The System Sulfuric Acid-Magnesium Sulfate-Water: Europa’s Ocean Properties Related to Thermal State.


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Overview. Europa’s aqueous evolution is modeled in the system H2O-H2SO4-MgSO4. For a thin ice crust, the ocean is thick, warm (~267 K) and dominated by MgSO4; for a thick ice crust, the ocean layer is thin, cold (as long as 211 K), and dominated by H2SO4.

Introduction: Theoretical and laboratory studies of chondritic leachates [1-4] predict a sulfate brine crust/ocean and allow a hydrated sulfate surface on Europa and other icy satellites. Interpretations of Galileo NIMS data support these models, indicating that Europa has both icy terrains and nonice terrains apparently surfaced by some type of hydrated sulfate. Good alternative spectral matches include magnesium/sodium sulfates contaminated by sulfur or sulfuric acid contaminated by sulfur [5,6]. Both classes of substances can be derived from an initial carbonaceous chondrite composition of Europa. These materials are not mutually exclusive, and so a third possibility is that both sets of materials are present. This paper explores the chemical differentiation due to progressive freezing of a model ocean enriched in both magnesium sulfate and sulfuric acid, which we believe is a natural consequence of expected processes.

Initial composition: Magnesium sulfate in this model is produced by low-temperature leaching of chondritic material, whereas sulfuric acid is generated by high-temperature devolatilization and venting of SO2 into the ocean, followed by low-temperature aqueous chemistry. Sulfuric acid also would be produced by radiolysis of surface salts and ice containing Iogenic sulfur impurities implanted from the Jovian magnetosphere.

The amount of endogenic sulfuric acid is likely to greatly exceed that produced by radiolysis, if SO2 volcanism on Io and the rate of S and O loss from Io is any hint at what might be occurring on Europa’s seafloor. An estimated minimum European inventory of SO2 is calculated from the amount of SO2 Io has lost over geologic time (assuming recent loss rates have been characteristic of the past); that amount is then scaled to Europa’s smaller silicate mass. This calculation suggests a minimum of 2.04×1011 kg of H2SO4 after reaction (5) of reference [3] has taken place. The low-temperature chondritic leaching model suggests 3.72×1011 kg of highly soluble sulfate salts (MgSO4 + Na2SO4, approximated here as just MgSO4), and 8.08×1011 kg of H2O.

This initial composition corresponds to 67.32% H2O - MgSO4 - Na2SO4. Notable in these systems, and quite explicitly in the high-temperature parts of the fields of hepta- and hexahydrates of magnesium sulfate in the ternary system. Theoretical and laboratory studies of phase relations and crystallization behavior this system.

Model results: In Figure 3 we show some results of an idealized model of cooling and fractional crystallization of an initial ocean. These results suggest that a Europan ocean could evolve through a wide range of pressure- and temperature-dependent compositions, starting with a warm magnesium sulfate-dominated composition and evolving to a cold sulfuric acid dominated ocean. Spaun and Head [4] have previously modeled the fractional crystallization of an ocean in the binary system H2O - MgSO4, and Kargel et al. [3] have presented various satellite models based mainly on fractional melting in the system H2O - MgSO4 - Na2SO4. Notable in these systems, and quite unlike that explored here, is the absence of any solute that strongly depresses the melting point of ice. In this sense, H2SO4 plays a role more similar to that of ammonia or multicomponent chlorides, all of which are very effective freezing-point depressants in aqueous systems. It will be an important next step to consider the role of chlorides and Na2SO4 added into the ternary system considered here.

Systematic changes in the ocean’s mass, density, viscosity, electrical conductivity, and other properties, and systematic growth of the floating crust and subsurface oceanic salt layers would accompany this cooling. In future work, we will explore (1) possible constraints on this evolution from magnetometer data, and (2) geological implications.
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Figure 1 (below). Phase diagram of system $H_2O-H_2SO_4$. Data of [10], reinterpreted by [11].

Figure 2 (upper right). Ternary phase diagram of system $H_2O-H_2SO_4-MgSO_4$ (0.1 MPa, preliminary).

Figure 3 (lower right). Model of Europa’s oceanic chemical evolution and ice crust thickness variation with oceanic temperature. (Preliminary, based on Fig. 2 and Model D’ of reference [3] with $SO_2$ added).