NUMERICAL EVOLUTIONARY MODELING OF THE MARTIAN POLAR LAYERED DEPOSITS TO INFER THE ROLE OF ICE-TECTONICS.

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Introduction: Martian polar layered deposits (PLDs) strongly resemble the sedimentary architecture of the internal layering of the East Antarctic Ice Sheet (EAIS). Data from the Shallow Subsurface Radar (SHARAD) instrument on NASA's Mars Reconnaissance Orbiter was used to create several cross section profiles in an effort to visualize the internal stratigraphy of the PLDs [1, 2, 3, 4]. Fluid deposits sequestered in the PLDs (Figure 1) and at the base of the ice cap have been previously described in the literature [1, 5, 6]. Mechanisms responsible for PLD formation are a matter of ongoing debate [7], however by better understanding their evolution, their formation processes can be better constrained. Furthermore, both their formation and evolution have relevant importance in the search for biosignatures, highlighting past and present climate changes, as well as atmospheric composition.

Methodology: Layered ice is simulated by a mesh of cells compiled into a Hybrid Cellular Automata (HCA) model. Three major types of links exists between adjacent cells: 1. Intralayer relations link cells within a single layer and consist of rigid relationships derived from average volume and surface preservation conditions, physical boundary conditions, and rock rheology. 2. Inter-layer relations regulate the relationships among separate layers adjacent to each other.

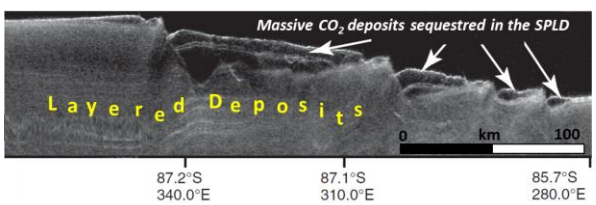

Figure 1: Depth converted radargram showing south polar layered deposits and the CO2 deposits sequestred in the ice. SHARAD radargram 5968-01 from [1]

These relationships take into account the weaker rheology of interlayer material, physical boundary conditions, and volume preservation conditions, while partial freedom is given to surface variations. 3. Discontinuous relationships correspond to the presence of ruptures such as faults. No kinematic links exist across cells separated by individual faults aside from physical boundary conditions and slip-induced stresses [8]. The combination of the Finite Element Method (FEM) and Cellular Automata (CA) approaches allow us to replicate the natural material anisotropies, such as rocks and ice sheet internal layering, as well as simulate complex tectonic evolutionary paths [9, 10]. The HCA evolutionary modeling of the internal layering of the EAIS highlights the interaction between the active bedrock tectonics and the ice sheet dynamics (including ice flow, erosion, and sedimentation, [11]). A similar approach was applied to the Martian PLDs at both the northern and southern polar ice caps to explore the role played by ice-tectonic movements on their present stratigraphy.

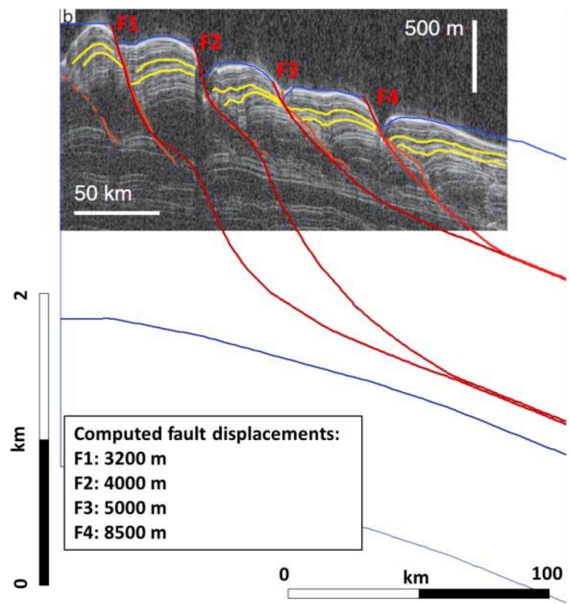

Figure 2: HCA numerical model of the ice layered deposits from Mars north polar region. F1-F4 indicates the location of inferred faults occurring in correspondence of to the spiral troughs. Subset of SHARAD radargram 1294501 from [2].

Results: The HCA numerical approach allowed to kinematically simulate the internal architecture of the layered deposits from both the north (Figure 2) and the south Martian ice caps. In particular the observed stratigraphy (ie. geometries and thicknesses of the ice layers) was replicated and demonstrated to have resulted from the relative, normal movement among blocks separated by shear discontinuities with a listric shape (normal faults). In some places the fit between the internal layering observed in the radar data and the geometries produced from the numerical model was achieved with subordinate fault inversions. The spiral troughs that characterize the northern polar ice cap occur at the same location of the modeled shear discontinuities. This suggests a possible ice-tectonic origin of these morphological features that exposes the outcrop of the PLDs in the northern polar ice cap. Computed final fault displacement for the ice-faults shown in Figure 2 are: F1: 3200m; F2: 4000m; F3: 5000m; F4: 8500m. Please note that the model vertical exaggeration is over 50:1, thus the modeled faults in the real vertical scale are nearly horizontal (dip < 3° at their upper tip).

Conclusions: The PLDs result from the relative, normal movement among blocks separated by listric shear discontinuities The presence of these low angle shear discontinuities/faults within the ice cap may relate to the presence of fluids/water (eg. sequestered CO2) within the ice layers or at the base of the ice cap that reduce the shear strength of the ice. In this way the ice faults may provide preferential pathways of enhanced fluid migration. Fluids and biological material stored in the ice can thus reach the surface and the atmosphere following the trajectories of enhanced permeability within the ice.

Multiple radargrams in Antarctica showed layered geometries similar to the Martian PLDs and suggests that the EAIS is a possible terrestrial analogue. Thus, HCA methodology has the potential of being an effective tool in identifying sites capable of exhibiting biosignatures.

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