Phosphate Mineralogy of Petrologic Type 4-6 L Ordinary Chondrites

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Introduction

- Phosphate minerals occur as secondary products in equilibrated ordinary chondrites. The presence of fluids during metamorphism may influence the occurrence and composition of these minerals.
- Phosphate minerals in this study are apatite, $Ca_5(PO_4)_3X$, and merrillite, $Na_2(Mg,Fe^{2+})_2Ca_{18}(PO_4)_{14}$.
- The X anion site in apatite typically contains F, Cl, and OH. Measuring the relative abundance of these anions in apatite helps us to understand the composition and evolution of fluids present on OC parent asteroids during metamorphism.
- Occurrences and compositions of apatite and merrillite have been studied previously in H and LL ordinary chondrites [1-3]. This study extends the previous work to L chondrites, allowing for direct comparisons between all three OC classes.

Samples and Methods

- We studied phosphate minerals in Santa Barbara (L4), Elenovka (L5), and Bruderheim (L6). All three are falls with low to moderate shock levels.
- We examined textures using SEM and analyzed individual grains with quantitative electron microprobe (WDS) techniques according to the method described by [3].

Results

- **The three L chondrites in this study show a similar size distribution of phosphate grains ranging from 20 to 300 µm.** The average size for apatite is 100 µm and merrillite is 130 µm. Merrillite represents an average of 70% of the phosphate grains present.
- **Typical textures of apatite and merrillite are illustrated in Figure 1.** Fine-scale fracturing is common in types 4 and 5 (Figs. 1a-d) but much less common in type 6 (Figs. 1e,f).
- **Apatite and merrillite are commonly found in direct contact with large metal and sulfide grains (Figs. 1b,d,f) as well as along the rims of holes (Figs. 1c,e).** There does not seem to be any preferred association with a single silicate phase and both phosphate minerals occur randomly with olivine, pyroxene, and feldspar.
- **We did not observe the two phosphates occurring together, with the exception of a single grain in L4 Santa Barbara in which merrillite and apatite are intergrown (Fig. 1a).** This texture is different from reaction relationships seen between apatite and merrillite in type 4 H and LL chondrites [1-3].
- **Apatite compositions (Fig. 2) show average Cl/F ratios of 12.1, 10.5, and 8.8 wt% (6.5, 5.6, and 4.7 atom percent) for Santa Barbara, Elenovka, and Bruderheim respectively.** Cl and F showed a similar range in values across all three samples irrespective of petrologic type. An average of 15% of the X anion site is not occupied by Cl or F. SIMS analyses of apatite in LL chondrites with similar compositions have shown that OH is low in abundance [3], so we label the third apex of the X anion ternary as "other" on Figure 2.
- **The range in merrillite Mg/(Mg+Fe) values decreases with increasing petrologic type (Fig.4).** Merrillite compositions show Mg/(Mg+Fe) values of 0.69-0.95 for Santa Barbara (L4), 0.89-0.95 for Elenovka (L5), and 0.84-0.94 for Bruderheim (L6).

