INTEGRATING ELEMENTAL X-RAY MAPPING AND MINERAL ANALYSIS TECHNIQUES TO ESTIMATE THE PROVENANCE OF THE HOWARDITES ON VESTA. I. R. Erb[1] and J. S. Boesenberg[2], [1]Wellesley College, 21 Wellesley College Rd., Wellesley, MA 02481, ierb@wellesley.edu, [2]Earth and Planetary Sciences, American Museum of Natural History, Central Park West, New York, NY 10024, .bosenbrg@amnh.org.

Introduction: Last year, [1] suggested that individual diogenite, cumulate eucrite and basaltic eucrite meteorites may form sets that show different types of extensive fractionation trends [shown using Ti/(Ti+Cr) versus Fe/(Fe+Mg) fractionation trends in howardite pyroxene]. Each three member set deriving from a different common source magma. However, one of the complexities was trying to determine whether the continuous fractionation trends are formed by a single, extensive fractionation sequence or possibly by multiple, short overlapping sequences (i.e., are the fractionation sequences from one source or multiple source magmas?). To better interpret the data, we have begun elemental x-ray mapping of thin sections that were previously analyzed for their mineral compositions. By comparing the mineral modes from the clasts and mineral fragments in the large fraction to those in the small fraction, we can obtain an estimate of whether the individual howardite meteorites contain clasts and fragments from one or more than one provenance. Then, we can compare those results to the pyroxene fractionation trends of [1] to see if a consistent picture of the howardites emerges.

Samples and Technique: Seven howardite thin sections were studied: Bholghati (4243-3), Hughes 005 (4843-1), Mundrabilla 020 (4803-1), Winterhaven (5104-2), Zmenj (437-1), LEW 87005 (,3) and MIL 07661 (,6). The first five sections are from the American Museum of Natural History meteorite collection and the last two from the NASA/Johnson Space Center Antarctic meteorite collection. The thin sections were chosen so they did not include any excessively large clast or fragment (no one fragment or clast exceeded 5% of the total thin section sample area) that would skew the large fraction preferentially. Obvious impact-melt clasts and carbonaceous chondrite clasts within the sections were also excluded from the study since they do not contain the primary HED igneous mineralogy. Si, Ti, Al, Cr, Fe, Mg, Ca, S, Ni and P x-ray maps as well as backscattered electron images were obtained at a 6 micron per pixel resolution on all thin sections using the AMNH Cameca SX-100 microprobe. Utilizing these elements, up to eight different mineral phases could be determined including pyroxene, feldspar, tridymite, chromite, ilmenite, phosphate, troilite and metal. The delineation between the large and small size fractions was set at 200 microns, following [2] who had performed a similar survey using a grain counting rather than an x-ray mapping technique. A complication with this methodology is that during metamorphism, clast boundaries become increasingly obscured.

Results: The mineral modes of the two size fractions obtained from our mapping are shown in Table 1. The two size fractions in Bholghati, Hughes 020, Winterhaven, and MIL 07661 all contain roughly the same proportion of the seven (or eight) minerals determined. In contrast, the mineral proportions for the small and large size fractions in Mundrabilla 020, Zmenj and LEW 87005 vary dramatically.

Discussion: Following an impact on an asteroid such as Vesta, the presumed HED parent body, large clasts and fragments will rain out of the impact plume relatively quickly and remain in the immediate vicinity of the crater. However, finer-grained material, buoyed up by the plume, will spread over a much larger surface area, perhaps even attaining a global distribution. Thus, fine-grained fragments are more likely to be expected as foreign components than larger fragments in any given howardite. By comparing the size fractions, an estimate can be made to determine whether any given howardite contains material derived from a single locality or multiple ones. This also helps us determine what proportion of the rock types that are mapped on the surface of Vesta by the DAWN mission derive from the region they are presently found in. Howardites have long been thought to represent well-mixed impact breccias that contain clasts and mineral fragments that derive from a variety of potentially global sources, however this assumption may not be correct if we find that most howardites derive from single, yet individual localities.

A survey by [2] using a grain counting technique (different from the x-ray mapping technique used here), on the Yurtuk, Frankfort, Pavlovka and Malvern howardites and the polymict eucrite ALHA 77302, found that modally within the finer fraction there is a smaller number of lithic clasts, but a larger proportion of feldspar versus pyroxene. For the 4 howardites whose size fractions contain roughly equal mineral proportions, our study also finds that there is approximately a 5% increase in feldspar in the smaller fraction. This suggests that brecciation and mixing are the primary factors influencing the mode and that the finer-sized fraction is in fact sampling only locally derived material.

