A NEW HYPOTHESIS FOR THE ORIGIN OF MASS MOVEMENTS ON CALLISTO. Stephen E. Wood¹, Jeffrey M. Moore², Kristin L. Ivarson¹, Iryna Danilina¹, and Molly Johnson¹, Dept. of Earth and Space Sciences, Univ. of Washington, Seattle WA, 98195-1310, sewood@ess.washington.edu, NASA Ames Research Center, Moffett Field, CA, 94035, jeff.moore@nasa.gov.

Introduction: Callisto exhibits discrete mass movements that are larger and apparently more common than seen on other icy Galilean satellites (Fig. 1), as well as the most degraded surface [1,2]. While impact erosion and regolith formation are expected to operate with similar vigor on Callisto as on Ganymede, most of the areas observed at high resolution on Callisto have an appearance that implies that some additional process is at work, most likely sublimation-driven landform modification and mass wasting [1-3]. Moore et al. [1999] concluded that the extent of surface degradation indicates an ice more volatile than H₂O is probably involved; the most likely candidate being CO₂. Two mechanisms have been proposed - undermining/over-steepening of slopes by sublimation erosion and seismic triggering - which may work together to trigger the mass movements [1-3].

Here we propose a different mechanism, whereby slope instability is created by condensation of CO₂ ice that gradually accumulates in the near-surface pore space on the coldest interior walls of impact craters. The source of this ice is a CO₂ vapor flux driven upward by the geothermal gradient through a porous megaregolith containing some fraction of CO₂ ice at depth. Based on previous theoretical work related to deep ground ice on Mars, we believe that this deep CO₂ ice would have developed a particular vertical distribution that we refer to as Steady-State Pore (SSP) ice.

Steady-State Pore Ice: SSP ice can be maintained in dynamic equilibrium anywhere that has the following attributes:

- A porous, permeable regolith,
- A reservoir of volatile condensate (ice or liquid) within or just beneath the regolith,
- A temperature gradient, and
- A surface where the ice is not thermally stable on a regional (>10 km) scale.

The idea of SSP ice was first suggested in the planetary science literature by Clifford (1993) [4] in his comprehensive study of the subsurface hydrology of Mars. But the first explicit modeling and theoretical analysis of this phenomenon was presented in Mellon et al. (1997) [5]. They showed that in times or places where ground ice is undergoing long-term sublimation and diffusive loss, the ice table (the shallowest depth where any pore ice exists) will not continue to recede indefinitely to greater depths. While a geothermal temperature gradient will continue to drive vapor upward toward the surface, beyond a certain point it will

Fig. 1 - Lobate mass movement deposit on the floor of 15 km diameter crater on Callisto. [3]

Fig. 2 - Possible evolution of subsurface CO₂ ice on Callisto assuming an initial CO₂ ice volume fraction of 10% and two different values of the CO₂-ice-free pore size. A non-porous CO₂ ice table would quickly retreat from its assumed initial depth of 1m to below zSSP0, the SSP ice table (dotted line), after which its maximum retreat rate is controlled by conditions at zSSP0. The depth of zSSP0 also increases with time due to a declining interior heat flux (assumed function shown in lower plot). At any given time, the CO₂ ice fraction increases with depth from zero just above zSSP0 to higher values below. We note that the CO₂ vapor flux predicted for the present day is close to the estimated minimum value of 1E-7 kg/m²/yr required to maintain Callisto’s observed CO₂ atmosphere [6].
recondense at shallower colder depths, and persist in the regolith as interstitial ice partially filling the pore space as long as a source of vapor remains below. Once this occurs, a steady-state profile of ice volume fraction develops, with net mass loss only occurring from the base of the porous ice layer.

One of the reasons that SSP ice is important and useful is that as soon as this profile starts to develop it determines, and keeps constant, the loss rate of volatiles beneath it. The vapor flux at any depth with ice present can be written as

\[ F_v = D_{\text{eff}} * \frac{d}{dT}(\rho_{v,\text{eq}}(T)) * \frac{dT}{dz}, \]

where \( \rho_{v,\text{eq}}(T) \) is the equilibrium vapor density. All else being equal, the middle term would cause the flux to increase with depth. But this would lead to secular ice accumulation in the pores as the flux from below each point exceeds the flux above so the pores become increasingly constricted, reducing \( D_{\text{eff}} \). This self-regulating mechanism (negative feedback) enables the SSP profile to maintain a constant vapor flux throughout its depth with an ice content that increases gradually downward but remains constant in time as long as vapor is supplied from below. The value of \( F_v \) is therefore completely determined by the heat flow and the properties of the regolith at \( z_{\text{SSP,0}} \), which is typically within meters of the surface. Using estimated values for Callisto’s heat flow [ref] and near-surface pore size, our calculated \( F_v \) values are shown in Fig. 2.

**Implications of Surface Perturbation to SSP Ice:**
The behavior and required conditions for SSP Ice just described may apply regionally on Callisto, but small-scale local perturbations in surface temperature could have significant effects on landscape evolution, as described in Fig. 3. Further details and relevant model calculations will be presented.

**References:**

**Fig. 4** – Supporting results from our 3-D Topographic Radiative Thermal Model [7] for Callistian crater at 20°N. (A) Assumed albedo map with dark gray (dust mantled) areas at 20% and white (frosty) areas at 80%. (B) Model-calculated diurnal max. temperatures. Interior slopes have \( T_{\text{max}} = 75-95K \) and exterior slopes have \( T_{\text{max}} = 106-113K. \)