Apatite Analyses

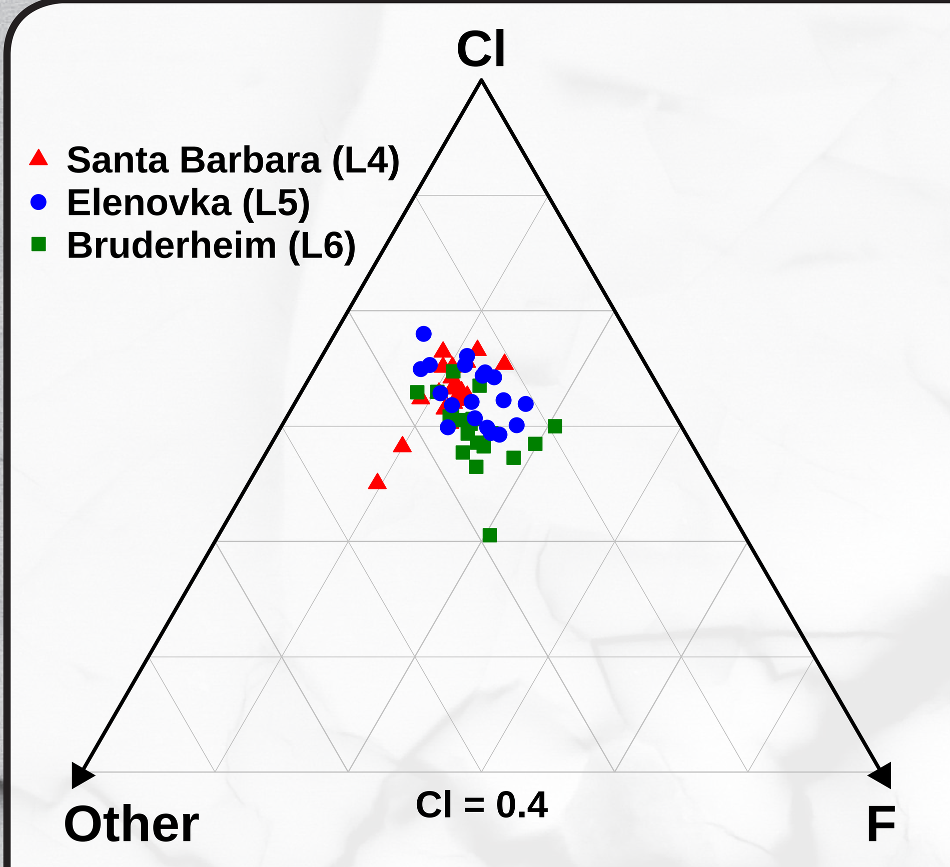

Figure 2: Electron microprobe analyses of apatite in types 4-6 L ordinary chondrites. Each point is a single analysis. Cl and F were analyzed directly and "Other" represents X-site anions calculated by difference.

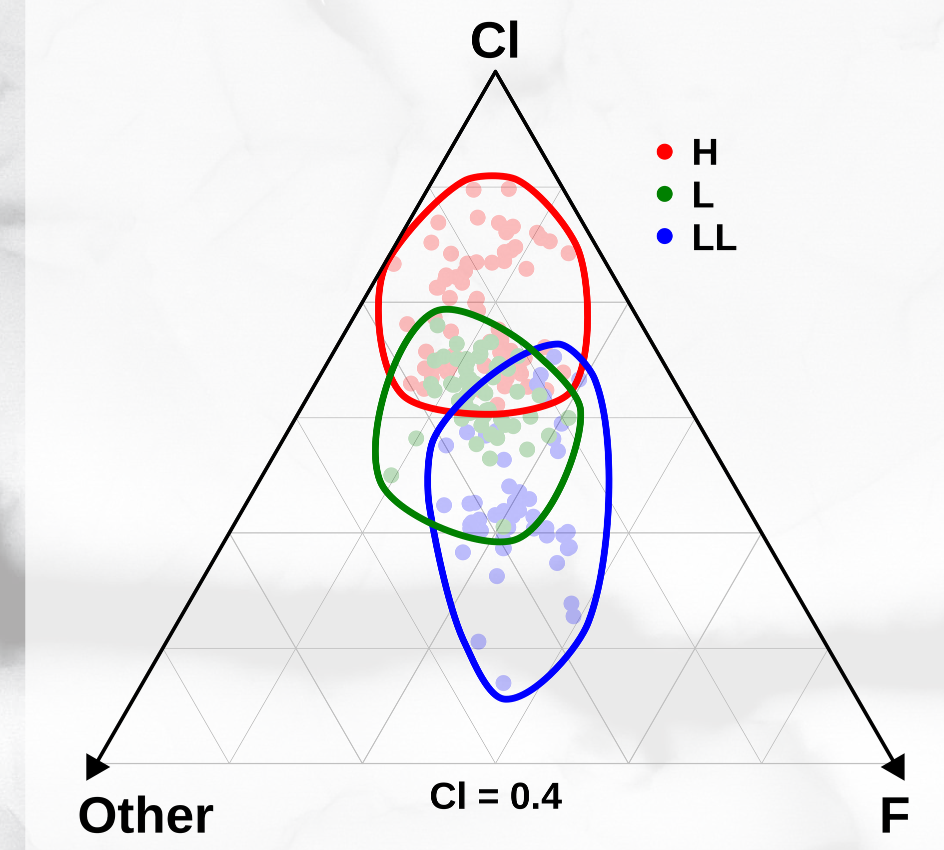

Figure 3: Apatite compositions in equilibrated H [1], L (this study), and LL [3] chondrites. Each point is a single analysis and each outlined field is a single chondrite group, containing analyses from petrologic types 4-6.

