BASIN RELAXATION AS A PROBE OF PLUTO'S THERMAL HISTORY.

S. Kamata[1] and F. Nimmo[1] [1]Dept. Earth and Planetary Sciences, University of California Santa Cruz, 1156 High St, Santa Cruz CA 95064 (kamata@mail.sci.hokudai.ac.jp).

Summary: We investigated impact basin relaxation on Pluto for two distinctly different interior models: with and without a subsurface ocean. The presence of a subsurface ocean does not significantly affect the long-term basin relaxation state. However, the reference viscosity of ice, which is a key parameter for the thermal history of Pluto, largely determines the long-term basin relaxation state.

Introduction: Impact basins produce stresses which can potentially drive lateral flow in the subsurface. Depending on the thermal (and thus viscosity) structure, these basins will therefore relax over time. As a result, impact basins provide a probe of the thermal history of a planetary body [1-4].

Pluto, like most other icy bodies, is likely to possess large impact basins. Below we carry out an analysis of the extent of basin relaxation on Pluto which can be compared with forthcoming *New Horizons* observations.

Pluto's Thermal History: Pluto is most likely a differentiated body, consisting of a rocky core and an H_2O layer [5]. The main source of heat is radioactive decay. Whether Pluto possesses a subsurface ocean beneath its ice shell depends mainly on whether the ice shell is convecting or conducting [6,7]. A conductive shell will result in a long-lived subsurface ocean, while a convecting shell never develops such an ocean [7]. The tectonic consequences of these two situations are quite different [7]. Another potential way of distinguishing between them is to model the extent to which basins of different diameters relax. In this study, we investigate the effect of the presence of a subsurface ocean on the relaxation state of a large impact basin on Pluto. We also investigate the effect of the reference viscosity, which is a primary factor controlling the convective state of the shell, on basin relaxation state.

Method and Model: Our relaxation code is described in [8]. Briefly, we calculate the spheroidal deformation of a Maxwell viscoelastic body induced by a surface load. We expand the load into spherical harmonics, and calculations are carried out for each harmonic degree. Pluto is assumed to have a 330 km-thick H_2O layer overlying an elastic silicate core, whose radius is 850 km. For this initial study, we use two distinctly different time-independent viscosity structures: a structure with a relatively rigid shell overlying either a convecting interior or a subsurface ocean (Figure 1). These structures are similar to those derived by a previous study [7]. We use a radial 2 km-grid structure for the viscosity, density, and elasticity profiles. Parameter values are taken from a previous study [7]. We do not consider the density difference between ice and water nor the effect of partial melting of ice.

Preliminary Results: Figure 2 shows the relaxation of perturbations of different spherical harmonic degree l (the basin diameter D is given by $D \sim 2\pi R/l$, where R is the radius of Pluto). Here the reference viscosity is taken to be 4.16 x 10^{15} Pa s. As expected, short-wavelength (large l) basins relax less than long-wavelength basins, and relaxation proceeds at an exponentially-decaying rate. The initial behavior of the "ocean" and "no ocean" cases is quite different – "ocean" cases experience an essentially instantaneous initial rebound, because the ocean is inviscid, while "no ocean" cases undergo a more delayed rebound, because of a low but finite viscosity of the convecting ice. The longer-term relaxation behavior is controlled by the higher-viscosity ice in the near-surface, and is identical for the two cases. This is because the near-surface viscosity structure is the same (Figure 1). As a result, the present-day relaxation state of a basin cannot necessarily be used to distinguish between "ocean" and "no ocean" cases.

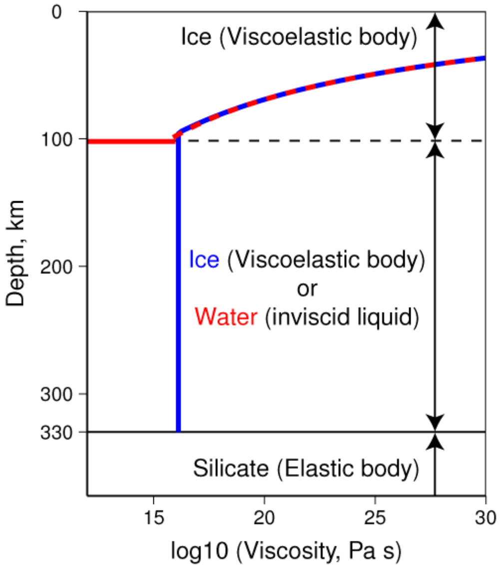

Figure 1. The viscosity structure for a reference viscosity of 4.16 x 10^{15} Pa s. The red curve shows the viscosity profile for a model with a ~230 km-thick subsurface ocean (i.e., inviscid liquid) beneath a rigid shell. The blue curve shows the viscosity profile for a model without a subsurface ocean. The former and the latter are called an "ocean" case and a "no ocean" case, respectively, in the main text. The lower and upper bounds for the viscosity are 10^{12} and 10^{30} Pa s, respectively.

