Origin of Venusian Canali, Channel and Valley Networks: Basalt or Not? T.K.P. Gregg[1] and S.E.H. Sakimoto[2], [1]Dept. of Geology, University at Buffalo, Buffalo NY 14260 (tgregg@buffalo.edu), [2]Space Science Institute, Boulder, CO 80301 (ssakimoto@spacescience.org).

Introduction: Although liquid water is not currently stable on the Venusian surface, a remarkable variety of channels and valley networks are observed in the Venusian plains [1, 2]. Their intriguing morphologies and remarkable dimensions (including the longest channel in the Solar System) has raised as-yet unanswered questions about their origins. These features are embedded in the plains, suggesting that they could have resurfaced vast portions of the plains.

Background: The exceptional length of some canali (≤7700 km) and uniform width along their lengths leads to the hypothesis that these required exotic, low-viscosity lavas to form (e.g., komatiites, sulfur or carbonatites). The end-member models for canali formation are simplified to: 1) a constructional origin, where the canali are drained lava tubes or channels; or 2) an erosional origin, where the low-viscosity lavas mechanically or thermally eroded into a pre-existing substrate. Existing Magellan synthetic aperture radar (SAR), altimetry, and derived stereo altimetry [3] are not sufficient to clearly resolve the cross-flow profiles of these features. Although some canali show radar-bright returns along their margins that have been interpreted to be levees [4], this does not confirm a constructional origin.

Venusian canali are morphologically similar to lunar sinuous rilles, although most canali do not have an irregular depression at the source [5], although some compound channels do show this feature [1, 5]. On the Moon, formation via thermal erosion of a pre-existing substrate has been proposed as a possible origin for these source depressions [e.g., 6, 7]. If Venusian canali were generated by thermo-mechanical erosion, their lack of source depressions is an enigma.

Valley networks defined by amphitheater-shaped heads, flat floors and steep walls (such as the “Gumby” feature [8]) with morphologic similarities to groundwater sapping channel, and the possibility of “groundlava” has been suggested [9]. This would require the presence of lavas with solidification temperatures below that of the Venusian surface.

These Venusian channels and valley networks present a paradox. First, they are most likely formed by flowing lava. Second, the great lengths and widths of the Venusian channels and valley networks far surpass terrestrial ones, leading to hypotheses that Venusian channel-forming lavas are composed of something other than tholeiitic basalts. Third, the available compositional information for the Venusian plains are consistent with tholeiitic basalts [10]; on Earth and the Moon, we infer that the plains are the same composition as the lava channels they contain. The paradox for Venus, therefore, is why would the channels and valley networks be composed of lavas distinct from the plains compositions?

An updated series of models can help resolve this apparent paradox. Prior studies of canali have made major simplification assumptions. For example, Williams et al. [11] impose a gravity-current approximation of velocity from an assumed turbulent flow and calculate cooling from the resulting assumed well-mixed core. In contrast, Harrington and Williams-Jones [12] used FLOWGO [13] which employs “bulk-averaged” properties and uses a 1-D incremental, stepped downhill modeling. These, and other similar approaches that assume or approximate velocities and rheologies may yield misleading results, such as requiring very low viscosities for long flow lengths. With recent advances in multiphysics modeling, many of these prior simplifications can be abandoned, and a more physically realistic model, relying on fewer assumptions, can be built.

Methods: We consider the canali Apisuahts Vallis (Fig. 1) within Lada Terra as an example of a canali with a particularly well constrained geometry. It is ~160 km long, 0.8 km wide, 30 m deep, with an average underlying slope of 0.2° [14]. Here, we explore lava flow emplacement and cooling for both laminar and turbulent flow conditions for several rheologies in 3D flow. We solve for both isothermal flow and constant rheology as well as temperature-dependent rheology with conductive, convective, and radiative cooling. We use COMSOL 6.0 multiphysics [15] to solve the incompressible 3D momentum and continuity equations directly for the velocity field, and the 3D energy equation for temperatures. Where rheology is temperature-dependent, the velocity and temperature

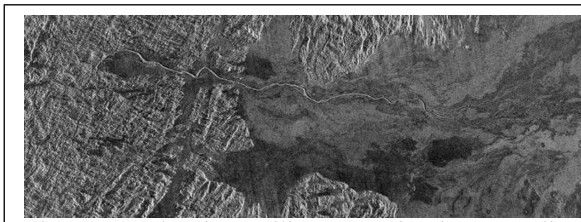

Figure 1. Apisuahts Vallis, a ~160 km long canali. Magellan radar image is centered at at 66.3°S, 16°E. Image courtesy of NASA PDS imaging node.

