PHOSPHATE MINERALS IN SEMARKONA (LL3.0). J.S. Goreva and D.S. Lauretta, Lunar and Planetary Laboratory, University of Arizona, Tucson AZ 85721, jgoreva@lpl.arizona.edu

Introduction. Direct observations of phosphates in unequilibrated ordinary chondrites (UOC) indicate that prior to metamorphism, phosphorus was associated with the metal phase (e.g. [1]-[3]). The alloying of P in Fe-Ni metal is a predicted consequence of calculations of gas-solid equilibrium under solar nebular conditions (e.g. [4]). Parent body conditions appear to have been sufficiently oxidizing that phosphates formed early even in the most primitive chondrites. Presumably, P reacts with an external source of Ca and O on the metal grain boundaries to form Ca-phosphates [2]. Both apatite and merrillite are observed in UOC. However, the conditions and timing of the phosphate nucleation is not constrained.

The distribution and chemistry of P-phases in UOCs is highly complex. Through the petrographic study and electron microprobe analyses in this work we attempt to look at the details of the phosphate distribution in the Semarkona (LL3.0) chondrite.

Results and Discussion. Figure 1a is an overlay of P-Kα x-ray map of the Semarkona USNM 1805-14 thin section on a BSE image. It is evident that there are number of well-defined P-rich regions on in and outside chondrules. We will discuss the 3 most common occurrences of phosphates in this section – Ca-phosphate rims around chondrules and chondrule fragments, Ca-phosphates in the mesostasis of type-II chondrules, and P-rich phases associated with magnetite in the matrix.

Chondrule Rims. Thin Ca-phosphate rims surround many chondrules and chondrule fragments in Semarkona. These rims are not necessarily associated with metal phase, however, they do seem to be more prominent around fragmented and/or plastically deformed FeO-rich chondrules (Figure 1b). Figure 2 illustrates an example of such a rim. In this case Ca most likely was supplied by a Ca-rich matrix (in the lower right corner of the image). The quantitative analysis of phases smaller than 2 μm did not produce satisfactory results, however larger fragments were identified as merrillite, Ca-phosphate with up to 7 wt. % of Fe, Mg and Na oxides. Cl content is at or below detection limit.

Figure 1. Phosphorus x-ray map (red pixels) overlaid on a). BSE image, b). Fe x-ray map of Semarkona LL3.0 chondrite.

Figure 2. Merrillite in chondrule rims

Type II chondrules. P-distribution in type II chondrules of Semarkona is very complex. Jones (1990) reported up to 0.17% P₂O₅ in olivine within type IIa Semarkona chondrules. Grossman (2000) describes P-zoning in type II chondrules within type 3 ordinary chondrites. Although such zoning was not observed in the Semarkona section the latter author studied, our observations support Grossman’s interpretation of the ability of phosphate-rich phases to form not only at the chondrule boundaries during the parent body alteration or metamorphism but also within microcrystalline mesostasis. Figure 3 shows merrillite dendrites (similar in composition to the phosphate rims discussed above) within Si, Al, Ca, Fe, P – rich mesostasis.
**Fe-rich assemblages.** Third most common occurrence of P-rich phases is associated with thick Fe-rich rims surrounding type-I chondrules as well as Fe-rich assemblages within Semarkona Matrix. The assemblage in Figure 4 consists of magnetite and Fe-Ni metal core with layers of Fe-rich silicates and Ni-rich sulfides. Phosphorus is dissolved in the olivine (up to 5 wt.% P₂O₅) and forms individual phosphates too small for a quantitative analyses. Although we did not detect carbidies, this assemblage is similar to the carbide-magnetite assemblages CMAs described in type 3 ordinary chondrites before. Taylor et al. (1981) attributed the formation of CMAs to gas-solid reactions in the solar nebula. Krot et al. (1997) argued that metal and troilite have been replaced by carbides and magnetite in the parent body by low-temperature reaction with a C-H-O fluid.

![Figure 3. Merrillite in mesostasis of type II chondrules.](image)

**Figure 3.** Merrillite in mesostasis of type II chondrules.

Conclusions. The Semarkona matrix consists largely of phyllosilicates (mainly smectite) indicating low-temperature (likely below 250°C, [7]) aqueous alteration of the asteroid. Formation of the phosphates on the chondrule boundaries and within magnetite assemblages in the matrix can be attributed to this process.

However, mineralogy and chemistry of chondrules does not seem to be affected by aqueous alteration (see [8] for review). Nevertheless phosphates form within type-II chondrule mesostasis as well on the chondrule boundary.

It is likely that those type-II chondrules that were plastically deformed (presumably during the accretion) were heated sufficiently to drive out part of the phosphorus and immediately deposit Ca-phosphates in the thin rims discussed above (Figure 2). On the other hand, phosphorus from the residual melts within chondrules could have formed an immiscible component within the feldspatic melt producing Ca-phosphates as in Figure 3. Alternatively, phosphates crystallized during the reheating of mesostasis either prior or after to the accretion.

Interestingly, all our microprobe analyses of phosphate rims around chondrules and within magnetite assemblages within matrix consistently came up to ~92 wt. % totals. Such low totals might be explained by the presence of light elements, not measured during the analyses. Although in the thin section studied we did not see carbidies and carbonates observed in Semarkona ([8] for review), presence of carbonate for phosphate substitution as well as OH could account for differences in chemical analyses. If holds true, this further supports Krot’s et al. (1997) low-temperature origin of the magnetite assemblages due to the reactions of UOC with C-H-O-bearing fluids. Further study is in progress.

Phosphate minerals are of a primary importance in petrogenesis of ordinary chondrites. They are major sinks for the rare earth elements and actinides. However, petrographic observations to date could not distinguish which Ca-phosphate phase (apatite or merrillite) formed first. In this study did not find any Cl-apatites, so abundant in ordinary chondrites of higher metamorphic grades. This leads us to believe that merrillite nucleated first, however the question in what form, when and where Cl came from remains unanswered.