Merrillite Analyses

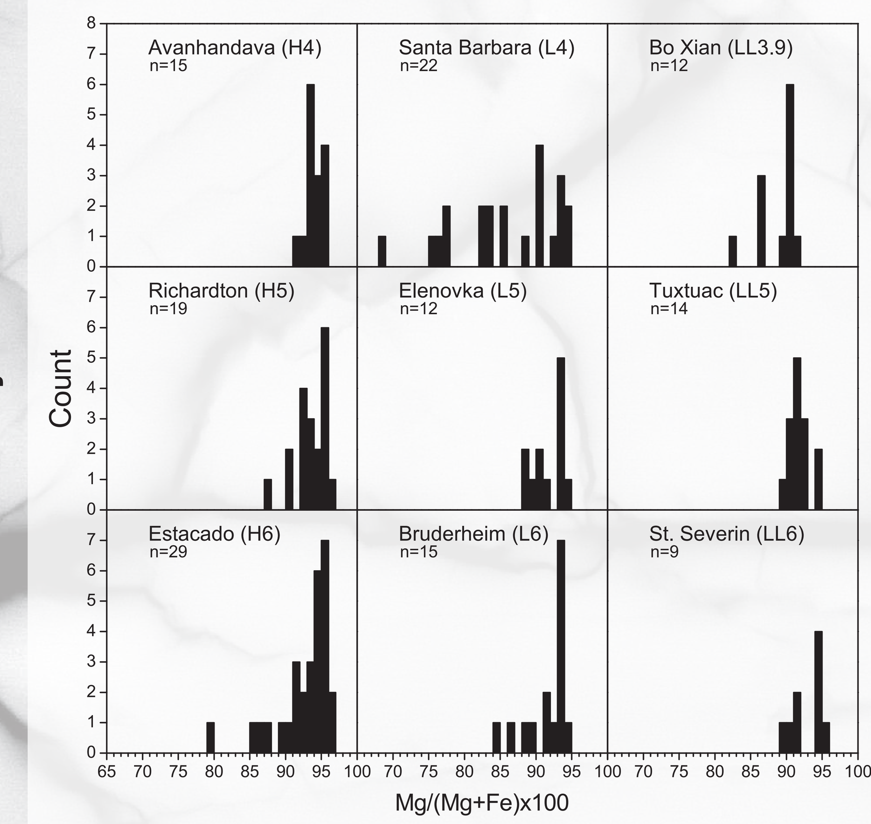

Figure 4: Electron microprobe analyses of merrillite in types 4-6 H [1], L (this study), and LL [2,3] ordinary chondrites.

Santa Barbara (L4)

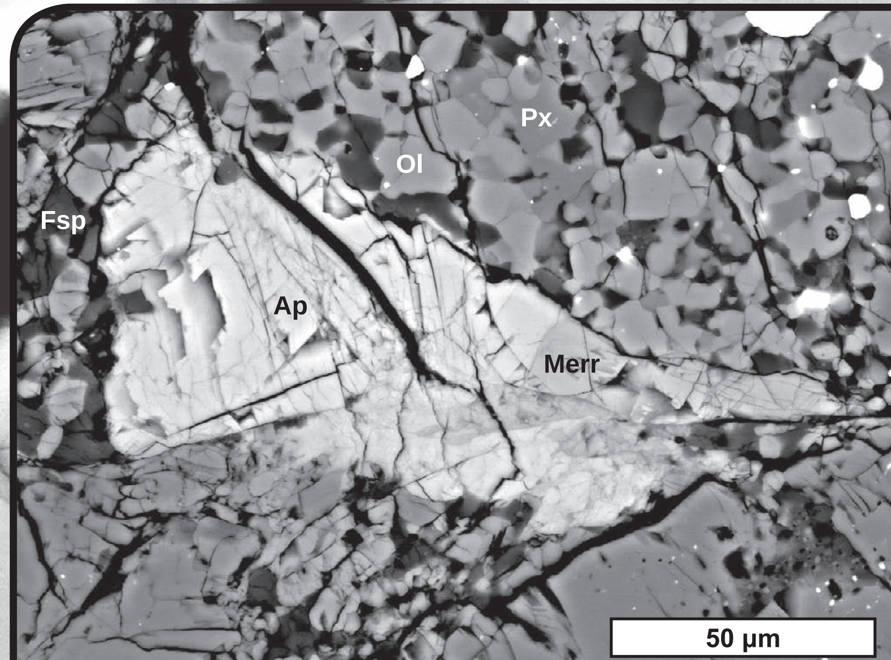

Figure 1a: Santa Barbara (L4) apatite and merrillite intergrown but without reaction texture common to H and LL type 4 [1-3].

