INDEPENDENT COMPONENT ANALYSIS OF HED METEORITES: PROSPECTIVE STUDY FOR INTERPRETATION OF GAMMA-RAY AND NEUTRON SPECTRA FOR THE DAWN MISSION.

T. Usui[1,2] and H. Iwamori[3], [1]Johnson Space Center, NASA, Mail Code KR, 2101 Nasa Parkway, Houston, TX 77058, USA. (tomohiro.usui@nasa.gov), [2]Lunar Planetary Institute, USRA, [2]Dept. Earth Planet. Sci., Tokyo Institute of Technology.

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]. Elemental abundances of Vesta's surface will be determined by a gamma-ray and neutron detector (GRaND), but the GRaND spatial resolution (>200 km) is significantly larger than the compositional heterogeneity of Vesta's surface [3]. Thus, drawing on HED geochemistry, mixing models have been proposed for interpretation of GRaND data [4, 5]. These mixing models, however, suggest that results of mixing calculations are influenced by the selection of elements and end-member components.

This study endeavors to develop a new mixing model based on a computational statistical technique of Independent Component Analysis (ICA). The ICA enables to seek representative components from a multivariate datasets and describe their mixing relations without assuming any end-member components [e.g., 6]. The performance and reliability of the ICA model is assessed based on geochemical and petrographic observations of the HED suite.

Methods: ICA has been recently established in information science to extract latent variables from multivariate observed data [e.g., 6]. The latent variables should be mutually independent with non-Gaussian distribution and referred to as independent components (ICs); note that IC does not indicate a geometric point but a vector in the compositional space. This study employs an ICA computer algorithm (FastICA) [7] to investigate bulk-rock compositions of 58 HED meteorites for 8 elements: Si, Ti, Al, Cr, Fe, Mn, Mg, and Ca. The results are shown in 3-dimensional (3D) plots, instead of conventional 2D plots, to better exhibit compositional structures of the HED meteorites and their potential ICs.

Results & Discussions: The ICA of the HED meteorites indicates that their bulk-rock compositions can be reduced into three ICs: IC-1, -2, and -3 (Fig. 1).

IC-1 represents a compositional variation of basaltic eucrites that extends from main-group (MG) eucrites toward incompatible-element (e.g., Ti) enriched eucrites (defined as Nuevo Laredo and Stannern trends [e.g., 8]) (Fig. 1a-b). Cumulate eucrites, which are more magnesian than basaltic eucrites, plot on the incompatible-element depleted side of IC-1. These suggest that IC-1 represents magmatic evolution of eucrites (e.g., crystal fractionation).

IC-2 represents a compositional variation of howardites and polymict eucrites that extends from diogenites to the MG-eucrites (Fig. 1a-b). Fig. 1c clearly indicates that cumulate eucrites (except for Binda) cannot be a major component of howardites because they plot outside of the howardite mixing trend bracketed by the diogenites and the MG-eucrites. This is consistent with petrographic observations that howardite are mixtures of diogenites and basaltic eucrites, although some howardites and polymict eucrites contain substantial cumulate eucrite components [e.g., 9].

IC-2 further indicates that the basaltic eucrite components in howardites are dominated by the MG-eucrites but not by the Nuevo Laredo- or Stannern-trend eucrites (Fig. 1a-b). Though identification of such specific basaltic eucrite components is petrologically difficult, similar results were reported by minor and trace element geochemical studies of the HED suite [10, 11].

IC-3 extends almost parallel to a trend defined by diogenites and olivine-bearing diogenites, suggesting mixing of olivine and orthopyroxene (Fig. 1a-b). This is consistent with the fact that these meteorites represent a suit of cumulate orthopyroxenites, harzburgites (ol+opx), and dunites (ol) [12, 13]. However, these cumulates are thought to be derived from different geochemical sources, and their constituent olivines and orthopyroxenes are compositionally individually different (e.g., Mg#) [12, 13]. Thus, IC-3 represents the olivine-orthopyroxene mixing, but it is not the simple mechanical mixing of these minerals with uniform compositions.

A few diogenites (Yamato Type-B) have higher TiO_2 (~0.25wt%), Al_2O_3 (~3.5 wt%), FeO (~19wt%), and CaO (~3.5wt%) contents, resulting in higher eucrite components than the other diogenites (Fig. 1). This is consistent with geochemical and petrographic observations that suggest that the Yamato Type-B diogenites would be intermediate between diogenites and eucrites [14].

Some polymict-HED breccias are known to contain substantial amounts of exogenous chondritic materials [e.g., 10]. These breccias are characterized by higher abundances of siderophile elements (e.g., Ni and Co) than typical monomictic eucrites and diogenites. An

ICA model including these siderophile elements may detect another IC that represents the mixing of such chondritic materials.

