“Avalanches” of the Martian North Polar Cap

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Motivation and objective

Every year HiRISE captures debris falls **in action** on the margins of the Martian north polar ice sheet

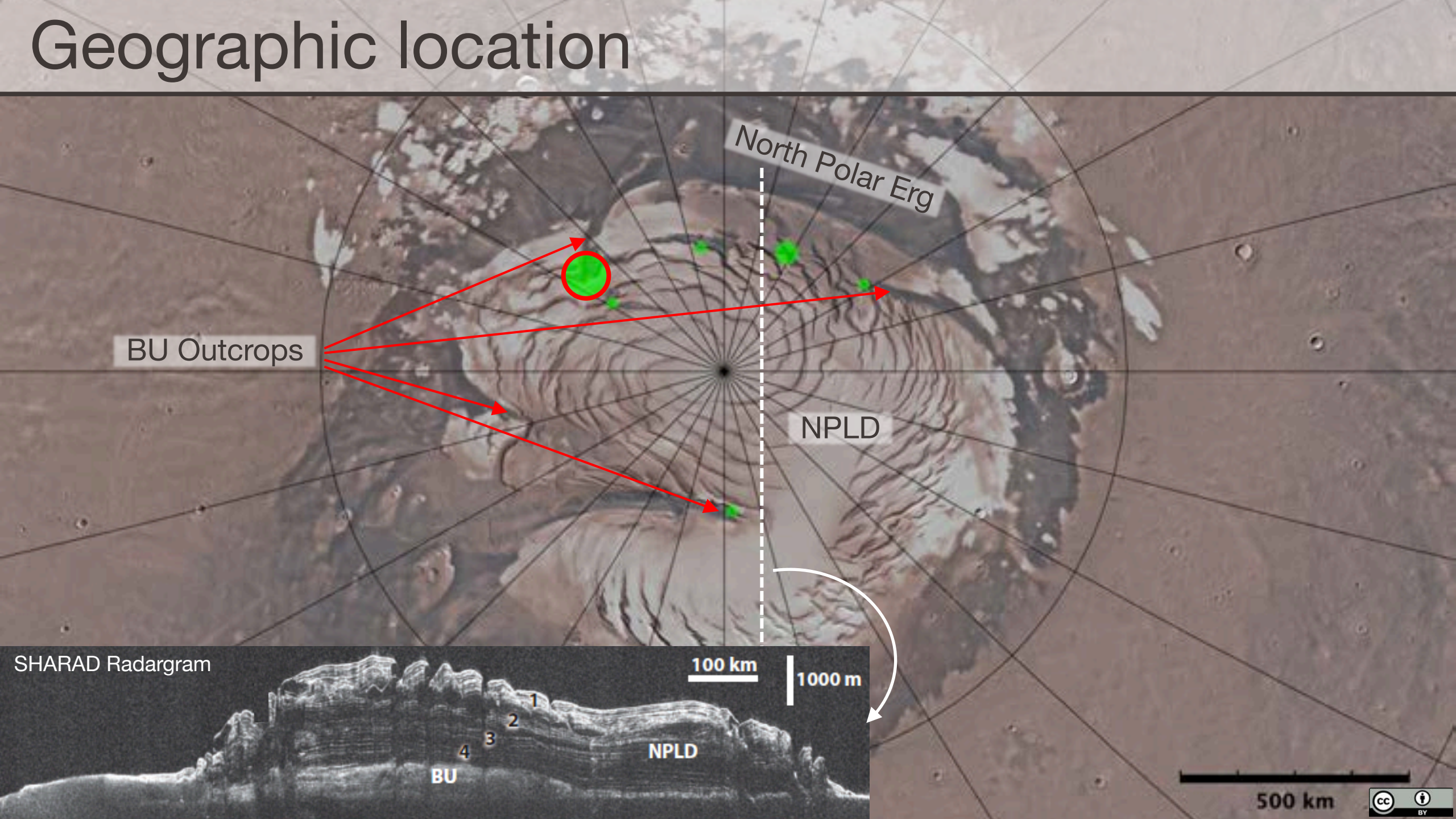
We wish to answer three key questions:

Q1. How common and frequent are these "avalanche"-like events?