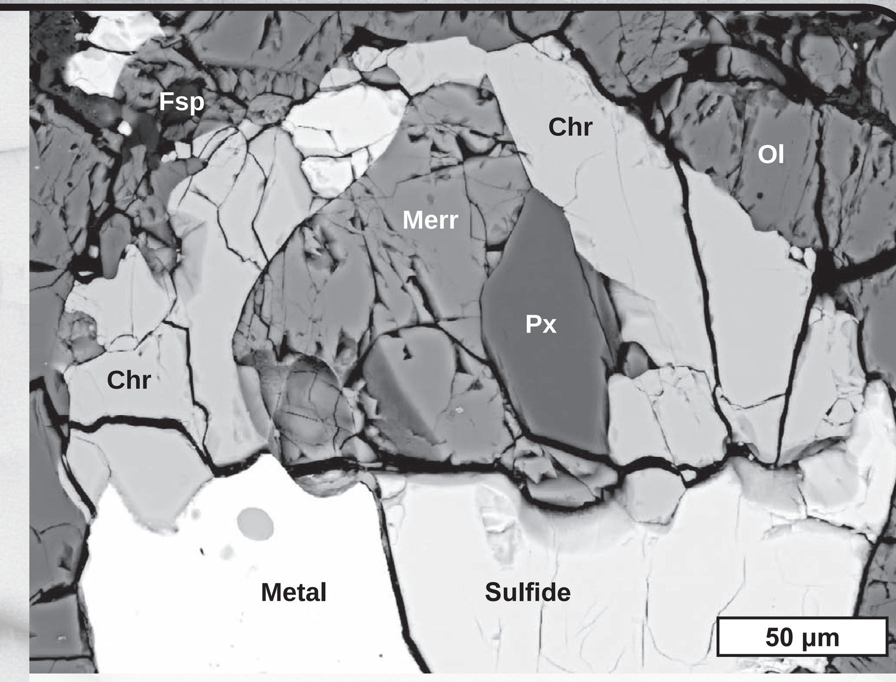

Figure 1b: Santa Barbara (L4) merrillite and pyroxene within metal (Fe,Ni), sulfide (troilite), and chromite assemblage.

Elenovka (L5)

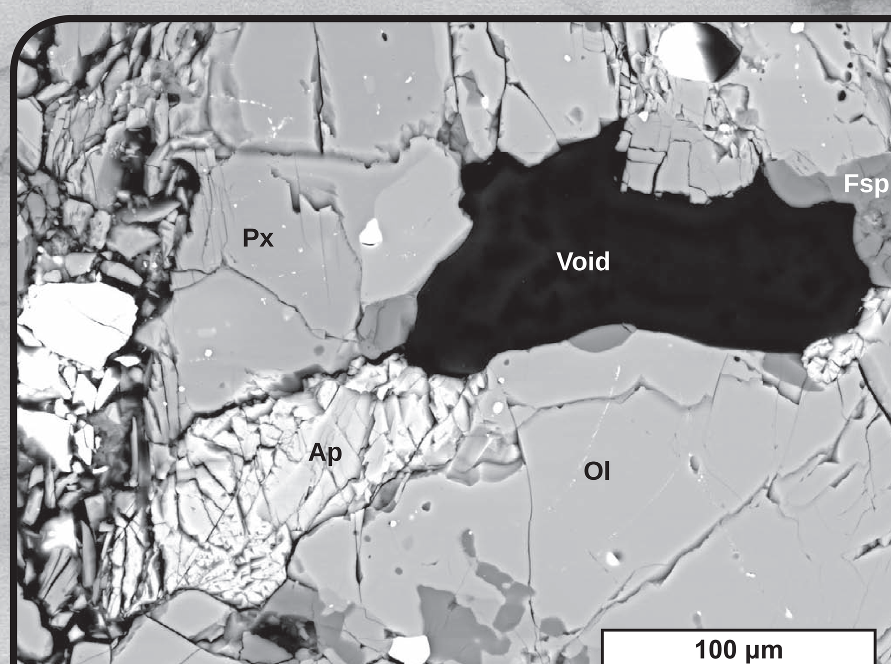

Figure 1c: Elenovka (L5) apatite with pyroxene, olivine, and feldspar adjacent to a void.

