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Role of Layered Minerals in the Emergence and Preservation of Proto-Proteins and Detection of Extraterrestrial Biosignatures

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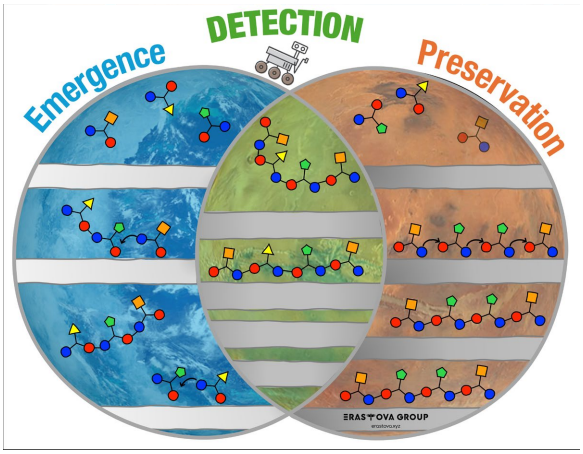

The origin of life remains one of the central enigmas in science, probing how inanimate matter transitioned into living systems. This talk explores the key role of layered minerals in prebiotic chemistry and biosignature preservation, integrating insights from space missions, laboratory experiments, and molecular modelling.

Clay minerals are hypothesised to have concentrated organic species, catalysed polymerisation reactions (e.g., peptide-bond formation), and shielded proto-biomolecules from harsh early Earth or extraterrestrial environments, making clay mineral-rich sights a priority for the search of extraterrestrial biosignatures. However, minerals' potential as primitive genetic materials remains limited due to their inability to sustain long-term information replication. Instead, we propose that minerals can transcribe environmental cycles (e.g., tidal or seasonal changes) into molecular sequences, allowing formed polymers to remain mobile and chemically active rather than overly protected, which would hinder their functionality.[1]

Leveraging statistics obtained from high-throughput molecular dynamics simulations, we bridge experimental gaps by providing insights into mineral-organic interactions under conditions unattainable in the lab, such as geological timescales or extraterrestrial settings like Mars. Our findings demonstrate that both smectite clays and layered double hydroxides can selectively adsorb amino acids and catalyse peptide formation, yet with very distinct mechanisms.[2,3] The produced polymer composition and yield are dictated by the mineral structure and environmental factors, which we discuss. While a peptide preserved within a clay may appear as a biosignature, we argue that such mineral-formed peptide is only a biosignature-lookalike. Based on statistics collected from our simulations, we are able to propose an approach to identify whether the mineral-encapsulated peptide is a pseudo-biosignature during space missions, based solely on its amino acid composition.

[1] Stewart, S. V., & Erastova, V. (2024). Understanding the Role of Layered Minerals in the Emergence and Preservation of Proto-Proteins and Detection of Traces of Early Life. *Accounts of Chemical Research*, *57*(17), 2453-2463.

[2] Erastova, V., Degiacomi, M. T., G. Fraser, D., & Greenwell, H. C. (2017). Mineral surface chemistry control for origin of prebiotic peptides. *Nature communications*, *8*(1), 2033.

[3] Stewart, S. V., Pollak, H., & Erastova, V. (*in prep*). Adsorption of proteinogenic amino acids on Mars analogue clay minerals.