Petrologic and oxygen-isotopic investigations of eucritic and anomalous mafic achondrites

Conference or Workshop Item

PETROLOGIC AND OXYGEN-ISOTOPIC INVESTIGATIONS OF EUCRITIC AND ANOMALOUS MAFIC ACHONDRITES. D. W. Mittlefehldt[1], R. C. Greenwood[2], Z. X. Peng[3], D. K. Ross[3,4], E. L. Berger[5], and T. J. Barrett[2], [1]Astromaterials Research Office, NASA Johnson Space Center, Houston, TX, USA (david.w.mittlefehldt@nasa.gov), [2]Dept. of Physical Sciences, The Open University, Milton Keynes, UK, [3]Jacobs Technology, NASA Johnson Space Center, Houston TX, USA, [4]UTEP-CASSMAR, [5]GCS-Jacobs JETS-NASA Johnson Space Center, Houston, TX USA.

Introduction: The most common asteroidal igneous meteorites are eucrite-type basalts and gabbros – rocks composed of ferroan pigeonite and augite, calcic plagioclase, silica, ilmenite, troilite, Ca-phosphate, chromite and Fe-metal [1]. These rocks are thought to have formed on a single asteroid along with howardites and diogenites (HEDs). However, Northwest Africa (NWA) 011 is mineralogically identical to eucrites, but has an O-isotopic composition distinct from them and was derived from a different asteroid [2]. Modern analyses with higher precision have shown that some eucrites have smaller O-isotopic differences that are nevertheless well-resolved from the group mean [3-5].

Divalent Mn and Fe are homologous species that do not greatly fractionate during igneous processes. Distinct parent body FeO/MnO are caused by nebular fractionations that engender differences in Fe^0/Fe^{2+}, Fe^{3+}/Fe^{2+}, Fe^{total}/Mn and/or Fe^{total}/S. Because of this, mafic mineral Fe/Mn can be used to fingerprint parent object sources [6]. Oxygen-anomalous NWA 011 also has pyroxene Fe/Mn distinct from that of O-normal eucrites [2]. Ibitira, which displays a much smaller O-isotopic anomaly [3, 4], has a resolvable difference in pyroxene Fe/Mn from normal eucrites [7].

We present the results of petrologic and O-isotopic studies of eucrites, and eucrite-type achondrites that are anomalous in O-isotopic composition *and/or* petrologic character (indicated here by blue font). Companion Cr isotopic studies on some of the meteorites discussed here are reported in [8].

Petrology: Including previous work done at JSC, we discuss six cumulate gabbros; Allan Hills (ALH) 85001, Elephant Moraine (EET) 87548, Moore County [9], Yamato (Y-) 791195 [10], Asuka (A-) 881394 and EET 92023, and 20 basalts; Bates Nunataks (BTN) 00300, Dominion Range (DOM) 08001, EET 87520, EET 90020, Grosvenor Mountains (GRO) 06059, Larkman Nunatak (LAR) 06875, Miller Range (MIL) 05041, MIL 07004, MIL 11290, Orlando, Sioux County, Stannern, Y-793164 (basalt clast) [10], Emmaville [11], EET 87542, Graves Nunataks (GRA) 98098, Ibitira [7], Pecora Escarpment (PCA) 82502, PCA 91007 and Queen Alexandra Range (QUE) 94484.

We focus on pyroxene compositions using their Fe/Mn to demonstrate differences. Eucrite-type mafic achondrites have been metamorphosed and their pigeonite contains augite exsolution lamellae [12]. We use only low-Ca pyroxenes for comparisons because Fe and Mn partition differently in pigeonite and augite. Cumulates and basalts are compared separately because pigeonite/melt partitioning results in a modest increase in pyroxene Fe/Mn during crystallization.

Cumulate eucrites show the expected increase in Fe/Mn with Fe/Mg (Fig. 1a). A-881394 pyroxenes have slightly lower Fe/Mg but slightly higher Fe/Mn than that of EET 87548. The relative probability distributions for their pyroxene Fe/Mn overlap (Fig. 1b), but their means are different at the 99% confidence level; A-881394 is anomalous in Fe/Mn. EET 92023 has pyroxene with Fe/Mg slightly higher than that of Moore County but much higher Fe/Mn (Figs. 1a, b); its pyroxene is anomalous with a mean Fe/Mn different from that of Moore County at the 99% confidence level. This cumulate contains ~0.5 vol% Ni-rich metal [13, 14], an anomalous characteristic among eucrites.

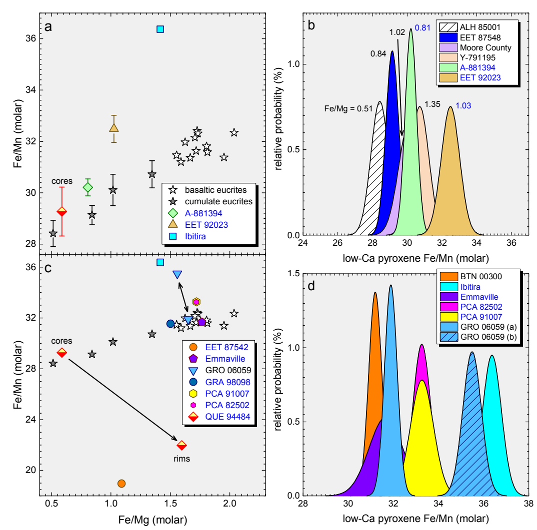

Figure 1. Low-Ca pyroxene compositions for cumulates (a, b) and basalts (c, d).