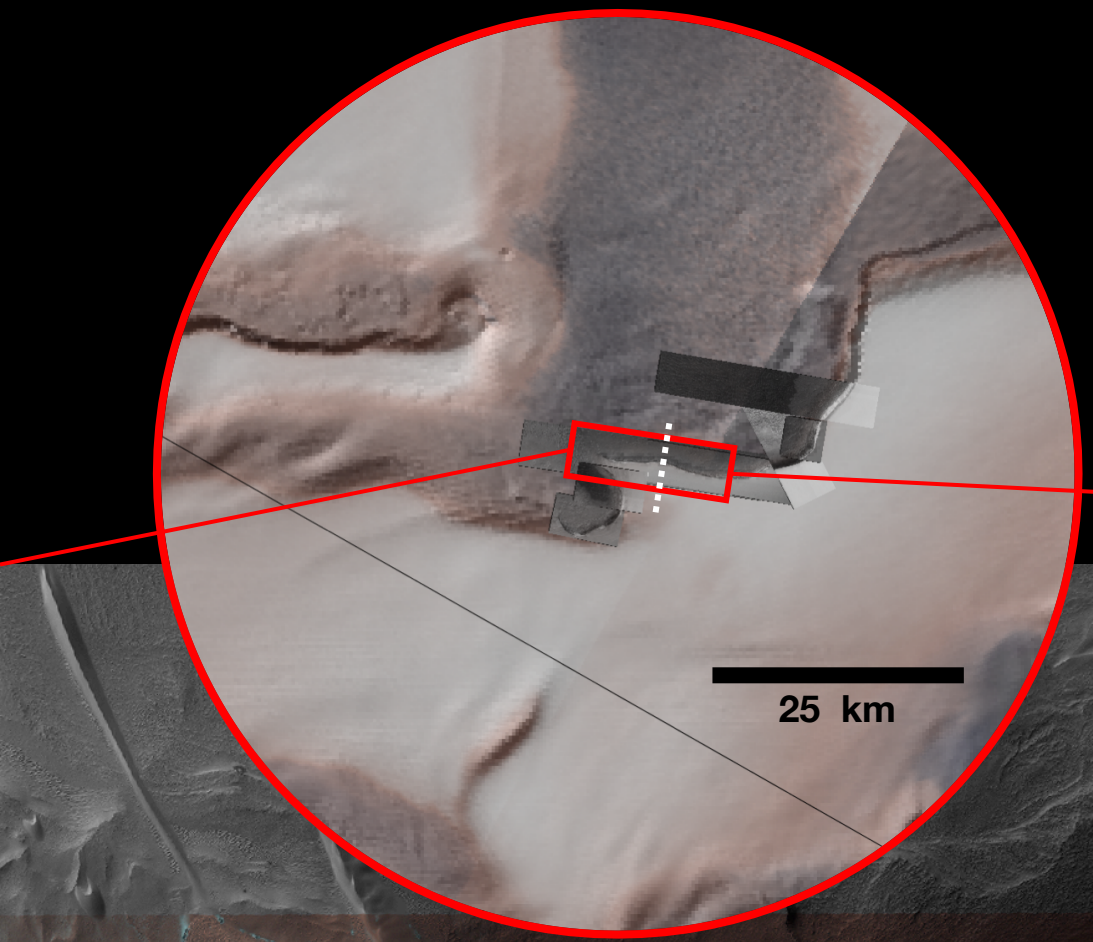
Q2. What triggers these events?

