Fracturing the Icy Polar Cliffs of Mars

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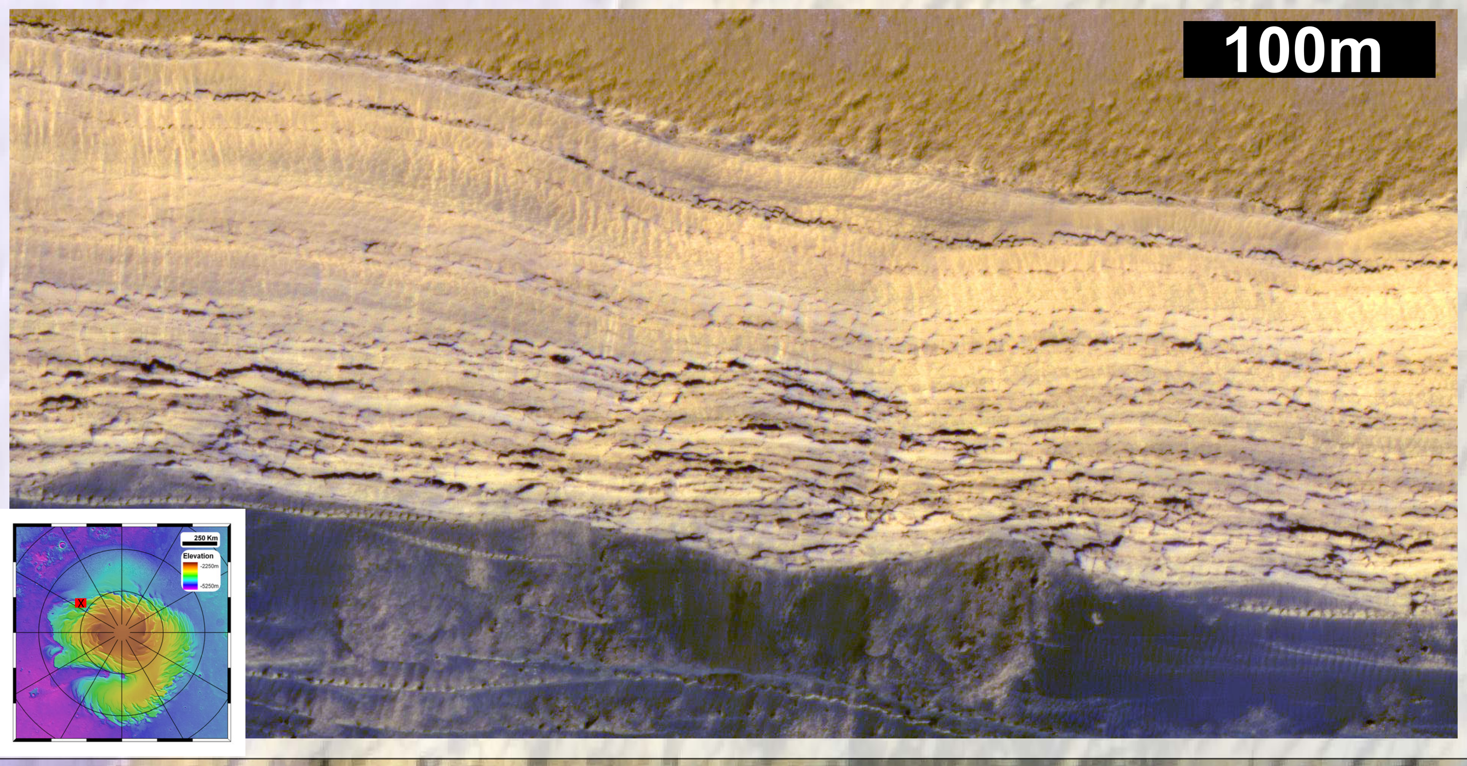
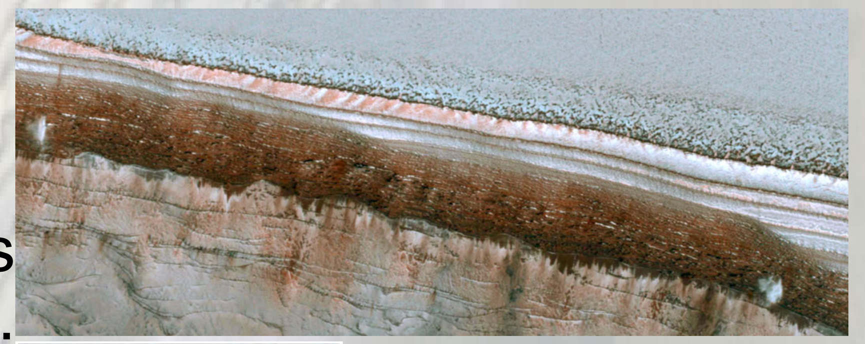
Quick Summary...

