FY24 Strategic Initiatives Research and Technology Development (SRTD)

Assessing Origin of Life (OOL) Scenarios for Exoplanet Studies

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Strategic Focus Area: Developing Tools for Scientific Optimization of Missions | **Strategic Initiative Leader:** Charles Lawrence

Objectives:

- Identify general origin-of-life (OOL) requirements for a habitable exoplanet (e.g., chemical nutrients, physical/energetic conditions, time duration). Identify conditions that would be most likely support prebiotic chemistry on exoplanets.
  - We define OOL as a **transcription and translation** (DNA -> RNA -> proteins) system, with enzyme-driven metabolic networks contained within a cellular membrane
- Assess planet system types (as a function of system age, atmospheric composition, size, mass, stellar type) that might be able to support prebiotic or OOL processes using a suite of theoretical models and lab experiments.
- Determine what observables can support evidence of OOL conditions at various points in a planet's geologic history.

Background:

- Current/future missions to determine exoplanet "habitability" aim to detect certain molecules (e.g., H_2O, CO_2, CH_4) in the planet's atmosphere
- To determine whether life exists on a planet, it must not just be habitable, it must also have facilitated an OOL event
- We have Earth as our only example of a 'successful' OOL, and from Earth we know that geological and mineral conditions are important

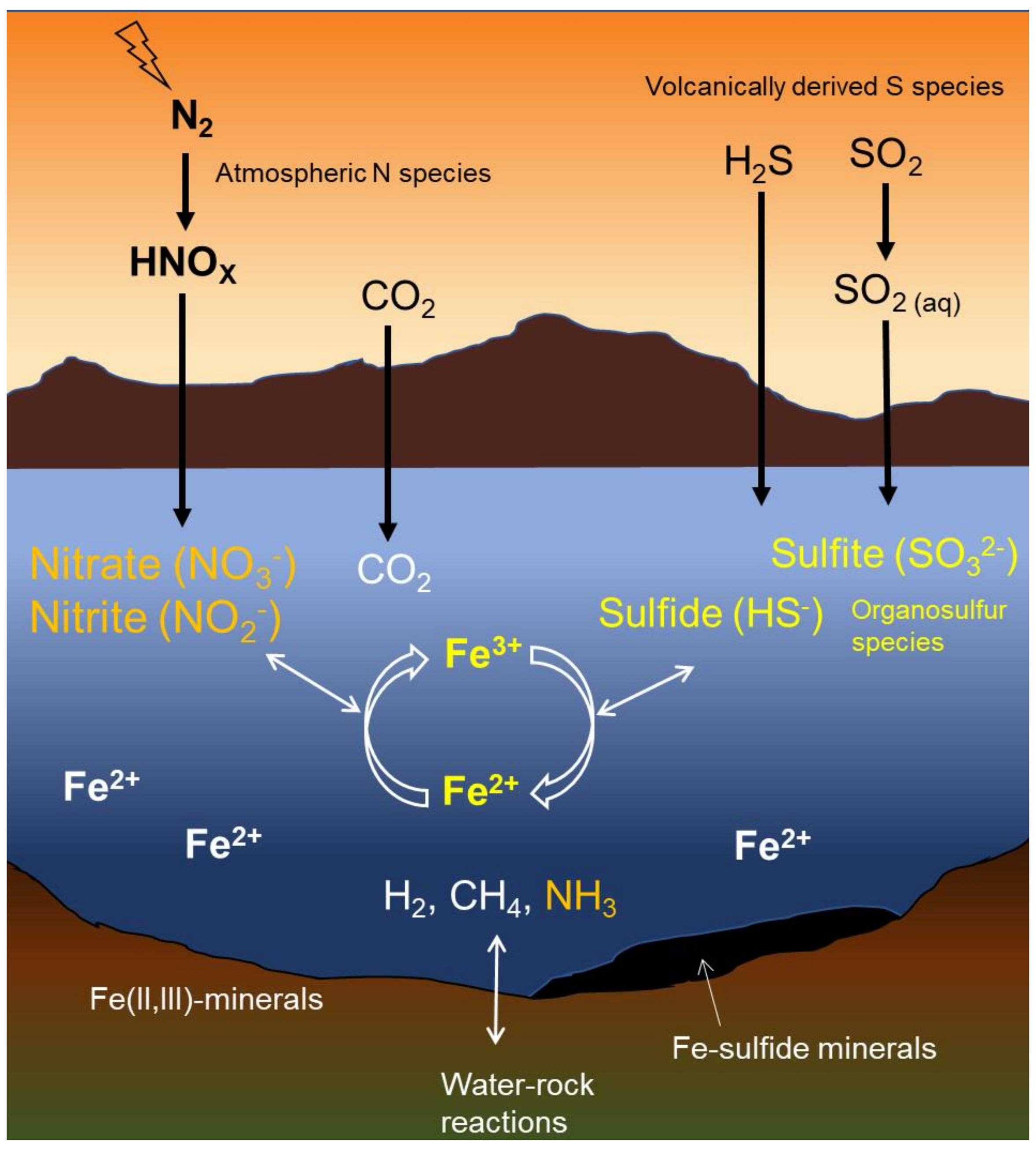

Figure 1: Origin of life on terrestrial planets depends on redox states & cycles of inorganic species (Fe, S, N, and so on). Minerals bearing these species (especially Fe) are important catalysts for OOL processes, so it is important to understand under what conditions they form on planets. This schematic shows how the different inorganics interact with one another, including how photochemistry in N_2-rich atmospheres results in dissolved oxidized N species (nitrate, nitrite) in the ocean, and oxidized and reduced S species react to form dissolved species in the ocean (e.g., sulfide).

