The first enzymes? Roles of mineral–molecule interactions in the origins of life

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Mineral surfaces interact with organic molecules in ways that may have played roles in life's origins more than 4 billion years ago [*1-3*]. Reactive mineral surfaces can concentrate and align select molecules from a complex mixture, including chiral selection. They can catalyze key reactions, including polymerization reactions. And mineral–molecule interactions can selectively stabilize or destabilize molecules in an aqueous environment.

Varied experimental methods, including batch adsorption, potentiometric titration, TEM imaging, and surface spectroscopy, reveal atomic-scale details of molecular adsorption and reactions on mineral surfaces [*4-6*]. Important findings include experimental confirmation that a given mineral-plus-organic-molecule system may display multiple binding configurations and extreme differences in adsorption potential, depending on ionic strength, pH, solute concentration, and the presence of competing or cooperating molecules [*7-9*].

A number of origins-of-life scenarios have invoked rare minerals (e.g., specific borates, phosphates, or molybdates) to achieve key chemical steps in prebiotic chemistry[*10*]–minerals that may not have been available 4 billion years ago in plausible terrestrial origin environments [*11*]. Nevertheless, because common rock-forming minerals incorporate significant trace and minor element impurities, virtually any type of surface reactive site (including those with B, P, or Mo) were ubiquitous in prebiotic settings [*12*].

This perspective underscores the need to develop large, reliable, open-access mineral data resources that record numerous compositional and other attributes for specimens from a wide range of environments [*13-14*]. Such a comprehensive, multidimensional mineral data infrastructure is key to understanding the possible range of nanoscale interactions between minerals and life, both today and at the dawn of life.

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