

Geochemical insights into the roles of endogenous metabolites on phosphate mineral formation in urine

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Phosphate minerals are highly insoluble phases that precipitate in a wide range of natural and engineered environments. In environmental engineering, we aim to induce phosphate precipitation to effectively remove dissolved phosphate from wastewater and potentially harvest the precipitate for use as fertilizers. Conversely, in the biomedical field, we want to inhibit phosphate precipitation in the human body to prevent the formation of phosphatic kidney stones and other pathological calcifications. It is imperative to understand the biogeochemical parameters that influence the rate of phosphate mineralization and the mineralogical properties of the precipitates.

Organics, such as endogenous metabolites, are present in urine. While it has been suggested that some metabolites may act as mineralization inhibitors, many metabolite-mineral interactions remain poorly understood or have not yet been investigated. In a sterile synthetic urine medium, we separately introduced different metabolites (hippurate, cysteine, citrate, creatinine, glycine, and taurine), and phosphate precipitation was induced in each experiment by raising the pH of the solution. Filtered urine was sampled before, immediately after, and 24 hours after precipitation was induced. Mineral precipitates were also collected immediately following and 24 hours after the precipitation was induced.

Mineral precipitates were analyzed using light microscopy, scanning electron microscopy with energy dispersive x-ray spectroscopy (SEM-EDS), and Fourier transform infrared spectroscopy (FTIR). The chemical composition of the urine at each time point was analyzed using inductively coupled plasma atomic emission spectroscopy (ICP-AES). Light microscopy and SEM-EDS showed mineral grains with characteristic struvite morphologies rich in magnesium and phosphorus, as well as a fine grained mineral phase rich in calcium and phosphorus. FTIR confirmed the presence of struvite and of a calcium-phosphate phase in all experiments. However, the spectra revealed some variability in the mineralogical composition and proportions of phosphate phases precipitated in each experiment. ICP-AES also showed that the amount of calcium, magnesium, and phosphorus removed varied between each system. Ultimately, we determined that the metabolites tested do not significantly change the total quantity of phosphate precipitated in the different experiments, but they do alter precipitate mineralogy in ways that deserve further investigation.