National Aeronautics and Space Administration

FY23 Innovative Spontaneous Concepts Research and Technology Development (ISC)

Life Detection Development and Data Assessment of Agnostic Nuclaic Acids

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Background

The ability for future astrobiology missions to measure and identify metabolites that would have a biological origin or currently be part of a biological process requires a structural and electrochemical comparison to "life as we know it" ecology and biology.

- This comparison needs to be agnostic and rely on atomic charges that are consistent with the biochemical structuring of a cell, independent of the phylogeny the components within it.
- In order for this identification and comparison to take place, known ordered strains of nucleic acids, known base pairs, and single species containing variations of both with respect to cell concentrations need to be measured to initialize this type of agnostic biological data.
- We show here the beginnings of this effort and the progress being made to bring this type of interpretation to the astrobiology and geobiology communities.

Objectives

Both past and present life have demonstrated the ability to survive in brine environments. The discovery of Icy Moons consisting of liquid water oceans, life detection missions have become a priority. There is a need for the development of technologies that can detect an array of potential biomarkers in these cryo-brine environments.

- This work examines the stability of solid-state nanopore technology in brine solutions relevant for astrobiology. Polyelectrolytes may be the universal signature of life. Examples of these polyelectrolytes are λ DNA and RNA.
- This linear structure allows the molecule to act as a template. As a result, these biomolecules indicate a potential for Darwinian evolution and a possible biosignature.
- The current state-of-the-art technology for nanopore devices utilizes a biologically based membrane. However, this nanopore is not ideal for long term space flight missions because the biological component in the membrane degrades quickly. The solid-state nanopore's analytical abilities and robustness makes them ideal for space missions.

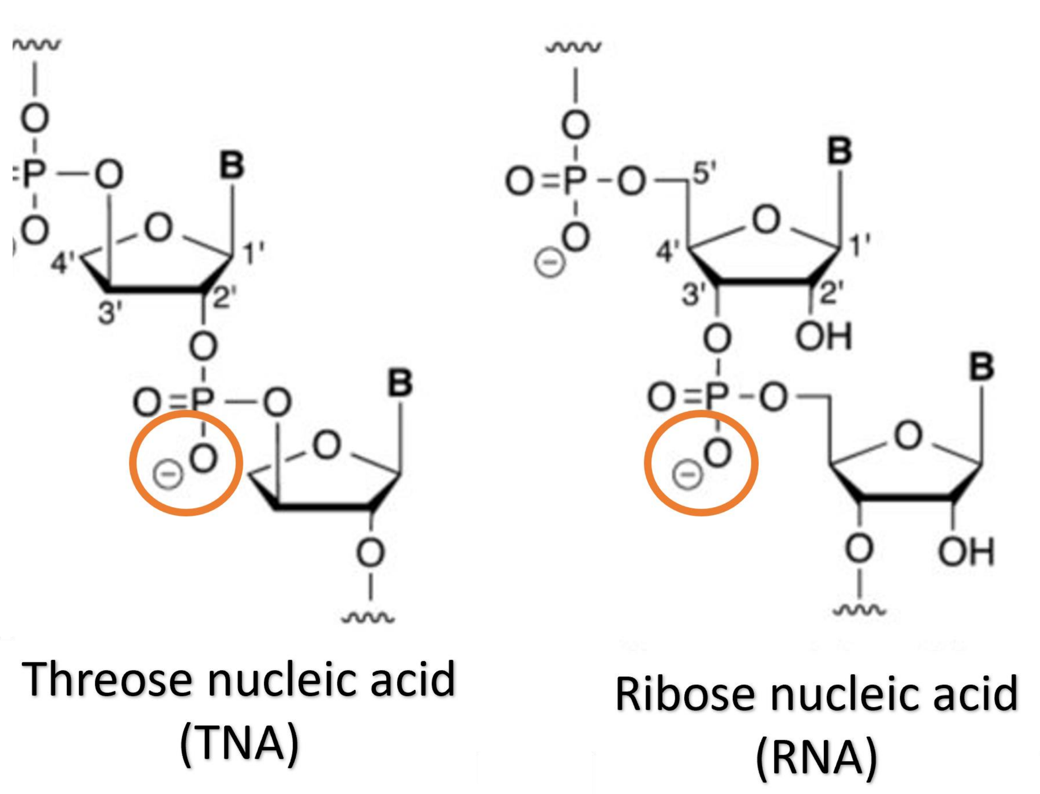


Fig. 1 Polyelectrolytes as Agnostic Biosignatures. These metabolites are bound within the biochemical structures of nucleic acids are the baseline for our agnostic measurements (alongside adjoining metabolites where present)

