HYDROTHERMAL ALTERATION OF MACROMOLECULAR ORGANIC MATTER WITHIN OCEAN WORLDS

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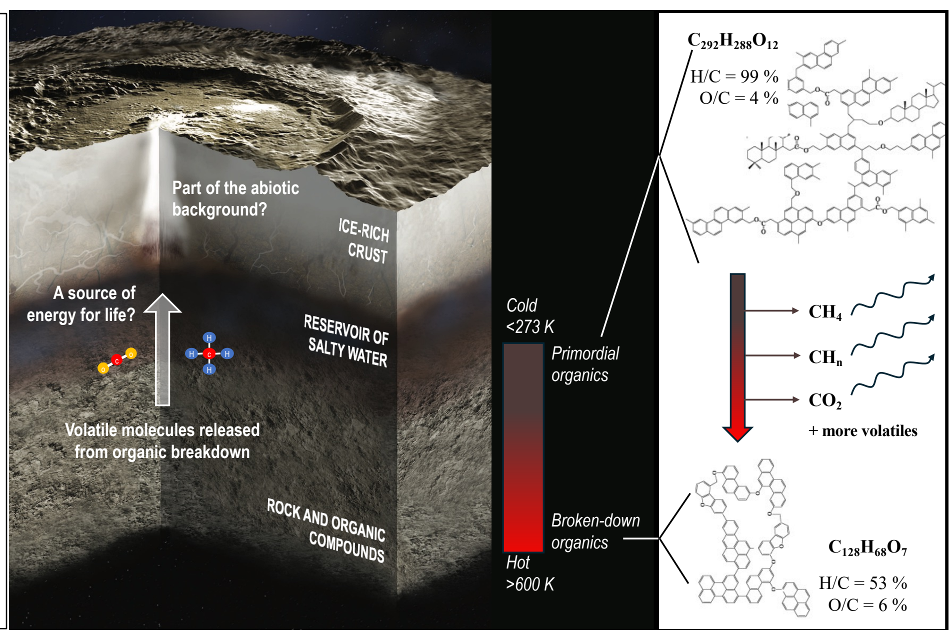
My NASA ECCA award supported my travel to the Earth and Planets Laboratory at Carnegie Science in Washington D.C. to collaborate with Drs. George Cody, Dionysis Foustoukos and Conel Alexander in March of 2026. During this collaboration, I conducted nine hydrothermal reaction experiments on synthetic macromolecular organic matter, simulating the alteration of meteoritic IOM within ocean world interiors.

Introduction:

Abiotic organic matter is strewn throughout our outer solar system[1,2]. Potentially habitable oases of prebiotic chemistry could have been commonplace[3]. Carbonaceous chondrite meteorites—some of the earliest formed rocks in the solar system—are several wt. % organic matter[2], implying that their parent bodies contained abundant organic matter in their interiors, too. It is not yet clear how organic matter in the outer solar system chemically reacted within the interiors of planetary bodies. There is great need for data and models that can describe the behavior of macromolecular organic matter (MOM) throughout the myriads of planetary environments. If one heats the primordial organic matter from a carbonaceous chondrite—the likely building block of most outer solar system objects what will be the chemical products? I traveled to Carnegie Science to begin to tackle one aspect of this multifaceted problem: the alteration and breakdown of MOM within ocean world interiors (Fig. 1).

Figure 1: Possible interior of a small, organic-rich ocean world (left). Deeper and hotter organic macromolecules break down and release volatiles (right). These compounds could infiltrate shallower regions of the interior, perhaps creating a source of energy for microbial life[3,7].



Experiments:

I conducted hydrous pyrolysis experiments on synthetic MOM samples following the methods of previously published studies[4-6]. I reacted MOM samples with water at three different temperatures (360 °C, 390 °C, and 420 °C) and three different durations ratios (3, 6, and 9 days). These experiments consisted of three steps:

(1) *MOM sample synthesization and preparation.* I sealed MOM, synthesized from the carbonization of sugar molecules, into silver hydrothermal reaction capsules with water.
(2) *MOM hydrous pyrolysis.* Each sealed capsule with MOM and water was placed in a hydrothermal reaction vessel and heated at 1 kbar for the prescribed duration and temperature. Upon completion, the capsules were placed in a freezer to later be analyzed.
(3) *Product analysis.* The solid residues within the sealed capsules will be analyzed with nuclear magnetic resonance spectroscopy.

Step 3 is in progress. The NMR results will be used to assess the molecular evolution of the MOM as a function of time and temperature and integrated into a thermodynamic and kinetic model to describe MOM evolution under ocean world interior conditions. The resulting data will inform how volatiles may be released from the metamorphism of ocean world interiors that are rich in organic matter.

Figure 2: (Left) Hydrothermal reaction vessels. Each sample was placed in a silver reaction capsule, then enclosed in a reaction vessel before being heated in a furnace with a thermocouple. (Right) The ssNMR instrument that is being used to analyze MOM products. NMR analysis is ongoing and will reveal MOM molecular evolution.

References: **[1]** Alexander, C. M. O. et al. Geochemistry 77, 227–256 (2017). **[2]** Alexander, C. M. O. et al. Geochim Cosmochim Acta 71, 4380–4403 (2007). **[3]** Courville, S. W. et al. Sci Adv 11, eadt3283 (2025). **[4]** Miller, K. E. et al. Geochim Cosmochim Acta 390, 38–56 (2025). **[5]** Foustoukos, D. I. et al. Geochim Cosmochim Acta 300, 44–64 (2021). **[6]** Cody, G. D. et al. Earth Planet Sci Lett 272, 446–455 (2008). **[7]** Courville, S. W. et al. Planet Sci J 4, 179 (2023).