Major and Trace Element Characterization of Pyroxenes in Polymict Eucrite Northwest Africa 6475: Contrasts with Juvinas, Stannern and Igdi, and Evaluation of Models for Eucrite Magmatic Evolution.

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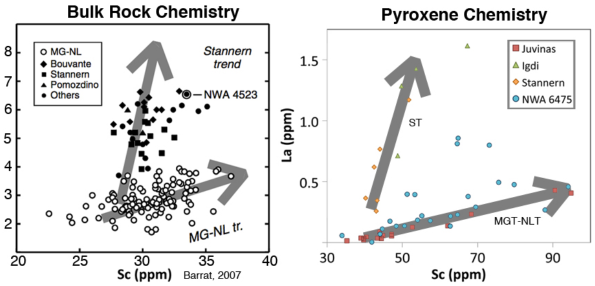
Introduction: Eucrites are the mafic component of the howardite, eucrite and diogenite (HED) suite of related meteorites [1]. It is believed that they formed the crustal lid above a magma ocean on a differentiated, small asteroid, presumably the asteroid Vesta or similar [2]. Three chemical groupings of eucrites have been observed [3]: the main group (MGT), comprising the majority of eucrites; the Nuevo-Laredo trend (NLT) with higher Fe content; and the Stannern trend (ST) with higher incompatible elements (eg: Ti, REE, etc). Existing models consider MGT eucrites to be the primitive eucrite magma compositions, while NLT eucrites are related to MGT eucrites by crystal fractionation of pyroxenes [4], and ST eucrites by partial melting of existing solid eucrites and reincorporation into primitive magmas [5].

We have compared the major, minor and trace element chemistry of pyroxenes from petrologically diverse clasts in the polymict eucrite NWA 6475 with specimens of Juvinas (MGT), Igdi (NLT) and Stannern (ST) (Fig. 1) in order to examine (1) the degree of chemical heterogeneity among different trends of eucrites and (2) the degree of chemical heterogeneity among different petrologies from a single meteorite. In light of our observations, we discuss the viability of existing models relating the three trends, which generally either do not couple major and trace element variations (eg: [5,6]), and/or fail to address variations in compatible trace elements (eg: [4,7]).

Polished slices of each meteorite were imaged by SEM and analyzed by electron microprobe (University of Washington) while pyroxene trace element concentrations were determined by LA-ICPMS (Washington State University).



Barrat, 2007

Figure 1. *Bulk compositions for the three eucrite trends [5] alongside pyroxene compositions for the three representative meteorites and NWA 6475. Arrows indicate typical trends. Note that Igdi pyroxenes have anomalously high La concentrations.*

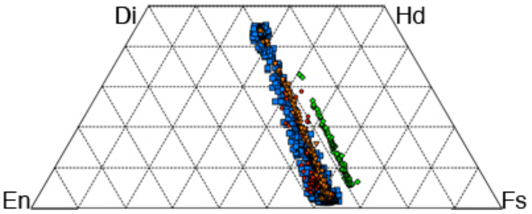


Figure 2. *Pyroxene compositions for 97 clasts in NWA 6475 (blue), Juvinas (red), Stannern (orange) and Idgi (green).*

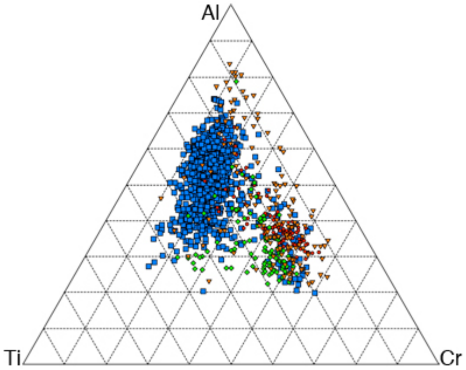


Figure 3. *Minor element variation for pyroxenes (color coding same as in Figure 2).*

Results: There is considerable overlap in pyroxene major and minor element compositions between Juvinas and Stannern (Fe/Mg of 2.65 and 2.73 respectively), while Igdi pyroxenes have significantly higher Fe/Mg ratios averaging 3.57 (Fig. 2 & 3). REE patterns can readily discriminate among these 4 different eucrites (Fig. 4), in particular, La abundance and La/Sm ratio. La is 0.05 ppm for Juvinas, 0.56 ppm for Stannern and 1.62 ppm for Igdi. La/Sm averages 0.15 for Juvinas, 0.61 for Stannern and 0.84 for Igdi.

Despite the wide textural variation among the 97 analyzed NWA 6475 eucritic clasts (from ophitic to varying sizes of granulitic), the pyroxenes have a narrow compositional range: Fe/Mg varies between 2.3 and 2.8, averaging 2.59. La is between 0.058 ppm and 1.19 ppm, averaging 0.36 ppm, similar to Stannern. La/Sm averages 0.19, similar to Juvinas.

