PRESS RELEASE

A new step towards the origin of life: Clays and the Moon, key to RNA formation

A recent study led by the Centro de Astrobiología (CAB), CSIC-INTA, proposes a new approach to the origin and replication of ribonucleic acid (RNA) on the early Earth, through the lens of complexity theory. The researchers have developed a theoretical and computational model called EarlyWorld that sheds light on one of science's greatest enigmas: the origin of life. The study, published in Communications Chemistry, suggests that the interaction between primitive RNA molecules and clay surfaces, under the influence of tides, may have facilitated the emergence of the first self-replicating systems on our planet.

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In origin-of-life research, the "**RNA World**" hypothesis posits that this nucleic acid preceded DNA and proteins. According to this model, the primitive life forms would have relied on RNA molecules capable of storing information and catalyzing biochemical reactions. But this raises a major question: how were the first RNA chains formed without catalytic molecules (enzymes), and how could they reliably replicate, an essential prerequisite for evolution?

"*The great conceptual and methodological challenge was to understand how simple molecules like nucleotides could join together to form RNA polymers capable of replication, thus taking the first steps on the pathway to life,*" explains **Carla Alejandre**, first author of the study.

Life as a complex system

The team developed a computational framework called ***EarlyWorld***, which not only reproduces physicochemical processes where nucleotides interact with a clay surface in the presence of water, but also conceives them as part of an **evolving complex system**. Using tools from **complexity theory**, the researchers modeled how RNA polymerization and replication could emerge from the interaction of simple components (nucleotides, clays, water) subjected to fluctuating dynamics.

"*Today, we clearly see that the scientific study of the origin of life, underway since Oparin's pioneering work over a century ago, requires the coordination of multiple disciplines. With this article, we have connected prebiotic chemistry, molecular evolution and complexity theory to shed some light on the network of interactions that gave rise to life on Earth about 4 billion years ago*," notes **Jacobo Aguirre**, coordinator of the study and head of the **Complexity and Astrobiology Group** at CAB.

Tides that drove life

The most striking finding of this study is that the authors proved that the efficiency of RNA polymerization and replication increases in **fluctuating environments**, such as cycles of flooding and drying caused by tides, compared with constant conditions. Moreover, the most favorable oscillation periods for the increase of molecular complexity match those of **spring tides** produced by the alignment of the early Earth, the Moon and the Sun.

"*This work highlights the importance of heterogeneous environments for the origin(s) of life, such as the bottoms of small coastal ponds. In these settings, water, mineral salts, clays, nucleotides, and RNA chains could periodically interact thanks to the action of spring tides*," points out **Carlos Briones**, co-author of the study.

Why does modern RNA have four "letters"?

Another contribution of the study is the comparison of different possible genetic alphabets (with 2, 4, or even 6 nucleotides), which is essential for understanding RNA's ability to serve as a repository of heritable information.

*"Our analysis shows that the current **four-letter alphabet of RNA**, with the flexibility to allow non-canonical base pairs like G–U in addition to canonical A–U and G–C pairs, offers the optimal balance between replication speed and sequence diversity*," adds **Adrián Aguirre-Tamaral**, co-author of the study.

Implications for understanding life on Earth and beyond

These results not only help reconstruct the first steps of terrestrial protobiology, but also guide the **search for life on exoplanets** —a central goal in astrobiology. According to this study, the presence of extraterrestrial life could be favored on planets with large moons, liquid water, clay surfaces, and fluctuating dynamics.

"*The origin of life was not a one-off accident, but the result of very specific physicochemical conditions that enabled the leap from chemistry to biology. Understanding this transition through the lens of complexity brings us closer to answering the question of whether we are alone in the Universe*", concludes **Jacobo Aguirre**.

About CAB

Centro de Astrobiología (CAB) is a joint research center of the National Institute of Aerospace Technology (INTA) and the National Research Council (CSIC) of Spain. Created in 1999, it was the world's first center dedicated specifically to astrobiological research and the first non-US associate member of NASA's Astrobiology Institute (now the NASA Astrobiology Program). It is an interdisciplinary research center whose main objective is to study the origin, presence and influence of life in the universe from a transdisciplinary approach. In 2017, CAB was distinguished by the Ministry of Science and Innovation as "María de Maeztu Unit of Excellence".

CAB has led the development of the REMS, TWINS and MEDA instruments, all operational on Mars since August 2012, November 2018 and February 2021, respectively; as well as the science of the RLS and RAX Raman instruments, which will be launched in this decade on board of ExoMars and MMX missions. In addition, CAB develops the SOLID instrument, aimed at the search for life in planetary exploration.

Likewise, CAB participates in different missions and instruments of great astrobiological relevance, such as CARMENES, CHEOPS, PLATO, BepiColombo, DART, Hera, the MIRI y NIRSpec instruments at JWST and the HARMONI instrument at ESO's Extremely Large Telescope (ELT).

More information

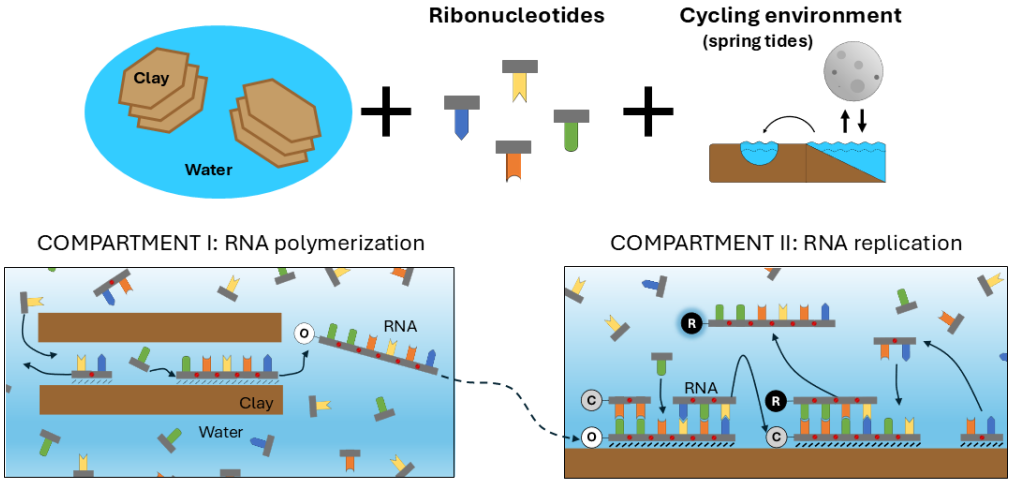

Figure: The results of this research suggest that oscillating environments on early Earth, such as the bottoms of coastal ponds regularly filled by spring tides, facilitated the non-enzymatic polymerization and replication of RNA at clay–water interfaces within different mineral compartments.

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