FORMATION OF TI-CR FRACTIONATION TRENDS IN HOWARDITE PYROXENE. J. S. Boesenberg[1] and I. R. Erb[2], [1]Earth and Planetary Sciences, American Museum of Natural History, Central Park West, New York, NY 10024, bosenbrg@amnh.org, [2]Wellesley College, 21 Wellesley College Rd., Wellesley, MA 02481, ierb@wellesley.edu.

Introduction: Last year, [1] reported on the petrology and chemistry of the Winterhaven howardite. An interesting aspect of this howardite was the presence of an unusual Ti/(Ti+Cr) versus Fe/(Fe+Mg) trend found in the pyroxene (Fig. 1) and chromite - ulvospinel. The trend suggests that the diogenitic and eucritic clasts in Winterhaven formed during a single, continuous fractional crystallization sequence, much like that originally suggested by [2, 3] for diogenite and eucrite formation. We have analyzed an additional ten howardites to determine the different types of Ti/(Ti+Cr) versus Fe/(Fe+Mg) trends that exist in howardite pyroxenes and how these trends support or refute diogenite and eucrite formation models. We have also analyzed the unequilibrated eucrite, Pasamonte.

Samples and Technique: Ten howardite thin sections (Bholghati 4243-3, Bialystok 4007-1, Chaves 4022-1, Hughes 005 4843-1, Le Teilleul 650-2, Luotolax 4085-1, Mundrabilla 020 4803-1, Pavlovka 525-2, Petersburg 2252-1, Zmenj 437-1) and one eucrite section (Pasamonte 4460-1) from the American Museum of Natural History meteorite collection were analyzed by electron microprobe. Profiles from core to rim were made on 20 to 60 pyroxene grains from assorted clasts and mineral fragments of various sizes from each section. The only clasts that were excluded were obvious impact-melt clasts, which still contained glass.

Results & Discussion: The diverse Ti/(Ti+Cr) vs. Fe/(Fe+Mg) trends found in pyroxene in 11 howardites and one eucrite are shown in Figure 1. There are six different identifiable patterns seen in the data. 1) Winterhaven, at present, is still the most unusual having a trend that resembles an exaggerated square root symbol. Both early chromite and later ilmenite fractionation during pyroxene crystallization appear to cause this complex trend [1]. 2) Le Teilleul (top right) has a trend similar to Winterhaven, but is missing the late, high Fe, decreasing Ti portion of the trend. Texturally, Winterhaven and Le Teilleul are quite similar, though Le Teilleul contains substantially fewer basaltic clasts. 3) Bialystok pyroxene (center, top row) has a steadily increasing trend possibly reflecting a simple single trajectory fractionation sequence. Bialystok ilmenite seems to have crystallized following the exhaustion of pyroxene from the melt. 4) Hughes 005 and Petersburg pyroxene trends resemble that of Pasamonte, the unequilibrated eucrite (second row). They have a comma-like shape, with an initial shallow, but increasing slope, followed by a nearly vertical increase in Ti/(Ti+Cr) with constant Fe/(Fe+Mg). Shallow slopes at low Ti/(Ti+Cr) values probably reflect buffering of melt to constant Ti/(Ti+Cr) by early chromite. When Cr drops below the chromite saturation level, but prior to ilmenite becoming the liquidus oxide phase, Ti rises in the pyroxene. Nearly all of the augites found in the meteorites with this type of pattern contain the most Ti- and Fe-rich compositions. Pasamonte was analyzed to determine the shape of a simple eucrite fractionation sequence. 5) Bholghati, Chaves and Luotolax (third row) have trends similar to Bialystok pyroxene, but show much greater scatter. This scatter is possibly caused by diffusion of Ti into ulvospinel during metamorphism, where loss of Ti obscures and overprints the original crystallization trend. The broadening trend could also result from multiple trends being superimposed on each other – i.e., these howardites may contain samples of multiple magmatic systems. 6) Mundrabilla 020, Pavlovka and Zmenj (bottom row) are examples of what one might expect to find in nearly all of the howardites – multiple, short trends or unconnected clusters, consistent with howardites as impact-gardened breccias, where clasts of unrelated rock types are brought together to form a new rock.

Since we find that 8 of 11 howardites contain continuous, extensive diogenite-eucrite pyroxene trends and these trends vary in their shapes and slopes, a reconsideration of how the HED meteorites are interpreted appears to be necessary. The first implication is that many diogenite, cumulate eucrite and eucrite clasts in individual howardites are directly related to one another by fractionation. If this is true, then by extension of this logic, individual diogenite, cumulate eucrite and eucrite meteorites may also form sets with different types of fractionation trends. The problem is that at present we have no way of determining which specific samples go together to form these three-member sets. Second, each set likely derives from a different provenance of Vesta and results in slightly different chemistries and trends. (See J. S. Delaney's "Stratigraphy of Vesta" abstract in this volume). It is possible that some sets may only contain two members (i.e., diogenite plus cumulate eucrite, without eucrite). All of the sets probably experienced a similar basic fractionation process, but the details differ from set to set, based on local melting, geology and crystallization characteristics. The Nuevo Laredo and Stannern eucrites might be two prime examples of this phenomena, with each lacking known, specific complementary diogenite and cumulate eucrite samples.

Models by [4],[5],[6],[7] and [8] could be in basic agreement for producing single fractionation sequences as we suggest and would only require minor modification, if any. The model of [9], however, that suggests that noncumulate eucrites derived from a single liquid (magma ocean), independent of diogenites, may not be consistent with our results.

