THE INFLUENCE OF COMPLEX HYDROGEOLOGY ON LAKE FORMATION AT THE NORTH AND SOUTH POLAR REGIONS OF TITAN. D. G. Horvath[1], J. C. Andrews-Hanna[2], C. E. Newman[3], Y. Lian[3], [1]Planetary Science Institute, Tucson, AZ. [2]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ. [3]Aeolis Research, Chandler, AZ.

The north and south polar distribution of lakes on the hydrologically active (liquid methane-based) moon Titan has been attributed to the orbital behavior of the Saturn system [1]. However, climate models indicate that the orbital variations alone cannot explain the observed lake area asymmetry between the north and south polar regions. The ratio between the lake area in the south and north polar regions predicted by climate models is 0.59 [2] or 0.56 [3], compared to 0.04 observed [1]. This suggests that other factors must also play a role, such as the surface and subsurface hydrology [4, 5] between the north and south polar regions.

The lake area distribution at the north polar region has been reproduced by modeling the large-scale subsurface and surface hydrology of Titan coupled with a general circulation model of the present-day climate [6]. That work showed that subsurface flow contributes substantially to the fluid budget of lakes, but that a locally lower permeability around the pole and suppression of evaporation over the seas, due to either lake cooling effects or less volatile hydrocarbons in the large north polar seas, is required to explain the distribution of north polar lakes. Previous work, tested the relative importance of climate, topography, and permeability, showing that though climate and topography differences between the north and south polar regions exerts some control on the lake area differences, permeability has a stronger effect on the lake area [7]. Thus, differences in the hydrogeology between the north and south polar regions likely play a role in the lake asymmetry. Though homogenous higher and intermediate permeability models generally agree with the lake distributions at the south and north polar regions respectively [6, 7], both models have difficulty reproducing specific smaller lakes and seas (e.g., Ontario Lacus near the south pole).

In this study, we use results from a Titan general circulation model (TitanWRF [3]) and a hydrological model [6] to investigate the effects of a more complex hydrogeology and compare the predicted lake and hydraulic head distributions with observed lake distribution, and lakebed elevations and lake levels [11].

Methodology: The hydrological modeling was performed with a finite-difference model of unconfined saturated flow that incorporates an analytical solution to the overland flow equation. Recharge and surface runoff are determined using an Earth-based relationship dependent on the annual potential evaporation and precipitation rates from TitanWRF [3].

Though long-wavelength topographic models have been generated for Titan [8], we generate synthetic topography based on the statistical properties of the Synthetic Aperture Radar (SAR) topography [6]. This produces a fractal model of the topography at Titan's poles and includes SAR topography data where present. Additionally, we impose the large sea basins [10] as depressions, assuming that they have smoother surfaces than the surrounding terrain consistent with bathymetry [9]. This provides an accurate representation of both the actual long wavelength topography and the fractal nature of the short-wavelength topography for each polar region respectively.

The most significant topography difference between the north and south polar regions is the distribution and elevation of large basins [10]. Similar to Earth, basins on Titan have a unique morphology and composition compared to the surrounding terrain [9, 12]. The transport of material to these basins may produce a depositional 'sludge' layer at the bottom of these basins [9]. Therefore, we investigate the influence of low permeability material within the basins and lakes at the north and south polar regions and a higher permeability regional aquifer. Guided by past modeling work [6, 7], we start with a high permeability aquifer at both polar regions based on a best-fit to the south polar lake distribution [7]. We then systematically increase the permeability within the largest basins and filled lakes at both poles. However, here we only discuss the models that best-fit the observations at both polar regions under similar hydrogeological assumptions.

Results: At the north polar region, recharge at wetter, high latitudes drives subsurface flow to the surrounding depressions, while lower permeability material in the basin floor effectively retains the ponded methane in these basins (Fig. 1a). This results in a shallow hydraulic head gradient of ~ 20 m over 15° latitude producing an approximately equal head elevation with the 3 largest seas (Fig. 2b). Under similar hydrogeologic assumptions at the south polar region, small, high elevation basins at the wetter high latitudes result in few isolated lakes, essentially perched above the surrounding higher permeability regional aquifer (Fig. 1b). This predicts a lake area ratio between the north and south polar region of 0.14 closer to the observed asymmetry (0.04).

Both models agree well with the observed lake area distribution (Fig. 2a), though the north polar model under predicts lake area over the entire model. Previous

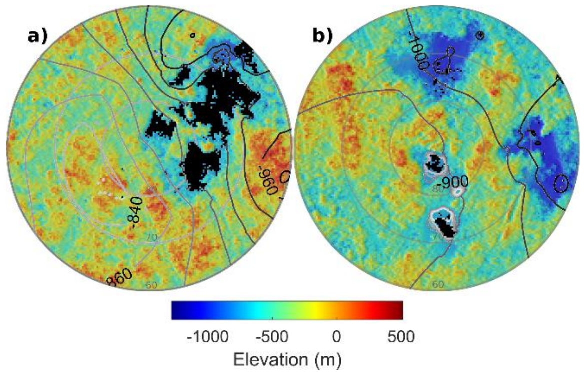

*Fig. 1. Modeled lake distribution (black) overlain on synthetic **(a)** north and **(b)** south polar topography models and respective climates assuming that the basins retain runoff and subsurface driven methane with a lower surface permeability.*

work found that the north polar region as better represented if conditions diverged slightly from the Earth scaling relationship, allowing more methane to infiltrate and runoff to the system [6]. Due to the low permeability nature of the basins, increasing the methane runoff results in a slight increase in the lake area (Fig. 2a, dotted line).

