MODELING HYDROTHERMAL VENTS ON EUROPA.

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Introduction:

The purpose of this study is to simulate conditions in hydrothermal systems on Europa using geochemical models. The ultimate goal is to investigate the possibility of life developing in Europa's subsurface ocean. We address questions such as "What organic compounds may form at europan hydrothermal vents and under what conditions will they form?" and "Is the chemical energy in Europa's ocean sufficient to sustain microbial life?" Terrestrial hydrothermal vents (commonly known as "black smokers") harbor diverse life forms and are thought to be sites at which life first arose on Earth [1]. Mixing of acidic, high-temperature hydrothermal fluids with cold, basic, ocean waters creates strong redox gradients. Redox potentials provide energy for metabolism in microbes.

We studied the effects of Fe-content in seafloor rock to investigate ocean composition/formation. Iron is important in terrestrial hydrothermal vents for the production of methane (CH_4) through serpentinization [2], nutrients for microbes [1], core differentiation, and ocean composition affected by water-rock interactions at the seafloor.

We also investigated the effects of temperature on the formation and evolution of hydrothermal vents, modeling typical vents at high temperature (~300°C) [3] and lower-temperature cold seeps [4].

Model Descriptions and Inputs:

Using Geochemist's Workbench [5], four models were run to explore effects of variation in the properties of hydrothermal vents: one "base" model; two that varied the Fe-content in the initial rock; and one that varied temperature (Table 1). In all models, water-rock ratios (W/R) = 1.

Model	Description	Fe/Mg ratio	Temperature
Control	Terrestrial basalt and seawater	0.064	275°C
50/50	Equal mass concentrations of basalt endmembers	0.744	275°C
CI chondrite	CI chondrite composition w/o SO_4^{2-}	0.456	275°C
Control, Low T	Control, T = 20°C	0.064	20°C

Table 1: *Input parameters for models with respective Fe/Mg ratios and temperatures.*

Results:

Varying the Fe-content in the initial rock had significant effects on the resulting fluid composition and mineral precipitation. The resulting fluid was Na/Cl-rich, most likely a remnant of the initial fluid composition. Models with higher Fe-content initial rock resulted in enrichment of CO_2(aq), SiO_2(aq), and $FeCl^+$ (Fig. 1). Increasing Fe-content of the initial rock also produced enrichment of talc, tremolite, and minnesotaite while lowering Fe-content enriched monticellite and brucite (Fig. 2).

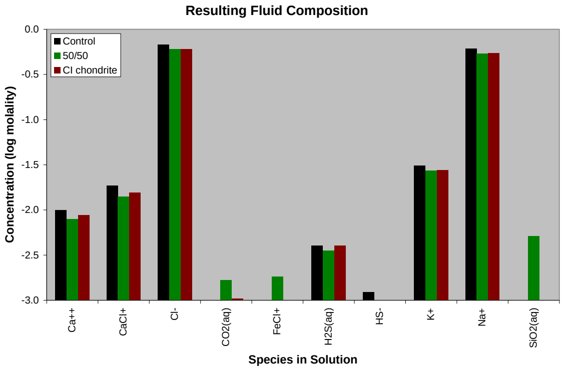

Figure 1: *End-member fluid compositions of three hydrothermal models showing variations due to differences in initial rock composition. Only species with log concentrations greater than -3 are shown.*

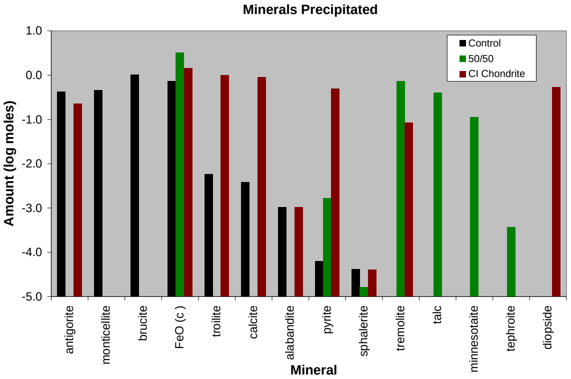

Figure 2: *Minerals that precipitated in each model, showing the variation in mineral formation with differing initial rock composition. Only minerals with log amounts greater than -5 are shown.*

Temperature plays a role in changing the resulting fluid composition and mineral precipitation. Although the fluid is still Na/Cl-rich, the high-temperature model results in enrichment of Ca, CaCl, and H_2(aq). The low-temperature model results in enrichment of CH_4(aq), NaCl, NaOH, and OH^- (Fig. 3). Lower temperatures also change which minerals precipitate. The high-temperature minerals included monticellite, calcite, pyrite, and sphalerite while the low-temperature minerals were enriched in andradite (Fig. 4).

