EFFECTS OF VARYING DEGREES OF METAMORPHIC EQUILIBRATION ON TRACE ELEMENT DISTRIBUTIONS IN THREE BASALTIC CLASTS FROM VACA MUERTA. Meenakshi Wadhwa[1] and Andrew M. Davis[2]. [1]Department of Geology, The Field Museum, Roosevelt Rd. at Lake Shore Dr., Chicago, IL 60605.[2]Enrico Fermi Inst., Univ. of Chicago, Chicago IL 60637.

The origin of silicate clasts in mesosiderites, particularly with reference to their possible relationship to the HED meteorites, has long been debated [1,2,3,4]. This issue has been difficult to resolve, in part, because most of these clasts have been overprinted by light to extensive metamorphic effects. In this study, we have made *in situ* ion microprobe analyses of the abundances of a variety of trace and minor elements (including REEs) in three different basaltic clasts from the mesosiderite Vaca Muerta. Our goal was to determine the effects of metamorphic equilibration on the distributions of these elements in the various minerals comprising the clasts and, thereby, to better constrain the petrogenesis of these silicate clasts. All three Vaca Muerta clasts studied here, Pebble 16, 4679 and 4677, are composed predominantly of pyroxene and plagioclase and have been have been classified as "monogenic basalts" by [4]. Petrographic descriptions of these clasts can be found in [4,5]. Silica and phosphates, the modal amounts of which in mesosiderite clasts can be used as indicators of the degree of metamorphic equilibration, are most abundant in 4677 (>1 vol. %), while 4679 and Pebble 16 appear to have minor to trace amounts of these phases.

Fig. 1 shows the range of concentrations of REE (relative to C1 chondrites) measured in plagioclase and phosphates from each of the three clasts (note that fluor-apatite was found to be present only in Pebble 16). Plagioclase in all three clasts has the characteristic HREE-depleted pattern with a positive Eu anomaly (Eu/Eu* ~16, ~20, and ~45, in Pebble 16, 4679 and 4677, respectively). In contrast with the clearly "metamorphic" REE patterns (i.e., LREE-depleted and, in some cases, with positive Eu anomalies) found in phosphates in some mesosiderite clasts [6,7], REE patterns in phosphates of all three clasts are slightly HREE-depleted, and have negative Eu anomalies. In Pebble 16, the REE abundances in whitlockite are uniformly high (La abundances vary only by a factor of ~1.5, with an average of ~7000 x C1), while those in the fluor-apatite are significantly lower (La ~100-200 x C1). Unlike in Pebble 16, REE abundances in whitlockite of clast 4679 vary by a factor of ~9 (La ~670-5700 x C1), while those in whitlockite of clast 4677 are uniformly low (La ~500-1000 x C1). This suggests that equilibration with silicates may have resulted in the mobilization of REEs from the phosphates, resulting on lower REE concentrations in this mineral in the more metamorphosed regions. If this is true, Pebble 16 may be least equilibrated, while clast 4679 appears to be variably effected by metamorphism and clast 4677 is highly metamorphosed.

The above sequence of variation in the degrees of metamorphism in the three clasts is also supported by the elemental zonation patterns in pyroxenes. The FeO/MnO ratio in pyroxenes is an indicator of the extent of metamorphic equilibration [3], such that a FeO/MnO ratio significantly lower than ~35 (which is similar to that in eucrites) is indicative of FeO reduction. The FeO/MnO ratio in pyroxenes of Pebble 16 is uniform at ~36, while that in clast 4679 is generally ~34 (although we analysed one pyroxene, Px2, which had a FeO/MnO ratio of only ~31). In clast 4677, the FeO/MnO ratio was typically ~28. Fig. 2 shows the range of REE concentrations in pyroxenes in each of these clasts. Note that pyroxenes of all three clasts have the characteristic LREE-depleted pattern. However, while pyroxenes of Pebble 16 have large Eu anomalies (Eu/Eu* ~0.1), those of 4677 have significantly smaller ones (Eu/Eu*>0.6). In clast 4679, pyroxenes also have large Eu anomalies (Eu/Eu* ~0.05-0.2), with the exception of one pyroxene Px2 (with FeO/MnO ratio ~31) which has a Eu/Eu* ~1. This may imply that the size of the Eu anomaly in pyroxenes of mesosiderite clasts is related to the extent of metamorphic equilibration.

Figs. 3 and 4 show plots of Zr vs. Ti and Y vs. Ti for pyroxenes for each of the three clasts. Circled areas show the range of compositions in pyroxenes of non-cumulate eucrites [8]. In Fig. 3 it can be seen that Zr and Ti abundances in pyroxenes of all three clasts fall along the compositional trend defined by pyroxenes of non-cumulate eucrites. This is consistent with similar source regions for the parent magmas of mesosiderite basaltic clasts and non-cumulate eucrites. Additionally, in Fig. 4, data points for pyroxenes of Pebble 16, as well most of those for pyroxenes of 4679, also fall along the trend defined by pyroxenes of non-cumulate eucrites. However, a single data point (Px2) from 4679, as well as all data points for 4677 pyroxenes, fall along a separate trend. It should be noted that pyroxene Px2 of 4679 is located adjacent to the whitlockite

with the lowest REE abundances (VM4679 Wh2 in Fig. 1). As discussed earlier, since the low REE concentrations in this whitlockite may be the result of equilibration with adjacent silicates, the REE abundances in the adjacent pyroxene Px2 may also have been redistributed (as may also be indicated by the Eu/Eu*; see above). This suggests that while tetravalent elements such as Ti and Zr may not have been significantly affected by the varying degrees of metamorphism as represented by the three clasts, Y and the REE may have been redistributed in pyroxenes of 4677, and in some pyroxenes of 4679.

