An Alternative Model for the Origin of the Stannern Trend Eucrites: Incompatible Element Depletion. N. Castle[1,2], C. D. K. Herd, [1]Lunar and Planetary Institute, USRA, Houston, Texas, USA, [2]Department of Earth and Atmospheric Sciences, University of Alberta, Edmonton, Alberta, Canada (castle@lpi.usra.edu).

Introduction: The eucrite meteorites, as the basaltic member of the HED meteorite suite [1], represent the primitive crust on a small differentiated body formed early in the solar system [2, 3], potentially the asteroid Vesta [4-8]. Eucrites are divided into several chemical classes [9-11]. The main group (MG), which is the dominant eucrite composition, is thought to represent the composition of a magma ocean from which the eucrites formed [12, 13]. The Nuevo-Laredo trend (NLT) is a fractional crystallization trend extending from the MG to lower Mg# with an increasing incompatible trace element (ITE) abundance. The Stannern trend eucrites (ST) have Mg# like the MG, but with significant enrichments in ITE. Cumulate eucrites (CE), have higher Mg# than the MG, and widely varying ITE contents; their compositions are (mostly) explicable as partial crystal cumulates from MG-NLT eucrite magmas [14-16]. Interpretation of eucritic history is made complicated by pervasive metamorphic overprinting that has erased igneous zoning from mineral grains in most eucrites [17-19].

The compositions of Stannern trend eucrites are difficult to reconcile with a magma ocean as it is difficult to generate ITE enrichment without decreasing Mg# [20]. One of the most successful models to date, from Barrat et al. [21], calls for ITE enrichment by incorporation of low-degree partial melts from pre-existing eucritic crust, likely occurring in small magma chambers isolated within the crust. We have performed a series of experiments on an unmetamorphosed eucrite (Northwest Africa [NWA] 7035) to test this Barrat model, and here present an alternative interpretation - that the Stannern trend represents ITE depletion from a relatively ITE-enriched magma ocean, rather than enrichment.

Sample and Methods: We selected NWA 7035 as starting material as a reasonable analogue for pristine (unequilibrated) eucritic crust. It is an unusual eucrite because it retains igneous zoning in pyroxene grains, with mineral compositions that span the range of typical (metamorphosed) eucrites. NWA 7035 is comparable to the more familiar eucrite, Pasamonte.

Starting materials were sub-sample tiles from slice MET 11633/1 of NWA 7035 (U. Alberta Meteorite Collection), which were heated by up to ~100°C above its solidus under a CO-CO_2 gas at ~IW. Most samples were held for 1 week, except for one run that lasted a day (sample C). The product mineral and glass compositions were determined by EMPA and LA-ICP-MS, and compared to the unheated sample. Bulk trace elements were determined by solution ICP-MS.

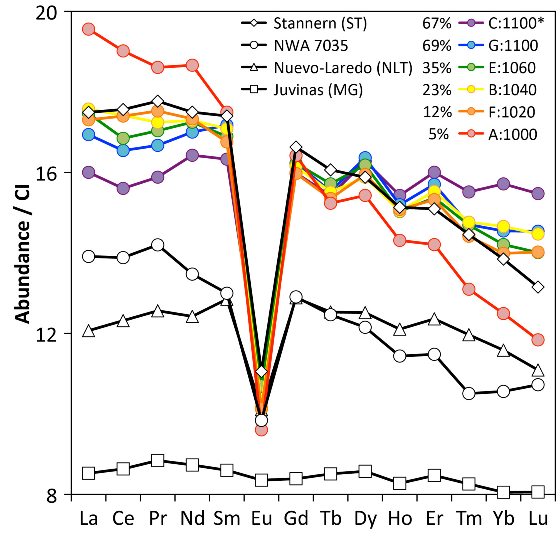

Figure 1: Best-fit REE compositions for calculated mixtures of experimental melts and Juvinas. The bulk compositions of Juvinas (MGT), Stannern (ST), and Nuevo-Laredo (NLT) are from [21]; the bulk composition of NWA 7035 is also shown for comparison.

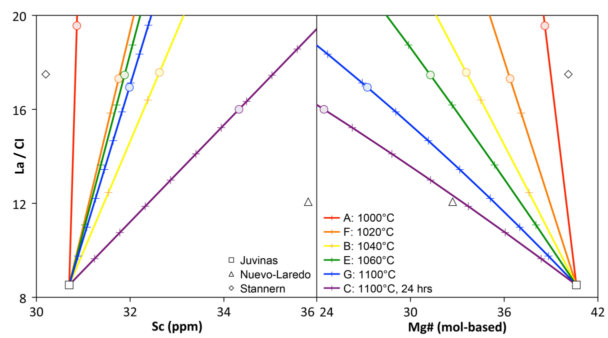

Figure 2: a) La-Sc mixing curves for the Juvinas bulk composition [21] with experimental melts. Sc is typically used as a trace element proxy for Mg#, but is sensitive to the ratio of pyroxene and plagioclase due to opposite partitioning behaviors in these minerals. b) La-Mg# mixing curves for the Juvinas bulk composition [21] compared with experimental melts. Colored circles represent mixtures from Fig. 1; tics are at 10% intervals of mixing.

