

ORIGIN AND DEVELOPMENT OF PHOSPHATE MINERALS IN METAMORPHOSED LL CHONDRITES. L. Dreeland and R. H. Jones, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131. drylake@unm.edu

Introduction: It is well known that the phosphate minerals apatite and merrillite occur within metamorphosed ordinary chondrites (OCs), but very few studies have taken place investigating their occurrences and compositions [e.g. 1]. Since phosphates are secondary minerals that may record the action of any fluids present during metamorphism, understanding the genesis of phosphates might contribute to a better understanding of the metamorphic histories of the OCs. Apatite is the dominant host for the halogens Cl and F. Both phosphate minerals are also hosts of trace elements including rare earth elements (REE), U and Th, which makes them important minerals for determining the chronology of early solar system processes [e.g. 2]. An understanding of their formation history and environment is therefore essential to interpreting OC ages.

We are currently carrying out a detailed survey of phosphate minerals in the LL chondrites [3-5]. Here we report a comparison of abundances, grain size distributions, mineral associations, and compositions of chlorapatite and merrillite in the LL chondrites Bjurböle (L/LL4), Tuxtuac (LL5), and St. Séverin (LL6).

Methods: The samples surveyed in this study include the following thin sections: St. Séverin, UNM 693; Tuxtuac, UNM 627; and Bjurböle, UNM 117. Elemental x-ray maps were created of large areas (Table 1) of each thin section using a JEOL 8200 electron microprobe, in order to locate merrillite and chlorapatite grains. A total of 377 phosphate grains were documented (Table 1). Further SEM studies of individual grains were carried out on the electron microprobe and on a JEOL 5800L SEM. Grains larger than 15 μm in diameter were selected for quantitative electron microprobe analysis. We used procedures designed to minimize any volatile loss or gain during analysis of apatite [6, 7]. Operating conditions consisted of an accelerating voltage of 15 kV, a 20 nA beam current and a 5 μm beam diameter. Peak count rates were monitored during analyses, and minor chlorine loss was observed in only a few of the analyses.

Table 1: Number of phosphate grains identified

	Bjurböle	Tuxtuac	St. Séverin
Area surveyed	108 mm ²	64 mm ²	126 mm ²
Chlorapatite	52	104	10
Merrillite	91	56	64

Results: *Grain size distribution.* Figure 1 shows grain size distributions for each sample. All phosphate grains identified were between 5 and 310 μm across. Most grains are in the size range 10-50 μm . Merrillite

and apatite have similar size ranges in each chondrite. There is no correlation between grain size and petrologic type for either merrillite or apatite.

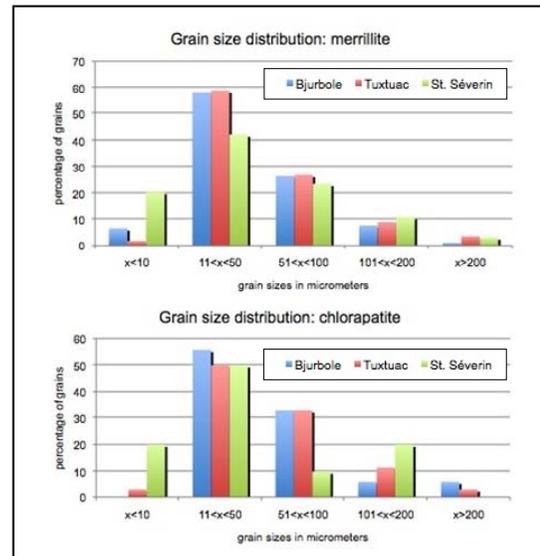


Figure 1: Grain size distributions of merrillite (top) and chlorapatite (bottom) in Bjurböle, Tuxtuac, and St. Séverin.

Phosphate mineral occurrences and textures. In all three samples, chlorapatite and merrillite were found to occur adjacent to a variety of minerals. In Bjurböle (LL4) and Tuxtuac (LL5), the phosphate minerals are randomly distributed throughout the sample, and are found enclosed within relict chondrules as well as in matrix. In both samples, both phosphate minerals are frequently located along the edges of holes and fractures. Additionally, in Bjurböle only, merrillite commonly occurs in association with troilite and Fe-Ni metals (Fig. 2a). In St. Séverin (LL6), merrillite grains are widely distributed, but chlorapatite grains are concentrated in a limited area within the sample. The largest chlorapatite grains occur adjacent to or in close proximity to two large (~700 μm) chromite-plagioclase assemblages [3].

Phosphate grains in St. Séverin show some textures that are not present in the other two chondrites. Along many phosphate grain boundaries in St. Séverin, we observe a “perforation” texture, consisting of strings of tiny pores, 0.5-2.0 μm in diameter, lining the boundaries between grains. Also, about 20% of the merrillite and chlorapatite grains in St. Séverin are enclosed within olivine grains, and boundaries between the phosphate mineral and the olivine appear to consist of a diffuse reaction zone, <1 μm across (Fig. 2b). Within

these phosphate grains, we observe trails of pores that could represent melt or fluid inclusions (Fig. 2b).

