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The transformation of magnesium phosphate minerals at atmospheric conditions: Mechanisms, kinetics, and environmental applications

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Abstract

Struvite ($MgNH_4PO_4{\cdot}6H_2O$), a magnesium phosphate mineral, is a promising recoverable phosphorus (P) and nitrogen (N) source and is employed as a slow-release agricultural fertilizer. However, struvite is unstable in air and transforms into two distinct crystalline phases, newberyite ($MgHPO_4{\cdot}3H_2O$) and dittmarite ($MgNH_4PO_4{\cdot}H_2O$), before breaking down into an amorphous phase. The transformation products of struvite have been indicated in the literature. However, published studies quantifying these processes have focused on struvite decomposition in solutions, and investigations in air have been conducted only at high temperatures, far from the conditions under which this mineral would be stored for use as a fertilizer. Furthermore, the kinetics are unknown, including transformation rates and mechanisms. Thus, we present complementary X-ray diffraction (XRD), vibrational spectroscopic, and light to electron microscopic data from which we determined the mechanisms for the transformation at 22–60 °C and breakdown of struvite in air. Our results revealed that its transformation into both newberyite and dittmarite follows a coupled dissolution-reprecipitation mechanism, with the reaction kinetics dominated by the diffusion of H_2O and NH_3 out of the struvite structure. The reaction pathways proved to be temperature dependent, with newberyite being the only transformation product at room temperature, even after 10 months. This transformation resulted from the loss of ammonia and three of the six water molecules. On the contrary, at higher temperatures, dittmarite was the major transformation product of struvite, formed through the release of five of the six water molecules while retaining the ammonia. At 60 °C and after 3 months, dittmarite breaks down into an amorphous magnesium phosphate phase. This study provides comprehensive insights into the kinetics and the underlying mechanisms governing the transformation of struvite at atmospheric conditions. Our findings have significant implications for the long-term storage of struvite and its subsequent utilization as a slow-release fertilizer.

Keywords: Struvite, newberyite, dittmarite, transformation, kinetics