Approach and Results

This work offers first steps for analyzing agnostic biosignatures in brine environments. The solid-state nanopores exposed to DJP and KCl solution did show significant change in pore structure. However, the changes in size are still within the operation parameter required for the experiments (< 5nm). Along with this, no solution appeared to impact the surface chemistry.

- Assessing pore stability in brine solutions is critical because they are immersed in these solutions for molecule identification (Figs 2,3). Large fluctuations of pore size could lead to inaccuracies in translocation measurements. By measuring chemical compositional changes we aimed to better understand potential surface charger changes and chemical processes that may be impacting pore stability in brine solutions.

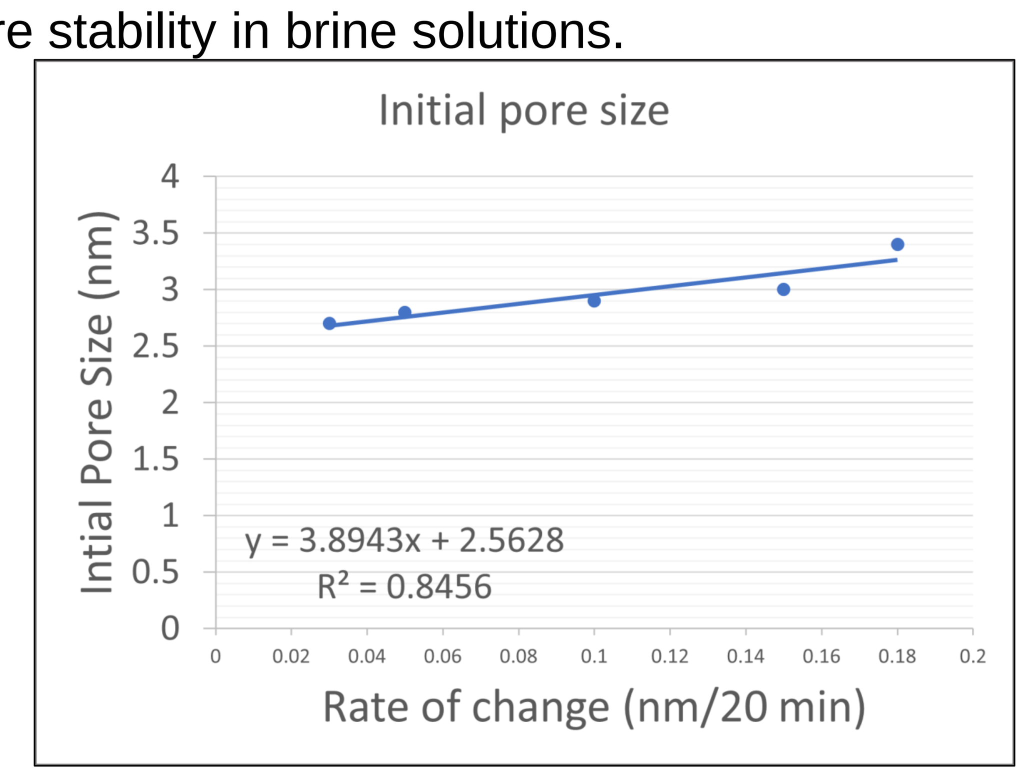
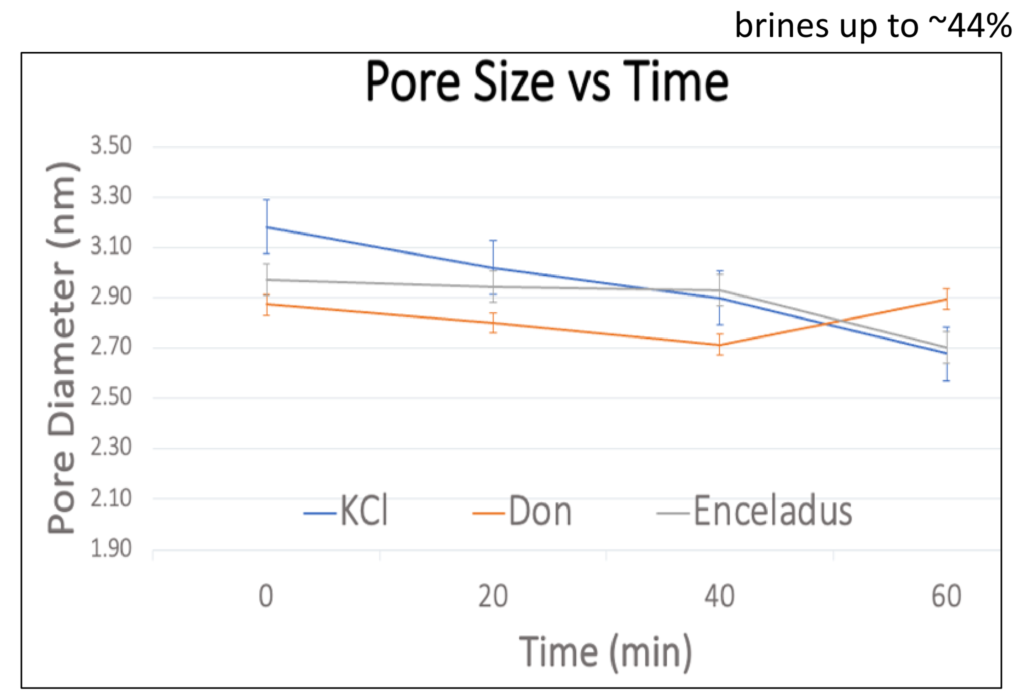


