A Hypothesis for the "No-Flow" Mars' North Polar Layered Deposits Observations

I. B. Smith[1,2] , [1]York University, Toronto, Canada; [2]Planetary Science Institute, Denver, CO. (ibsmith@yorku.ca)

Introduction: Ice has been detected on Mars in many places, from the polar caps, to mid-latitudes. In the mid-latitudes, there exists strong evidence for glacial flow (e.g. lobate debris aprons, lineated valley fill, concentric crater fill, and viscous flow features [1-5]). Most, if not all of these features exhibit primary and secondary features visible from the surface that are tell-tale signs of flow: convex-up axial profiles, arcuate contours, lobate toes, extended lineations - or flow lines, even crevasses and moraines. Questions remain about whether these features are flowing today or if they are in a flow hiatus, but there is consensus that they flowed to reach their current state.

This raises the possibility of flow for the ice-rich polar layered deposits (PLDs). Over several decades, numerous researchers have hypothesized that the north PLD flows currently [6-13]. Each made testable predictions about flow rates and resulting stratigraphy that can be tested using modern observations.

In this abstract, I compare predicted observations, based on models and theory with actual observations and show it is impossible to reconcile the two. Finally, I propose a new model that suggests that the NPLD cannot flow appreciably because vertical rheological heterogeneity disallows massive flow on the scale of the NPLD (~2,000 m thick) and restricts vertical deformation to individual layers that are meters thick.

Flow scenarios: Early flow scenarios predicted that the surface spiral troughs on both PLDs formed due to the presence of flow [6], are representative of a current flow state [7, 8] (Figs 1a and 1b), are currently directing flow conditions [9] (Fig 1f), should close due to topographic relaxation [10], or have formed after flow stopped [11, 12] (Fig 1c). Another model tries to explain away the persistence of the spiral troughs by having alternating local patterns and timing of bed freezing [13] followed by erosion. Finally, one model recognizes that flow may be un-observably slow in some locations, but marginal scarps on the NPLD reach 90°, and the stresses there should force flow of 0.1 to 1 m/a [14]. Each of these cases makes testable predictions, and many have already been disproven.

Evidence against bulk flow: Models that require the spiral troughs to form after flow completed [11-13] have two difficulties. First, they can't explain evidence that the spiral troughs have persisted and even grown over accumulation of ~1/2 of the entire NPLD thickness [15]. Second, bulk stratigraphy predicted by these models and one of purely basal flow [13] do not agree with observed stratigraphy at any location [16]. The observation of long lived spiral troughs also goes against topographic relaxation and vertical flow (Fig 1f) that would close the troughs [9, 10].

Further, the extremely steep marginal NPLD slopes have been studied extensively for avalanches, and even with active erosion, the surface is quite stable [17]. Current erosion could not balance even the lower end of the modeled velocity flow velocity [14], weakening the case for flow even in the most opportune location.

Finally, scenarios that account for trough persistence with alternating patterns of accumulation and ablation [7, 8] make very strong predictions about trough stratigraphy (Figs. 1a and 1b). These predictions have been tested by an all encompassing survey of spiral trough stratigraphy that found no evidence to support these stratigraphies [15] (Figs 1d and 1e).