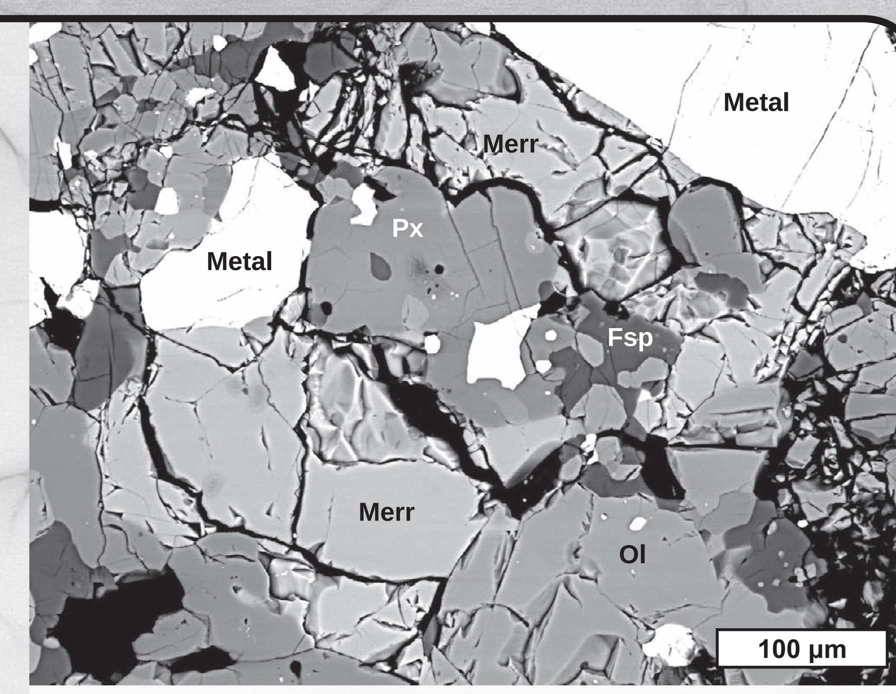

Figure 1d: Elenovka (L5) merrillite associated with metal (Fe,Ni), pyroxene, olivine, and feldspar.

Bruderheim (L6)

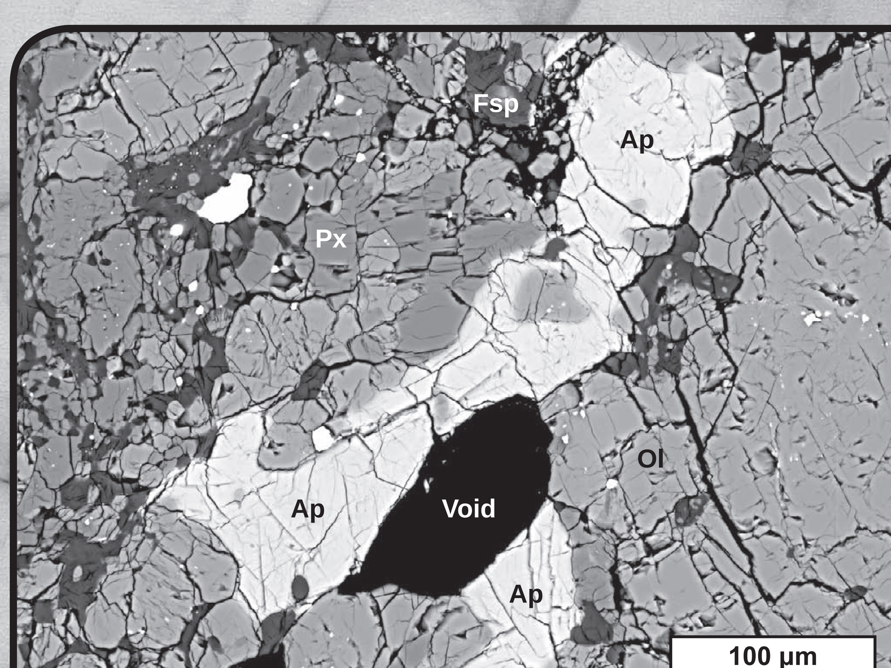

Figure 1e: Bruderheim (L6) apatite surrounding a void and associated with pyroxene, olivine, and feldspar.

