ON THE EVOLUTION OF TITAN'S SLOT CANYONS: PRELIMINARY ANALYSES USING FLUID DYANMICS. Tracy K.P. Gregg[1] and Susan E.H. Sakimoto[1,2], [1]Dept. of Geology, University at Buffalo, Buffalo NY 14260 (tgregg@buffalo.edu), [2]Space Science Institute, 4750 Walnut Street, Suite 205, Boulder, CO, 80301, (susansakimoto@gmail.com).

Introduction: The Cassini/Huygens mission [1] to the Saturnian system revealed Titan's complex surface geology [2], including a methane-based hydrologic cycle [3] (a "methanologic cycle"). Drainage networks [e.g., 4] surround lakes or seas [5] that look strikingly similar to terrestrial fluvial and lacustrine systems. Recent investigations of Titan's Punga and Ligeia Maria suggest that the liquid composition of these seas are most consistent with 80% methane, 20% nitrogen, and trace amounts of ethane [6].

Although Titan's fluvial and lacustrine systems appear broadly similar to those on Earth, there remain outstanding questions about channel flow, sediment transport, and sediment deposition with a methane-based fluid on Titan. Fluid rheology, velocity, channel size and shape, underlying slope, and gravitational acceleration affect whether a methane-based liquid will flow turbulently or laminarly, for example. The density contrast between a transporting fluid and a transported sediment particle exerts strong control over sediment transfer and settling rates. Understanding these complicated fluid dynamics is essential to constraining the rates of erosion, sediment transport, and sediment deposition on Titan.

Background: Burr and others [4] mapped Titan's drainage networks identified on Cassini Titan Radar Mapper (RADAR) [7] data. They concluded that half of these networks are rectangular in planform. They interpreted these results to indicate that Titan's surface experienced tension at some point in the past, resulting in rectangular zones of weakness (e.g., joints or faults) that were subsequently exploited by fluid flow. It is important to note, however, that the RADAR data they used covered ~40% of the moon at resolutions ranging from ~350 to 1700 m / pixel, precluding investigation of smaller channels or networks.

Using Cassini RADAR, Poggiali and others [8] measured the widths and depths of Vid Flumina, a drainage network that feeds into Ligeia Mare. Their results suggest that Vid Flumina contained liquid at the time the RADAR data were collected, and that the elevation of the liquid in the channels was similar to the elevation of liquid in Ligeia Mare. These observations are consistent with the liquid forming an equipotential surface, suggesting that the channels within Vid Flumina are presently drowned or embayed by liquid filling Ligeia Mare.

Significantly, channels within Vid Flumina were estimated to be <570 m deep, <1 km wide, and have wall slopes >40° [8]. These dimensions are consistent with terrestrial slot canyons, which are narrow, deep canyons that form in arid regions. On Earth, most of the erosion within slot canyons is abrasion of the wall rock that takes place during rare catastrophic flooding events [e.g., 9].

Here, we examine the effects of Titan's ambient conditions, fluid composition, and channel dimensions, on open channel velocity fields and shear stress distributions to predict potential sediment transport and deposition. Bed erosion and bed-load sediment transport depends strongly on bed shear stress whereas bank erosion (and subsequent and channel meanders or migration) depend strongly on side-wall shear stress. Although shear-stress distribution results from complex interactions between channel characteristics such as roughness, slope, geometry (shape and wall steepness), planetary gravity and other related variables, the calculation of the boundary shear stress requires knowledge of the fluid velocity profile or velocity distribution [e.g., 10]. This can be obtained by either solving for the velocity field from the continuity and momentum equations, or an averaged shear stress can be found by using an energy-balance approach to geometrically partitioning shear stress to the hydraulic wetted perimeter [e.g., 11], also known as the hydraulic radius separation method [12]. We expect Titan's settling velocity to be smaller than Earth's by roughly a factor of 5 for any given grain size, and Titan's frictional shear velocity to be smaller than Earth's by a factor of about 2 [13]. Additionally, for the same flow geometry and depth, material differences cause the Reynolds number (*Re*) for Titan's flows to be about 1.5 as large as those for similar terrestrial flows.

Methods: For this study, given the frictional shear velocity, settling velocity, and *Re* number differences, it is not clear that scaling approaches used for terrestrial flows will hold for Titan. Hence, we are employing a direct solving approach for Titan flow conditions as well as a terrestrial comparison case.