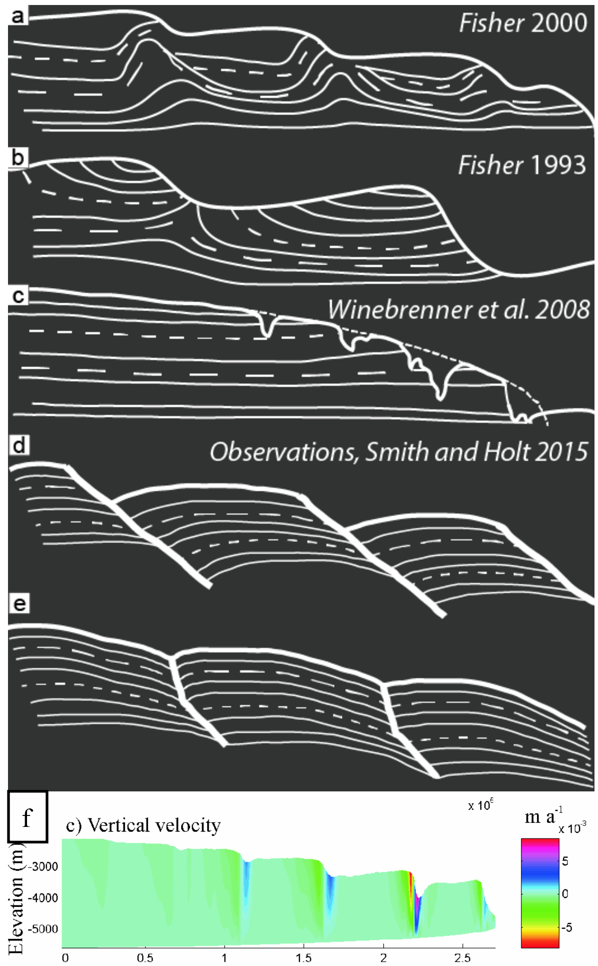


Figure 1: Flow predictions and observed stratigraphy. a) and b) Stratigraphy used to explain the persistence of spiral troughs while the north PLD undergoes flow [7,8]. c) Predicted stratigraphy of a flowing ice sheet with spiral troughs later cut into the surface [11]. d) and e) Interpreted stratigraphy near the spiral troughs. The troughs have persisted for extended durations, and their stratigraphy is incompatible with any flow hypothesis [5]). f) Modeled velocities that result from flowing ice near the spiral troughs [9]

This disagreement between model and observations, has led to a general consensus that the polar ice flows more slowly than other processes acting on the NPLD. This is an acceptable interpretation for the NPLD, which at ~4 Ma is quite young, but the SPLD is >8-24 times older than the entire NPLD, and the lower deposits may be much older. An SPLD maximum thickness of >3 km, and it's long lived history, that made it much warmer prior to 4 Ma, should have created conditions that resulted in observed flow features. Yet, no flow evidence has been presented at the SPLD.

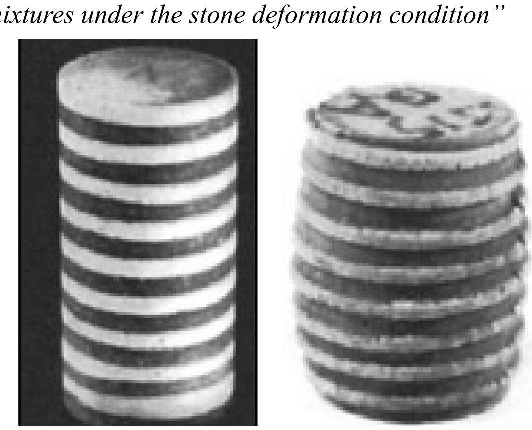
Controversy: One sticking point is that glaciological modeling always predicts flow, disallowing scenarios in which the PLD do not flow or flow extremely slowly. Perhaps the models are missing something.

To answer this question [18] conducted rheological experiments on impurity-laden ice, at ~5%, similar to the bulk composition of the NPLD. The conclusion was that, "*small particle fractions and small particle sizes have a negligible effect on ice flow behavior.*" In other words, impurities, such as dust, don't slow down flow until concentrations above 5-6% are reached.

Cause of Unobserved Flow: Here I propose a scenario in which the polar layered deposits do not act as a single, generic ice sheet (Figs. 2a and 2b). Instead, they act as a stack of thin ice sheets, where each icy layer is separated by a layer of dust-rich ice (>6%) that stiffens the overall PLDs [18]. In this scenario icy layers can only flow individually (Fig 1c) because the stiff layers inhibit flow and sliding. Thus, the viscosity of the icy layers is primarily expressed through lateral expansion. Because of the extreme ratio of NPLD diameter to individual layer thickness, almost no deformation can take place.