In conclusion, trace element microdistributions in mesosiderite clasts, while being useful indicators of the degree of metamorphic equilibration, can also provide information on the petrogenesis of these clasts. Specifically, this study shows that of the three clasts studied here, Pebble 16 is least equilibrated, while 4677 is heavily metamorphosed; 4679 appears to be variably metamorphosed. Additionally, comparison of pyroxene zoning trends in Pebble 16 and 4679 with those in non-cumulate eucrites suggests that the source regions and petrogenetic histories of basaltic clasts in mesosiderites were similar to those of non-cumulate eucrites. This is *consistent* with the formation of these basaltic clasts on the HED parent body.

References: [1] Mittlefehldt D. W. (1979) *Geochim. Cosmochim. Acta 43,* 1917. [2] Nehru C. E. *et al.* (1980) *Meteoritics 15,* 337. [3] Mittlefehldt D. W. (1990) *Geochim. Cosmochim. Acta 54,* 1165. [4] Rubin A. E. and Mittlefehldt D. W. (1992) *Geochim. Cosmochim. Acta 56,* 827. [5] Kimura M. *et al.* (1991) *Proc. NIPR Symp. Ant. Met. 4,* 263. [6] Crozaz G. *et al.* (1985) *Meteoritics 20,* 629. [7] Mittlefehldt D. W. (1992) *Science 257,* 1096. [8] Hsu W. and Crozaz G. (1996) *Geochim. Cosmochim. Acta* in press.

**Fig. 1: REE in Phosphates and Plagioclase of Vaca Muerta Clasts**

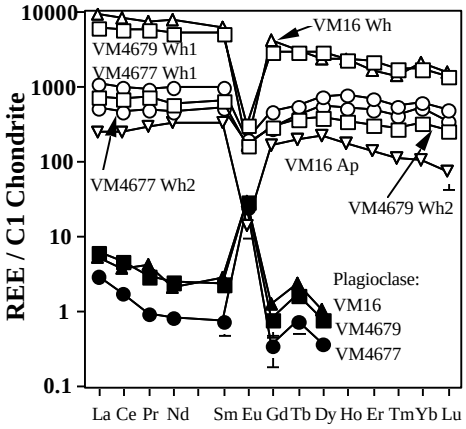



**Fig. 2: REE in Pyroxene of Vaca Muerta Clasts**

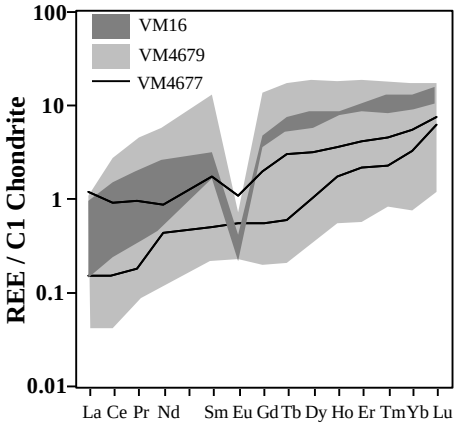



**Fig. 3: Zr vs. Ti for Pyroxene of Vaca Muerta Clasts**

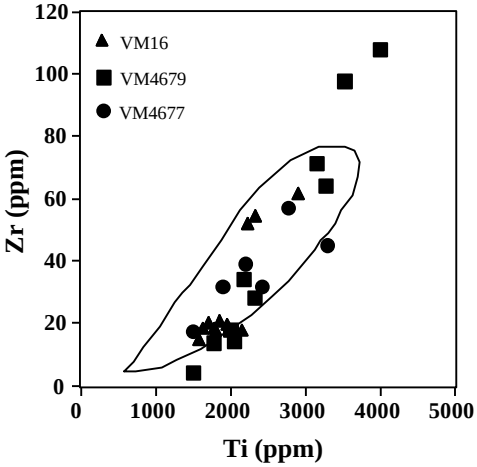
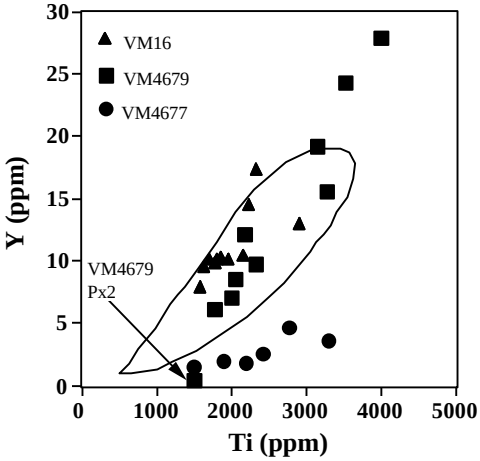



**Fig. 4: Y vs. Ti for Pyroxene of Vaca Muerta Clasts**




Note: Vm16 = Vaca Muerta Pebble 16; VM4679 = Vaca Muerta clast 4679; VM4677 = Vaca Muerta clast 4677; Wh = Whitlockite; Ap = Apatite; Px = Pyroxene.