National Aeronautics and Space Administration

Understanding abiotic organic chemistry driven by minerals in Ceres' and Enceladus' oceans

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Background: Developing methods for detection of organic molecules on ocean worlds is of strategic importance to JPL and NASA. Organics have already been detected on the surface of Ceres and in the plumes of Enceladus. However, organic detection – even detection of organics that are commonly found in Earth biology – does not necessarily mean life, because there are many processes that produce organics abiotically in geological systems. In order to understand whether future organic detections on the ocean worlds are convincingly suggestive of an extant biosphere, we must be able to distinguish biotic from abiotic organic signatures. Through the work proposed here, we will experimentally investigate abiotic chemical pathways in ocean world analog systems and determine which distributions of organics or biomarkers are reliable indicators (and which are not) to support habitability and life-detection efforts on these bodies.

Objectives:

- Test organic synthesis from simple precursors under Ceres relevant conditions.
- Identify the organic reaction pathways and products produced in green rust experiments.
- Identify the organic reaction pathways and products produced in clay experiments.
- Test the effect of sulfide and iron sulfide on organic reactions in a Ceres context.
- Compile a library of expected abiotic product distributions produced on ocean worlds as a function of geological parameters for green rust, clay, and sulfide minerals.
- Conduct tests of methods for extracting organics from minerals.
- Deliver the organic samples produced in these experiments to Task 3.

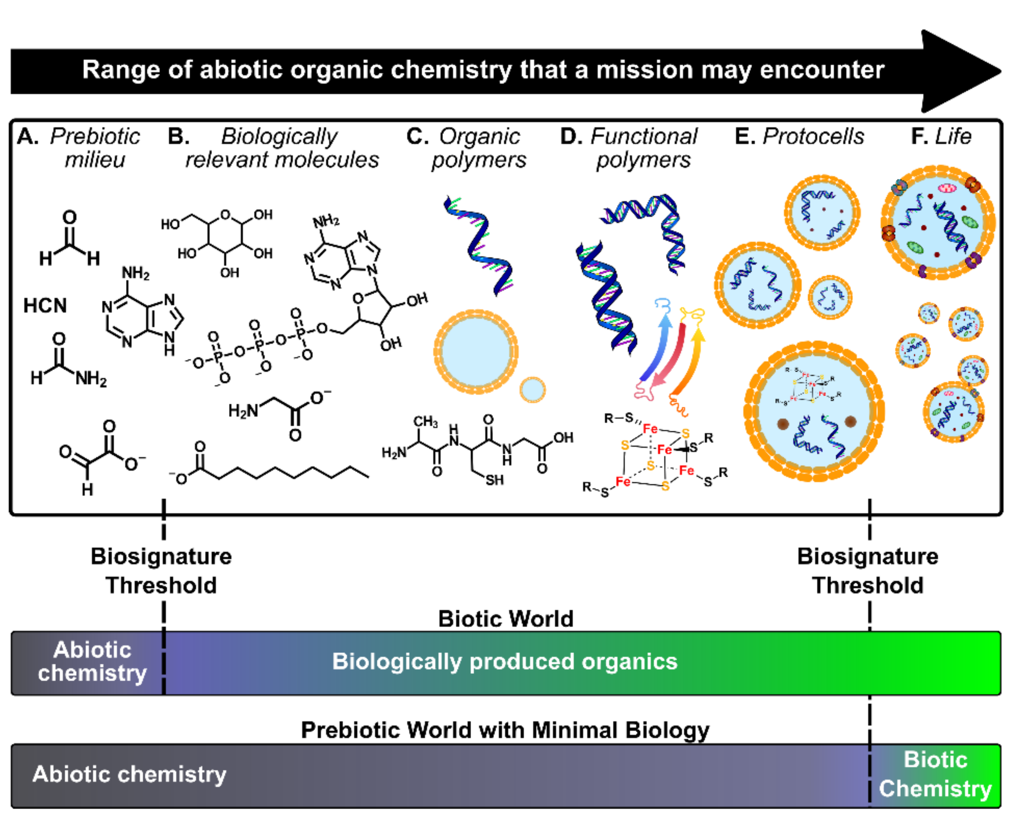


Figure 1: This shows the concept of the "biosignature threshold" – the boundary of complexity above which an organic detection would be interpreted as life. But this threshold is not the same for every planetary environment; it depends on the organic chemical history of that environment [1]. In particular, prebiotic reactions produce complex organic signatures that can be hard to distinguish from biotic signatures (Fig 2).

