ASSESSING DWARF PLANET CERES' HABITABILITY THROUGH TIME J. C. Castillo-Rogez[1] and M. Melwani Daswani[1], C. S. Cockell[2], [1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, Julie Julie.C.Castillo@jpl.nasa.gov, [2]School of Physics and Astronomy, University of Edinburgh, United Kingdom.

Introduction: NASA's Dawn and New Horizons missions have revealed that dwarf planets Ceres and Pluto are potentially astrobiologically significant objects [1, 2]. Further research is needed to better quantify the habitability potential of these bodies through time and at present. Interpreting hints of deep oceans and recent endogenic activity requires more sophisticated evolution models that account for the thermophysical properties of non-ice materials expected in these bodies—such as gas and salt hydrates [e.g., 3], and the investigation of new processes that have not been explored in detail to date, like the far-ranging consequences of mantle dehydration [4].

This study addresses the habitability potential of Ceres through time by combining the physical and chemical evolution of its interior. The results will be used to frame the conditions that can help maintain a deep liquid layer in Ceres until the present, from which recent geological features could be sourced.

Methodology: The numerical framework to be employed is based on the combination of the following pieces of code: (1) Geochemist's Workbench: Modeling of the composition of the early ocean [5]; (2) FREZCHEM: Modeling of the freezing of Ceres' crust [5]; (3) Perple_X and Rcrust: Modeling of fluid release from the rocky mantle [4,6]; (4) thermal modeling [7]. The combination of these tools is one novel aspect of the proposed methodology. Perple_X and Rcrust in particular have been introduced only recently for modeling the evolution of large icy world mantles [4]. The relationships between the pieces of code are presented in Figure 1 and 2.

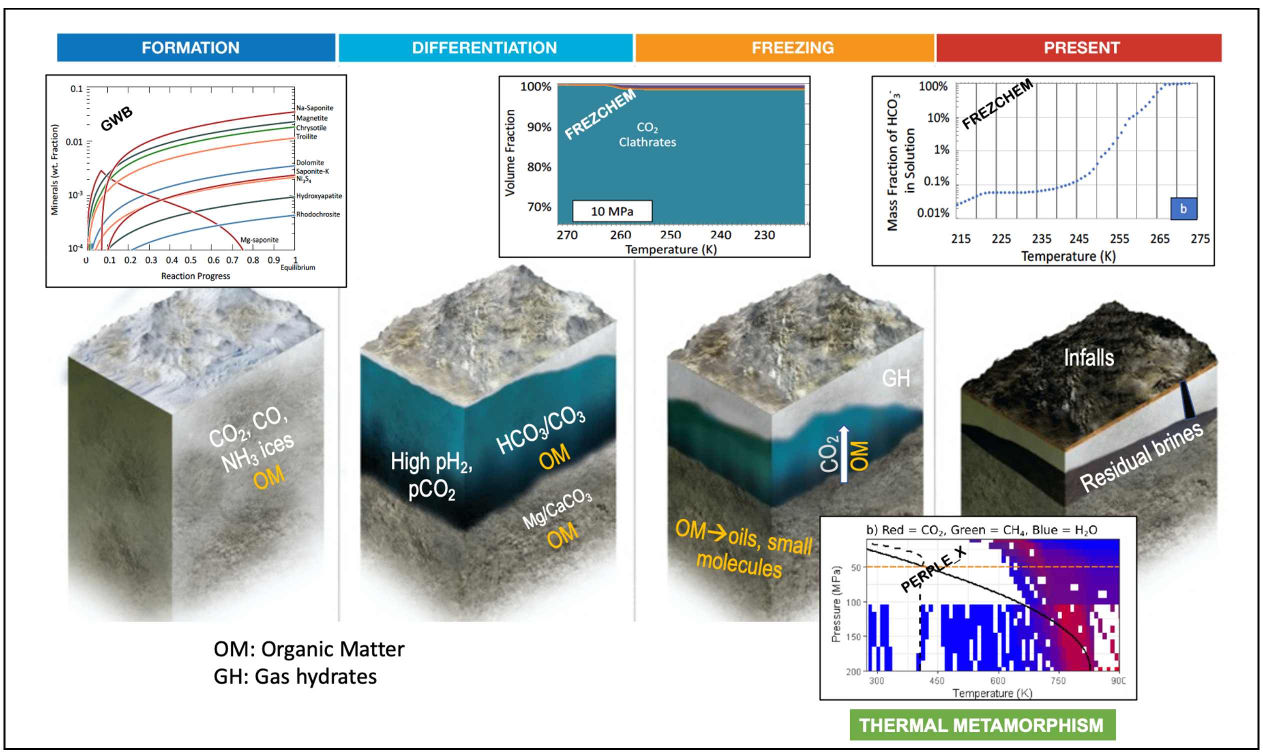

Figure 1. Four steps in the evolution of Ceres modeled in this study. Accretion conditions will account for various abundances of ammonia and carbon dioxide. Differentiation tracks aqueous alteration of the rock and composition of the ocean. During the freezing phase, gas hydrates may form but we will assume they may be partially destabilized by large impacts. Thermal metamorphism is a major event in Ceres' evolution that could lead to the formation of a late ocean or the input of fluids into residual brines.

