Mechanical energy at the origins of life

7 October 2024

Did mechanical energy power life's origins before chemical energy such as ATP was available?

Mechanobiology is a hot topic in science today, with special issues on the subject in scientific journals. Was mechanical energy a way to form chemical bonds before the origin of life made mechanobiology possible? This makes a lot of sense, because life was not around yet to synthesize ATP (adenosine triphosphate), the chemical energy molecule that powers many of the processes of life. With mechanochemistry, molecules are simply smashed together to form covalent bonds between them (Figure 1).

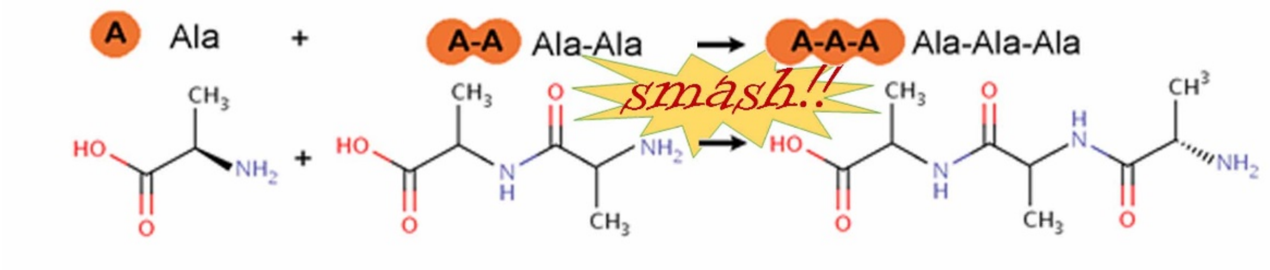

Figure 1. Mechanochemistry: smashing molecules together to make larger molecules such as polymers. Top: a monomer (single molecule) of the amino acid alanine (ala) is smashed against an alanine dimer (ala-ala) to form the alanine trimer (ala-ala-ala), a short version of the alanine polymer, polyalanine. Bottom: the molecular structures of the alanine monomer, dimer, and trimer. Alanine is one of the 20 amino acids that polymerize end-to-end to form proteins in living systems. Two amino acids form a bond between the carboxyl (-COOH) group at the end of one amino acid and the amino (-NH2) group at the end of the other amino acid, forming a carbonyl (-CONH) group and a water molecule (H2O). Water molecules are not shown in this figure. The carbonyl groups are shown in this figure as HN bonded to a carbon atom (C), shown only as an angle between 2 bonds; carbon atoms are also shown as an angle with a double bond (two bonds) to O.

Between mica sheets – a good place for mechanical energy to power the origins of life

Mica sheets provide mechanical energy at their split edges and bubbles between the sheets [1-3], as shown in this photograph of a piece of mica (Figure 2) and the diagram of mica in Figure 3.

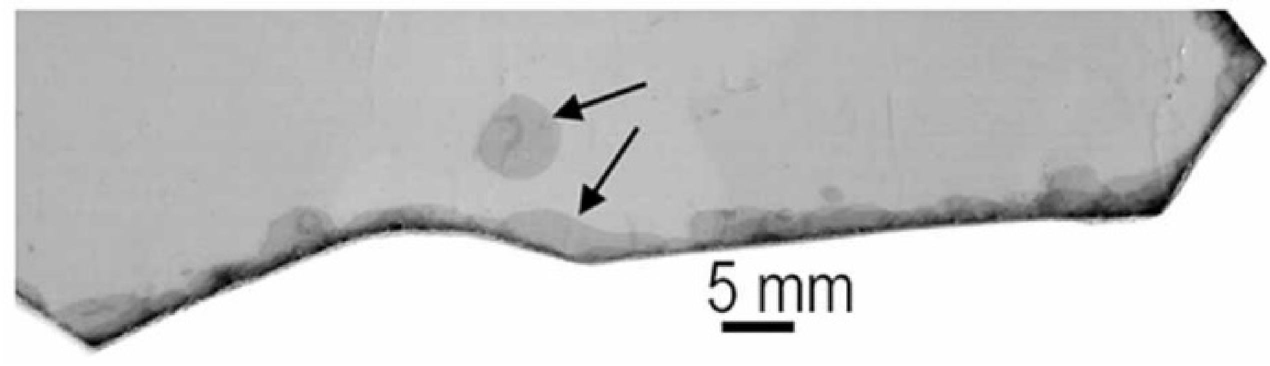

Figure 2. Photo of mica with air bubble and split edges (arrows). Mica is a layered silicate mineral. The photo shows muscovite mica. Biotite is an iron-rich black mica. Potassium ions hold mica sheets together, and K+ is present in high concentrations in all types of living cells.

Water moving in and out between the mica sheets will push the sheets open and shut (Fig. 3a), while cycles of heat and cold will cause bubbles between the sheets to expand and contract (Fig.3b). This movement creates mechanical energy. Mechanical energy can be used for polymer rearrangement, as diagrammed in Fig 3, and covalent bond formation, as diagrammed in Fig. 1. Mechanical energy can also be used to bleb off vesicles and protocells in a prebiotic form of cell division (Fig. 4).