Oxygen Isotopes: Acid-washed subsamples of a eucrite clast in NWA 6475 were analyzed in replicate for oxygen isotopes by laser fluorination (in per mil):

$\delta^{18}O$	$\delta^{17}O$	$\Delta^{17}O$
3.557, 3.550	1.630, 1.639	-0.242, -0.230

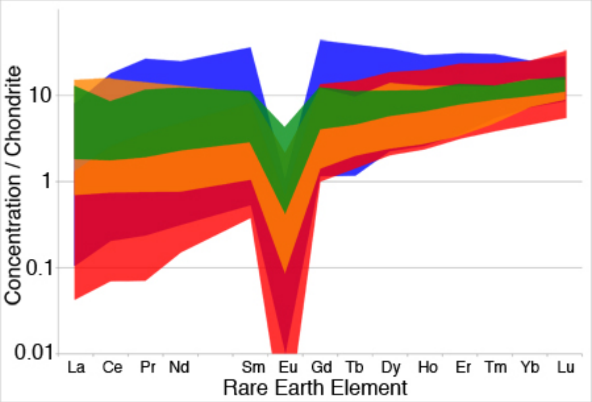


Figure 4. *Chondrite-normalized REE patterns for pyroxenes in 24 clasts in NWA 6475 (blue), Juvinas (red), Stannern (orange) and Idgi (green). Note that field widths are the observed range, not statistical distributions.*

Since these results plot in the middle of the field for typical eucrites [8], they are inconclusive in establishing whether NWA 6475 was derived from a separate parent body than most eucrites (including Juvinas and Stannern), but they do exclude any genetic relationship with otherwise similar eucrites such as Ibitira, NWA 2824 and Bunburra Rockhole [9] that have less negative Δ^{17}O values.

MGT → NLT Modeling: The difference in Fe/Mg ratios between MGT and NLT has been interpreted as a consequence of crystal fractionation of a typical MGT magma [4]. To test this hypothesis, we calculated a model crystallization sequence for a typical eucrite bulk composition utilizing MELTS [10]. Compositions modeled included Pasamonte, ALHA 76005, and an average of typical eucrite bulk compositions from the recent literature [11] with negligible variation in the model results. The results approximately reproduce the observed mineralogy in eucrites and confirms that Fe/Mg ratio should rise with differentiation. However, minor and trace elements will also vary significantly during crystal fractionation. Particularly, Cr is very compatible in pyroxene [12], so its abundance should correlate inversely with Fe/Mg ratios. This is not observed between Juvinas and Igdi pyroxenes, where there is little variation in Cr content (Fig. 2) but significant differences in Fe/Mg ratios. In addition, NWA 6475 pyroxenes, which typically have low Fe/Mg ratios, have the lowest Cr content of the meteorites studied. These results are consistent with literature data [13], which show no correlation between Fe and Cr content in pyroxenes from a subset of 20 MGT meteorites. Hence the observed geochemical trend in MGT to NLT pyroxenes requires either (1) a more complex process if they are genetically related, or (2) they are not cogenetic.

MGT → ST Modeling: The existing model to relate the MGT and ST is partial melting and reincorporation of solidified eucritic material into primitive eucritic magmas resulting in an increased REE abundance without a significant change in major element chemistry [5]. Partial melting of a eucritic composition results in an increase in Fe/Mg in the resulting melt, even if it can be small. Hence, in increase in REE abundance cannot be accompanied by a decrease in Fe/Mg. However, NWA 6475 has higher average REE abundance and lower Fe/Mg than for Juvinas. This conflict can be resolved in a number of ways: (1) the existence of a sub-MGT Fe/Mg source magma (contrary to [4] and subsequent work), (2) identification of NWA 6475 as a eucrite not originating on the common eucrite parent body, or (3) or rejection of the current mechanism relating MGT and ST eucrites.

Conclusions: There are significant difficulties with the proposed mechanisms to relate eucrites from the various chemical trends. A wide textural variety of clasts in polymict specimen NWA 6475 exhibits only minor variations in major, minor and trace element chemistry. Fe/Mg and Cr content do not inversely vary, as expected if cogenetic, making crystal fractionation mechanisms unlikely to produce the variation between the MGT and NLT eucrites. Variation in REE abundance does not correlate with changes in Fe/Mg ratio for all eucrites, causing difficulty in relating MGT and ST eucrites along a differentiation path. Our chemical data support the hypothesis that eucrites may not share a common origin, but represent materials from multiple similar parent bodies from the early solar system.

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