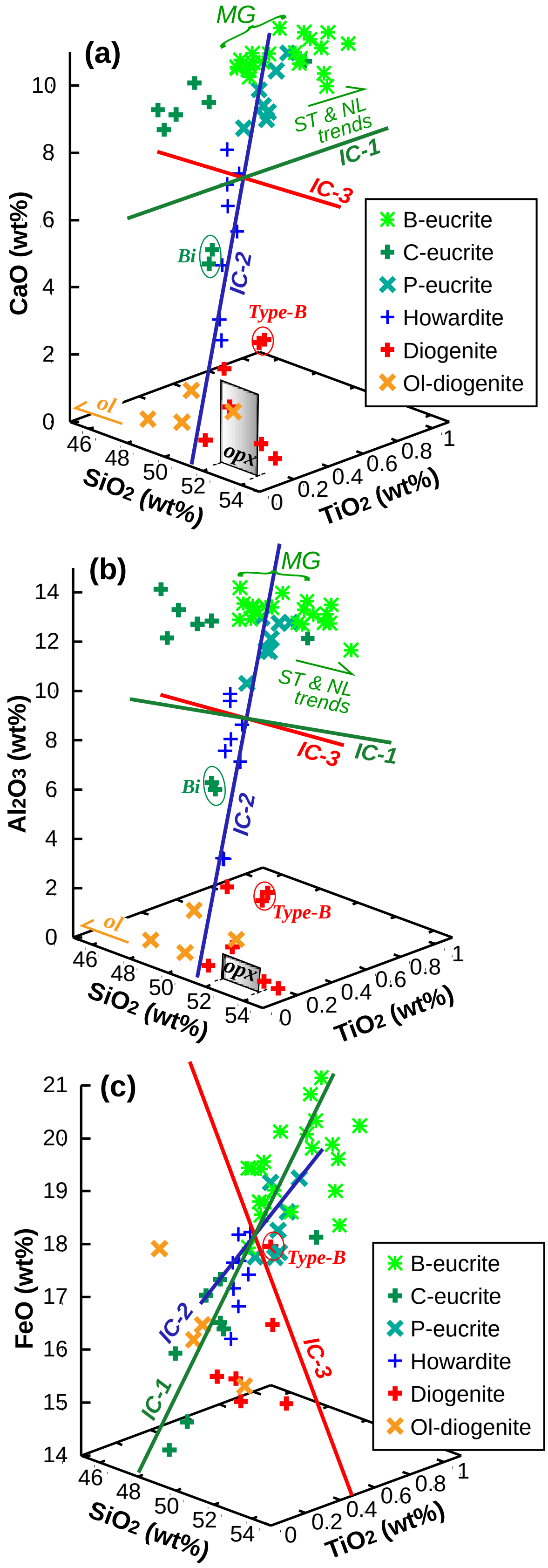

Figure 1: 3D plots of the 8-component ICA of the HED meteorites: (a) SiO_2-TiO_2-CaO, (b) SiO_2-TiO_2-Al_2O_3, (c) SiO_2-TiO_2-FeO. IC-1, -2, and -3 are shown as green, blue, and red lines, respectively. Approximate compositional ranges of olivines and orthopyroxenes in diogenites and olivine diogenites are also shown. Abbreviations: B-eucrite = basaltic eucrite; C-eucrite = cumulate eucrite; P-eucrite = polymict eucrite; Ol-diogenite= olivine diogenite, ol = olivine; opx = orthopyroxene; Type-B = Yamato Type-B diogenite (Y-75032, Y-791199); MG = main group; Bi = Binda; ST = Stannern; NL = Nuevo Laredo. Data sources are given in [4]

Our study demonstrates that the 8-component ICA can reasonably explain the compositional variations and the mixing relations of the HED suite based only on their bulk-rock compositions. However, prospective GRaND-analyzed elements are expected to be not as much as the 8-elements used in this model [3]. The next step is to revise the 8-component ICA model, without significant degradation of its performance, by reducing the components to employ only the GRaND-analyzed elements.

References: [1] Russell, C.T., et al. (2004) *Planet. Space Sci.*, *52*, 465-489. [2] Binzel, R.P. and Xu, S. (1993) *Science*, *260*, 186-191. [3] Prettyman, T.H., et al. (2003) *IEEE Trans. Nucl. Sci.*, *50*, 1190-1197. [4] Usui, T., et al. (2010) *MAPS*, *45*, 1170–1190. [5] Usui, T. and McSween, H.Y. (2007) *MAPS*, *42*, 255-269. [6] Hyvarinen, A., et al., *Independent Component Analysis*. 2001, p. 504. [7] Hyvarinen, A. (1999) *IEEE Transactions on Neural Networks*, *10*, 626-634. [8] Stolper, E. (1977) *GCA*, *41*, 587-611. [9] Mittlefehldt, D.W., *Achondrites*, in *Meteorites, Comets, and Planets*, 2003. p. 291-324. [10] Warren, P.H., et al. (2009) *GCA*, *73*, 5918-5943. [11] McSween, H., et al. (2010) *Space Science Reviews*, 1-34. [12] Mittlefehldt, D.W. (2000) *MAPS*, *35*, 901-912. [13] Mittlefehldt, D.W., et al. (in press) *MAPS*. [14] Mittlefehldt, D.W. and Lindstrom, M.M. (1993) *Proc. NIPR Symp. Antarct. Meteorites*, *6*, 268-292.