Fig. 3. Pore structure after repeated planetary analog brine usage. A critical path for this analysis is the slope of the size vs. pore change with respect to saline fluids. This is the same process for all isolated amino acids, isolated proteins, isolated RNA, isolated DNA, and their cellular version of each where all compositions exist but in widely varying sizes.

Fig. 3. Pore size changes with respect to different planetary brine solutions. Our KCl-only, Don Juan Pond, and Enceladus brine solutions all show minimal changes to pore structure, giving confidence in measurements being well above the quality control metric for hypersaline brines up to ~44%



Significance/Benefits to JPL and NASA:

The chemical composition and pore diameter were studied for solid-state nanopores exposed to standard electrolyte solution (1M KCl, 10mM Tris and 1mM EDTA, pH 7.5~8), Enceladus artificial seawater (pH = 5.46), and 10% of the estimated salt values for DJP (pH = 6.46) [4 and 5].

- These solutions varied in salt concentrations, pH, and conductivity. The KCl solution demonstrated the most significant change in diameter (~.3 nm). The Don Juan Pond had an average decrease in diameter of ~.1nm.
- Following this trend, the Enceladus plume analog had little to no change in pore diameter. Both the KCl solution and the DJP solutions showed a significant p-values in pore size change. These results bode well for Ocean Worlds exploration for small plume volumes and their compatibility to be agnostically measured similar to the DJP brines.

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Publications:

- Garner, M., Perl, S.M., Xia, C., Foreman, C. (2023) Characterizing Physical and Chemical Stability of Solid-State Nanopores in Planetary Relevant Brine Solutions. 15-18, May, 2023, Brines Across the Solar System: Ancient and Future Brines. Reno, Nevada
- Perl, S.M., Celestian, A.J., Cockell, C.S., Corsetti, F.A., Basu, C., Nisson, D.M., Garner, M., Valera, J., Javier, B.M. (2023) Microbial Pigment Robustness in Martian and Ocean Worlds Brines and Evaporites. 54th Lunar and Planetary Science Conference, held virtually, 13-17 March, 2023. LPI Contribution No. 2434

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