

ANTIPODAL TERRAINS PRODUCED BY SPUTNIK PLANITIA-FORMING IMPACT IMPLY PLUTO HAS A THICK OCEAN AND HYDRATED CORE. C. A. Denton^{1*}, B. C. Johnson^{1,2}, S. Wakita¹, A. M. Freed¹, H. J. Melosh^{1,2,4} and S. A. Stern³, ¹Department of Earth, Atmospheric, and Planetary Science, Purdue University, West Lafayette, IN, USA, ²Department of Physics and Astronomy, Purdue University, West Lafayette, IN, USA, ³Southwest Research Institute, Boulder, CO, USA (*denton15@purdue.edu). ⁴Deceased

Introduction: Recent analysis of New Horizons data revealed an ~1000-km-diameter region of large-scale lineations antipodal to Sputnik Planitia (SP), Pluto's massive 1200 x 2000-km elliptical impact basin [1,2]. These lineations superficially resemble antipodal terrains associated with massive impact basins elsewhere in the Solar System, including Caloris on Mercury and Imbrium on the Moon [3-4]. Here we propose a similar formation mechanism: seismic focusing of impact-generated stress waves. The extent and mode of deformation experienced at the antipode to large impacts is directly related to variations in bulk properties of the target body [3-5], which influence how stress waves are focused and/or dissipated. To identify the interior structure of Pluto most consistent with an ~1000-km-diameter zone of antipodal deformation, we simulate the SP-forming impact and track stress waves as they travel through a Pluto-like target body and deform the antipode, exploring a range of ice shell/ocean thicknesses and core compositions [6].

Methods: Following [7] we use the iSALE shock physics code [8-10] to simulate 300, 350, 400, and 450-km-diameter icy impactors striking Pluto at 2 km/s [11], with the same model setup [12-14]. We vary preimpact ocean thickness (0, 50, 100, 150 km) and core composition (dunite [14], serpentine [15]), and extend axisymmetric 2-km-resolution to the entirety of Pluto to resolve antipodal deformation. The combined ice shell/ocean thickness is held constant at 328 km, consistent with core/planetary radius estimates [7]. We then infer resulting deformation at the antipode through measurements of material velocity, displacement, and strain in the ice shell during/after stress wave arrival [5].

Results: We find that the model that best reproduces both SP and the 1000-km-region of antipodal deformation includes a 400-km impactor, a 150-km-thick ocean and a serpentine core. Wave passage for our best fit case is shown in Fig. 1, and illustrates the process of stress wave focusing at the antipode to SP. The contrast in sound speeds between Pluto's water-ice shell (~3300 m/s) and its serpentine core (5300 m/s) causes the impact-induced stress wave to be transmitted quickly through the core (1b) and much more slowly through the overlying ice shell (1c). The temporal separation of the initially hemispherically expanding stress wave produces separate arrivals at the antipode, as observed in two strong peaks (> 35 m/s) in downward

material velocity after impact (Figs. 1b,c). The compressional wave in the ocean is further delayed.

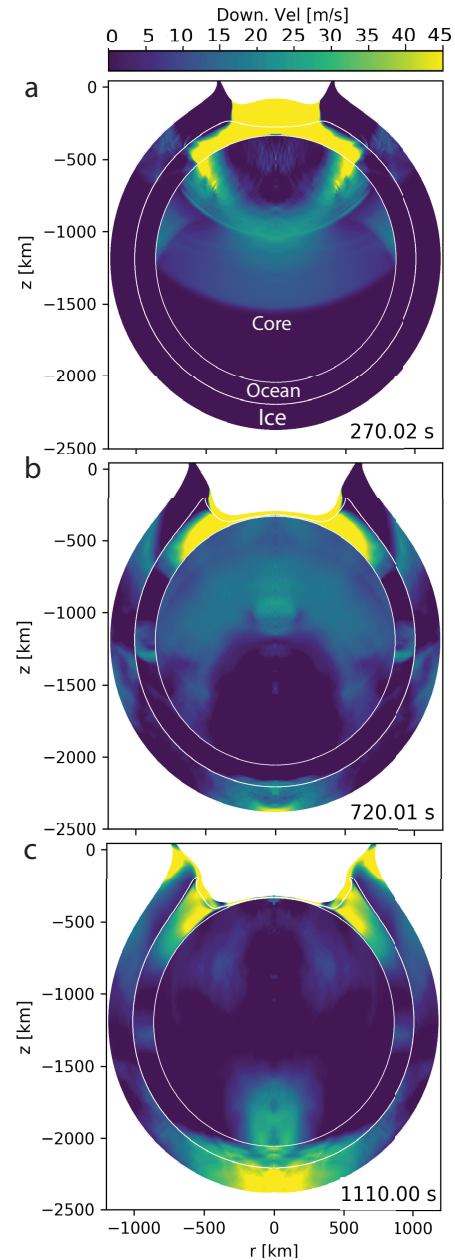


Figure 1. Cross-sections showing wave passage through Pluto's interior following impact of a 400-km-diameter impactor into a Pluto-like target with a 150-km-thick ocean and serpentine core. **1a.** Wave becomes temporally separated between materials. **1b.** Arrival of core wave to antipode. **1c.** Wave arrival in ice shell.

