**GEOCHEMICAL CONSTRAINTS ON EUROPA'S OCEAN COMPOSITION AND POSSIBLE SIGNATURES OF HYDROTHERMAL ACTIVITY.** W. G. Levine[1], M.A. Leitner[2], S. D. Vance[1], [1]Jet Propulsion Laboratory, Caltech, Pasadena, CA 91109, wLevine@caltech.edu, [2]Department of Geological Sciences, Cornell University, Ithaca, NY 14853.

**Introduction:** We assess Europa's ocean composition, considering both its present density and estimated sources and sinks for water. Precipitated minerals and ion concentrations in resulting fluids from different bulk composition rocks provide a check on previously published work, and an agnostic starting point for more detailed investigations of Europa's composition, chemical evolution, and present activity in preparation for future exploration missions.

**Candidate Materials:** CI and CV chondrites are among the most primordial materials in the solar system, and are often assumed as the starting seafloor material for models of Europa's ocean chemistry [1-4]. In contrast, studies accounting for Europa's moment of inertia conclude that an ordinary chondrite is a better fit for the accreting material [5].

**Geochemical Inputs:** We determined model accretion mineralogies and elemental ratios from the major compositions of seven candidate materials (CI, CM, CV, H, L, and LL chondrites, and P-type asteroids) [6]. Lists of 10-14 commonly-found minerals were compiled for each rock type. We imposed constraints on major elemental ratios of Mg/Si, Ca/Si, Mg/Ca, Fe/Mg, and Fe/S using Excel Solver's minimization software. The P-type chondrite was modeled as 31% CI, 49% CM, and 20% Tagish Lake chondrite [7].

**Ocean Compositions:** To assess pathways for Europa's bulk geochemical evolution, we applied the same bulk silicate Earth model for ocean composition [3] to each model bulk rock material for Europa.

First, the bulk silicate earth model used assumes a differentiated Europa and is comprised of (BSE mass), in descending order, the ocean (100km), upper continental crust, lower continental crust, and oceanic crust. Extraction parameters are applied based on Earth's major geochemical reservoirs to determine the mineralogy that can react with hydrothermal fluid [3]. We consider potential mantle and ocean thicknesses and their candiate accretionary materials to compare with corresponding planetary moments of inertia [5]. Finally, water flux estimates for Europan history, determined from radiolysis rates [8], cometary impact rates, and Europa's currently estimated ocean thickness [3] were used to put more geophysical constraints on starting materials. Given these constraints, we suggest that P-type asteroids provide a good match to available geochemical and geophysical constraints.

| Model | Major Minerals in Rock Type | Sum Deviation from Ratios |
|---|---|---|
| CI | Olivine, Chrysotile, Enstatite | 0.295 |
| CM | Olivine, Enstatite, Troilite | 1.337 (mostly due to Fe/Mg) |
| CV | Olivine, Magnetite, Diopside | 1.778 (mostly due to Fe/S) |
| H | Olivine, Enstatite, Diopside, Magnetite | 2.378 (mostly due to Fe/Mg) |
| L | Olivine, Ferrosilite, Enstatite, Diopside | 3.762 (mostly due to Fe/S) |
| LL | Olivine, Ferrosilite, Enstatite, Diopside | 1.205 (mostly due to Fe/Mg) |
| P | Olivine, Enstatite, Dolomite, Anorthite | 1.257 (mostly due to Mg/Ca) |

Figure 1. **Candidate Rock Models**. Basic mineralogy and the differences from theoretical values of elemental ratios for all seven used initial rocks in Geochemist's Work-

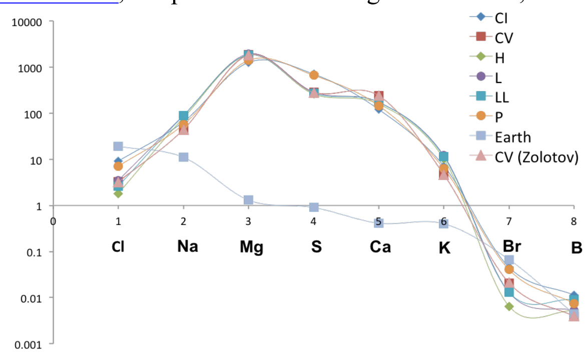


Figure 2. **Elemental Abundances in Europan Ocean from Total BSE Extractions**. Values, in g $kg^{-1}$ of water on a logarithmic scale. The numbers 1-8 correspond to Cl, Na, Mg, S, Ca, K, Br, and B, respectively.

**Hydrothermal Alteration:** We model the alteration of our mineralogical suites using Geochemist's Workbench (GWB) [10]. For all models, the water-rock ratio (W/R) was set to 1, temperature was 275°C, and the initial pH was 4.2 [11], consistent with a modern moderately oxidized ocean [12] .

**Results:** Europan ocean compositions were computed from a bulk silicate earth model with an Fe core. Figure 2 shows that the compositions are within roughly 10% of previous estimates [3] for CI, CV, and H. Thus, we extend the method to L, LL, and P type chondrites (also pictured).

Carbonaceous chondrite models of Europa have higher final pH than ordinary chondrite models, but all values are acidic. pH increases with the amount of aqueous alteration in the rock's history.