Experimentation has determined that weak samples with uniform rheological behavior (An in Fig 3) are overall weaker than samples that have alternating layers of weak (An) and strong (Qtz) material [19] (Fig 3). In essence, vertically stratified materials are stronger than their weakest component.

Figure 3: Image and quote from [21] "the bulk flow strength of layered composites increases with decreasing thickness of the layer" and "thin-layered rocks compressed normal to the layering are rheologically stronger than homogeneous, isotropic mixtures under the stone deformation condition"



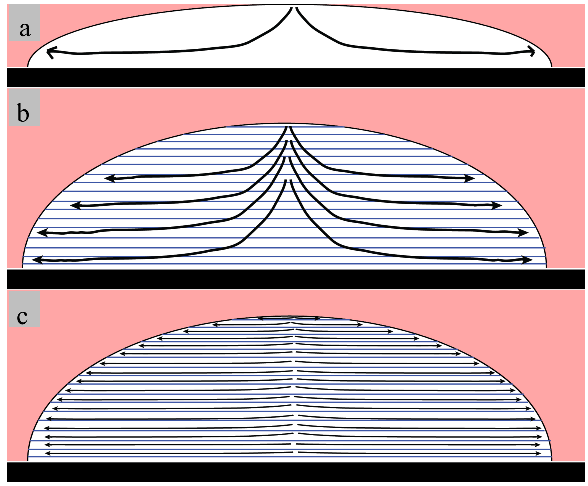


Figure 2: *Flow scenarios. a) Generic ice sheet. Flow spreads from center outwards. b) Long-time interpretation of the NPLD. The volume of ice flows as in (a), and the layers do not play a major role. Stratigraphy like in Fig 1a should occur when spiral troughs are present. c) Flow interpretation that includes a multi-layer, stacked composite ice sheet. Each layer flows, as would a thicker ice sheet, but very little vertical deformation can occur.*

In this presentation, I plan to present the case against flow and simple laboratory experiments demonstrating the efficacy of the heterogeneously stacked flow hypothesis. I will demonstrate that individual layers themselves flow but do not deform the entire ice sheet, as previously predicted. This allows for the PLD to retain their steep slopes and prevents many of the predicted flow features to form.

The major component of this hypothesis is that the dust layers hinder flow. Thus, constraining the friction coefficient, viscosity, tensile strength and compressibility of the dust layers becomes an important next step for testing the stacked, multi-layer flow scenario.

References: [1] Sharp (1973) *J. Geophys. Res., 78*, 4073-4083. [2] Squyres (1978) *Icarus*, 34, 600-613. [3] Squyres (1979) *J. Geophys. Res.*, 84, 8087-8096. [4] Hubbard et al., (2014) *The Cryosphere*, 8, 2047-2061. [5] Brough et al., (2016) *Icarus*, 274, 37-49. [6] Weijermars (1986). *EPSL* (ISSN 76, 227–240. [7] Fisher (1993). *Icarus* 105, 501–511. [8] Fisher (2000) *Icarus* 144, 289–294. [9] Hvidberg (2003). *A. of Glaciology* 37, 363–369. [10] Pathare and Paige (2005) *Icarus* 174, 419–443. [11] Winebrenner *et al.,* (2008) *Icarus* 195, 90–105. [12] Nye *et al.*, (2000) *Icarus* 144, 449–455. [13] Fisher et al., (2010) *JGR Planets*., 115, E00E12 [14] Sori et al., (2016). *GRL* 43, 541–549. [15] Smith and Holt (2015) *JGR Planets* JE004720. [16] Karlsson *et al.*, (2011). *GRL* 38, L24204. [17] Fanara et al. (2019) *Icarus* 113434. [18] Qi et al. (2018) *GRL* 45, 12,757-12,765. [19] Ji et al. (2000) *JGR: Solid Earth* 105, 16651–16664.