Phosphorus-Olivine-Assemblages (POAs): a paragenetic model for P-bearing phases in primitive meteorites

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Introduction: Phosphate minerals (e.g., apatite ($Ca_5[PO_4]_3[OH,Cl,F]$), merrillite ($Ca_9NaMg[PO_4]_7$)) are emerging as crucial tools in the investigation of extraterrestrial volatile, thermal, and collisional histories (*1*–*5*). However, the mechanisms involved in the formation (and deformation/destruction) of phosphate minerals in primitive meteorites remain unclear, hindering our ability to confidently interpret an important record of chemical, isotopic, and structural information. Here, we provide further observations and arguments in support of a key role for olivine in the paragenesis of P-bearing phases in chondrites (*1*).

Paragenesis of POAs: By Back-Scatter-Electron, Electron-Back-Scatter-Diffraction, and Cathodoluminscence imaging investigation of the Chelyabink LL5 chondrite, we developed a new model of meteorite phosphate paragenesis. Figure 1 presents a schematic overview of our proposed Phosphorus-Olivine-Assemblage (POA) scheme. Phosphorus in a reduced oxidation state is initially hosted by metal, following nebular condensation (*6*). Parent body radiogenic metamorphism results in progressive oxidation of reduced phases, in which siderophile elements are known to progressively migrate out of metal hosts (*7*). Observations of partially equilibrated chondrites reveal P-enriched grains of olivine, formed during metamorphic reactions with migrating fluids (*8*) – a type I POA. In more fully to completely equilibrated chondrites, P is hosted quantiatively by phosphate minerals (*1*). These phosphate minerals share a close textural relationship with olivine, in particular sharing grain boundary contacts and large inclusions of either phase in the other. Olivine inclusions in a given grain are observed to preserve similar crystallographic orentiations. These observations support interpretation of olivine-phosphate textural association as resulting from olivine-replacement reactions (*1*), presumably initially at the expense of (now-consumed) P-rich olivine, which we define as Type II POAs. Finally, highly shocked meteorites contain shock melt portions in which phosphates are absent; instead, P is found principally in the latest generation of quench olivine crystals (*1*) – Type III POAs.

Conclusions: Textural constraints from unequilibrated, equilibrated, and shocked meteorites support a paragenesis for POAs leading from metal, through P-rich olivine and subsequent replacement by phosphate minerals, to P-rich silicates in shock-melted lithologies. This model provides a useful paragenetic context for interpreting the information preserved by each of these phases in a given meteorite. Our POA classification scheme supports the use of metal/silicate compositions for tracing parent body equilibration; phosphates as tracers of volatile species during parent body metamorphism; and high-T P-rich olivine as a sensitive tracer of post-impact crystallization processes.

References:

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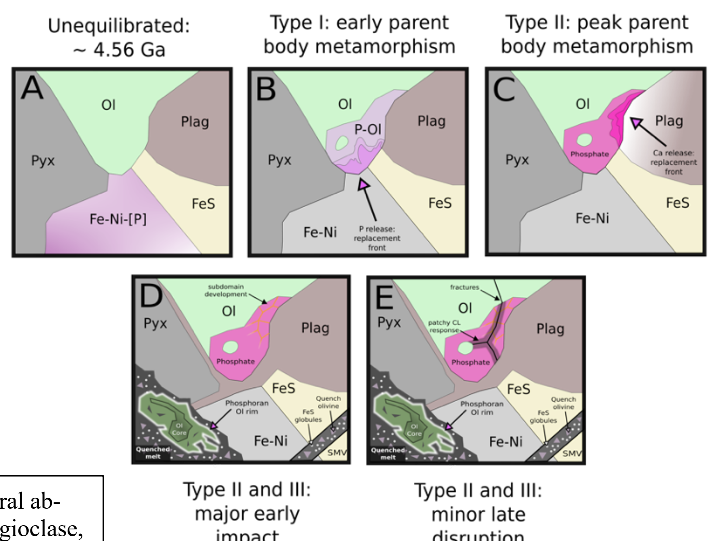

Figure 1: schematic view of POA paragenesis. Mineral abbreviations: Ol = olivine, Pyx = pyroxene, Plag = plagioclase, SMV = shock-melt-vein.