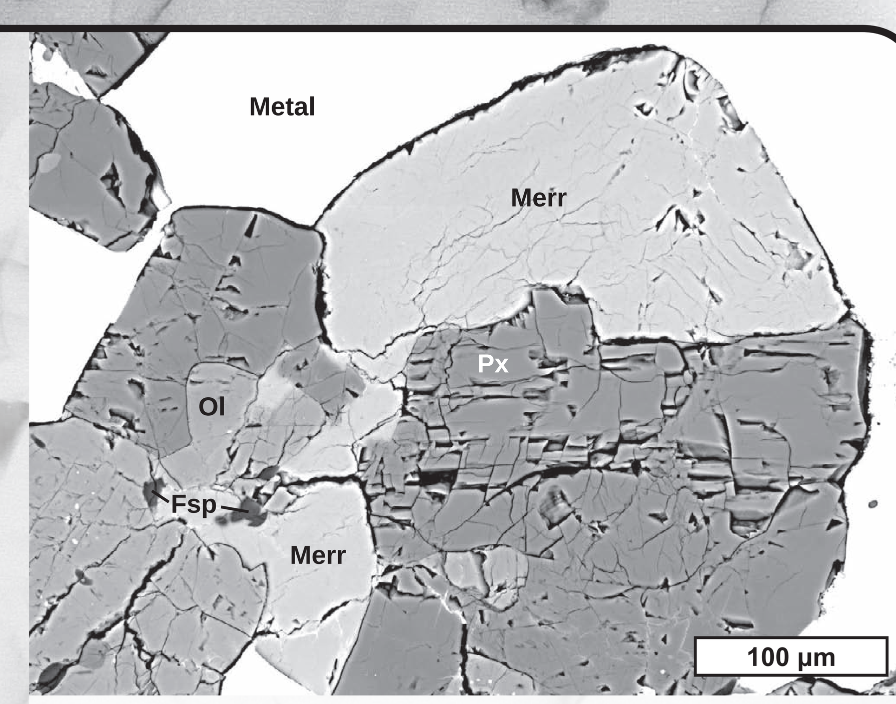

Figure 1f: Bruderheim (L6) merrillite adjacent to metal (Fe,Ni) and associated with pyroxene, olivine, and feldspar.

Discussion

- **Apatite compositions in L chondrites are intermediate to H and LL chondrites (Fig. 3).** This suggests the presence of distinct fluid compositions on each of the ordinary chondrite parent bodies.
- **Apatite shows no significant compositional equilibration trend with increasing petrologic type.** This suggests apatite formed during or after peak metamorphic temperatures. This is consistent with analysis of both H [1] and LL [3] chondrites.
- **Merrillite Mg/(Mg+Fe) values in L chondrites show a possible trend of compositional equilibration from L4 to L5/L6.** This suggests that merrillite formed at an earlier stage than apatite during metamorphism. A similar but less prominent trend is seen in LL but not in H chondrites.
- **There may be a slight trend toward higher Cl content in apatite with lower petrologic type in the L group (Fig. 2).** This suggests the evolution of a fluid towards more Cl rich compositions, possibly as the fluid migrates to shallower depths in the parent body.
- **Phosphate mineral grains do not show significant differences in size or texture across the petrologic types in the L chondrites we studied.** This is different from both H and LL chondrites which show progressive textural equilibration with increasing petrologic type. We believe this is because the samples studied are not representative of the entire range of metamorphic conditions. Future studies will include additional samples to test this hypothesis.
- **In addition to phosphates, textural and compositional changes in secondary feldspar also occur during metamorphism [5,6].** Studies of feldspar show that the metamorphic environment in the H group is different from that of the L and LL groups. Similarly, the merrillite equilibration trend in L chondrites is closer to LL than H chondrites.
- **Metamorphic environments on the three OC parent bodies were each subtly different and differences can likely be attributed to the compositions and availability of fluids.**

References: [1] Jones R. H. et al. (2012) LPS XLIII, Abstract #2029 [2] Dreeland L. A. and Jones R. H. (2011) LPS XLII, Abstract #2523 [3] Jones R. H. et al. (2011) LPS XLII, Abstract #2464 [4] Jones R. H. et al. (2011) LPS XLII, Abstract #2435 [5] Kovach H. A. and Jones R. H. (2010) Meteorit. Planet. Sci., 45, 246–264. [6] Gallegos J. and Jones R. H. (2011) 74th Met. Soc., Abstract #5433