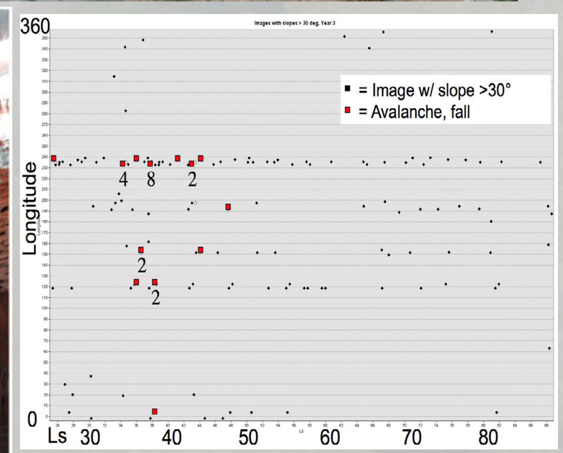
1. Avalanches are common on steep polar cliffs in early Spring. These scarps are also heavily fractured (Russell et al., GRL, 2008).
2. Thermally driven expansion and contraction creates stresses that can easily form these fractures to depths of many meters.
3. During avalanches the cliffs are under compresional stresses, which may cause exfoliation of material and trigger the falls.

Fractures, Avalanches and Blockfalls

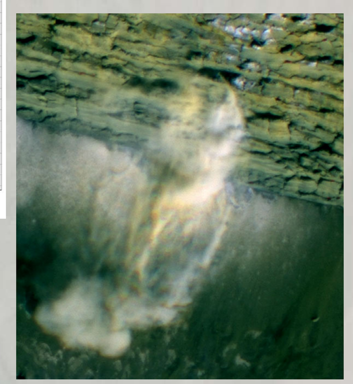
Steep scarps up to 70 degrees bound portions of the North Polar Layered Deposits. They are pervasively fractured and commonly have blockfall deposits around their base. Avalanches are commonly seen (sometimes many falls in one image) from L_s 8 - 48. Avalanches appear to emerge from defrosted scarp faces.







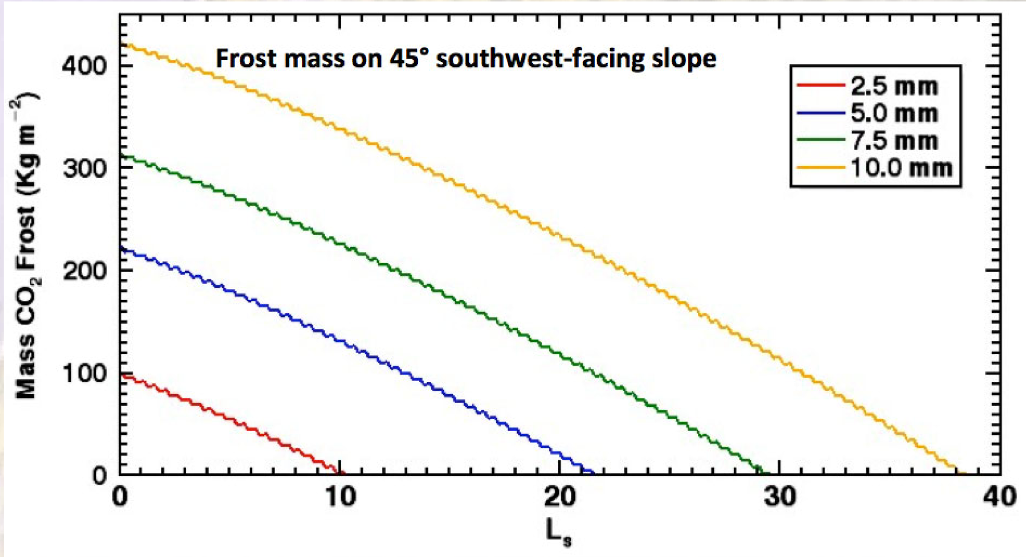
From Russell et al. (LPSC 2012)