Pyroxene compositions of O-anomalous metabasalt Emmaville cannot be distinguished from normal basaltic eucrites (Fig. 1c) [11]; its pyroxene Fe/Mn relative probability distribution overlaps those of normal eucrites (e.g., BTN 00300; Fig. 1d). PCA 82502 and PCA 91007 are identical, brecciated, vesicular, fine-grained basalts containing pyroxenes with identical compositions that are resolvable from normal eucrites in Fe/Mn (Figs. 1c, d). Petrologically anomalous QUE 94484 is an unbrecciated, unequilibrated basalt with astonishingly lower Fe/Mn in pyroxene rims compared to cores (Fig. 1c) [14, 15]. Core compositions mimic cumulate eucrite pyroxenes (Fig. 1a) and are consistent with early-crystallized pyroxene from a normal eucritic magma. EET 87542 is a brecciated, Fe-metal-rich basalt with the lowest Fe/Mn among mafic achondrites (Fig. 1c). GRA 98098 is a metamorphosed basalt with cm-sized tridymite forming veins. It contains unusually Cl-rich Ca-phosphates [16], but has pyroxene compositions within the range of normal basaltic eucrites (Fig. 1c). GRO 06059 is a brecciated rock that contains two populations of low-Ca pyroxene; most grains are normal in Fe/Mn but several isolated grain fragments have Fe/Mn like that of Ibitira (Fig. 1 c, d).

Oxygen Isotopic Compositions: Oxygen isotope analyses have been done on EET 87520, EET 87542, EET 92023, GRA 98098, PCA 82502 and QUE 94484 (Fig. 2). Our analysis of EET 92023 confirms its anomalous O-isotopic composition [17] with a $\Delta^{17}O'$ within ranges found for A-881394 [5] and Bunburra Rockhole [18]. PCA 82502 has a $\Delta^{17}O'$ just outside the 3σ confidence limit on the HED mean used to identify O-anomalous mafic achondrites [19], and plots close to analyses of PCA 91007 with which it is paired on petrologic grounds. EET 87520, EET 87542, GRA 98098 and QUE 94484 are isotopically normal.

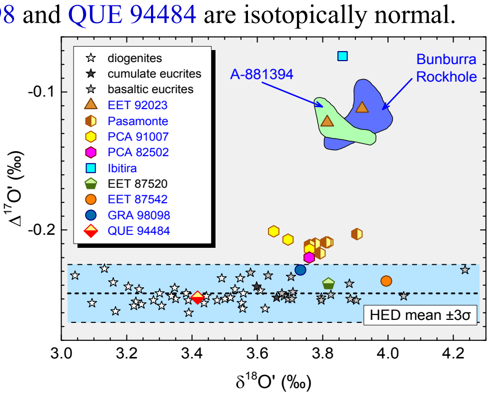

Figure 2. O-isotope compositions of mafic achondrites, diogenites and eucrites; this study and [4, 5, 17-19].

Discussion: The anomalous petrologic characteristics of EET 87542 and QUE 94484 are caused by late-stage reduction of FeO engendering the anomalous pyroxene Fe/Mn (Fig. 1c) [15, 20]. Their normal O-isotopic compositions (Fig. 2) argue that this occurred on the HED parent asteroid. GRA 98098 has pyroxene Fe/Mn and O-isotope compositions indistinguishable from normal basaltic eucrites and we conclude that it, too, hails from the HED asteroid. (See [8] for Cr isotopic results.) PCA 82502 and PCA 91007 have coupled O-isotopic and pyroxene-composition anomalies (Figs. 1d, 2). Their $\Delta^{17}O'$ are more than 3σ from the HED mean, and at the 99% confidence level, each of their mean pyroxene Fe/Mn are different from that of average normal basaltic eucrite. The paired PCA basalts are unusual in containing vesicles, rare in basaltic eucrites, suggesting their magma contained higher volatile contents. These anomalous characteristics favor the hypothesis that they are derived from a different asteroid, which might include Pasamonte (Fig. 2) [5]. Cumulate gabbros A-881394 and EET 92023 are distinguishable from cumulate eucrites in pyroxene Fe/Mn (Fig. 1) and vastly so in $\Delta^{17}O'$ (Fig. 2), suggesting separate asteroids. A-881394 contains more calcic plagioclase than does EET 92023, An_{98} vs. An_{89-94}, and the difference in their pyroxene Fe/Mn is greater than seems consistent with igneous fractionation (Fig. 1a). This suggests that these rocks are from two different asteroids. (See [8] for Cr isotopic results.)

Our analyses of GRO 06059 indicate caution should be used in interpreting the petrologic data. The two pyroxene populations in it occupy both ends of the Fe/Mn range from normal basaltic eucrites to Ibitira (Fig. 1). GRO 06059 is a breccia containing different lithologic components, including impact-melt clasts; it might be a polymict eucrite. The high-Fe/Mn pyroxenes are grain fragments in the matrix; their parent lithology has yet to be identified. Continuing petrologic work on it will focus on understanding the origin of its pyroxene Fe/Mn populations.

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