Unlike the study of [2], we find several howardites have a substantial difference between the small and large size fraction mineral modes. These include Mundrabilla 020, Zmenj and LEW 87005. The smaller size fraction in Mundrabilla 020 and Zmenj does contain a higher feldspar proportion than the large fraction, however, with LEW 87005, the feldspar proportion is much higher in the larger fraction. In fact, the feldspar grains in general are noticeably larger and more abundant than in most other howardite sections. This difference between size fractions is consistent with the original idea that howardites are composed of a global mix of clasts and fragments from the surface of Vesta.

By comparing these mapping results with the pyroxene fractionation trends generated last year [1], an interesting correlation appears. Those howardites that contain extensive and continuous fractionation trends in Ti-Cr versus Fe-Mg in pyroxene are consistently those found to contain approximately equal mineral modes in the large and small size fractions, while those with short trends or unconnected clusters have different large and small size fraction mineral modes.

But why does this correlation exist? The exact explanation appears to be the result of the mixing efficiency, with every howardite actually representing one of three possible mixed populations. A howardite might consist of clasts and fragments that either: 1) are locally-derived, do not contain foreign clasts, but are well-mixed; 2) are more globally-derived, contain foreign clasts, but are well-mixed; 3) are locally-derived but are missing components due to an inefficient mixing process.

The problem for the future is how to differentiate between options 2 and 3. One possible solution is to graph the size distribution of the clasts and mineral fragments for a given howardite thin section. A typical population should exponentially increase in abundance with decreasing clast diameter. If a portion of the population is missing and that portion represents part of the smaller-sized clasts, then it is reasonable to conclude that the howardite derives from a local region, since inefficient mixing should result in a larger than normal clast population.

Conclusion: If we assume that 1) the mineral chemistry and element maps results continue to correlate with future studied samples; 2) the explanations for the populations are correct; and 3) the howardites represent random sites on Vesta, then based on the 13 howardites we have so far processed for their pyroxene compositions, 70% of the visible surface rocks on Vesta derive from the region they are presently found in (9 of 13 howardites contain continuous and extensive Ti-Cr versus Fe-Mg trends).

References: [1] Boesenberg J. S. and Erb I. R. (2011) *LPS XLII,* 1017 (CD-ROM). [2] Labotka T. C. and Papike J. J. (1980) *Proc. Lunar Planet. Sci. Conf. 11*, 1103-1130.

Table 1. Mineral Modes of Small and Large Clast and Fragment Fractions (in %).

	Bholghati		Hughes 005		MIL 07661		Winterhaven	
	Sm	Lg	Sm	Lg	Sm	Lg	Sm	Lg
Pyroxene	69.2	72.8	52.2	59.7	82.0	83.7	73.1	76.3
Feldspar	24.3	20.4	42.1	35.7	10.2	6.2	19.9	12.8
Ilmenite	1.1	1.1	1.3	0.5	2.0	1.9	1.4	0.8
Chromite/Ulvospinel	1.0	0.4	0.6	0.3	1.1	1.5	1.3	0.9
Fe-metal	0.7	0.8	0.5	0.8	1.4	1.8	1.9	3.8
Troilite	1.5	1.2	0.8	1.4	1.5	1.6	1.9	3.1
Tridymite	2.9	4.0	2.9	4.0	1.8	3.0	0.5	2.3
Phosphate	0.4	0.4	0.8	0.6	n.d.	n.d.	n.d.	n.d.
Total Sample Area (mm^2)	118.6		74.1		97.3		144.7	

	Mundrabilla 020		Zmenj		LEW 87005	
	Sm	Lg	Sm	Lg	Sm	Lg
Pyroxene	61.2	70.4	66.7	78.7	44.9	16.3
Feldspar	31.8	24.4	17.0	7.9	41.2	70.2
Ilmenite	1.1	0.6	2.5	0.9	1.2	1.1
Chromite/Ulvospinel	0.9	0.5	3.9	3.4	1.8	1.9
Fe-metal	0.7	0.7	5.7	4.3	4.8	5.3
Troilite	1.0	0.7	1.6	3.6	2.7	1.8
Tridymite	4.0	2.8	2.6	1.2	3.3	3.4
Phosphate	0.5	0.5	n.d.	n.d.	n.d.	n.d.
Total Sample Area (mm^2)	55.2		55.3		123.8	

n.d. - not determined