Thermal Model

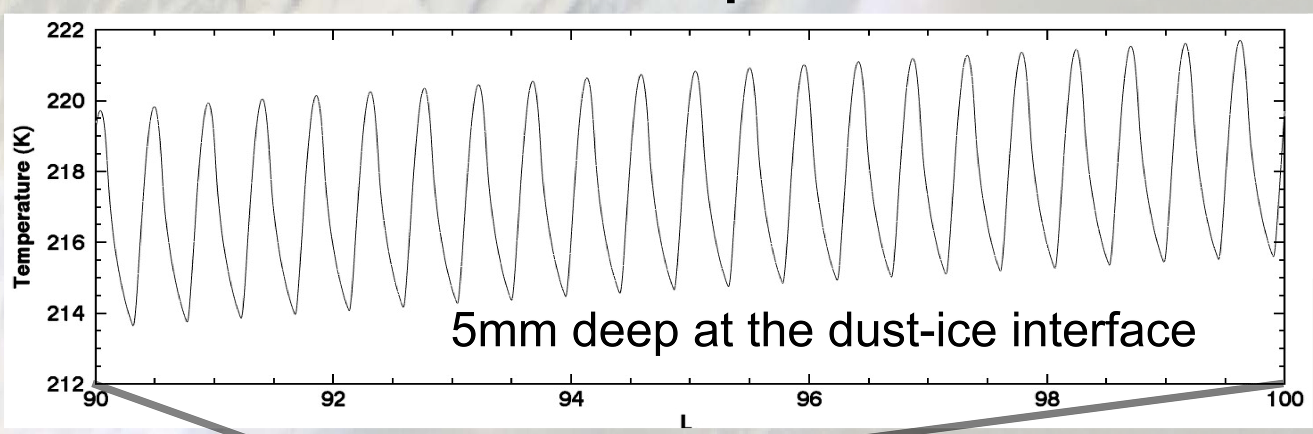
To investigate the thermal stresses in the scarp we simulate its temperature using a 1D semi-implicit thermal conduction model which includes radiation scattered from the surrounding flat plane toward the scarp.

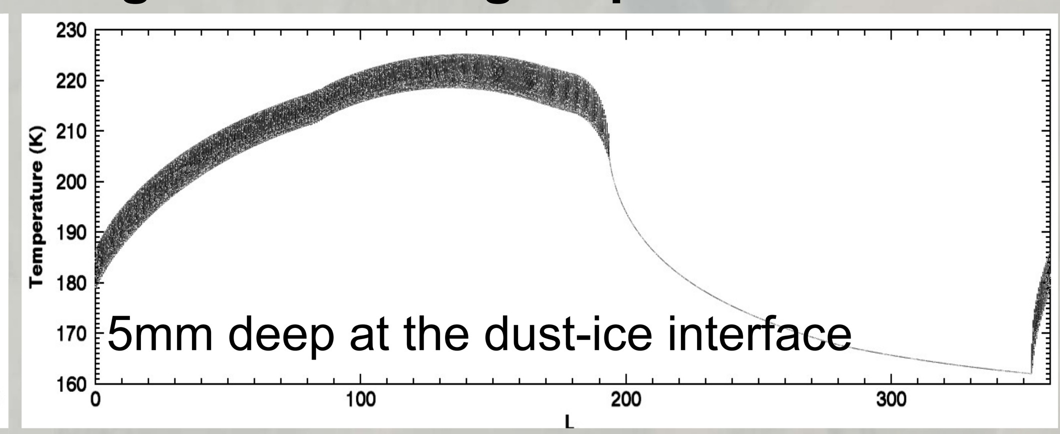
A critical model parameter is the dust thickness on top of the water ice. We use the defrosting date of the 45 degree sloped portions of the scarp to constrain this thickness to be ~5mm.