Additional analyses may be needed on Mundrabilla 020, Pavlovka and Zmenj pyroxene to verify the lack of extensive, continuous trends like those in other howardites. Additional howardites and eucrites will be analyzed in the future to expand the database, establishing crystallization trends linking the HED meteorite suite, and clarifying Vesta's petrogical history.

References: [1] Boesenberg J. S. (2010) *LPS XLI*, 1787. [2] Mason B. (1962) Meteorites. Wiley. [3] Mason B. et al. (1979) *Smithsonian Contrib. Earth Sci. 22*, 27-45. [4] Mason B. (1967) *Amer. Scientist 51*, 429-455. [5] Reid A. M. et al. (1979) *Lunar Planet Sci. X*, 1022-1024. [6] Takeda H. (1979) *Icarus 40*, 455-470. [7] Delaney J. S. (1987) *Lunar Planet Sci. XVII*, 166-167. [8] Mittlefehldt D. W. (1994) *Geochim. Cosmochim. Acta 58*,1537-1552. [9] Barrat J. A. et al. (2000) *Meteorit. Planet. Sci. 35*, 1087-1100.

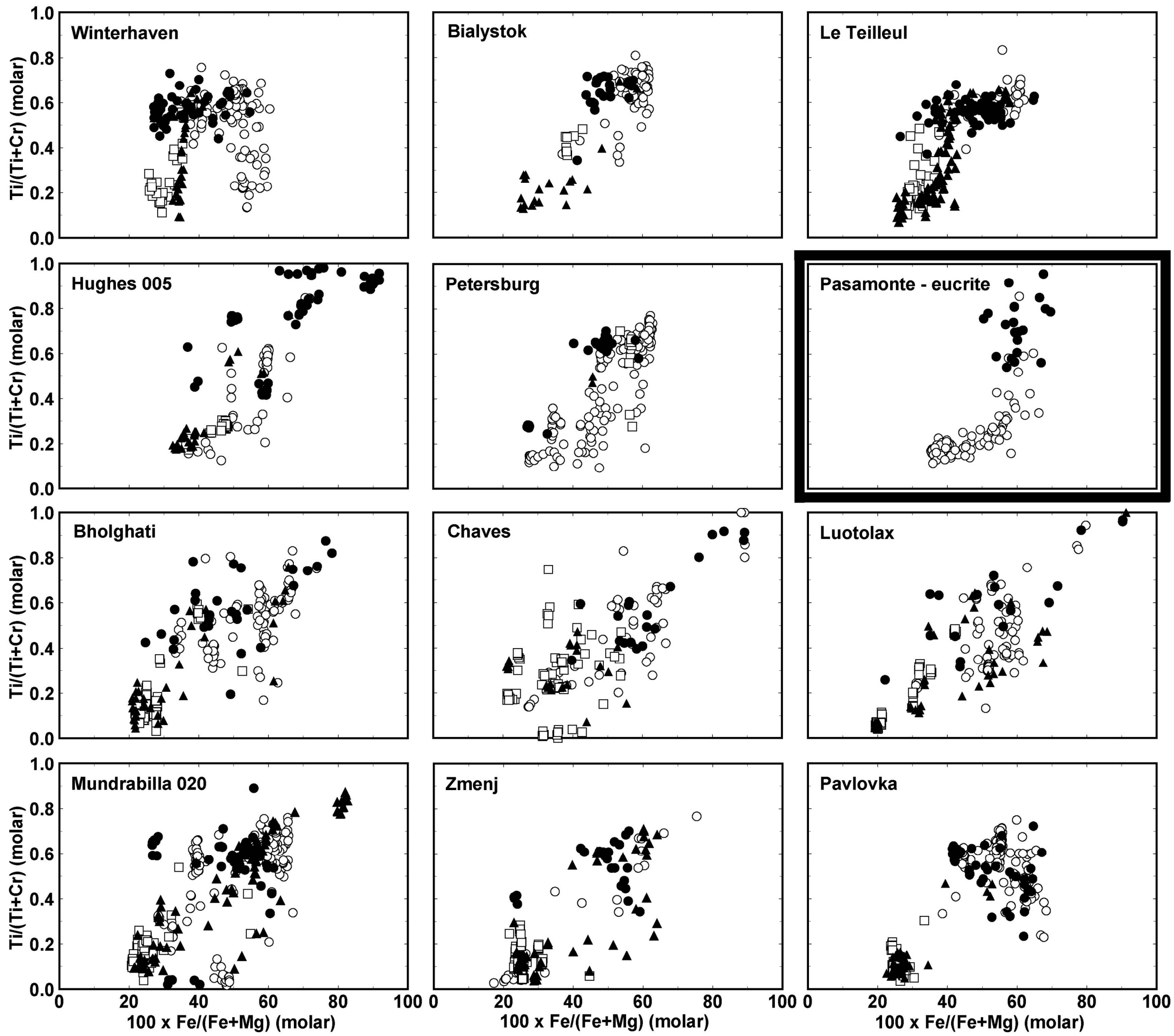

Figure 1. The diverse Ti/(Ti+Cr) vs. Fe/(Fe+Mg) trends found in pyroxene from 11 howardites and one eucrite (outlined above). Open squares are pyroxenes from diogenite clasts and mineral fragments >200 microns in diameter. Closed triangles are pyroxenes from mineral clasts ≤200 microns in diameter. Open circles are orthopyroxene and pigeonite from basaltic clasts. Closed circles are augite grains or lamellae.