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Modeling the Volatile Speciation of High Temperature Fluids on Europa

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Introduction

Volatiles produced in high temperature fluids by outgassing of accreted chondritic material during Europa's formation, or by magmatic/hydrothermal activity in Europa's present-day silicate interior, may be a key source of chemical energy in Europa's ocean ([4] and [6]). 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 key importance are the volatiles H_2, CH_4, CO_2, N_2, and NH_3 which can be detected by the MASPEX instrument [1], and the anions HCO_3^-, CO_3^{-2}, and NH_4^+ which can be detected by the SUDA instrument [3], on Europa Clipper. The fluxes of these volatiles into the ocean, which depend on the geochemical properties of high temperature fluids and the amount of heat transferred from the silicate interior, need to be estimated to assess the habitability of the ocean. Here, we explore how the pH, oxidation state, temperature, pressure, and total carbon/nitrogen budgets of Europa's interior govern the input of volatiles to the ocean.

Methodology

We calculate the speciation of carbon and nitrogen volatiles in Europa's magmatically derived fluids from the molal ratios of volatiles consistent with chemical equilibrium. Using geochemical analogs of hydrothermal systems on Earth [7] and Enceladus' ocean [2], we consider a plausible range of values for temperature, pH, oxidation state (which we represent by hydrogen activity, a_{H_2}), and total carbon/nitrogen budgets in Europa's interior. We convert the ideal molal ratios of each species into concentrations using mass balance relationships for carbon and nitrogen. In determining values for the concentrations of total carbon and nitrogen, we consider analogs of Earth, carbonaceous chondrites, and comets. To characterize the effect of each individual geochemical parameter on fluid composition, nominal reference values are utilized for all but the parameter of interest in each calculation.

Results & Discussion

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 Figures 1 and 2, where we have fixed the pressure at the Europa seafloor pressure (1500 bar) and the oxidation state (aH_2) at the fayalite-magnetite-quartz (FMQ) buffer:

$$1.5\underbrace{Fe_2SiO_4}_{\text{fayalite}} + H_2O \rightarrow \underbrace{Fe_3O_4}_{\text{magnetite}} + 1.5\underbrace{SiO_2}_{\text{quartz}} + H_2. \quad (1)$$

Under these conditions, we find that temperature has the strongest control over speciation of carbon and nitrogen volatiles at high temperatures, while pH has the strongest control over the speciation at lower temperatures. At temperatures greater than $\sim$ 500°C, the most oxidized volatiles (CO_2 and N_2) dominate over reduced volatiles if equilibrium can be reached. At the low to mid temperature range (200-500°C), reduced species (CH_4, NH_3 or NH_4^+) are more abundant, but the relative abundances of these volatiles depend on pH.

We consider how each of the parameters in our model would affect the concentration of volatiles into the ocean, and the composition of Europa's hydrothermal fluid. Finally, we discuss the impact that each of our considered variables could have on the amount of chemical energy available in the ocean, and the potential for these variables to be constrained by future observations from Europa Clipper.

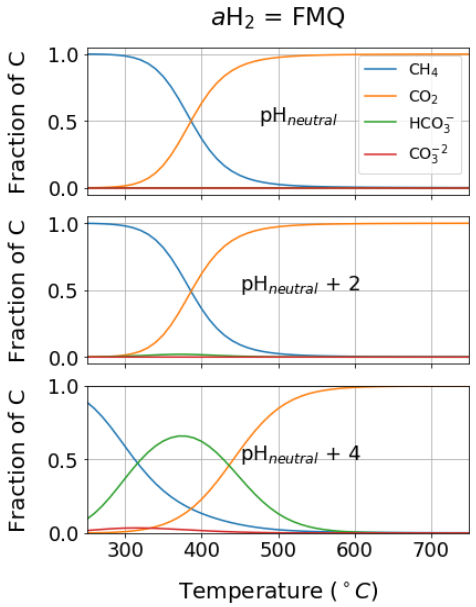

Figure 1: The speciation of carbon volatiles in high-temperature fluids within Europa as a function of temperature, for $pH_{Neutral}$ (top), $pH_{Neutral}$ + 2 (middle), and $pH_{Neutral}$ + 4 (bottom) at 1500 bar and a_{H_2} along the FMQ buffer, where $pH_{Neutral}$ was calculated for each temperature. Here, we have considered $pH_{Neutral}$ and above because the speciation of carbon volatiles is fixed at values lower than $pH_{Neutral}$ + 2, with either CH_4 or CO_2 as the predominant species. At higher pH values, the anions HCO_3^- and CO_3^{-2} can reach appreciable abundances.

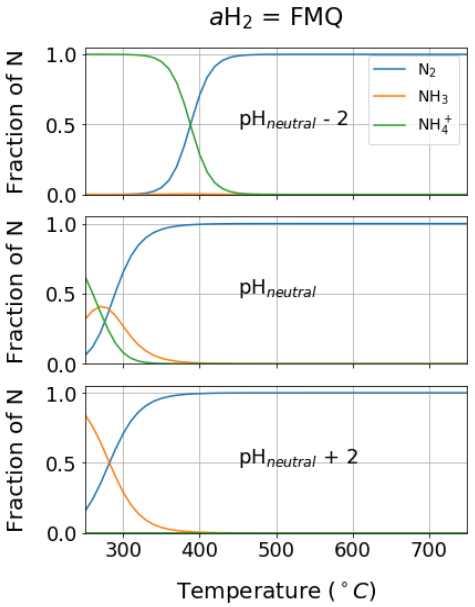

Figure 2: The speciation of nitrogen volatiles in high-temperature fluids within Europa as a function of temperature, for $pH_{Neutral}$ - 2 (top), $pH_{Neutral}$ (middle), and $pH_{Neutral}$ + 2 (bottom) at 1500 bar and a_{H_2} along the FMQ buffer. Above $pH_{Neutral}$, N_2 predominates except at lower ($< 300°C$) temperatures where NH_3 predominates. Below $pH_{Neutral}$, NH_4^+ becomes the more abundant reduced form of nitrogen, and can predominate over N_2 up to slightly higher temperatures ($\sim 400°C$). A constraint of 0.9 mol N/kg H_2O on the total nitrogen concentration, ΣN, from carbonaceous chondrites [5] has been applied.

References

[1] Brockwell, T. G., Meech, K. J., Pickens, K., et al.: The mass spectrometer for planetary exploration (MASPEX), 2016 IEEE Aerospace Conference, IEEE, 1–17, 2016

[2] Glein, C., Postberg, F., & Vance, S.: The Geochemistry of Enceladus: Composition and Controls, Enceladus and the Icy Moons of Saturn, 39, 2018

[3] Kempf, S., Altobelli, N., Briois, C., et al.: SUDA: A dust mass spectrometer for compositional surface mapping for a mission to Europa, International Workshop on Instrumentation for Planetary Missions, 3, 7, 2014

[4] Lowell, R. P., & DuBose, M.: Hydrothermal systems on Europa, Geophysical Research Letters, 32, 5, 2005.

[5] Marty, B.: The origins and concentrations of water, carbon, nitrogen and noblegases on earth, Earth and Planetary Science Letters, 313, 56–66, 2012.

[6] Vance, S., Hand, K., & Pappalardo, R.:, Geophysical controls of chemical disequilibria in Europa, Geophysical Research Letters, 43, 4871, 2016.

[7] Wetzel, L. R., Shock, E. L.: Distinguishing ultramafic-from basalt-hosted submarine hydrothermal systems by comparing calculated vent fluid compositions, Journal of Geophysical Research: Solid Earth, 105, 8319, 2000