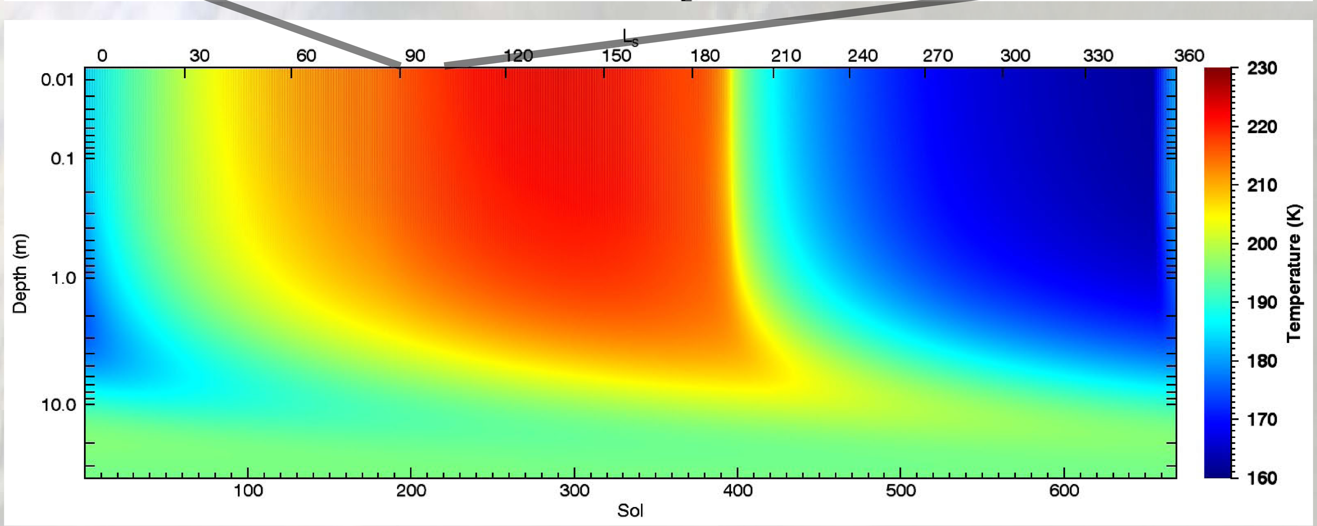


Typical scarp orientations at this locations are south-west. HiRISE imagery brackets the defrosting date.

Temperature results for a 70 degree SW-facing slope







Strong diurnal temperature swings due to the steep slope.

Large amplitude seasonal thermal cycle.

Annual thermal wave penetrates a little over 10m.

Stress Model

We use the thermal results to drive expansion and contraction of the water ice and calculate stresses created in a viscoelastic solid.

Stress perpendicular to the scarp face and strain parallel to the scarp face are zero.

