A SATURNIAN RNA WORLD? FIRST STEPS TOWARD EVALUATING THE STABILITY OF LIFE'S PRECURSOR MOLCEULES IN AN ENCELADUS OCEAN. C. L. Keele[1], M. L. Urquhart[1], and S. M. Taylor[1], [1]University of Texas at Dallas, 800 West Campbell Road, Richardson, TX 75080 (cxk124130@utdallas.edu).

Introduction: Enceladus, with evidence for abundant liquid water, may be one of the most promising astrobiological candidates in the solar system. Astrobiological goals motivating an Enceladus sample return mission have been argued to be more advanced than for any other body in the solar system [1]. A subsurface ocean is surmised from the eruption of geysers, containing water, salt, and organics, on the moon's south polar terrain [2]. This is the most accessible liquid water outside of Earth and it provides the greatest potential for sampling. As a result, the moon is a natural laboratory for prebiotic chemistry.

According to the 'RNA world' hypothesis, RNA molecules, once assembled from a nucleotide soup, catalyze the synthesis of themselves [3]. These self-replicating molecules might have supported Darwinian evolution without the need for other encoded molecules [4]. RNA could have slowly evolved through mutations and then began to synthesize proteins [3]. Proteins then performed the essential reactions of biology more efficiently and rapidly, eventually largely replacing RNA [3]. Later, DNA could have appeared as a stable linear information store and fully relegated RNA to its present role as intermediary [3].

Here we examine the expected lifetime of a regional subsurface ocean and the implications for derived estimates of the stability of precursor molecules critical to life, such as RNA and proteins. The temperature, pressure, and salinity of an Enceladus ocean are integral in determining the survivability of these precursor molecules. If liquid water is present only periodically, for example, what would be the survivability of RNA world's precursor molecules between periods of aqueous activity? If a subsurface ocean remains indefinitely, how suitable are conditions for the production and survivability of the complex organic molecules necessary for an RNA world-based origin for life?

Subsurface Ocean: Enceladus's density of approximately 1608 kg/m^3 implies that a large fraction of the moon's mass is H_2O [5]. In a differentiated model, this layer is 96 km thick [6]. Evidence for liquid water existing in this layer comes from the presence of ammonia in the plume material [7]. A regional subsurface ocean at depths of 30 to 40 km and extending up to 50^o south latitude is consistent with gravity measurements from the Cassini spacecraft, though a global ocean cannot be ruled out [8]. Estimates for how long a subsurface ocean can exist at Enceladus vary widely in the literature as shown in Table 1. Understanding timescales of and conditions of the aqueous activity on Enceladus are critical to understanding the prebiotic chemistry in the ocean layer.

Table 1: Enceladus Ocean Survivability Timelines

Conditions	Timeline
Global ocean, constant tidal heating, Maxwell rheology [14].	40 km thick ocean freezes in 30 Ma.
Steady tidal heating augmented by episodic heating [5].	Ocean maintained indefinitely.
An-elastic, Burgers rheology, conducting ice [16].	Ocean maintained indefinitely.
Regional ocean, eccentricity 5 times present day value [17].	Ocean maintained indefinitely.

Heat Sources: Cassini has located approximately 100 geysers erupting from four fractures on the moon's south polar terrain [2]. Estimates of the energy release in this region range from 4.7 GW to 15.8 GW, depending on wavelength [5].

From analysis of 2008 Cassini Composite Infrared Spectrometer (CIRS) 10 to 600 cm^{-1} thermal emission spectra, estimated endogenic power is 15.8 GW [10]. Passive emission from the solar-heated surface was modeled and removed. CIRS measurements at 600 to 1100 cm^{-1} spectra estimated this to be 4.2 GW [10].

Present day core radiogenic heating from ^{26}Al and ^{60}Fe provides an estimated 0.3 GW of heating, which according to Travis and Schubert is not enough to maintain a subsurface ocean [5]. Energy from serpentinization of forsterite and enstatite [11] can add significant heating on a geologically short interval, but this heat can be lost in less than 1 Ga [5].