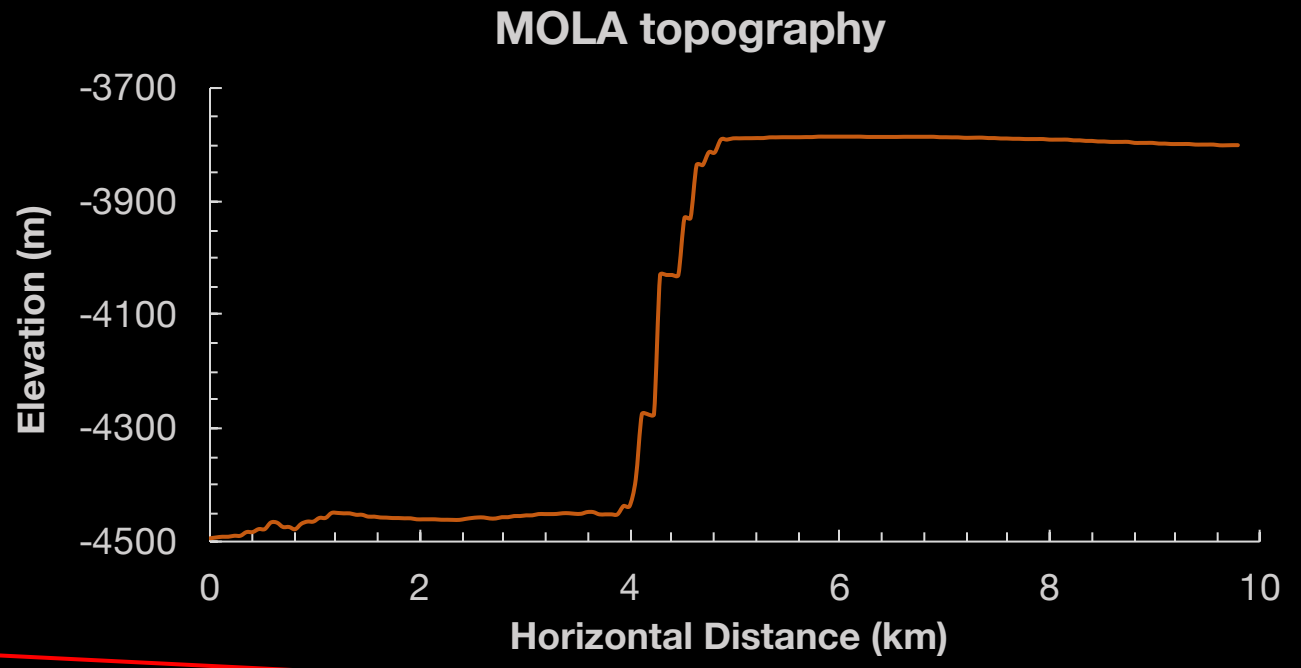
Q3. What is the importance of these events in shaping and eroding the north polar cap?