Internal ocean thickness has a strong effect on the extent and degree of antipodal deformation (Fig. 2). For a stress wave encountering the boundary between high- and low-sound-speed materials, the amplitude of the transmitted wave depends on the acoustic impedance difference; as such, a larger contrast in sound speed reduces wave transmission. The contrast in sound speeds between the core (serpentine ~5300, dunite ~6500 m/s) and the ocean (~1900 m/s, Fig. 2b) far exceeds that of the core and the ice shell. Additionally, shear waves are not transmitted through the strengthless ocean. Thus, an ocean decreases transmission of stress waves through the core to the antipode, initially reducing deformation (Fig. 2a,b). However, transmission from the ice shell to the ocean is also inhibited; when the ice shell is thin, energy and deformation are concentrated in the near-surface. This waveguide effect offsets reduced transmission from the core, resulting in larger antipodal deformation (Fig 2d).

Variations in core composition produce a separate trend in antipodal deformation: when a serpentine core is used instead of dunite, the decrease in core sound speeds reduces the strong impedance contrast between Pluto's core and the overlying ocean, reducing stress wave reflection and increasing transmission. As such, overall energy transmission to the antipode is increased when the core is serpentinized through hydrothermal alteration, regardless of the presence or thickness of an overlying ocean (Fig. 2), and overall antipodal deformation is maximized in a scenario that incorporates both a 150-km ocean and a serpentine core.

To determine characteristics of the potential deformation experienced at the antipode to SP, we infer structural responses based on the magnitude and regional extent of strains (Fig. 2). Expected strain near the antipode was calculated from tracer particle locations before and after impact at 10 km depth. As the majority of the region surrounding the antipode undergoes extension, graben are expected. For our best fit case (Fig. 2d) a zone of elevated extensional strain, as inferred by sustained strains of 1-3%, extends ~100-500 km from the antipode, consistent with the observed ~1000-km zone of antipodal disruption. Thus, if the lineations are indeed associated with antipodal deformation from the formation of SP, we expect them to be the remnants of a graben system produced from accommodation of the widespread extensional strains observed in our model results. Our best fit suggests that, for an impact origin, the extent of the observed lineations is most consistent with antipodal deformation associated with a 150-km-thick ocean and a hydrated core at the time of SP's formation, further supporting the presence of an ancient subsurface ocean as well as significant water-rock interactions in Pluto's interior.

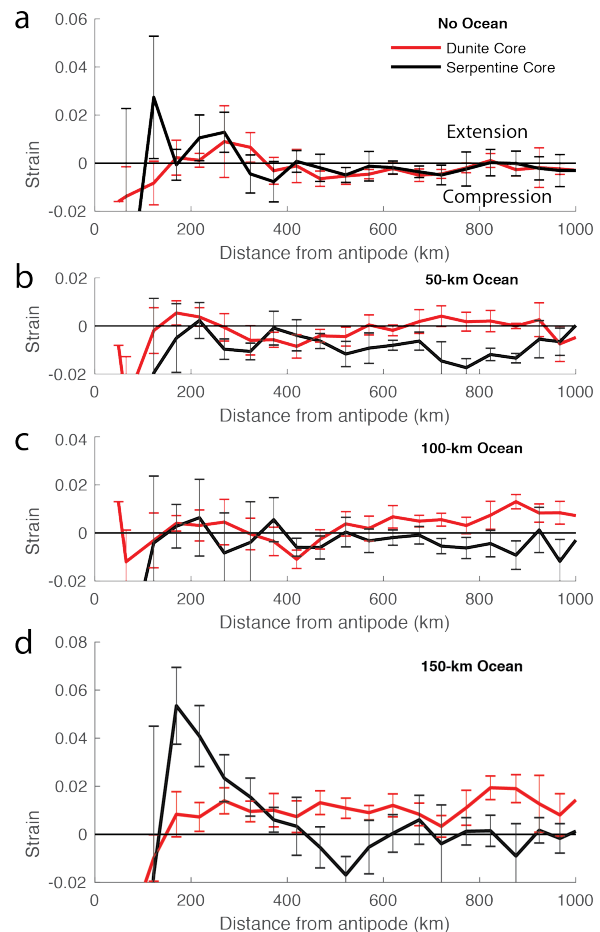


Figure 2. Strain near the antipode measured at 10 km depth for **2a.** No ocean. **2b.** A 50-km-thick ocean. **2c.** A 100-km-thick ocean. **2d.** A 150-km-thick ocean, for both dunite (red) and serpentine (black) cores.

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