$\sigma_{11}=\sigma_{22}=\sigma$ & $\sigma_{33}=0$

Model is similar to that used for polygon formation by Mellon (JGR, 1997).

$$\varepsilon^{Elastic} = \frac{1+\nu}{E}\sigma - \frac{\nu}{E}\sigma_{KK}$$

$$\frac{\partial}{\partial t}\varepsilon^{Elastic} = \left(\frac{1-\nu}{E}\right)\dot{\sigma} - \left(\frac{1-\nu}{E^2}\right)\frac{\partial E}{\partial T}\dot{T}\sigma$$

$$\varepsilon^{Thermal} = \alpha\left(T - T_o\right)$$

$$\frac{\partial}{\partial t}\varepsilon^{Thermal} = \left(T - T_o\right)\frac{\partial \alpha}{\partial T}\dot{T} + \alpha\dot{T}$$

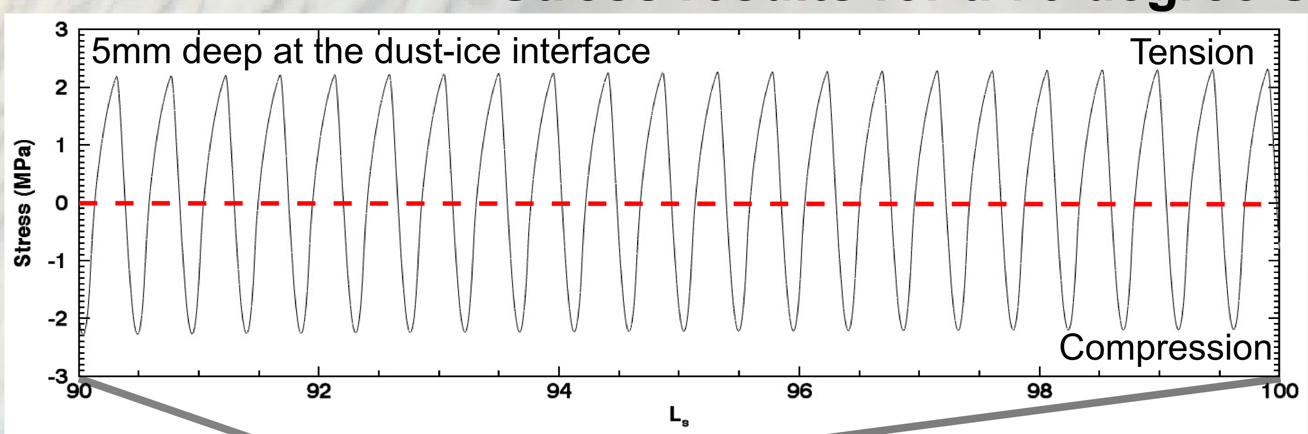
$$\frac{\partial}{\partial t}\varepsilon^{Viscous} = A\, e^{-Q/RT}\left(\sigma - \sigma_{KK}/3\right)^n$$

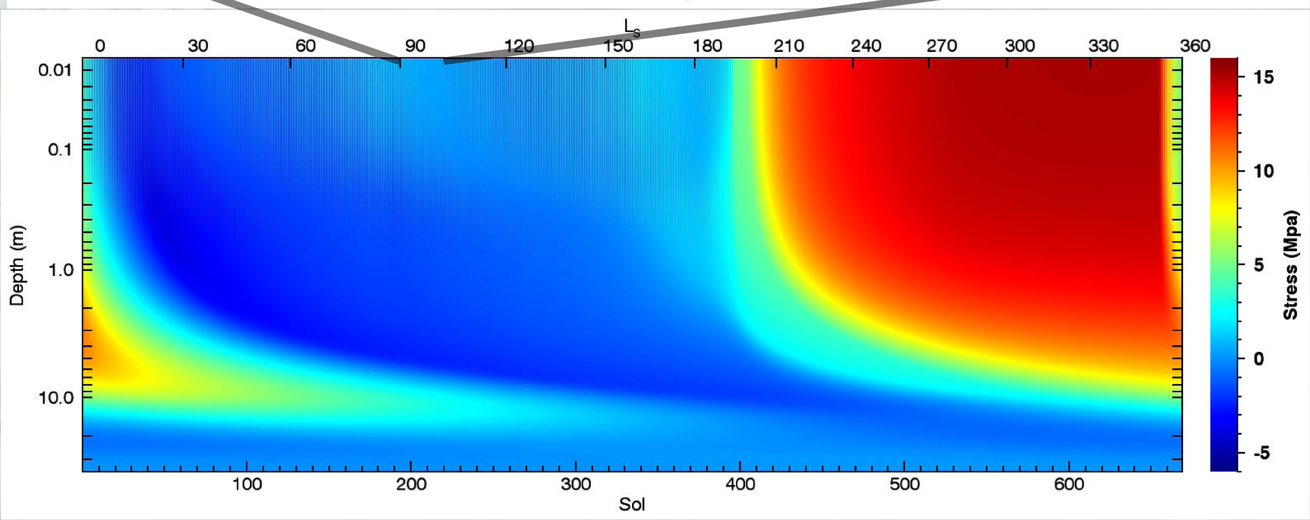
$$\frac{\partial}{\partial t}\varepsilon^{Viscous} = \left(A\left[\tfrac{2}{3}\right]^n\right)e^{-Q/RT}\left(\sigma/2\right)^n$$