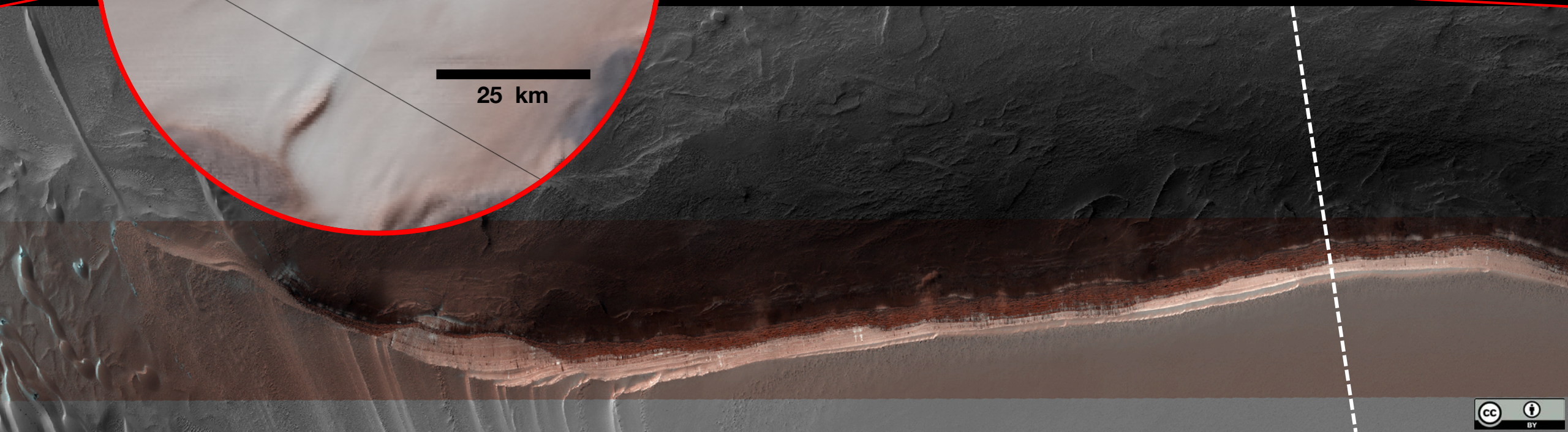
Geographic location



“Discovery” scarp







MY 29 Ls 34°

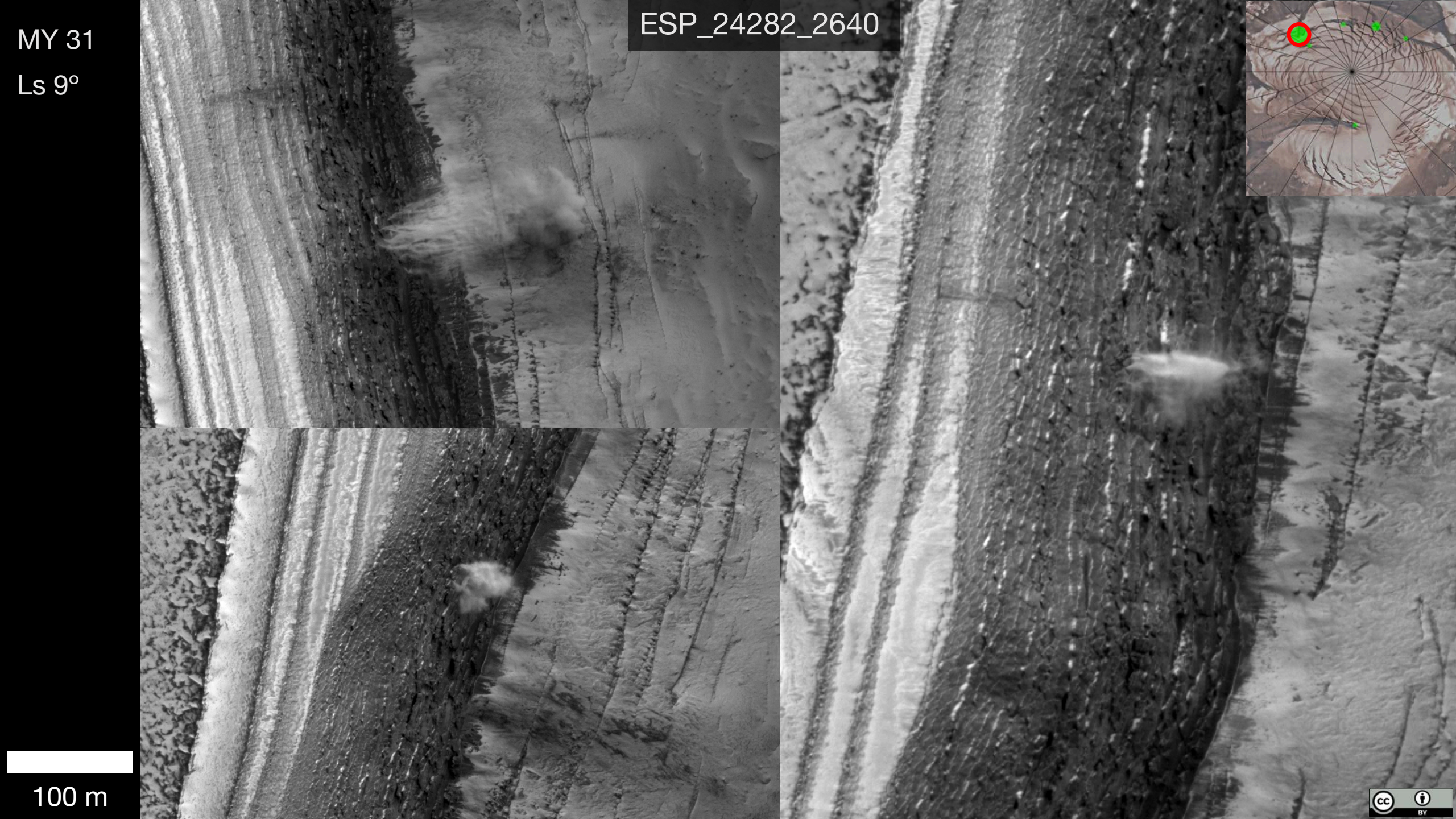
(19 February 2008)

