

## Towards Co-evolution of Membranes and Metabolism

**Chenyu Wei,<sup>a,b</sup> Michael Wilson,<sup>a,b</sup> Andrew Pohorille<sup>a,b,\*</sup>**

<sup>a</sup>*Dept. of Pharmaceutical Chemistry, University of California San Francisco, San Francisco, CA, USA,* <sup>b</sup>*Exobiology Branch,*

*NASA Ames Research Center, Moffett Field, CA 94035, USA*

*\*Corresponding author: Andrew.Pohorille@nasa.gov*

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Conceptually, the most robust way to explain how primitive cell-like structures acquired and increased their capabilities is on the basis of Darwinian evolution. A population of protocells containing material that produced more environmentally fit progeny would increase in time at the expense of other protocells. In this scenario, protocellular boundaries were inextricably connected to the metabolism they encapsulated: to be inheritable, early metabolism must have led to an increased rate of growth and division of vesicles and, similarly, transport through vesicle boundaries must have supported the evolution of metabolism. Everything that could not be delivered from the environment had to be produced and retained inside protocells.

Despite their importance to the understanding of the origin of life, only a few cases of coupling between metabolism and membrane-related processes have been identified so far. For example, reactions inside fatty-acid vesicles have been linked to their competitive growth and division, and mechanisms by which membrane permeability might have coupled to information polymers have been proposed and explained. Most recently, it has been shown that a dipeptide inside fatty-acid vesicles catalyzes the formation of another dipeptide that binds to vesicle walls and, by doing so, promotes their growth at the expense of other vesicles, thus demonstrating evolutionary advantage of small, membrane-bound peptides.

It has been shown that the appearance of phospholipids imparted selective advantage to protocells bound by phospholipid-containing membranes, eventually driving fatty-acid vesicles to extinction. Phospholipid membranes, however, are nearly impermeable to charged species. Yet, the ability to transport ions across membranes was vital for regulating cellular volume, pH homeostasis, generating energy and sensing the environment. To account for this, evolutionary scenarios for the emergence of simple ion channels, protein structures surrounding water-filled pores in the membrane that facilitate ion transport, have been developed.

We will review recent progress in experimental and theoretical studies on coupling properties of membranes to metabolism, with the focus on how they impose constraints on scenarios for the origin of life, and discuss how these studies form the basis for future work on this topic.