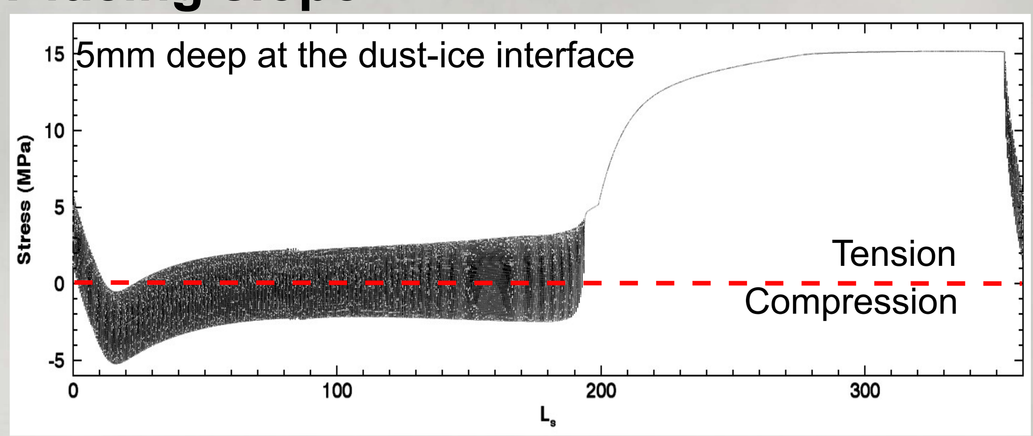
$$\varepsilon^{Thermal} = \varepsilon^{Elastic} + \varepsilon^{Viscous}$$

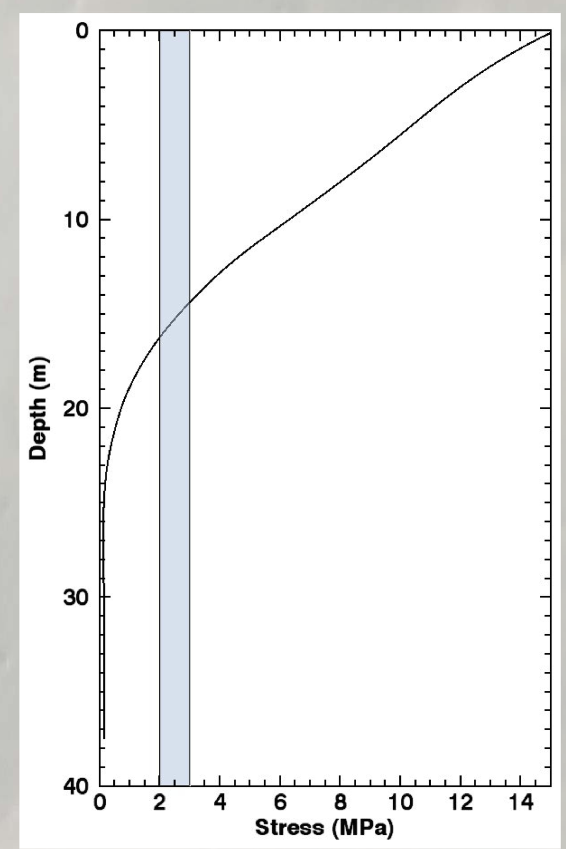
$$\frac{\partial}{\partial t}\varepsilon^{Thermal} = \frac{\partial}{\partial t}\varepsilon^{Elastic} + \frac{\partial}{\partial t}\varepsilon^{Viscous}$$