Results and Discussion: Melt was formed in experiments as low as 1000°C, ~80°C below the previously reported solidus [22]. All experimental glasses have ITE contents substantially higher than Juvinas (i.e, the MG), and so could in theory be suitable contributors to Stannern-like rare earth element (REE) patterns (**Fig. 1**). Similar mixing curves can be generated for other elements, including Sc (**Fig. 2a**) and major elements (e.g., Mg#, **Fig. 2b**).

It is remarkable that all of the partial melts can be mixed with MG eucrites to produce Stannern-like REE patterns, but other elements do not match so easily. For Sc, a better match for the ST might be achieved if a longer equilibration time were allowed: C and G (purple and blue) were both run at 1100°C, but C was only equilibrated for one day. The much lower Sc content of G suggests that if the system were equilibrated for an even longer duration it may result in a lower Sc content melt.

The difficulty in matching major elements, e.g. Mg# (Fig. 2b), is not easily resolved. To generate a less ferroan partial melt would require melting of a different eucrite - a zoned eucrite with a less ferroan rim composition. To match the ST, the rim composition would have to be no more ferroan than the MG; this implies a cumulate composition, excepting in the case of ideal equilibrium crystallization. Two difficulties arise: first, the more magnesian the compositon, the higher the solidus temperature and, therefore, the less likely the rock is to participate in melting; if there are more ferroan materials present, they should melt before these cumulates would melt. Second, the relative rarity of CEs makes it unlikely that cumulates would be melted to the exclusion of the, more typical, basaltic compositions. The combination of these two factors suggests that under the Barrat model there should be a correlation between Mg# and ITE enrichment in ST eucrites, which is not observed.

While it is difficult to enrich a magma in ITE without affecting other elements, it is comparatively easy to deplete an unequilibrated rock, particularly one with an ITE-rich mesostasis. Notably, the majority of the ITE content of NWA 7035 was incorporated in the melt at a low degree of melting in our experiemtns – further melting did little to change the ITE content of the restite. If the partial melt could be extracted, then this would leave behind an ITE-depleted sample. As the degree of ITE depletion is relatively insensitive to melting, the ITE concentration in the restite should be readily reproducible, as long as the majority of the mesostasis is involved in the melting.

There is some evidence that extraction of low-degree partial melts did occur on the HED parent body. Some zoned eucrites have ferroan zones along fractures and pyroxene grain boundaries, consistent with metasomatism by a ferroan fluid [23-26]. These zones typically contain troilite and fayalite, and, at high degrees, anorthitic plagioclase. There is some debate over the origin of this metasomatism [24], but similar textures were produced in our (anhydrous) experimental charges (**Fig. 3**), suggesting that infiltration by partial melts of eucritic material is responsible.

The pervasiveness of metamorphosed eucrites may also support this argument. Most eucrites, whatever their composition, have homogeneous pre-exsolution pyroxene compositions. It is easy to imagine that such a pervasive metamorphic event, resulting in such widespread homogenization of pyroxene grains, could have a peak metamorphic temperature a few tens of degrees above the solidus. If this is the case, then the Stannern trend would result not from ITE enrichment of a magma, but by varying degrees of efficiency of extraction of the resulting low-degree partial melts. A major implication of this hypothesis is that it would change the estimate of ITE concentrations in the magma ocean to be within or greater than the ST.

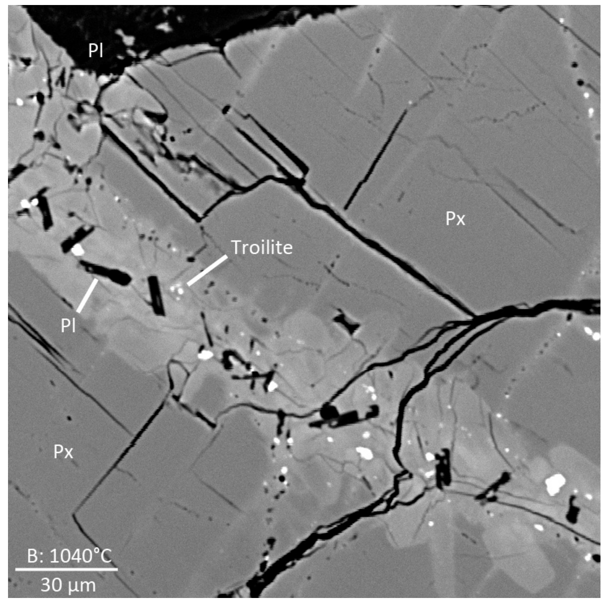

Figure 3: BSE image of a ferroan zone along a gracture in a pyroxene grain, caused by infiltration of a partial melt. Also present are fayalite and troilite grains (bright), and plagioclase laths (dark).

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