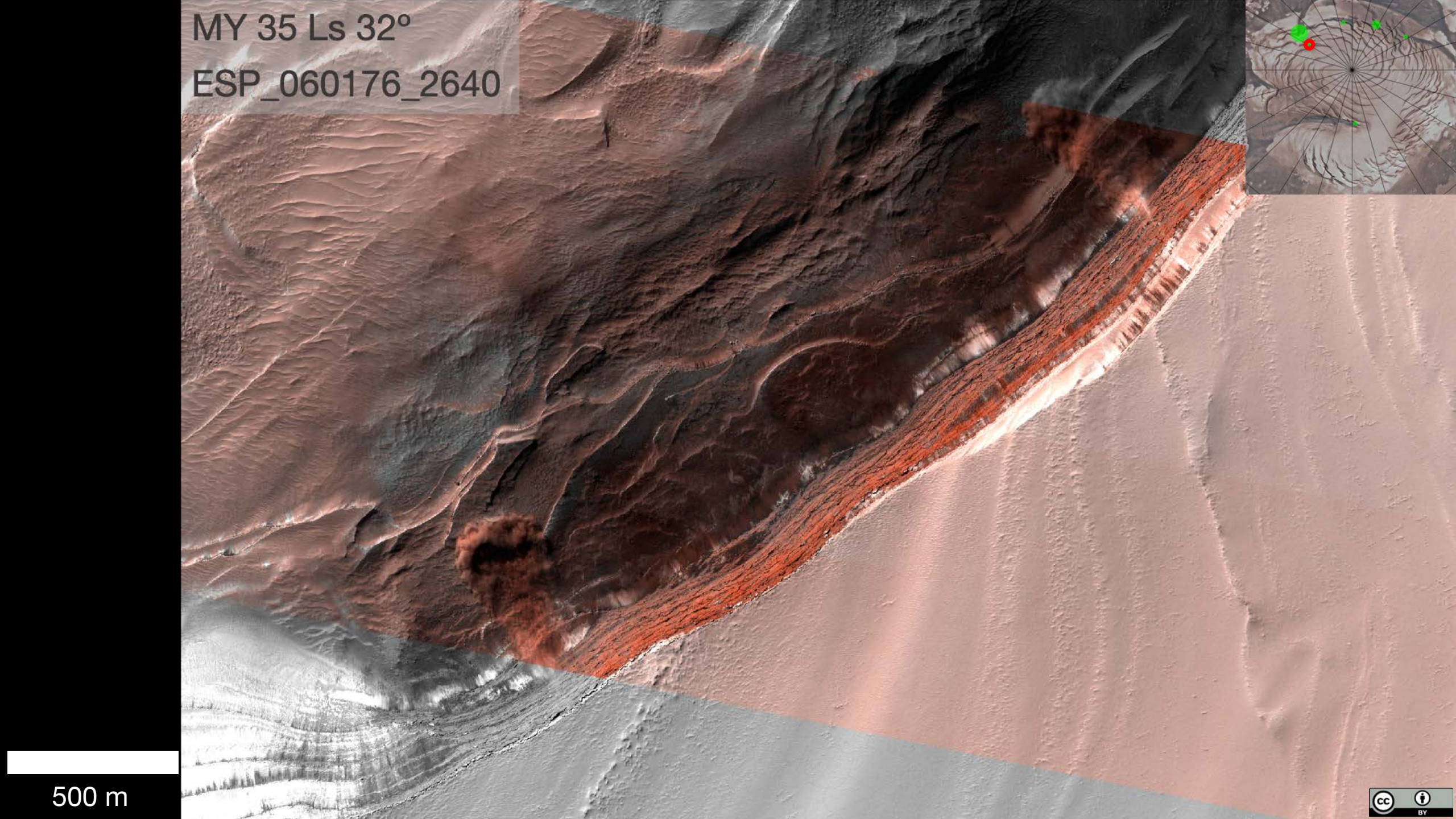
5 simultaneous events captured occurring on one scarp