Computational Approach. We use COMSOL multiphysics® [14] with the computational fluid dynamics (CFD), particle tracing, and subsurface (e.g., allows for a porous substrate) modules to calculate velocity fields and wall shear stress as well as to trace particle paths.

Initial runs are for isothermal, 3-D, turbulent flow conditions for a set of rectangular, trapezoidal, triangular and truncated wedge channel cross-sections suggested by Cassini radar data [8] and terrestrial channels suggested as potential Titan comparative examples [12]. This allows direct exploration of the differences in calculated velocity fields and shear-stress distributions, which control erosion and sediment-load carrying capacities. Figure 1 shows an example of a channel flow model schematic for canyon flow at Titan's near-polar channel Vid Flumina main trunk at present or higher fluid levels. Here, canyon depth is 300m, canyon width (at top) is 700m, and canyon width at base is 100m, as estimated from wall slopes of >40° [8]. We assume methane material parameters at 97K of: density, $\rho_{methane}$ = 446 kg m^{-3}; viscosity, $\mu_{methane}$=0.0001784 Pa s. Boundary conditions for the cross-sectional area faces are periodic to preserve uniform flow in the y direction (Fig. 1), and flow is driven by the y-component of the gravity. We explored a range of underlying slopes, because that parameter is not well constrained for Titan. Side and basal walls are no-slip, and the top surface is free of shear stress. Because the presence of the free surface and tilted side walls may encourage secondary flow structures, we explored different Reynolds Averaged Navier-Stokes (RANS) and Large Eddy Simulation (LES) turbulence model approaches [15].

Preliminary Results: We find significant differences between terrestrial and Titan flow regimes. First, Titan material and ambient conditions generate smaller frictional shear velocities and smaller settling velocities than would be found in similar terrestrial channels. Additionally, for Titan flows, *Re* values are on average 1.5 times higher than for comparable terrestrial channels. As for any open-channel flow, the non-uniform shear stress distribution and free surface generate non-uniform local Reynolds numbers and turbulence variations and thus significant computational convergence challenges. Care must be taken in turbulence model selection for each simulation's expected Re number, and boundary condition and driving force inputs must also be chosen judiciously. Preliminary computational solutions for boundary wall shear stress confirm that Titan channel wall values are smaller than those found in similar terrestrial channels, and thus erosive capabilities correspondingly smaller.

Discussion, Implications, and Future Work: Smaller frictional shear velocity means particles are less easily entrained in Titan flows than terrestrial flows, but the lower settling velocity means that once entrained, they will be carried further at lower velocities before deposition. Both considerations should discourage—relative to terrestrial channels—the development of channel meander structures, and transport delta sediments considerably further out into any standing bodies of liquid. Higher Titan *Re* values result in slightly thinner boundary layers and a faster change to transitional and turbulent flows; and, once turbulent, a tendency to generate secondary flow structures (like eddies) sooner than for comparable terrestrial flows, which should also help to keep small sediment particles is suspension longer than for terrestrial flows. Because of the lower wall shear stress values for Titan, it may require catastrophic or high flow-rate conditions to cause the majority of channel erosion there.

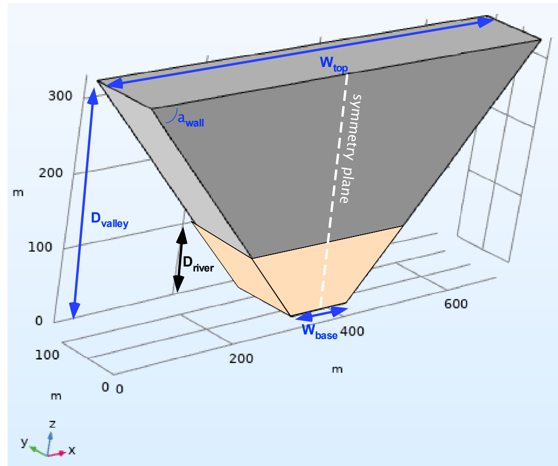

Figure 1. Channel flow model schematic for Vid Flumina, Titan channel main trunk (location "g" from Table 1, Poggiali et al. [8]) with valley width of 700 m, depth of 330 m, and wall slopes >40° (here 45°). See text for boundary conditions.

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