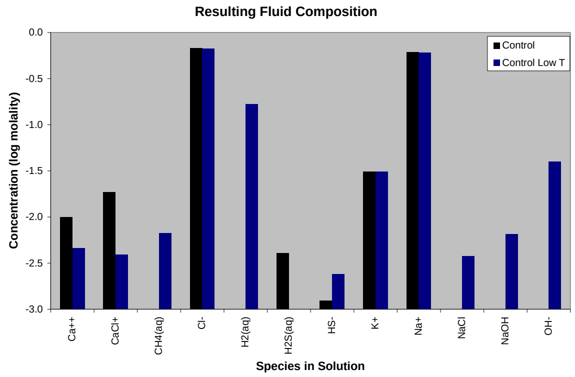

Figure 3: *Resulting fluid composition of high- (275°C) and low- (20°C) temperature models. Only species with log concentrations greater than -3 are shown.*

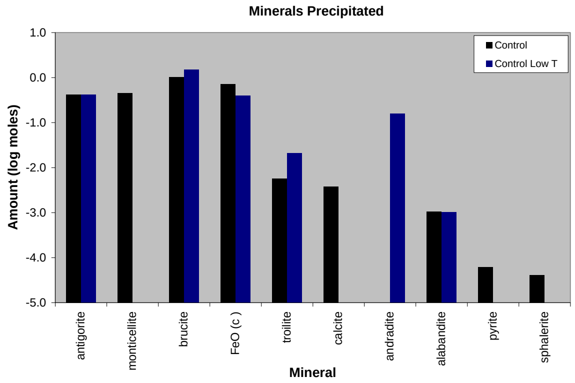

Figure 4: *Resulting mineral compositions for high- (275°C) and low- (20°C) temperature models. Only minerals with log amounts greater than -5 are shown.*

Conclusions and Implications for Europa:

The presence of hydrothermal vents at the bottom of Europa's ocean will affect the ocean's composition. We have shown that different ocean floor compositions and different temperatures of the vent will result in different mineral formation and different vent fluid composition. Certain minerals that form at hydrothermal vents serve as a nutrient source for microbes near the vent. For example, the iron reducing microbe *Shewanella putrefaciens* would benefit from the formation of iron-based minerals [6], such as andradite [$Ca_3Fe_2(SiO_4)_3$], pyrite [FeS_2], or minnesotaite [$Fe_3Si_4O_{10}(OH)_2$]. Additionally, the mixing of vent fluids with ocean water can produce redox reaction potentials that provide an energy source to microbes ($\Delta Eh > \sim 800$ kJ/mmol at $T < 40^oC$) via sulfide and/or methane oxidation [5] or methantrophy [7]. Thermal energy produced by serpentinization, as suggested by the formation of antigorite [$Mg_{24}Si_{17}O_{42.5}(OH)_2$] and brucite [$Mg(OH)_2$] in our models, could also serve as a modest source of thermal energy in the absence of tidal heating [8,9]. Minerals formed at hydrothermal vents could be transported to Europa's surface via conductive currents and surface eruptions, where they could be detected by future exploration missions. These observations serve as a possible indicator to processes occurring below Europa's surface.

Future Work:

The present results can be used to determine chemical reactions, using the slopes of the lines tracing mineral concentrations to determine the stoichiometric balance for each step of the reaction. Further analysis of current results can also provide insight into methane production in low-T hydrothermal systems, redox reactions (potentially providing chemical energy for microbes) and mineral formation (acting as nutrients for microbes). Varying the initial fluid composition and water-rock ratios will allow us to broaden the context of our study of the evolution of hydrothermal systems. Another important factor related to Europa's oxidation state – and to interpretations of surface chemistry as related to ocean composition – is the dominant phase of sulfur in Europa's ocean (sulfate- vs. sulfide-rich). Finally, using the SUPCRT database [10], we can alter the default database of GWB to study effects from high pressures and low temperatures in Europa's ocean [2, 11].

References:

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