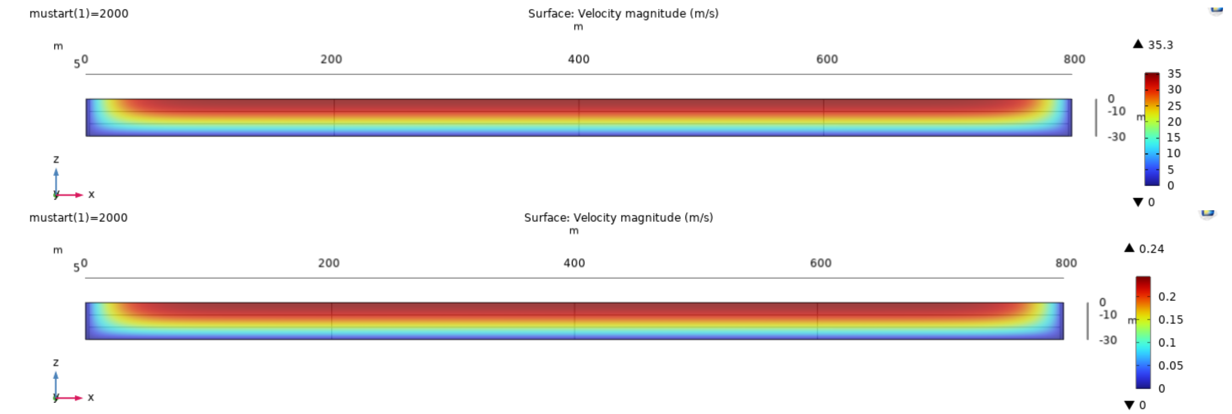

Figure 2. Isothermal velocity solutions for (top) Newtonian isothermal flow with U_{max} of 35 m s^{-1}, flow rate of 1.85E6 m^3s^{-1}, and U_{avg} = 22 m s^{-1}, and (bottom) high-yield-stress, shear-thinning rheology (n=0.8), with U_{max} of 0.24 m s^{-1}, flow rate of 1.87 x 10^3 m^3s^{-1}, and U_{avg} = 0.16 m s^{-1}. Note different velocity scales.

solutions are coupled through rheology. We use the generalized non-Newtonian Herschel Bulkley rheology, given by:

$$\tau = \tau_0 + k\dot{\gamma}^n \quad (1)$$

where τ is shear stress, τ_0 is yield stress, k is the consistency index, $\dot{\gamma}$ is shear rate, and n is the flow index. This simplifies to Newtonian rheology when n=1 and τ_0=0; Bingham rheology when τ_0>0 and n=1; shear thinning when n<1, and shear thickening when n>1. Each parameter may be a function of temperature.

Each COMSOL solution yields a 3D velocity and temperature solution, and we used these to derive flow rate, maximum velocity, average velocity, flow surface shear rates, and Reynolds number (Re).

Results: All solutions are for a lava density of 2800 kg m^{-3}, flow depth of 30 m, flow width of 800 m, and underlying slope of 0.1° or 0.2°. A Newtonian rheology in Apisuahts Vallis (Fig. 2A) and shear thinning with a yield stress (Fig. 2B) are shown.

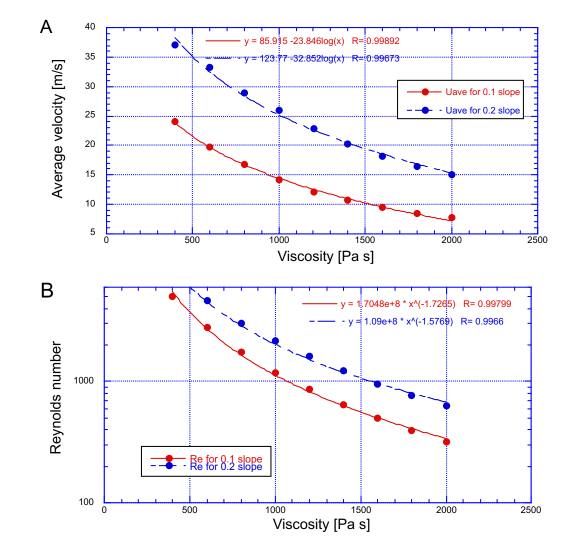

Figure 3. Laminar flow results for slopes of 0.1° and 0.2°.

Figure 3 shows Reynolds number (Re) as a function of dynamic (Newtonian) viscosity in isothermal laminar flow for slopes of 0.1° and 0.2° for multiple model runs. These are curve fit (as shown) to provide general relationships for the viscosity range, and all of the curves for this flow cross section aspect ratio can be combined into a single relationship.

Discussion: Solving for a range of parameter values allows the determination of empirical equations for Re, max (U_{max}) and average velocities (U_{avg}) as a function of viscosity for this channel geometry for each set of rheologic and cooling conditions. Non-Newtonian behavior tends to reduce flow speeds, as it effectively reduces the size of the faster-moving flow core, and viscosity gradients inhibit the transition to turbulent flow. Adding cooling further reduces the effective core flow thickness, retards velocity, and inhibits turbulence. Thus, fewer of these flows should be assumed to be fully turbulent (and thus "thermally well mixed") than has been inferred from prior, more simplified models, so basalt is a reasonable lava composition.

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