Precipitated materials were grouped by major mineralogical class. Figure 3 shows silicate production, divided into serpentines and other silicates. Serpentines, mostly antigorite, were found only in rocks with higher iron content (C-, H, and P). For ordinary silicates, talc production increases sharply once rock

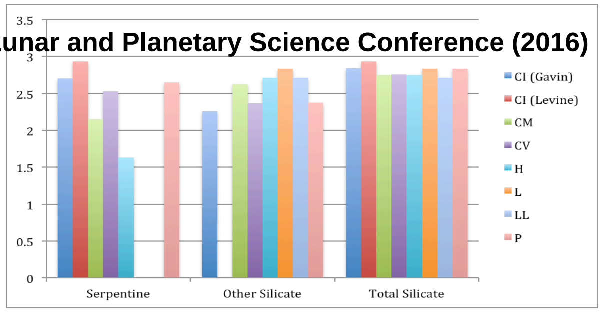


Figure 3. **Precipitated Silicates**. Amount of silicate formed (Log[g]) for each rock model sorted into serpentines and other silicates.

models reach 20% Fe by weight, in line with previous studies [11]. The models precipitated similar amounts of total silicates.

Figure 4 shows metal oxides, sulfides, and carbonates. Sulfides precipitated the most from C-type rocks as pyrite or troilite. By contrast, oxides precipitated the most from ordinary chondrites, typically as magnetite and FeO. Carbonates, most commonly calcite, only precipitated from carbonaceous, LL, and P models. Ordinary chondrites have elevated concentrations of $Ca^{2+}$ and $CaCl^{+}$ in the product fluids, as shown in Figure 5. If Europa formed from ordinary chondrite material, its present-day ocean could have higher levels of calcium ions by a factor of 5. Determining such relatively small differences requires a tight handle on ocean pH [12].

**Conclusions:** In places such as Earth's Lost City vent field, life catalyzes reactions between coexisting oxidized and reduced species. At Europa, carbonaceous chondrite bulk materials, by precipitating sulfides and dark-colored metallic oxides, may create hydrothermal chemistry resembling Earth's black smoker vents, whereas ordinary chondrite models, by precipitating more talc, create systems more analogous to Earth's white smokers.

Species produced at hydrothermal systems can be transported to the surface of Europa by ocean currents and surface eruptions. Decreasing carbonate precipitation from carbonacoues to ordinary chondrites creates differences in global calcium ion levels among the starting materials. Future missions to Europa may detect this and other minerals and could give insight about Europan accreting material.

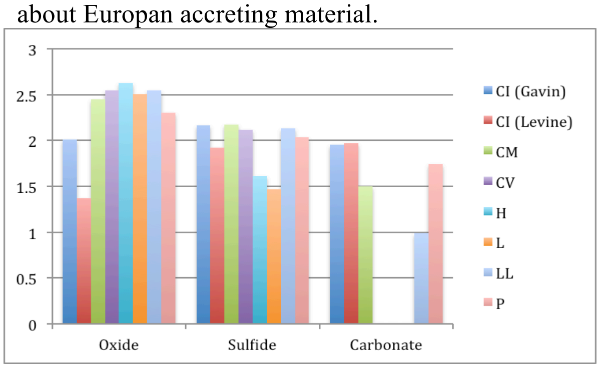


Figure 4. **Oxides, Sulfates, and Carbonates.** Shows the amount of other mineral classes precipitated (g/kg of reactant rock on a log scale) for each of the simulated chondrite rock models.

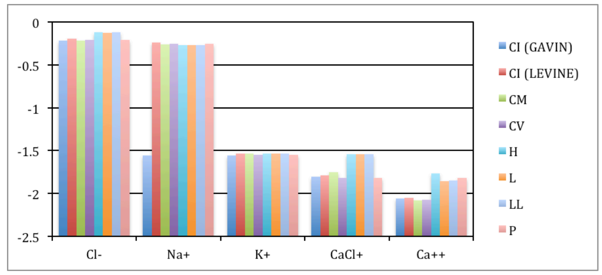


Figure 5. **Resulting Fluid Composition**. Log[M] of five ions of interest that were commonly found in the final fluids for all simulated rock models.

**Future Work:** We can analyze alternative scenarios for Europa's hydrothermal alteration by varying W/R, pH, and temperature. For example, an early ocean on Europa would probably have been more reducing, with an alkaline pH as high as 12 [12]. The amount of available rock for reaction would have varied through time as the seafloor cooled [13].

We can also consider Europa in the context of the other Galilean satellites, which have related, but different geological histories. Such comparisons will be valuable for investigations of water loss and other processes, which may be conducted by future missions such as JUICE and NASA's Europa Mission.

Another major question not adequately considered in this or other models of Europa's ocean chemistry is the degree of alteration in Europa's mantle and seafloor crust, by analogy to mantle convection, continental processing, hotspots on Earth, which can be investigated using increasingly sophisticated thermodynamically consistent models [14]

**Acknowledgments:** This work was performed at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with NASA. Government sponsorship is acknowledged. This work was supported by the NASA Astrobiology Institute Icy Worlds Project

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