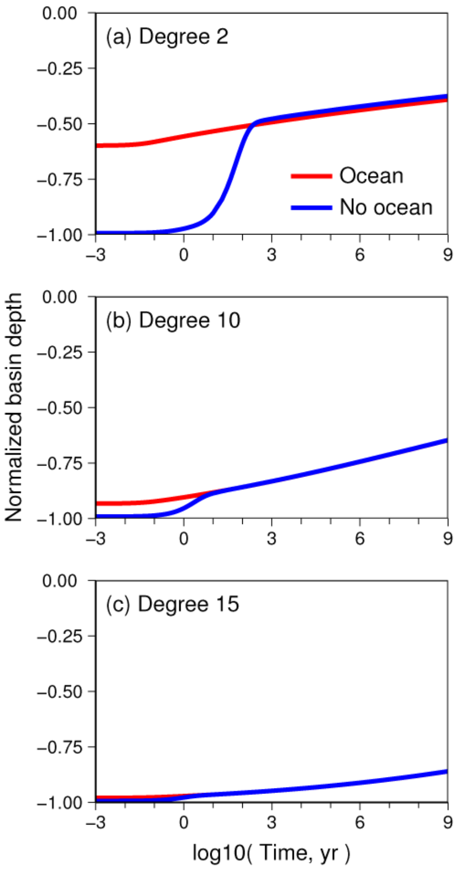

Figure 2. The time evolution of the normalized basin depth for three different harmonic degrees. Here, -1 for the vertical axis is the initial condition without an elastic response. Results for the reference viscosity of 4.16 x 10^{15} Pa s are shown. The red and blue curves show results for the interior structure with and without a subsurface ocean.

On the other hand, the relaxation rate is sensitive to the reference viscosity assumed (i.e. the viscosity at the base of the ice shell). Figure 3 compares the time evolution of the basin depth with six different reference viscosities. Evidently, changing the reference viscosity has a significant effect on the likely relaxation state of the basins.

The reference viscosity ultimately depends on both the grain size of the ice, and the temperature of the subsurface ocean. Furthermore, the reference viscosity controls whether or not convection can occur, and thus whether or not an ocean will develop [7]. Hence, we can still use the degree of basin relaxation state as an indirect probe of whether or not Pluto possesses (or possessed) a subsurface ocean.

Discussion: The next step is to apply our relaxation calculations to the thermal evolution results of [7], in which the viscosity structure and shell thickness evolves with time. Doing so will also allow us to assess the effect of different levels of radioactive heating on basin relaxation, because the radiogenic budget of Pluto is not very well constrained.

As noted above, we assume the same density for the ice and water. The density difference between them may cause vertical forces at an ice-water boundary and may affect basin relaxation. In addition, melting of ice and freezing of ocean during basin relaxation is not considered. Melting of ice and the freezing of a subsurface ocean can occur over Gyr [7]; the formation and refreezing of a subsurface ocean may occur during basin relaxation. Further investigations of such effects on basin relaxation would be necessary.

A potential complication for the method outlined here is that impact velocities on Pluto are low, and as a result the depth:diameter ratios of unrelaxed craters may differ from those on other icy satellites [9]. As a result, determining the extent of basin relaxation may be more difficult than usual.

References: [1] Robuchon et al. Icarus 214, 82-90, 2011. [2] White et al. Icarus 223, 699-709, 2013. [3] Kamata et al. JGR 118, 398-415, 2013. [4] Mohit and Phillips, GRL 34, L21204, 2007. [5] McKinnon et al. in Pluto and Charon, pp. 295-343, 1997. [6] Hussmann et al. Icarus 185, 258-273, 2006. [7] Robuchon and Nimmo, Icarus 216, 426-439, 2011. [8] Kamata et al. JGR 117, E02004, 2012. [9] Bray, New Horizons workshop, 2013.

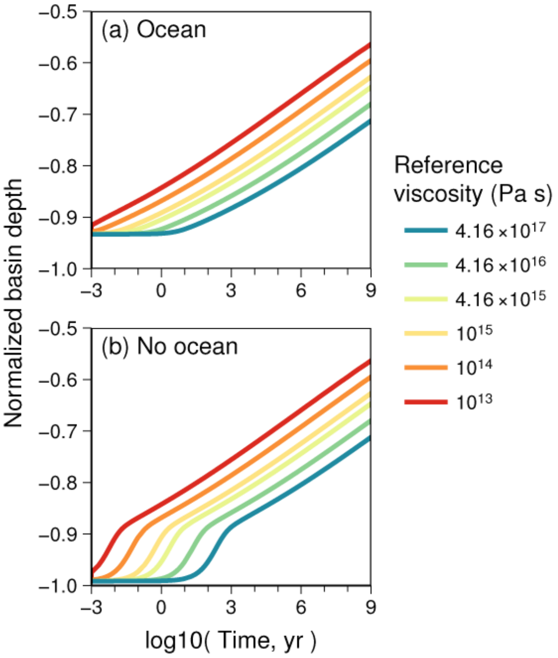

Figure 3. The time evolution of the normalized basin depth. Results for harmonic degree 10 are shown. See legends for the values of the reference viscosity. A one-order difference in the reference viscosity leads to a one-order difference in the basin relaxation, as expected.