ROLE OF NON-WATER ICES IN DRIVING SALINITY AND ELECTRICAL CONDUCTIVITY IN OCEAN WORLDS

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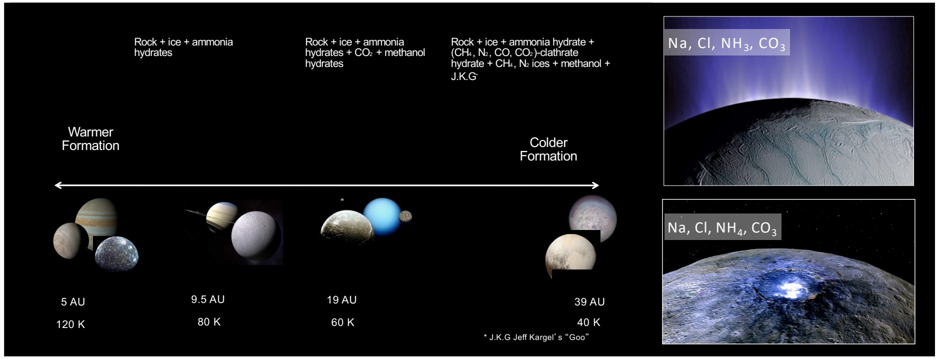
Motivations: In recent formation models of giant planet systems, icy moons could acquire part of their materials from pebbles scattered from regions farther in the outer solar system. For the Galilean satellites, this implies a greater content in cometary volatiles than assumed in previous models. Recent evolution models also show that early oceans could be enriched in CO_2 and NH_3 following the breakdown of carbonates and organic compounds as a result of the thermal metamorphism of accreted carbonaceous chondritic materials. Carbonates have been found at Enceladus and Ceres; the latter also displays evidence for ammonium in multiple forms on its surface. Lastly, this study is responsive to the ongoing interest in future missions to the Galilean moons, Enceladus, Titan, Triton and the moons of Uranus, Pluto's system, and Ceres, many of which would include magnetometers.

Summary of Approach: We assess the fate of accreted volatiles using the Geochemist's Workbench (GWB) [1] at 1 atm. GWB computes electrical conductivity (EC) using the approach of [2] which is suitable for ionic strengths up to 1 mol/kg over the range 0°C–95 °C and pH (1–10). The EC estimates presented below assume that the hydrosphere is all liquid, i.e., not accounting for what occurs to solute concentrations in liquids upon freezing of an ice shell. [1] Bethke, C.M. (2007) *Geochemical and Biogeochemical Reaction Modeling*, 2nd ed., CUP. [2] McCleskey, R. B., et al. (2012) GCA 77, 369-382.



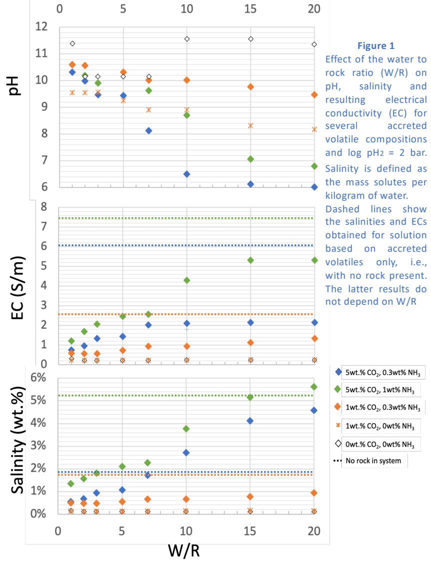


Figure 1
Effect of the water to rock ratio (W/R) on pH, salinity and resulting electrical conductivity (EC) for several accreted volatile compositions and log pH_2 = 2 bar. Salinity is defined as the mass solutes per kilogram of water. Dashed lines show the salinities and ECs obtained for solution based on accreted volatiles only, i.e., with no rock present. The latter results do not depend on W/R

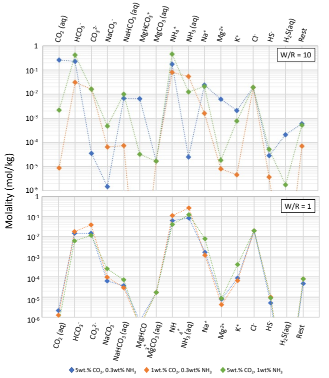


Figure 2
Concentrations of the main solutes obtained for three different solutions introduced in Figure 1 for (Top) W/R = 10 and (Bottom) W/R = 1. This figure shows HCO_3^-, CO_3^{2-}, and NH_4^+ are the main contributors to salinity by up to one order to magnitude more than Cl^-, alkali, and alkaline earth metals.

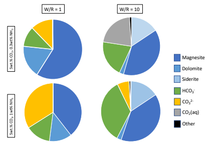


Figure 3
Speciation of carbon-based compounds (solid and solutes) in mol.% for two reference compositions and W/R. Magnesite is systematically formed in these examples. Siderite is the second dominant form of solid carbonate at higher W/R while dolomite dominates at low W/R. In solution, bicarbonate dominates over the carbonate ion at high W/R, while the two are found in roughly equal proportions at low W/R. The "other" category encompasses solutes such as $NaCO_3^-$, $NaHCO_3$(aq), $MgHCO_3^+$, $MgCO_3$(aq),

The most abundant volatile compounds expected from cometary composition yield oceans enriched in CO_3^{2-} and HCO_3^-, which could represent another endmember of interest for describing the oceans of large icy moons and dwarf planets, besides chlorine- and sulfate-based oceans. The amount of accreted NH_3 and the water to rock ratio control the solubility of carbonates. Carbonates derived from CO and CO_2 in particular set a minimum conductivity of 1.5 S/m for the minimum fractions of these compounds observed at short period comets, provided that NH_3 is also present. Higher concentrations in CO_2 and NH_3 could increase the EC above 5 S/m prior to concentration upon freezing of the ocean.

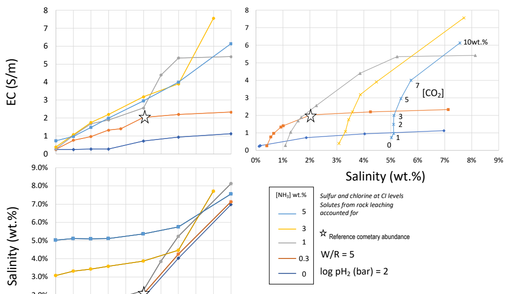


Figure 4
Salinity and EC as a function of accreted CO_2 and NH_3 abundances, calculated at 0˚C and ambient pressure, prior to concentration, following [2] whose method is applicable over the whole range of compositions explored. [2] McCleskey, R. B., et al. (2012) GCA 77, 369-382. [3] Mumma, M., Charnley, S. (2011) AREPS 49, 471-524.

Summary: Oceans expected in icy moons and dwarf planets, including Europa, some of the Uranian satellites, and Neptune's satellite Triton, could have high electrical conductivities due to abundant non-water ices, even if the extent of rock leaching during differentiation was limited and chlorine and sulfur abundances were at low, CI carbonaceous chondritic levels. The effects of non-H_2O ices require thorough quantification to aid the planning and future interpretation of magnetic induction experiments at candidate ocean worlds. This involves expanding the database of EC obtained in pressures, temperatures, and salinities relevant to ocean worlds.