National Aeronautics and Space Administration

Carbon Cycle in Small Ocean Worlds

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Program: FY21 R&TD Strategic Initiative **Strategic Focus Area: Fate of Organics in Ocean Worlds**

Objectives

The overarching goal of this task is to track the fate of carbon compounds in small ocean worlds, such as in dwarf planets (e.g., Ceres) and mid-sized icy moons (e.g., Enceladus, Uranus' satellites). The focus of this task is to (G1) quantify the geochemical cycles in small ocean worlds with a focus on carbon; (G2) provide input (e.g., pH, redox, key minerals and volatiles in solution) on the experimental conditions for the two other tasks in this initiative (Task 2 "Understanding abiotic organic chemistry driven by minerals in Ceres' and Enceladus' oceans" led by L. Barge and Task 3 "Organic Chemical Transformations on the Surfaces of Ceres and Enceladus" by R. Hodyss.)

Background

Ocean worlds are of significant interest for finding life in the solar system, since some dwarf planets or icy moons show evidence of water-rock chemistry, a past or present liquid water ocean, and geochemical disequilibria that may be able to support life through hydrothermal processes. Developing methods for detection of organic molecules that are also found in terrestrial biology is one way for trying to identify whether or not life is present on these worlds, and organic matter (OM) has already been detected on the surface of Ceres and in the plumes of Enceladus. However, organic detection – even detection of organic compounds that are commonly found in Earth biology – does not necessarily mean life, because there are many processes that produce these compounds abiotically in geological systems.

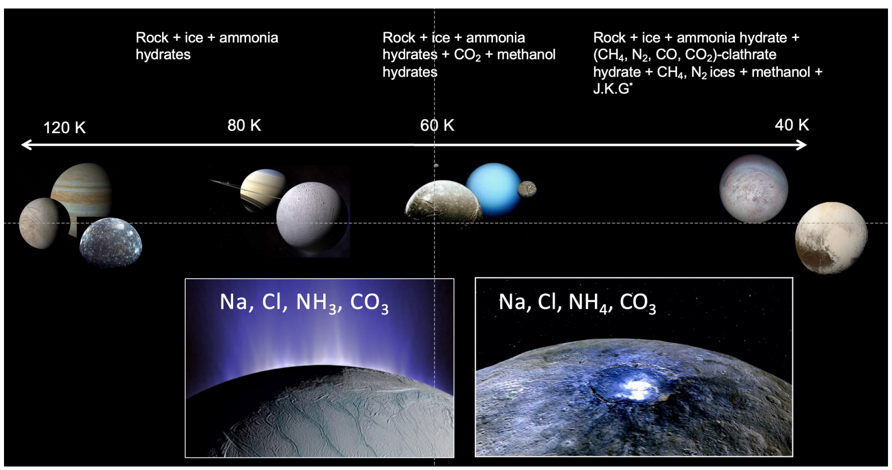

Figure 1. Composition of ices as a function of distance from the Sun. Bottom pictures illustrate the consequences of the accretion of carbon dioxide and ammonia in icy moons (e.g., Enceladus) and dwarf planets (e.g., Ceres)

Approach and Results

The approach combines geochemical modeling covering a wide range of pressure and temperatures relevant to small ocean worlds, and volatile compositions addressing formation conditions at a wide range of bodies (from Europa to Triton/Pluto). The code includes a combined thermal-geochemical-freezing model (Figure 2). The approach will also incorporate knowledge based on the study of the fate of organics in carbonaceous chondrites.

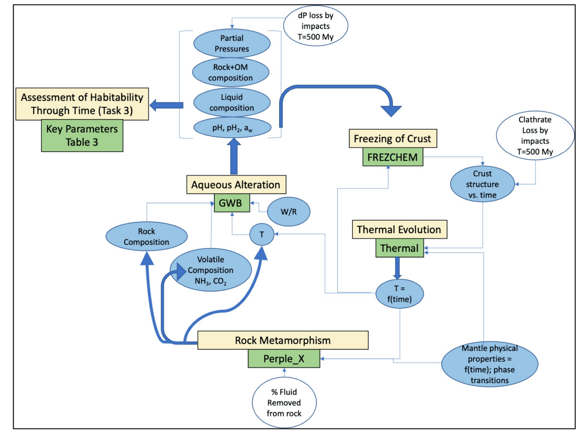

Figure 2. Geochemical modeling using Geochemist's Workbench (GWB) is coupled with FREZCHEM GWB tracks the production of carbonates while FREZCHEM tracks the production of clathrate hydrates using the output of GWB. Rock evolution uses metamorphic modeling of Ceres' rocky mantle with the software Perple_X.

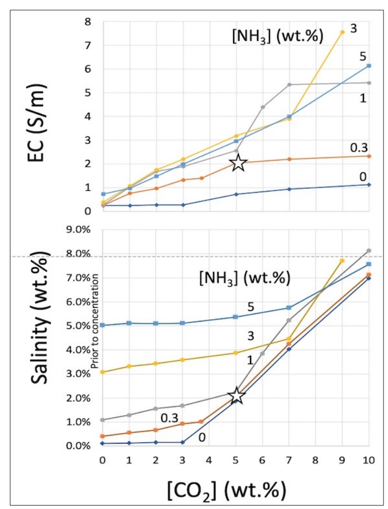

Figure 3. Salinity and EC as a function of accreted CO_2 and NH_3 abundances, calculated at $0^{\circ}C$ and ambient pressure, prior to concentration.

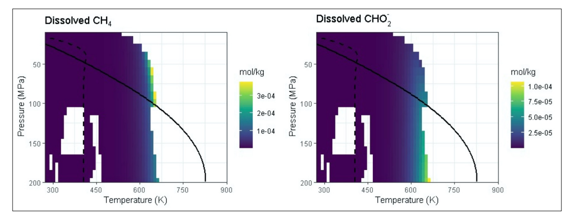

Figure 4. Concentration of hydrocarbons dissolved in free fluids produced during the thermal evolution of Ceres. This model of Ceres was run with 25% H2O in addition to that contained by CM chondrites, a 30 vol. % maximum fluid capacity in the upper layer and no pore space in the bottom layer. Dashed curve: geotherm at 100 Myr after formation. Solid curve: present day geotherm; (left) Dissolved methane; (right) Dissolved formate. "Gaps" in the plot are regions of stability for certain hydrated minerals like serpentine and carbonates, like magnesite.

Significance/Benefits to JPL and NASA

Characterizing the nature and origin of organic matter found at Ceres should be an important objective of follow-on missions at these bodies. This initiative brings a much needed foundation for a realistic assessment of the significance of organic matter found at icy bodies across the solar system.
Hence, this strategic initiative is aligned with the JPL Quest to understand "has there been life elsewhere in our solar system? Could it be there today?" and falls under the JPL Strategic Theme " Life in Ocean Worlds."

Clearance Number:
RPC/JPL Task Number: R20011

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