THE EFFECT OF RAYLEIGH-TAYLOR INSTABILITIES ON THE THICKNESS OF UNDIFFERENTIATED CRUST ON KUIPER BELT OBJECTS. S. J. Desch,1 M. E. Rubin1 and M. Neveu,1
1School of Earth and Space Exploration, Arizona State University (steve.desch@asu.edu).

Introduction: The existence of subsurface water on Kuiper Belt Objects (KBOs) is a recently recognized possibility. Calculations by [1] suggest that the present-day Kuiper belt may contain liquid water comparable in total mass to the Earth’s ocean. This liquid would be in contact with a relatively warm rocky core, enabling chemical reactions like serpentinitization that may be favorable for habitability. The existence of subsurface water is greatly aided by the presence of a thick (50-100 km) layer of ice and thermally insulating rock, that remains cold enough during the KBO’s evolution to remain undifferentiated.

The calculations by [1] of the internal structure and thermal evolution of Kuiper belt objects (KBOs) uniquely predict that KBOs should only partially differentiate, with rock and ice separating into a rocky core and icy mantle, below an undifferentiated crust of ice and rock. An objection to these models is that a dense rock/ice layer resting on an icy mantle is gravitationally unstable and prone to Rayleigh-Taylor (RT) instabilities, and may potentially overturn. Here we calculate the ability of RT instabilities to act in KBOs, and determine the thickness of undifferentiated crusts.

Calculation: To calculate the growth rate of RT instabilities, we use the formulation of [2], who calculated the growth rates in the case that viscosity in the dense layer varies exponentially with temperature, which varies linearly with depth. We use the treatment of [3] to calculate the ice viscosity, including such non-Newtonian creep mechanisms as dislocation creep, grain-boundary sliding and basal slip, as well as diffusion creep. We find that for Charon-like bodies (mean density 1.65 g cm−3, radius 605 km), crustal overturn within the age of the solar system is only possible for ice viscosities corresponding to temperatures much higher than typical KBO surface temperatures of 40 to 60 K. Given the fact that thermal evolution models [1] predict that shells within KBOs remain at their maximum temperatures for about 1.5 Gyr, a minimum temperature of 150 K is needed for RT instabilities to overturn layers. Due to the effectively exponential dependence of viscosity on temperature, a similar cutoff temperature arises for KBOs across the range of plausible parameters.

We couple this result to thermal evolution models of KBOs [1] to calculate the thickness of undifferentiated crust on KBOs. We find that on Charon-like bodies the RT instabilities cannot act on geological timescales within about 60 km of the surface. This is less than the 85 km previously calculated for Charon by [1], but is still significant, representing ≈ 25% of the mass of the KBO. While RT instabilities can overturn some of the dense ice/rock layer with the underlying pure ice mantle, their effects are ultimately limited by the low temperatures and high ice viscosities of KBOs.

These calculations referred to Charon specifically, but they are more universal than this. There is little sensitivity of the critical temperature for differentiation to the specific parameters describing a KBO; it is usually around 150 K. Temperatures about 100 K higher than the typical surface temperature are needed to soften the ice enough for layers to overturn. Given typical temperature gradients in bodies around Charon’s size, 0.5 K/km, it is likely that all KBOs that accrete as cold homogeneous ice/rock mixtures will retain undifferentiated crusts. We explore these and other issues in [4].

Unfortunately, refined calculations presented in [4] also indicate that the slight decrease in crustal thickness from 85 to 60 km, does affect the length of time a subsurface ocean can exist. Including only the effects of ammonia as an antifreeze, [4] calculate that Charon would retain subsurface liquid for 3.5 Gyr (compared to the 4.5 Gyr calculated by [1]). Inclusion of methanol as an antifreeze may prolong the lifetime of the ocean 0.5 – 1 Gyr.

Regardless of the details, the conclusion stands that thick, undifferentiated crusts of ice and thermally insulating rock will exist around KBOs, and they will aid in the retention of subsurface liquid. A significant amount of liquid water may exist in KBOs, enhancing the habitability of these bodies.

References: