



## **Probing the behavior of peptides and proteins on mineral surfaces**

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To direct processes of biomineralization, organisms utilize organic matrices and soluble macromolecules to template nucleation, stabilize non-equilibrium phases and modulate the growth kinetics of inorganic solids. These processes occur in the oceans on such a large scale that they influence many aspects of seawater chemistry and result in large-scale sequestration of CO<sub>2</sub> in the form of carbonate sediments that chronicle the interplay between biota and environment. Attempts to use the fossil record as a proxy for ancient environments and the progression of geochemical processes, or alternatively, to direct those processes towards artificial CO<sub>2</sub> sequestration, require an understanding of the structural relationships, chemical interactions, and mechanistic impacts of proteins on mineral surfaces. In order to develop that understanding, we have used a combination of in situ AFM and molecular modeling to investigate the effect of peptides and proteins on the growth of carbonates, phosphates, and oxalates. Recently, specially designed cantilevers have enabled us to obtain true single molecule resolution and directly image protein interactions with atomic steps. We find that the slow adsorption dynamics, strong electrostatic interactions and tendency towards clustering peculiar to macromolecules lead to acceleration, inhibition, and even switching of growth between two distinct, stable states. This behavior can be understood with a mechanistic model that relates growth modification to the relative timescales for protein adsorption and step propagation, as well as the multi-state nature of the adsorption process. Finally, we discuss implications for natural controls over mineralization as well as the technological challenge of directing the timing and rate of crystallization.