NEW CONSTRAINTS ON PLUTO'S LITHOSPHERE FROM TECTONICS, CRYOVOLCANISM, AND SPUTNIK PLANITIA LOADING MODELS. P. J. McGovern¹, O. L White²,³, and P. M. Schenk¹,¹ Lunar and Planetary Institute, USRA (3600 Bay Area Blvd., Houston, TX, 77058; mcgovern@lpi.usra.edu),² SETI Institute, Mountain View, CA, 94043,³ NASA Ames Research Center, Moffett Field, CA, 94035.

Introduction: Pluto’s encounter hemisphere is dominated by Sputnik Planitia (SP), a vast, high albedo, glacial deposit composed of primarily N2 ice that is filling an elongate impact basin reaching several km deep [1-4]. Some tectonic lineations in the uplands surrounding SP are oriented roughly radially to SP, and may potentially derive from the loading of the Sputnik basin with N2 ice [5,6]. Potential cryovolcanic features include two annular massifs to the south of SP, Wright and Piccard Montes [2,4]. To the west of SP, accumulations of dark material that mantle and fill portions of fossae may represent ammoniated water ice deposits erupted as cryoclastic materials from fissures along these troughs [7,8]. The close spatial association of these putative cryovolcanic features with SP and surrounding tectonism is suggestive of a relationship based on enhancement of cryomagma ascent potential in an annular region beyond a large load on Pluto’s H2O ice shell/lithosphere [9]. Here we create detailed Finite Element Method (FEM) models of impact-driven lithospheric loading on Pluto and evaluate scenarios that are consistent with the spatial distribution of proposed cryovolcanic centers.

Modeling: We use the COMSOL Multiphysics FEM code to calculate spherical-geometry models of the response of Pluto’s icy shell lithosphere to infill of a Sputnik-sized impact basin (r_p = 500 km) by N2 ice. We use a flat-bottomed initial basin profile (maximum depth h_0 = 3 km) to resemble observations of relatively "fresh" or “pristine” basins [e.g. 10] and the results of hydrocode impact models [e.g. 11,12]. The N2 ice load configuration was iteratively adjusted to re-create the observed 2-km offset between average basin interior surface height and regional topographic level. The model also includes a “crustal collar” buoyant load at the base of the lithosphere, with Gaussian half-width 65 km and center at r_p = 650 km, reflecting crustal thickening expected from the impact process [11-13]. The thickness of the elastic shell lithosphere (T_e) was set to values of 30, 50 and 70 km.

Fault type characterization. We characterize the faulting type predicted by the stress tensor within the shell using the Aψ parameter [14]. Values range over ±180°, with specific fault types corresponding to the labels above the brightest colors in Fig. 1B at values ±150° (thrust), ±90° (strike-slip) and ±30° (normal), with the sign determining the specific orientations of the faults, as labeled in Fig. 1.

Magma ascent criteria. We use two criteria for cryomagma ascent [15]: 1) The stress orientation criterion requires that the least compressive stress be oriented horizontally to allow vertical dikes to form. 2) The formulation of [16] calculates the vertical gradient of tectonic stress (horizontal minus vertical normal stress), which when divided by planetary gravity gives an effective buoyant density Δρ_{eb} that can offset negative buoyancy of water in ice (about -80 kg/m^3).

Results: For the T_e = 50 km case (Fig. 1), the applied loads (peak N2 load thickness = 4.7 km) produce compressional horizontal stress components ε_h and ε_f near the symmetry axis throughout most of the thickness of the lithosphere, grading from proximal generic compression to concentric thrust near the load edge, although any faults thus produced would be obscured by the N2 ice load. With increasing radial distance r_p, an narrow zone of strike-slip is seen, followed by a broad zone of predicted faulting (failure criterion exceeded for 460 < r_p <980 km) consisting of proximal radial normal faulting and distal strike-slip mode (for r_p > 750 km). For 200 < r_p < 790 km, a strike-slip regime is seen at the lower part of the lithosphere. These findings stem from the extensional out-of-plane stress produced by the membrane response of a curved (spherical) lithosphere [17]. The superposition of central downward load and outer buoyant also contributes to the observed relations.

The effective buoyant density calculated from the vertical gradient of the out-of-plane tectonic stress shows a region ranging from ≈ 580-720 km where Δρ_{eb} is greater than 80 kg/m^3, thereby allowing cryomagma ascent despite the negative buoyancy of water in ice. This region also satisfies the stress orientation criterion (σ_t > 0) throughout its entirety, again owing to the extensional membrane component of stress.

Models with T_e = 30 km and 70 km require peak N2 load thicknesses of 9.5 km and 2.8 km, respectively, to fulfill the topographic constraint. The former case is characterized by a strike-slip regime in the entire trans-basin lithosphere, save for a narrow annulus of predicted radial normal faulting directly above the collar load, and also an extensive depth and radial range of predicted faulting due to high stress magnitudes. The latter case is characterized by low stress magnitudes and a concentric normal fault regime from 480 < r_p < 700 km, in marked contrast to observations. Further, Δρ_{eb} values are well below the 80 kg/m^3 threshold, even with the crustal collar load.
merely doubling \( h_0 \) for the \( T_e = 50 \) km model sextuples the load thickness required to reach the observed -2 km elevation offset. Thus, we suggest that the original depth of the basin cannot be significantly deeper than 3 km, a finding consistent with the “warm” Pluto SP impact models of [12].

Cryomagmatism. Stress gradients for models with lospheres significantly thicker than 50 km are unlikely to provide any enhancement of cryomagma ascent in the regions surrounding the basin. Thus, if lospheric stresses have aided cryomagma ascent around SP, we suggest that Pluto’s \( T_e \) is less than about 50 km. Proposed sites of cryomagmatism include Hekla Cavus, Uncama Fossa, Pioneer Terra, Virgil Fossae, Wright Mons, and Piccard Mons (at distances 554, 614, 792, 908, 956, and 1263 km from the center of SP at 25°N, 175°E, respectively). The first three fall into radial ranges that overlap with zones of enhanced magma ascent in one or more of our models, but the Montes and Virgil Fossae fall beyond the zones with peak enhancement (\( \Delta \rho_{\text{eb}} > 80 \text{ kg/m}^3 \)). In the case of the Montes, they are closer to the south-southeast extension of SP, a zone of loading that might become a significant or even primary influence in that region, suggesting the need for further non-axisymmetric models. Virgil Fossae lie on a radially-oriented system of fractures, suggesting that they could be connected down-strike to the enhanced zone.