Stress results for a 70 degree SW-facing slope









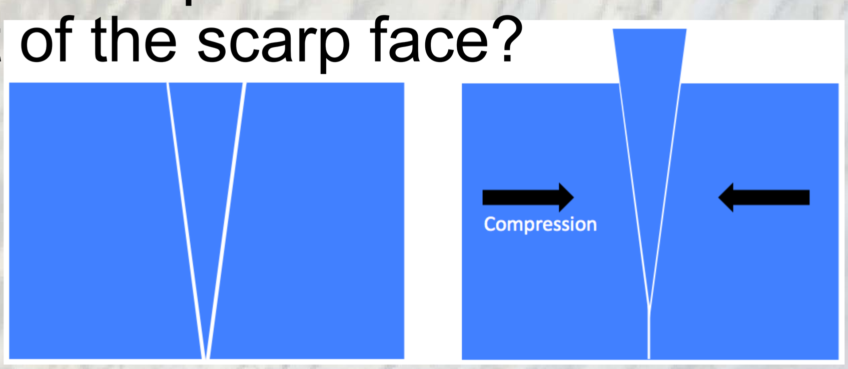
Near-surface ice must fracture (typical tensional strength 2-3 MPa).

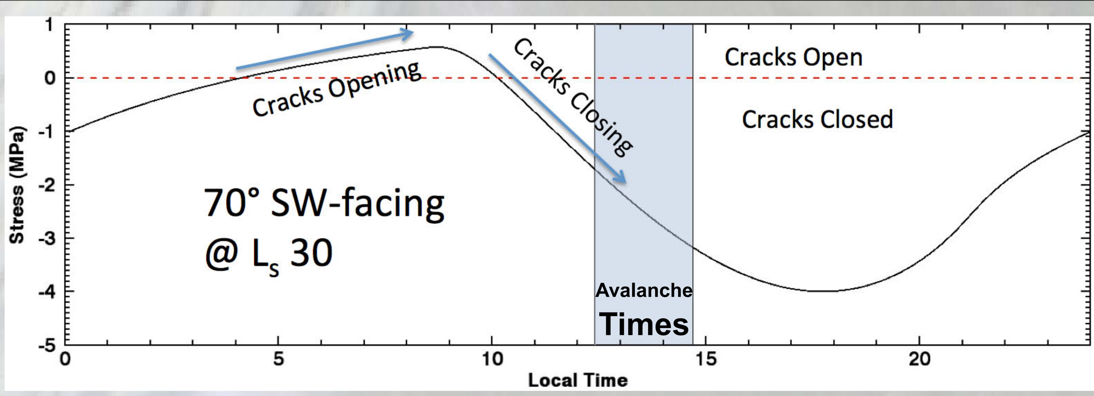
Stresses decay with depth.

