Taking Advantage of Disorder on Amorphous and Crystalline Phases in Biomineralization

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One of the most unexpected discoveries in the field of biomineralization is that commonly formed crystalline phases such as calcium carbonates and phosphates do not form directly out of solution. They form from highly unstable amorphous precursor phases that with time transform into the stable crystalline deposit. The first example of such a process in a living organism was discovered in chiton teeth in the 1960's, but was thought to be an oddity. Only after evidence of such a strategy was found in the calcitic spicules of embryonic sea urchins, was the possibility that this is a widespread strategy in biomineralization considered. Since then amorphous calcium carbonate (ACC) has been shown to be a precursor phase in adult echinoderms, in mollusk larval and adult shells, in crustaceans, annelids, and most recently in bone. The mechanistic details of these transformations are still not well understood. In the larval sea urchin spicule, packages of ACC some 40-70 nm in diameter, transform into calcite by secondary nucleation, and then progressively induce crystallization of neighboring packages. Intermediate stages toward crystallization were identified, involving more than one ACC phase. Analysis of the continuously forming fin bone of a strain of zebrafish showed that the initial mineral deposit is amorphous calcium phosphate (ACP), forming as discrete packages inside cells, then excreted into the extracellular collagen where it crystallizes into platelets of carbonated hydroxyapatite. It is clear that the amorphous mineral precursor strategy for forming crystals is widespread in biomineralization.

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