EFFECT OF FLOW ON THE INTERNAL STRUCTURE OF THE MARTIAN NORTH POLAR LAYERED DEPOSITS. K. E. Fishbaugh[1] and C. S. Hvidberg[2], [1]International Space Science Institute, Hallerstrasse 6, Bern, Switzerland CH 3012, fishbaugh@issi.unibe.ch; [2]Niels Bohr Institute, University of Copenhagen, Juliane Maries Vej 30, Copenhagen, Denmark DK 2100, ch@gfy.ku.dk.

Introduction: The varying deposition rates of ice and particulates reflected in the alternating bright and dark layering of the martian polar layered deposits (PLD) has sparked an interest in correlating the PLD layering with changes in orbital parameters such as obliquity [e.g.,1, 2, 3]. If this correlation exists, the polar layers may be an invaluable record of Mars' recent climate history as changes in orbital parameters are major regulators of climate. In order to attach particular layers or layer sequences to particular changes in orbital parameters, one must assume that the stratigraphic sequence has been preserved and that a timescale can be reconstructed.

If the layers are subject to flow, the stratigraphy can be affected in several ways. As pointed out by Clifford et al. [3], flow can stretch and thin layers, the amount increasing with depth in the ice. This process leaves intact the climate record possibly recorded in the PLD, but the timescale needs to be adjusted (e.g., with flow models that assume a certain deposition rate and take the layer thinning into account). In some cases, ice flow may disturb the stratigraphic record. For example, large scale flow can create disconformities, and localized flow instabilities can lead to folding and boudinage.

The goal of this study is to determine what effects flow might have on the internal layer structure of the north polar cap and whether these effects are observed in the data.

Initial Assumptions. We begin the flow modeling by assuming an initial layer structure and then allowing it to flow, using two different mass balance scenarios. We term the initial layer structure a "Layer Cake". Each layer is initially flat and of equal thickness. This scenario involves the least complicated assumptions about the unknown mass balance (deposition and ablation) history of the cap. Additionally, the PLD are deposited relatively quickly on a geologic timescale so that flow is assumed not to have affected the ice sheet to an appreciable degree until after most of it was deposited. If the cap has been flowing (at an appreciable rate) throughout its history, the situation involves many more parameters whose values are unknown. We do not attempt to model how troughs are formed, though, as explained below, we assume the presence of troughs (through their effect on the mass balance) in one of our model runs. It is also assumed that throughout the time during which the cap has been flowing, the mass balance has not changed.

Flow modeling: The flow model is a simple isothermal, two-dimensional, time-varying, numerical model. The model assumes that ice deforms according to a power law (Glen's flow law) simplified to shear stresses only, and solves the mass conservation equation. The model assumes a mass balance (deposition and sublimation pattern) and allows the ice cap to evolve over time. Model outputs are surface evolution, internal layer structure, and particle trajectories of ice particles deposited at the surface. We run the model on a Layer Cake ice cap with two example mass balance patterns.

Model 1: No deposition or sublimation. The Layer Cake flows but no further deposition or ablation has occurred since the layers were deposited. This serves as an end-member example and is only an approximation of reality if the shapes of the cap and its layers have been affected more by flow than by mass balance since their deposition. The purpose of this model is to isolate the effect of flow on the layer structure.

Model 2: Fisher Accublation. The Layer Cake flows, and its mass balance is described by Fisher Accublation [4] in which deposition occurs on the flats areas between polar troughs and ablation occurs within the troughs. This could most accurately describe the current mass balance of the northern cap. The purpose of this model is to study the combined effect of flow and deposition/sublimation associated with polar troughs. Note that the troughs remain in a fixed position in this model.

The flow models can be improved by considering more complicated initial layer structures and by adding the effects of changing obliquity on temperatures and hence on flow rates.

