Effects Of Fluid Viscosity on Melt Migration Behavior in Polycrystalline Ice with Implications for Icy Moons

Daniel Lukens[1], Christine McCarthy[2], Maheenuz Zaman[2], Marc A. Hesse[3]

[1]Brown University, Providence, RI, [2]Lamont-Doherty Earth Observatory, Columbia University, Palisades, NY, [3]Jackson School of Geosciences, The University of Texas at Austin, Austin, TX

Mechanisms for the transport of astrobiologically relevant material from icy moon surfaces to their subsurface oceans may include the coupling of Darcy-like porous flow of brine with a deforming solid polycrystalline ice matrix. The ease at which the solid ice matrix deforms controls how efficiently melt can be transported through icy planetary shells, and the distance over which it can feel changes in pressure. Matrix compaction rate has previously been found to be dependent on temperature, salinity, and axial pressure. This theoretical framework, established from terrestrial mantle melt extraction and recently refined experimentally for planetary ices, assumes that the viscosity of the fluid does not directly affect the bulk compaction rate given a significantly more viscous solid matrix. However, the effect of fluid viscosity on the compaction rate of two-phase polycrystalline materials has not been tested experimentally. To address this, uniaxial compaction experiments were conducted on two-phase samples composed of polycrystalline ice with silicone oils of three viscosities: 0.0093 Pa·s, 0.096 Pa·s, and 0.97 Pa·s. Experiments were carried out at -10°C and axial pressures of 0.33 MPa, 0.77 MPa, and 1.72 MPa. Samples were 25 mm in diameter and up to 55 mm in length and experienced strains up to 0.25 during compaction. By identifying the effect of fluid viscosity, as well as that of the fluid wetting angle, we are able to broaden constitutive relations relating compaction rate with sample porosity evolution and refine calculations for the melt's compaction length. Implications are direct for icy bodies like Europa and Enceladus, where melt viscosity may vary by several orders of magnitude.