An additional proposed source of energy is from tidal dissipation provided by an eccentric orbit pumped by a 2:1 resonance with Dione [12]. If Enceladus is in an equilibrium resonant configuration with other saturnian satellites, and assuming a Q_S tidal factor of 18,000, tidal heating is estimated to be 1.1 GW [13]. Assuming Maxwellian behavior, the observed heat flux and any possible subsurface ocean is not in equilibrium [14]. A non-Maxwellian, an-elastic model shows episodic heating can be induced for some parameter ranges, on a timescale on the order of 100 Ma and heating magnitude up to 1.5 GW [15]. A separate an-elastic model assuming Burgers rheology and conducting ice can support an ocean maintained on the long term [16]. During periods of increased orbital eccentricity, a regional ocean could be maintained indefinitely [17].

Species Present (Including Organics): Plume samples analyzed by Cassini's Ion and Neutral Mass Spectrometer (INMS) were found to contain primarily water [7]. Table 2 shows a subset of the composition of samples taken during the 9 October 2008 flyby of Enceladus, which had the highest signal-to-noise ratio to that date. This enabled the identification of trace species, including organics such as benzene, which were undetectable in other fly-bys [7]. Highlighted in red are species that are indicative of more complex organics in the aqueous environment.

Table 2: Plume Composition [7]

Species	Volume Mixing Ratio
H_2O	0.90 ± 0.01
CO_2	0.053 ± 0.001
CO	[0.044]*
H_2	[0.39]*
H_2CO	$(3.1 \pm 1) \times 10^{-3}$
CH_3OH	$(1.5 \pm 0.6) \times 10^{-4}$
C_2H_4O	$<7.0 \times 10^{-4}$
C_2H_6O	$<3.0 \times 10^{-4}$
H_2S	$(2.1 \pm 1) \times 10^{-5}$
^{40}Ar	$(3.1 \pm 0.3) \times 10^{-4}$
NH_3	$(8.2 \pm 0.2) \times 10^{-3}$
N_2	<0.011
HCN	$<7.4 \times 10^{-3}$
CH_4	$(9.1 \pm 0.5) \times 10^{-3}$
C_2H_4	<0.012
C_4H_{10}	$<7.2 \times 10^{-4}$
C_5H_6	$<2.7 \times 10^{-6}$
C_5H_{12}	$<6.2 \times 10^{-5}$
C_6H_6	$(8.1 \pm 0.1) \times 10^{-5}$

*Values included in H_2O and CO_2. Nine additional hydrocarbons not listed here. Red text indicates species crucial to the development of life.

In addition, other elements required for life, including phosphorous, potassium, sulfur and calcium, are likely to be present, due to the interaction between water and rock [1].

Precursor Molecules: The hydrocarbons observed in the plume present the possibility for life's precursor molecules to eventually form in an Enceladus ocean. In the presence of simple mineral catalysts, the polymerization of formaldehyde forms a mixture of sugars, including ribose, part of the backbone of RNA and DNA [18]. Polymerization of hydrogen cyanide is an important step in producing amino acids and nitrogenous bases [19]. Adenine and guanine, as well as glycine, have been shown to form in frozen solutions of ammonium cyanide [20].

Stability of RNA and DNA: In a strand of primitive RNA, composed of perhaps several hundred base pairs, the breakdown of an individual base pair could disable prebiotic functioning of the molecule such as self-replication. DNA is unstable over long periods of time, and RNA is more chemically unstable. For example, a study on the *Bacillus subtilis* bacterium found that in an acidic buffer solution, the purine bases would detach from the sugar of the DNA backbone at a rate of one base pair per month [21]. A hypothetical strand of RNA can be expected to decay faster under identical conditions. If aqueous conditions are temporally or spatially sporatic on Enceladus, would RNA-world steps towards biology begin anew due to macromolecule decay between each occurance of a favorable environment?

Future Work: Additional effort will be focused on determining the long-term stability of large prebiogenic organic molecules in ice and in aqueous solutions, in both the absence and presence of high concentrations of ammonia.

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