The Volatile Composition of Europa's Ocean

C. Ray[1,2], C. R. Glein[2], J. H Waite[2,1] , and K. E. Miller[2], [1]Department of Physics and Astronomy, The University of Texas at San Antonio, San Antonio, TX 78249, [2]Space Science and Engineering Division, Southwest Research Institute, 6220 Culebra Road, San Antonio, TX 78238

Introduction: Volatiles produced in high temperature fluids by magmatic/hydrothermal activity in Europa's present-day silicate interior may be a key source of chemical energy in Europa's ocean ([1] and [2]). Transport to the ocean of reduced volatiles produced by such processes could couple with the delivery of surface oxidants to create chemical disequilibria, which may provide energy for life. Of primary importance are the volatiles H_2, CH_4, CO_2, N_2, and NH_3 which can be detected by the MASPEX instrument [3], and the anions HCO_3^-, CO_3^{-2}, and NH_4^+ which can be detected by the SUDA instrument [4], on Europa Clipper. The concentrations of these volatiles in the ocean depend on the geochemical properties of high temperature fluids. Future measurements from Europa Clipper can be compared with the predictions presented herein, and used to assess the availability of chemical energy within the ocean. Here, we establish an interpretive framework that explores how the pH, oxidation state, temperature, pressure, and total carbon and nitrogen budgets in Europa's interior govern the concentrations of volatiles in the ocean.

Methodology: Using geochemical analogs of Earth [5], Enceladus' ocean [6], Io [7], and chondrites [8], we consider plausible ranges of values for temperature, pH, oxidation state (which we represent by hydrogen activity, aH_2), pressure, and total carbon/nitrogen budgets in Europa's interior. We generate >70,000 models with different combinations of parameters within these ranges, with the goal of characterizing how each geochemical parameter affects the detailed speciation (volatile assemblage). For each model, we calculate the molal ratios of volatiles consistent with chemical equilibrium in Europa's magmatically derived fluids. We convert the ideal molal ratios of each species into concentrations using mass balance relationships for carbon and nitrogen. We examine how the speciation changes as a function of each of our considered parameters, characterizing the effect of a single parameter by fixing others at nominal reference values.

Results: We present the volatile speciation of high-temperature fluids on Europa for different combinations of pH, H_2 activity, temperature, pressure, and total carbon/nitrogen concentrations. An example is shown in Figure 1, where we have plotted the concentrations of different carbon species predicted for our models with pH set to pH neutral and total dissolved carbon set to 1mmol/kg H_2O. Temperature and H_2 activity are both variable in the example shown. Our models span five log units of H_2 activity around the fayalite-magnetite-quartz (FMQ) buffer, shown in different colors on Figure 1, which represents a wide range in oxidation state. Within a given value for the oxidation state, the spread in the predicted speciation is due to variable temperature. Under these conditions, we find that methane is the predominant carbon volatile produced, except at relatively oxidized (aH_2 < FMQ) conditions, where CO_2 dominates. Oxidation state also changes the abundance of carbonate species, with these species being more prevalent at more oxidized (aH_2 < FMQ) conditions. We also use these types of figures to determine which concentrations are predicted most frequently for a given species. This is useful for predicting the range of concentrations most likely to be observed by Europa Clipper, assuming all sets of parameters are equally likely.

We consider how each of the parameters in our model would affect the concentration of volatiles in Europa's ocean and possible plumes. Finally, we discuss the potential for these variables to be constrained by future observations from Europa Clipper using our models.

