorites) and the Moon (Apollo rocks and lunar meteorites) are also shown.

The K/Th ratio of the HED suite is greater than that of lunar rocks (0.4×10^3) but less than Earth (3.2×10^3) and Mars (3.7×10^3) (Fig. 1b). Mesosiderites and Ibitira have slightly lower K/Th ratios than that of HEDs, whereas angrites and NWA 011 show distinctly lower and higher K/Th values than that of HED, respectively. However, since NWA 011 is highly heterogeneous [9], its K-Th data are probably not representative. Likewise,

K-Th data for angrites, mesosiderites and Ibitira are also limited. Despite such sparse data available for these differentiated meteorites, Fig. 1b suggests that GRaND should require an analytical uncertainty for the K/Th ratio of <30 relative% (1σ) with a few hundred ppb level detection limit for Th in order to distinguish HEDs from achondrites from other parent bodies (except for some mesosiderites).

A new mixing model: A linear mixing model was proposed [4] for interpreting GRaND data, because GRaND spatial resolution is larger than that of spectral (compositional) heterogeneity of Vesta's surface. Compositions on Vesta's surface can be modeled by mixing of three end-member components: diogenite, basaltic eucrite, and cumulate eucrite. These three end-members are distinctly resolved in a two-dimensional diagram that consists of molar element ratio of [Mg+Fe]/Si and Al/Si [4]. However, reliability of the mixing model depends on how accurately and precisely GRaND determines these elements. Thus, a new mixing model is derived that specifically considers the analytical performance of GRaND for individual elements.

The Lunar Prospector Gamma Ray Spectrometer (LP-GRS) could yield information on the analytical performance of GRaND, because LP-GRS has a gamma ray sensor with approximately the same volume, detection efficiency, and pulse height resolution [10]. The most promising GRaND-analyzed elements are Fe and Th, which are associated with intense and well resolved spectral features. Abundances of Mg, K and Ti, for which individual gamma rays are not resolved, are also determined by a spectral unmixing algorithm [6]. Among the elements above, Fe, Th, K, and Ti are incompatible. Two-dimensional diagrams using only these incompatible elements (e.g. Fe *versus* K, Fig. 2a) can distinguish basaltic eucrite from diogenite and cumulate eucrite, but they cannot separate the latter two. Thus, an element pair that consists of [Mg+Fe] and K is employed for the new mixing model (Fig. 2b). The sum product [Mg+Fe] is better discriminator than Mg for separating diogenites and cumulate eucrites, whereas K could be replaced by another incompatible element Ti.

In selecting three meteorites as end-member components, we can delineate mixing lines (Fig. 2b) and thus obtain a unique value of a mixing ratio for GRaND data. Shalka, Serra de Magé and Stannern are employed as end-member components representing diogenite, cumulate eucrite and basaltic eucrites, respectively. Because these three meteorites plot near the ends of the ranges of individual meteorite groups in the mixing plot (Fig. 2b), most chemical compositions

of the Vesta's surface could likely be explained by the mixing of these three components, by postulating that the analyzed surface of Vesta is analogous to HED meteorites. Therefore, the new mixing model, based on the [Mg+Fe] *versus* K diagram, can substitute for the previous mixing model [4] if Al and Si are not measured with sufficient accuracy during the mission.
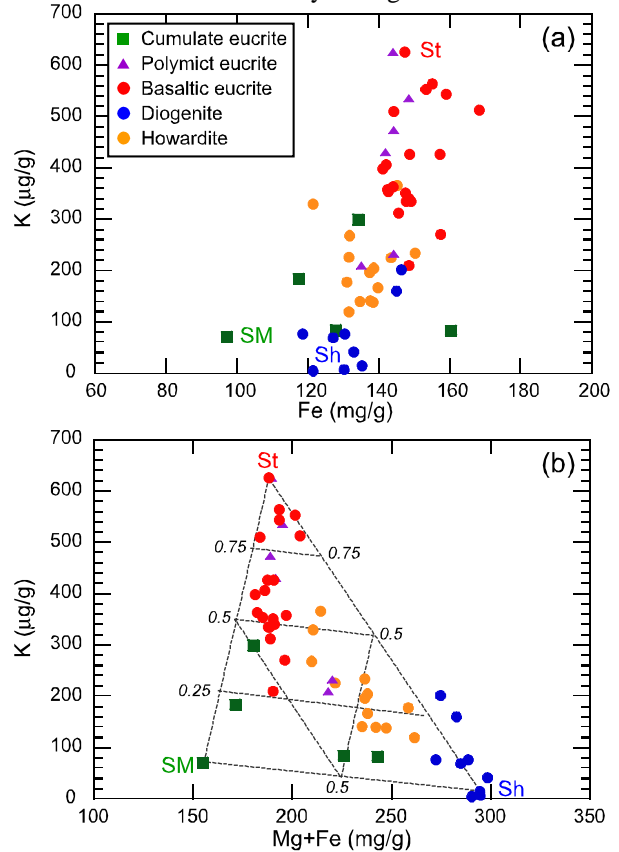

Fig. 2: (a) Whole-rock K versus Fe and (b) K versus [Mg+Fe] for HED meteorites (mean values from the same literature in Fig. 1). Lines show binary mixing calculations. Abbreviations: Sh = Shalka (diogenite); SM = Serra de Magé (cumulate eucrite); St = Stannern (basaltic eucrite).

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