(Russell et al. 2008, *GRL*)

Led to intensive monitoring of this and other similar scarps…


MY 30 Ls 34°
ESP_016173_2640
500 m

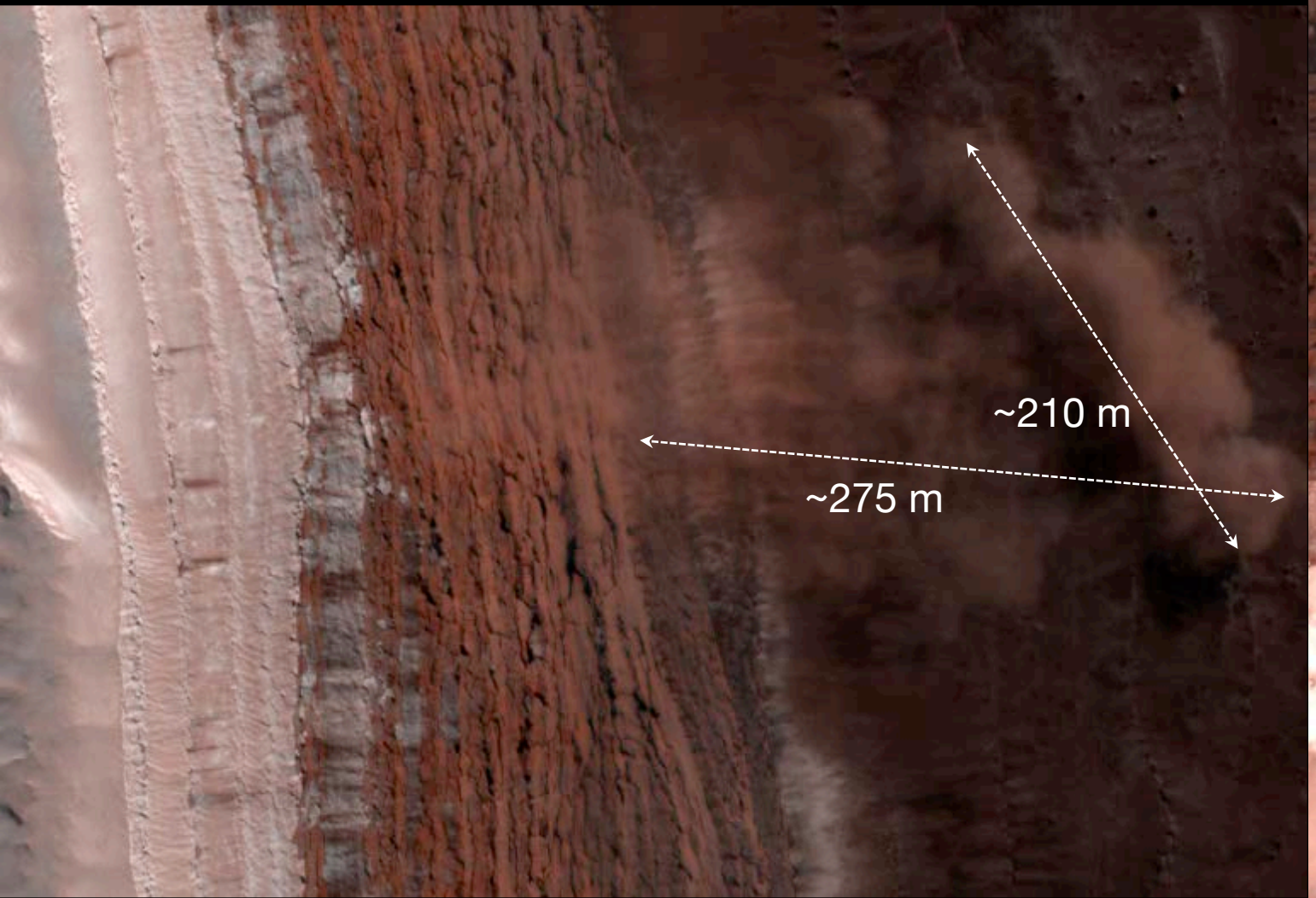