References: [1] Lowell, R. P. and Dubose M. (2005) *GRL, 32,* 5. [2] Vance, S., Hand, K., & Pappalardo, R. (2016) *GRL, 43,* 4871. [3] Brockwell, T. G., Meech, K. J., Pickens, K. et al. (2016) *2016 IEEE Aerospace Conference, IEEE,* 1-17 [4] Kempf, S., Altobelli, N., Brios, C. et al. (2014), *International Workshop on Instrumentation for Planetary Missions,* 3, 7. [5] Wetzel, L. R., Shock, E. L. (2000) *JGR: Solid Earth*, 105, 8319. [6] Glein, C., Postberg, F., & Vance, S. (2018) *Enceladus and the Icy Moons of Saturn*, 39. [7] Zolotov, M. Y., & Fegley Jr, B. (2000). *GRL*, *27*(17), 2789-2792. [8] Schaefer, L., & Fegley Jr, B. (2017). *ApJ*, 843(2), 1

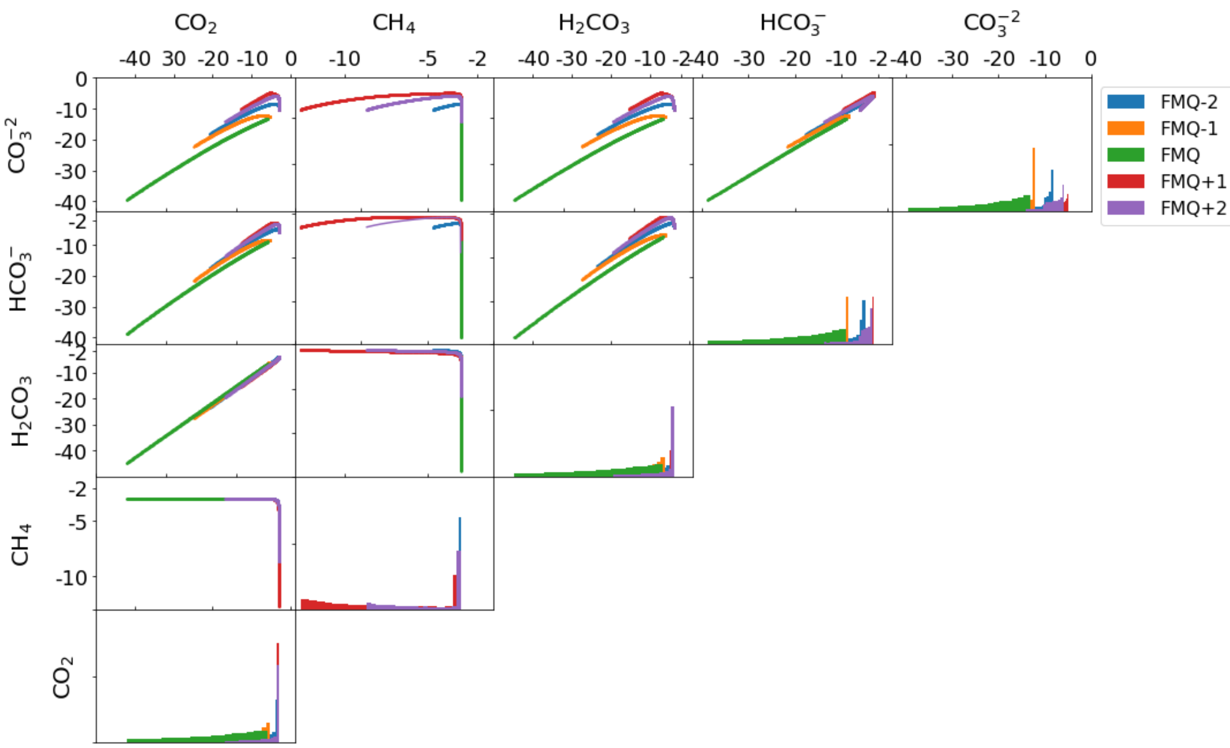

Figure 1: carbon speciation predicted for models at neutral pH and total carbon = 1mmol/kg H_2O, with temperature between 0 and 500°C and aH_2 between two log units above and below the fayalite-magnetite-quartz (FMQ) buffer. Scatterplots indicate the concentrations of two different compounds predicted for each model in mol/kg H_2O, which is useful for determining how each species is affected by a given parameter. Histograms (panels with the same species on each axis) indicate the relative frequency of values for a single compound. All histograms are normalized and plotted on a y-axis scale of zero to one. Different oxidation states are color-coded, while variation within a single oxidation state is due to changing temperature.