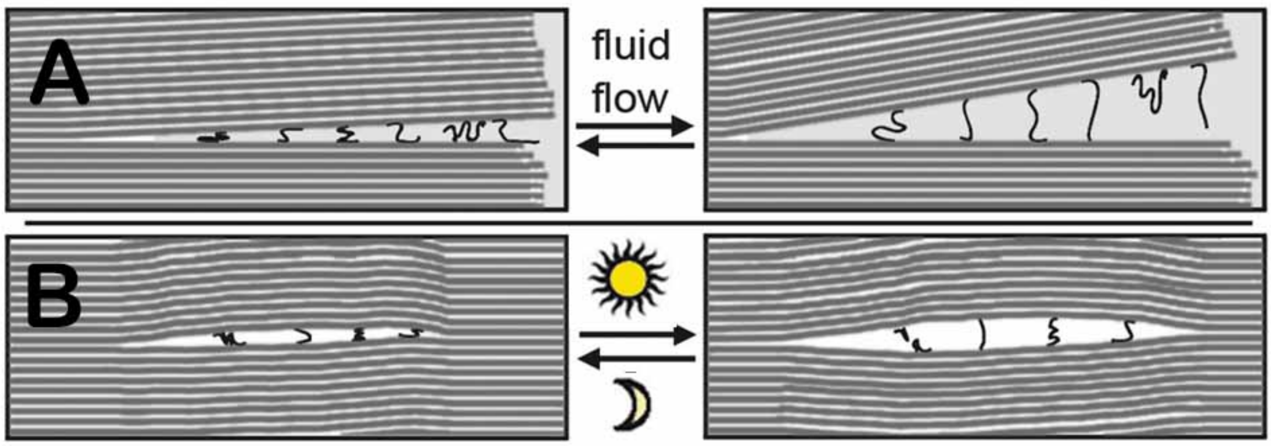

Figure 3. Water movements push mica sheets open and shut at their edges in A. Cycles of heating and cooling cause air bubbles within the mica sheets to expand and contract in B.

How might life have started between the sheets of mica?

In the Early stage (Fig. 4 left), individual ~1nm (nanometer) sheets of mica are seen. In the Later stage (Fig. 4 right), larger prebiotic structures have developed, and the individual mica sheets are not visible. Different prebiotic chemistries occur in different niches (spaces) between mica sheets. These niches provide partially enclosed spaces for the molecular evolution of the different structures that are essential for life's processes. Lipid- coated vesicles form in the Early phase and encapsulate the molecular structures that form between the mica sheets. The vesicles fuse to form protocells in the Later phase.

Mechanochemistry is typically accomplished by ball milling or grinding in a mortar and pestle today. Therefore, mechanical energy at the origin of life might have been less elegant than what is possible with mica sheets.

Potassium is a neglected ingredient in almost all research about the origins of life

Why is the sodium/potassium [Na/K] ratio so low in living cells when the Na/K ratio is high in seawater and land water? If life started in water on land or in the sea, would early life have built an energy-intensive pump in its cell membranes to produce high intracellular concentrations of potassium ions [K^+]?

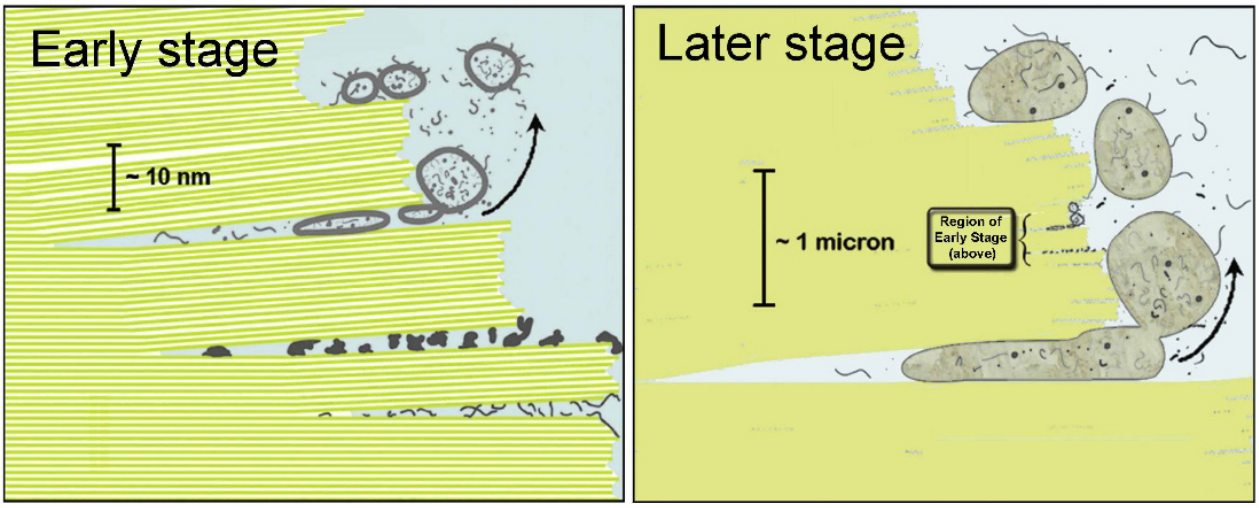

Figure 4. Early and Later stages of life's origins in micaceous clay. 10nm is approximately the thickness of ten mica sheers. One micron is approximately the thickness of 1000 mica sheets.

Life likely started in an environment with high [K^+], such as the environment between mica sheets.

References

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