Layer Correlation and Determination of Structure: We compare the layer structure predicted by the flow models to observations of the actual layers using image (primarily MOC) and MOLA data. For our preliminary analysis of layer structure visible in MOC images, we choose example PLD outcrops based on the following criteria: 1) images identified by [5] as containing their "marker bed" and 2) images of layered deposit outcrops containing other conspicuous layers which could possibly be used as markers; we will term the latter layers "reference layers" so as not to confuse them with the "marker bed" of [5]. The correlations of particular reference layers from one location to another are performed based on morphology. While the morphology can change from one location to the next, in most cases, a distinct layer remains distinct, regardless of its small-scale surface texture. Additionally, the pattern of layering surrounding a reference layer (e.g., a package of thin layers above) can also be used to identify it.

The chosen example images have been registered to a MOLA DEM (res.≈120m/pix) by S. Byrne as described in [6] and have errors in their positions of about 10–100m [7]. For our study we are interested in the overall large scale structure of the layering, thus the inaccuracies are relatively insignificant. In the example images, we have located reference layers and the marker bed, and we have derived elevations of those layers from the co-registered MOLA data.

Figure 1 shows preliminary results of the layer correlation. It is evident that the upper layers curve while the lower layers are flatter and appear more like the Layer Cake. Previous flow modeling has shown that when one begins with a Layer Cake ice sheet and allows it to flow, the upper layers will follow the surface of the ice sheet (and so will curve) while the lower layers will follow the base [4]. However, if an ablation zone is present near the ice sheet margin, flow can bring deep layers to shallower depths near the margin and can thicken them as well, a possibility for which we will search in the MOC data.

We plan to perform more layer correlations in more areas of the cap (including THEMIS images), to search for possible unconformities, and to investigate layer thinning with depth. These analyses will help us to better understand the internal stratigraphy of the north polar cap and to better compare it to the layering pattern predicted by flow models. Additionally, we plan to improve the accuracy of our reference layer elevation measurements by better registering image data to the MOLA DEMs.

Comparison with Previous Studies: Using Fourier Analysis of layer packages and matching analyses similar to those used for deep sea cores, Milkovich and Head [8] find that the layers within the northern PLD are curving. Those results are consistent with the upper layer structure in our layer correlation analysis and in previous flow models [e.g., 4].

Byrne and Ivanov [7] also predict this structure for at least the upper layers of the southern PLD and suggest that the layers were initially deposited on a mound. Due to the shape of the layer structure they constructed and comparison with theoretical shapes formed by a flowing ice cap, the authors also suggest that flow may not have been as important in determining cap shape in the south as has mass balance (unless the mass balance is distributed non-uniformly or the flow properties vary within the cap). Indeed, the shapes, ages [9], and geologic histories [10, 11] of the two caps are dissimilar so that one could also expect their flow histories to be dissimilar.

Our analyses can be useful for studies involving interpretation of the climate record within the polar layered deposits and for interpretation of MARSIS radar data of the caps.

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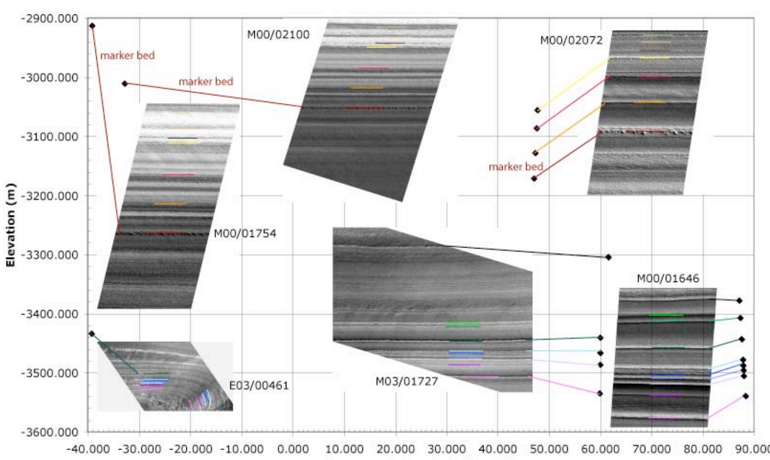

Figure 1. Layer correlations. Red "marker bed" refers to that defined by [5]. Other colors delineate other reference layers. Black dots indicate elevations of some example reference layers. Note that these preliminary results are presented in absolute elevation of the layers rather than depth from the surface of the ice cap, so that no information on the correlation between layer structure and ice cap surface shape is illustrated here. In the future, results will be presented in both formats.