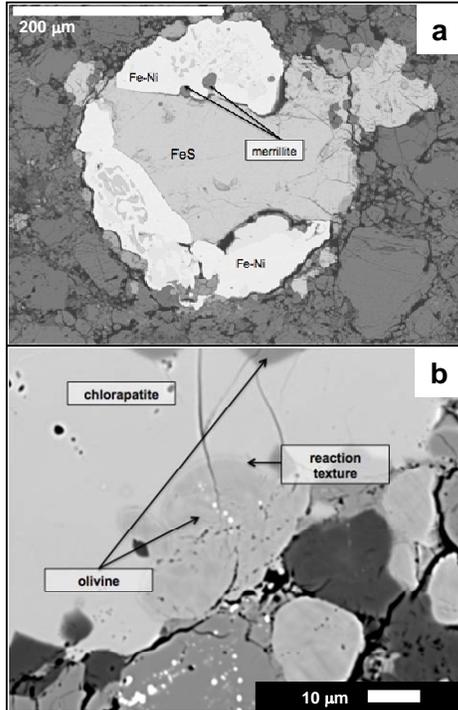


Figure 2: BSE images showing a) association of merrillite and metal in Bjurböle; b) reaction texture between chlorapatite and olivine in St. Séverin.

Phosphate mineral compositions. We have obtained electron microprobe analyses for phosphate minerals from St. Séverin and Tuxtuac, and analyses of Bjurböle are in progress. All analyses are close to the ideal formulae for chlorapatite $\text{Ca}_5(\text{PO}_4)_3(\text{Cl},\text{F},\text{OH})$ and merrillite, $\text{Na}_2(\text{Mg},\text{Fe}^{2+})_2\text{Ca}_{18}(\text{PO}_4)_{14}$.

Merrillite in both St. Séverin and Tuxtuac has uniform concentrations of Na_2O (mean of 2.81 ± 0.02 wt% for 23 analyses) and MgO ($3.47\% \pm 0.05$ wt %). However, FeO concentrations are variable, ranging from 0.36 – 0.68 wt % in Tuxtuac, and 0.31 – 0.74 wt % in St. Séverin. FeO varies from grain to grain, as well as within individual grains in both chondrites.

Chlorapatite also has variable FeO contents: 0.08 – 1.2 wt % in St. Séverin, and 0.07 – 0.57 wt % in Tuxtuac. Na_2O contents are uniform within each sample (mean of 0.29 wt% for St. Séverin, 0.40 wt% for Tuxtuac). Chlorapatite in St. Séverin and Tuxtuac has similar but variable F and Cl contents, and there is a strong negative correlation between F and Cl (Fig. 3).

Discussion: Phosphorous in merrillite and chlorapatite has been suggested to originate from metal grains [8]. We observed an association between merrillite and Fe-Ni metals in Bjurböle, but this association was not seen in the samples of higher petrologic type.

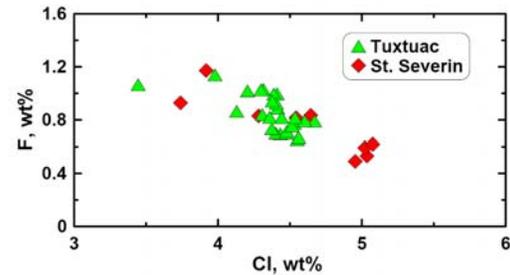


Figure 3: F and Cl contents of chlorapatite in St. Séverin (LL6) and Tuxtuac (LL5).

This is consistent with initial production of phosphates from the P in metal, and subsequent recrystallization during metamorphism.

Grain size distributions of phosphate minerals can give insights into the metamorphic environment in the LL chondrite parent body. We might expect to see a coarsening of phosphate grains with petrologic type as peak metamorphic temperatures and heating times increase. However, no correlation is observed between grain size distribution and petrologic type (Fig. 1). This indicates that phosphate mineral growth does not occur in the early stages of metamorphic heating. Compositional heterogeneity observed in F/Cl and FeO contents shows that the phosphates are not completely equilibrated throughout each chondrite. This is also consistent with the suggestion that at least some of the grains appear to have grown at a late stage, after peak metamorphic temperatures were reached.

One possible explanation for the lack of correlation between phosphate grain sizes and petrologic type is that fluids played an important role in grain growth. Reaction textures such as those observed between olivine and phosphate minerals in St. Séverin, and the presence of what appear to pores or fluid inclusions, also seen in phosphate minerals in Bo Xian (LL3.9) [4], might support this hypothesis, and we plan to characterize these textures further. In [5] we show that any fluids present on the LL chondrite parent body were extremely dry. If phosphate minerals indicate that fluids played a significant role in metamorphism, this would require a reconsideration of the environment of metamorphism for ordinary chondrites.

References: [1] Brearley A. J. and Jones R. H. (1998) In *Planetary Materials*, RIMS vol. 36, ed. J. Papike, Ch. 3 [2] Bouvier A. et al. (2007) *Geochim. Cosmochim., Acta* 71, 1583-1604 [3] Jones R.H. & Dreeland L. (2010) *LPSC XLI*, Abstract #1972 [4] Jones R.H. & Brearley A.J. (2010) *73rd Meteoritical Society*, Abstract #5276. [5] Jones R.H. et al. (2011) *LPSC XLII* [6] Stormer J.C. Jr. et al. (1993) *Am. Mineral.* 78, 641-648 [7] McCubbin et al. (2010) *Am. Mineral.* 95, 1141-1150. [8] Zanda B. et al. (1994) *Science* 265, 1846-1849.