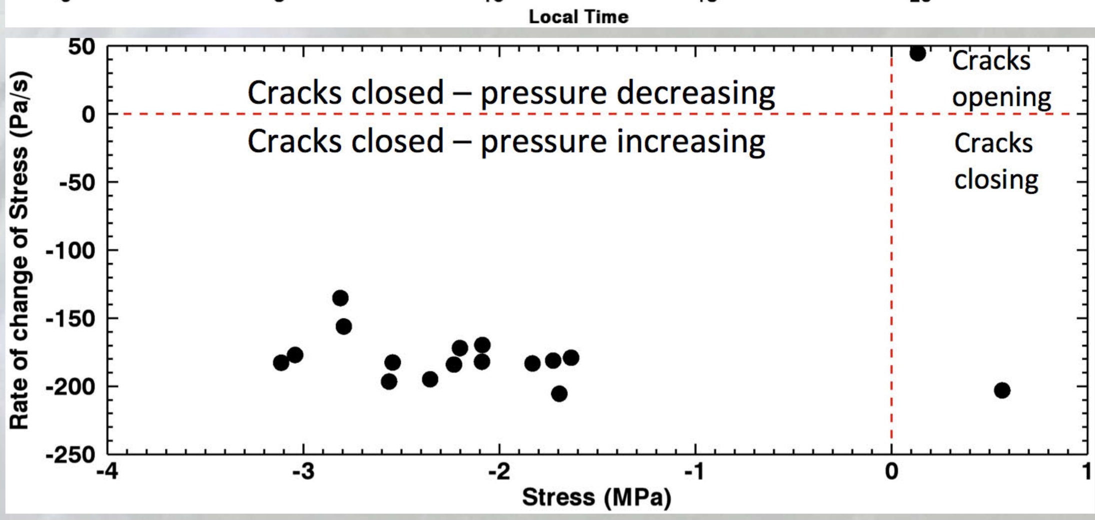
Fractures roughly perpendicular to scarp expected to depths of 15-16m.

Avalanche Triggers?

Near-surface scarp-parallel stress oscillates between compressive and extensional diurnally. Surface cracks may open and close in response to this. Could closing cracks squeeze blocks of material out of the scarp face?





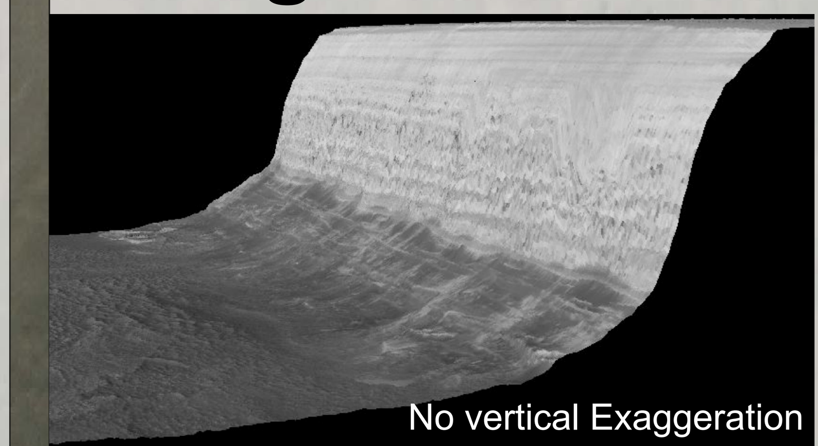


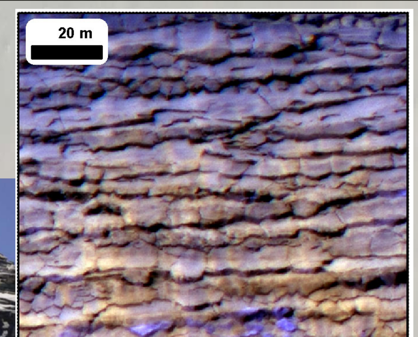
15/17 avalanches on this scarp occur when stress is compressive & increasing.

Could this be an observational effect?

Only one nightside image has shown an avalanche, but stress at this time was not strongly extensional.

Using HiRISE DTMs





With knowledge of scarp curvatures we can investigate the effect of surface-parallel compression on the formation of sheeting joints (Martel GRL, 2011). Formation of these joints lead to the exfoliation of similar-looking slabs on terrestrial granitic domes.