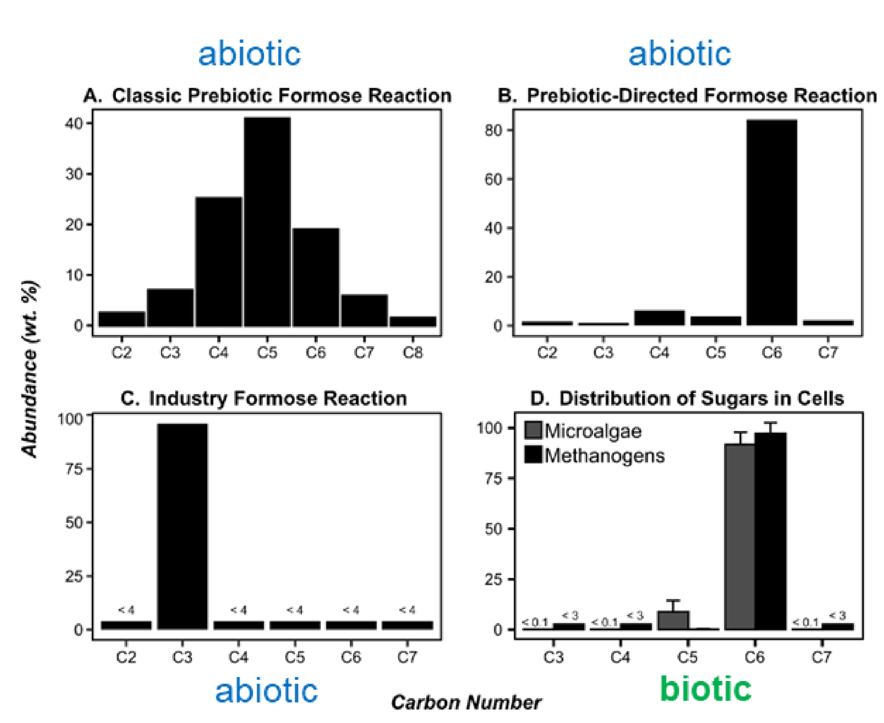
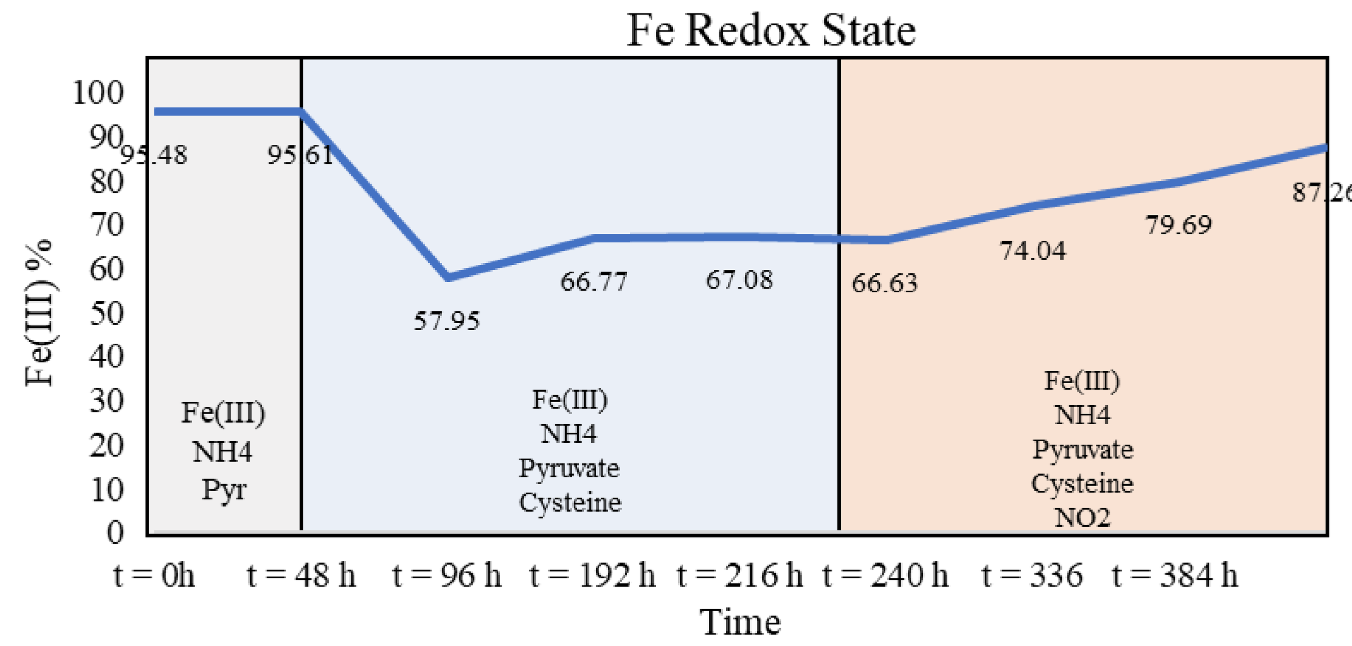


Figure 2: Example from [1] of how mineral-directed abiotic reactions can give organic distributions similar to biological reactions. A) abiotic formose reaction; B) prebiotic formose reaction; C) abiotic formose reaction from industry; D) biotic distribution of sugars in cells. To distinguish between abiotic and biotic in this reaction, a mission would have to differentiate not just between A and D, but also between Figs B and D, which would be more challenging.

Figure 3: Experiments testing oxidation state of iron minerals in the presence of a sulfur-bearing organic, cysteine. Minerals were synthesized at 100% Fe(III), then cysteine was added and a gradual Fe reduction was observed. Then an oxidant (nitrite) was added and a gradual Fe re-oxidation was observed. Since the oxidation state of the iron is a main driver of other organic chemistry, this organosulfur promoted redox cycling of iron might be able to cause the emergence of organic autocatalytic cycles.



Significance/Benefits to JPL and NASA: On ocean worlds such as Enceladus, underwater hydrothermal water-rock (serpentinization) reactions have been proposed as a process that could have driven the emergence of life on Earth, and this might have also occurred on ocean worlds and given rise to a biosphere that we could try to detect with missions. But it is also possible that organic-mineral ("prebiotic") chemistry on Ceres and/or Enceladus occurred, but did not actually lead to life; and that when exploring these worlds we will detect only remnants of "prebiotic systems". This work helped to expand our knowledge of abiotic complex organic chemistry that might be found on ocean worlds, and considerations for distinguishing between abiotic, prebiotic, and biotic on future ocean world missions.

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Publications:

[1] Barge L.M., Rodriguez L.E., Weber J.M., Theiling B.P. (2022) Determining the "Biosignature Threshold" for Life Detection on Biotic, Abiotic, or Prebiotic Worlds. *Astrobiology*, 22, 4, 481-493

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