Approach and Results:

We focus on **mineral/enzyme transitions** associated with three bioessential elements relevant to exoplanet environments and OOL on Earth: Iron (Fe), Nitrogen (N) and Sulfur (S).

- We successfully tested whether disulfide compounds could form under geological conditions
- We confirmed the presence of the dimer cystine from reactions of the S-bearing amino acid cysteine. This indicates that – contrary to previous claims – formation of these important protometabolic molecules does not require UV radiation and can be accomplished in a wider variety of prebiotic settings, e.g., in deep oceans of terrestrial planets
- We serendipitously discovered that N species (nitrate or nitrite) could oxidize the iron minerals present, thus creating a reversible oxidation / reduction reaction of Fe that results in pseudo-catalytic behavior, perhaps as the precursor to enzyme-like behavior (**Fig 2**). The paper has been submitted and is currently under review (Valadez et al. 2024, submitted)
- We will focus more on N redox chemistry in Y3
- We also made progress on experiments that could shed light on carbon redox chemistry on exoplanets toward the OOL – which requires both CO2 reduction and CH4 oxidation.

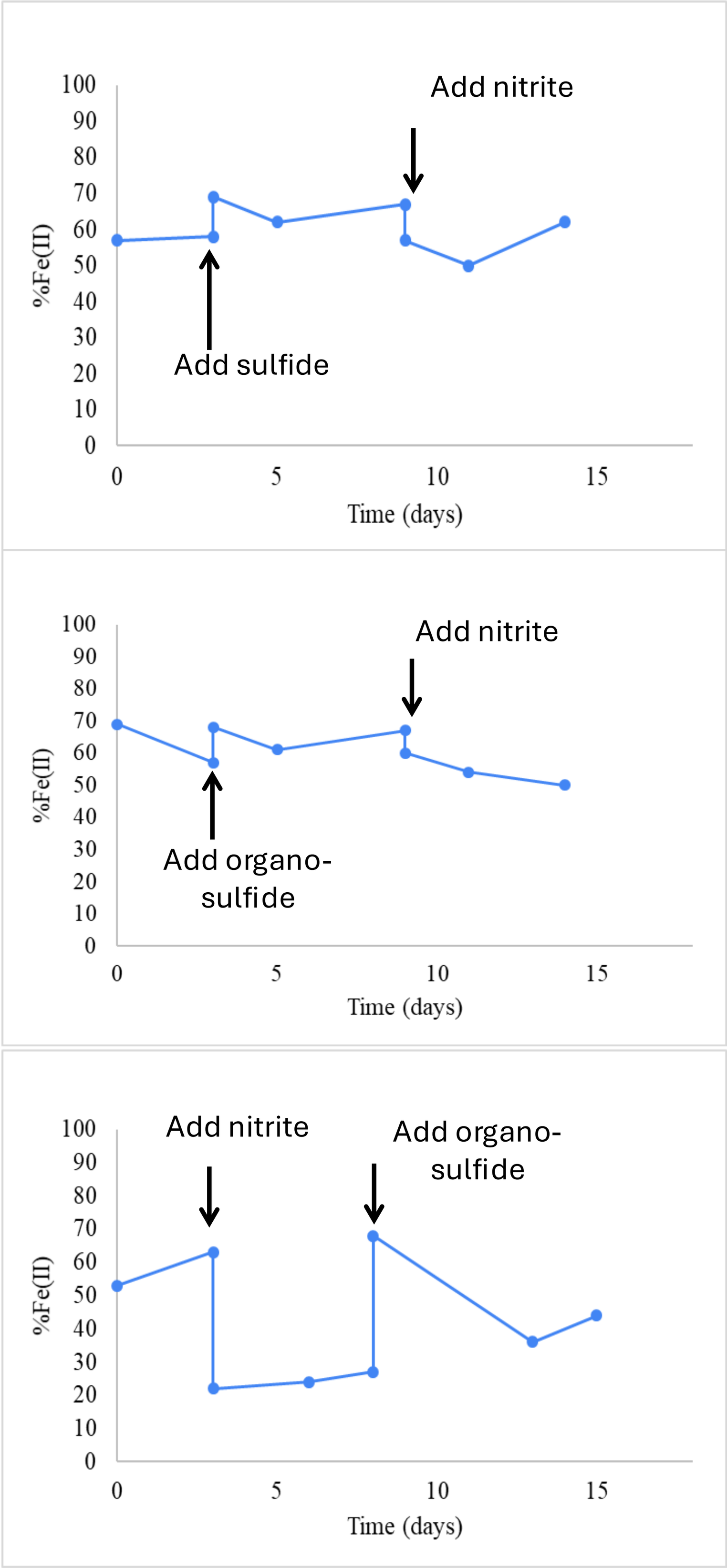

Figure 2: Plots showing how addition S and N species can increase/decrease the concentration of Fe (II). The addition of sulfide or organosulfide causes an increase in %Fe(II) in the mineral (Fe reduction); and addition of nitrite causes a decrease in Fe(II) in the mineral (Fe oxidation). Importantly the Fe redox transitions are reversible, which means that Fe minerals can be reversibly oxidized and reduced by these other N / S species. This can lead to very reactive behavior that can be important for prebiotic reactions with organics – which will be the topic of a future study.

Significance/Benefits to JPL and NASA:

- This research fills a crucial gap in infusing astrobiology and life detection into future exoplanet missions, including the Habitable Worlds Observatory (HWO).

Publications:

Valadez et al. 2024, submitted

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