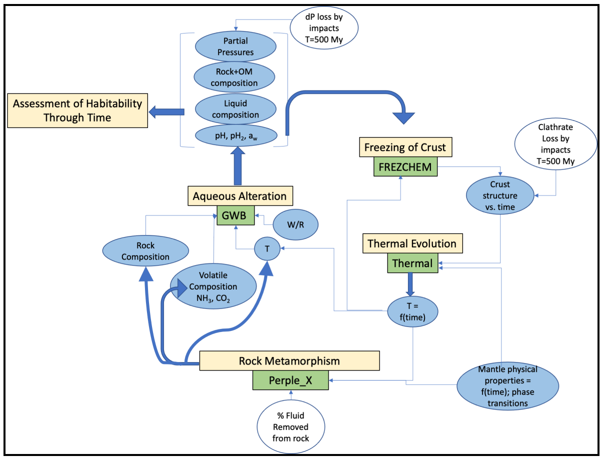

Figure 2. Relationships between the pieces of software via input/output parameters used in this study. Thick arrows indicate the main output from the modules; thin arrows connect the input parameters (blue bubbles) to the pieces of codes used in the modeling. T refers to temperature computed as a function of time. dP refers to partial pressures, W/R to water to rock ratio, OM to organic matter, a_w to species activity. White bubbles refer to specific scenarios.

Examples of Results: Figure 1 shows the output from the various codes used in this study. Figure 3 focuses on an example of Perplex_X output (from [6]) tracking the concentrations of solutes in fluids released from Ceres' rocky mantle as a consequence of thermal metamorphism. This example is based on a bulk composition (90% CI chondrite and 10% H_2O) with up to 30% porosity, which is consistent with the rocky mantle density derived from the Dawn observations [8]. These fluids could replenish residual brines and significantly shift their temperature, redox, and pH conditions; or even generate a late ocean layer. Preliminary results suggest that the composition of these fluids favors the formation of carbonates, which could relate to the large amount of carbonates found on Ceres' surface [9].

Acknowledgments: This work is funded by NASA's Habitable Worlds program NNH20ZDA001N-HW. Part of the research described in this abstract was carried out in part at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration. Government sponsorship is acknowledged.

References:

[1] Castillo-Rogez, J. C., et al. (2020) *Astrobiology* Feb 2020.269-291. [2] Nimmo, F., et al. (2016) *Nature* 540, 94–96. [3] Muñoz-Iglesias, V. and Prieto-Ballesteros, O. (2021) ACS Earth Space Chem. 5, 2626–2637. [4] Melwani Daswani, M., et al. (2021) *GRL* 48, e2021GL094143. [5] Castillo-Rogez, J. C., et al. (2018) *MAPS* 53, 1820-1843. [6] Melwani Daswani, M. and Castillo-Rogez, J. C. (2022) *PSJ*, in press. [7] Castillo-Rogez, J. C. et al. (2019) *GRL* 46, 1963-1972. [8] Ermakov, A. I. et al. (2017) *JGR* 122, 2267-2293. [9] Carrozzo, F. G. et al. (2018) *Science Adv.* 4, e1701645.

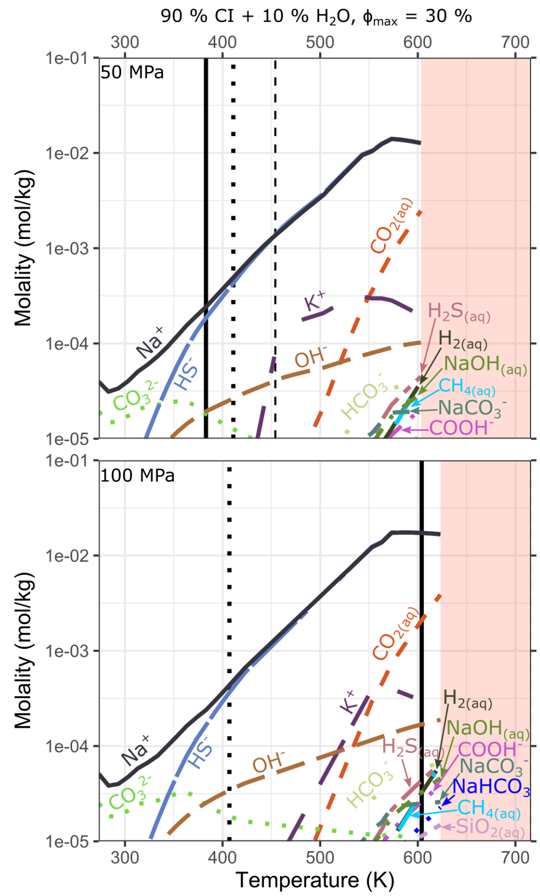

Figure 3. Solute concentrations in metamorphic fluids resulting from the evolution of a representative bulk composition for Ceres (90 wt% CI chondrite plus 10 wt% H_2O, maximum porosity = 30 vol%). Top: fluids produced at pressure of 50 MPa. Bottom: fluids at a pressure of 100 MPa. Dotted vertical line marks temperature at 100 Myr after formation, dashed vertical line marks 3 Gyr after formation and solid vertical line marks 4.5 Gyr after formation. Dashed vertical line coincides with the right Y axis position at 100 MPa. Pink areas correspond to supercritical water or immiscible solute regions. From [6].