The modeling results shown here are also in good agreement with the observed lake elevations and dry lakebed elevations [11] at the polar regions (Fig. 2b, c). The north polar region is best fit by the runoff scaled model (Fig. 2b), with the seas above the observed lake levels and all dry and partially filled lakes below this level. However, this model does have trouble reproducing the small, filled lakes. The nominal south polar model (no runoff scaling) likewise agrees with the observed lakebed elevations and the lake level observed in Ontario Lacus (Fig. 2c).

Discussion: These results suggest that a complex geologic structure likely exists at both the north and south polar regions. Differences in the topographic distribution, in particular the elevation and size of basins located at wetter latitudes, between the north and south polar region can influence the lake distribution under similar hydrogeologic assumptions. At the north polar region, large basins tend to be deeper and concentrated above 70° N within the wettest northern latitudes. In contrast, at the south polar region, the two deepest basins are located at or below 70° S, while the two smaller basins sit at higher elevations in wetter latitudes above 70° S. These results also highlight the importance of geologic controlled retention of methane in the large basins, also shown in previous work [6]. Though a permeability difference between the north and south polar regions is possible given evidence for a possible polar deposit [13] and karstic features [14], we show that similar hydrogeologic assumptions at the north and south polar regions will influence the hydrology to produce a lake asymmetry closer to that observed between the north and south polar regions.

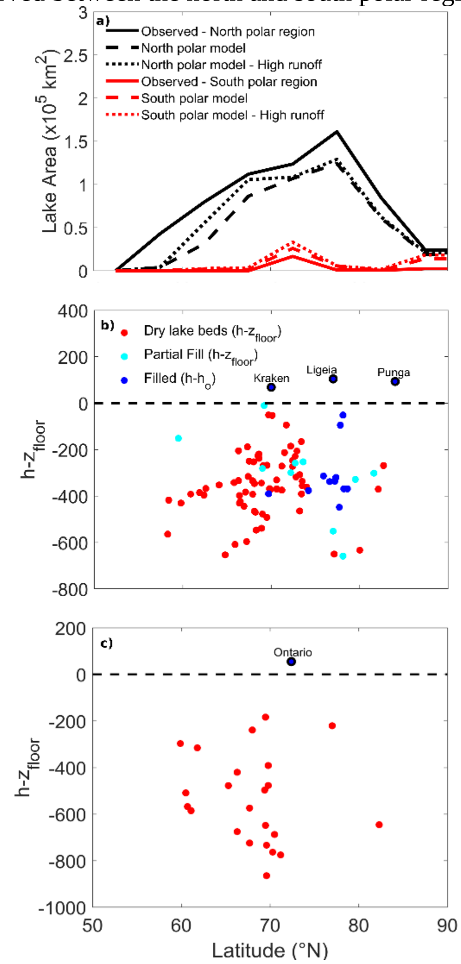

***Fig. 2. a)** The lake area over latitude for the low permeability basin models at the north and south polar regions. Comparison of these models (dashed lines in **a)**) to the lakebed elevations determined by [11] at the **b)** north polar region and **c)** south polar region. The modeled hydraulic head (h) is compared to the elevation (z_{floor}) of dry and partially filled lakebeds and the observed lake levels (h_o) for filled lakes and large seas.*

References: [1] Aharonson et al. (2009), *Nat. Geosci., 2*, 851-854. [2] Faulk et al. (2019), *Nat. Astron.*, doi:10.1038/s41550-019-0963-0. [3] Newman et al. (2016), *Icarus, 267*, 106-134. [4] Hayes et al. (2008), *GRL*, 35, L09204. [5] Lorenz (2014), *GRL*, *41*, L061133. [6] Horvath et al. (2016), *Icarus,277,* 103-124. [7] Horvath et al. (2020), *LPSC, 51*, 2716. [8] Corlies et al. (2017), *GRL, 44,* L075518 [9] Le Gale et al. (2016), *JGR, 121*, 233-251. [10] Birch et al. (2017), *Icarus*, 282, 214-236. [11] Hayes et al. (2017), *GRL, 44*, 11,745-11,753. [12] Birch et al. (2018), *Icarus, 310*, 140-148. *45*, 5320-5328. [13] Turtle et al. (2018), *GRL, 45*, 5320-5328. [14] Mitchell et al. (2008), *LPSC, 39*, 2170.