ON THE ROLE OF OCEANS IN THE THERMAL EVOLUTION AND HABITABILITY OF SUPER-EUROPAS AND SUPER-GANYMEDES. S. D. Vance[1,2], R. Barnes[2,3,4], J. M. Brown[2,3,4], O. Bollengier[2,3,4], B. Journaux[5], C. Sotin[1,2], M. Choukroun[1,2] [1]Jet Propulsion Laboratory, California Institute of Technology (MS 321-560, 4800 Oak Grove Dr., Pasadena, CA 91109, USA, svance@jpl.nasa.gov); [2]NASA Astrobiology Institute, Icy Worlds Team; [3]University of Washington, Seattle; [4]NASA Astrobiology Institute, Virtual Planetary Laboratory, [5]Laboratoire de Glaciologie et Géophysique de l'Environnement, Université Joseph Fourier, Grenoble, France.

Introduction: Oceans influence a planetary body's thermal and chemical evolution, and thus its prospects for supporting life. We examine parallels between oceans in our own solar system and in watery super Earths. Specifically, we consider ice-covered Earth-sized exoplanets that we term super-Europas and super-Ganymedes, a class of potentially habitable worlds that may be more abundant than Earth-like planets. By considering the thermodynamics of ocean materials, we can address how the history of extraterrestrial oceans will differ from Earth's.

Super-Europas and Super-Ganymedes: Deep oceans in Earth-sized planets will create similar pressure and temperature profiles as oceans in large icy moons (Fig. 1). Internal structure models for Earth-like exoplanets can be used to constrain compositions from observations of mass-radius (M-R) relationships. The incorporation of H_2O is least certain among the materials involved, and can have the strongest influence on the M-R relationship [1]. A planet's internal structure will be profoundly influenced by liquid-solid interactions that determine its mineralogical and thermal state through time [e.g., 2]. We present physical and orbital properties of hypothetical water-rich exoplanets beyond the habitable zone that possess sufficient internal energy to maintain a subsurface global ocean.

Geophysical Inverse Theory Used to Advance Aqueous Geochemistry: Accurate representation of the fluid chemical energy as a function of pressure, temperature and composition over a wide range of conditions is prerequisite for understanding phase equilibria and solubilities in multicomponent systems. We are developing a flexible computational methodology for describing Gibbs' free energy of water and aqueous solutions. Using local basis functions, the thermodynamic state surface can be adjusted to account for improved experimental constraints or results in new regimes of pressure and temperature (Fig. 1).

Application of New Equations of State to Exoplanet Interiors: Based on our experimental work on pure water, $MgSO_{4(aq)}$, $Na_2SO_{4(aq)}$, and ammonia-water mixtures, we are constructing user-friendly data sets based on Gibbs free energies, which can be used for geophysical and geochemical calculations. We will describe possible ocean chemistries and mantle structures in ice-covered exoplanets, including the potential for buoyant high-pressure ices [3]. The overarching goal of this work is to understand whether deep oceans create conditions amenable to life, and whether those conditions lead to observable surface and atmospheric signatures.

References:.[1] Grasset, O., Schneider, J., and Sotin, C. (2009). *ApJ*, 693(1):722. [2] Hu, Y. and Yang, J. (2014). *PNAS,* 111(2):629–634.[3] Vance, S., Bouffard, M., Choukroun, M., and Sotin, C. (2014). *Plan. Space Sci.*, 96:62–70.

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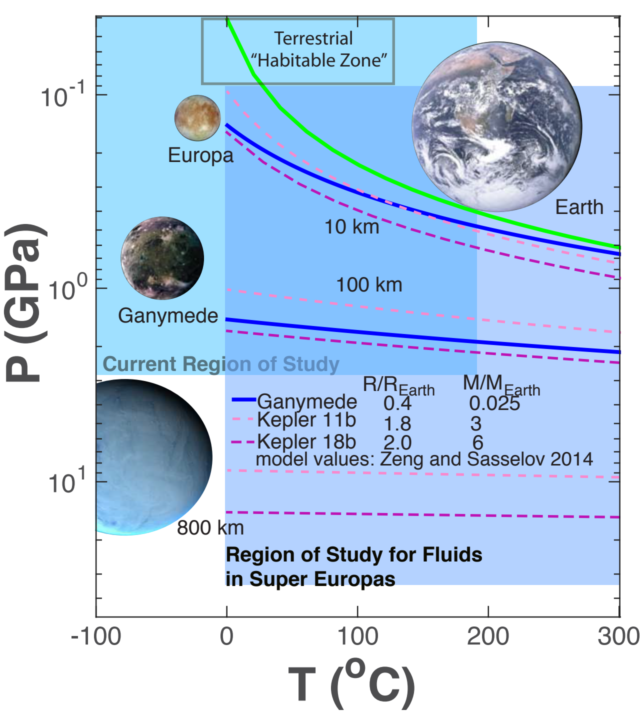

Figure 1. A 100 km-deep ocean on an Earth size planet has seafloor pressures comparable to Ganymede's. This figure portrays calculated pressure and temperature profiles in the upper mantles of selected objects, below putative or known H_2O rich layers. In each case, the plot of pressure (in GPa) versus temperature (in °C) begins at the estimated depth of the seafloor, with the overlying ocean assumed to be at a roughly constant temperature. We only consider radiogenic heating. Kepler objects are used only as examples with known mass and radius—these specific objects orbit too close to their host star to have oceans. We are constructing thermodynamic frameworks for aqueous systems appropriate to the extended pressure and temperature conditions occurring in oceans on other worlds.