ESP_24282_2640
MY 31
Ls 9°
100 m

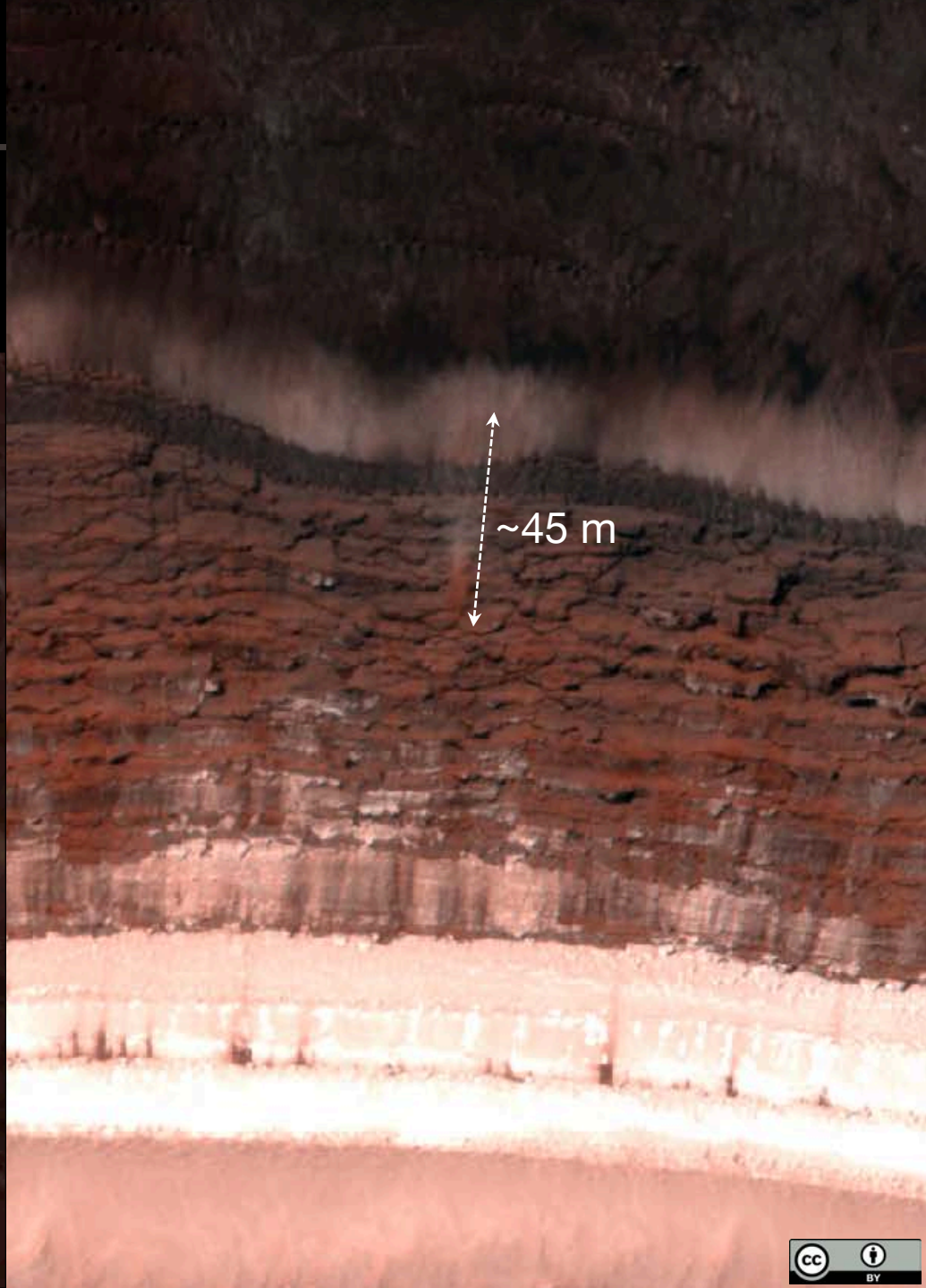

MY 35 Ls 32°
ESP_060176_2640
500 m

Dimensions and Morphology

10s → 100s of meters

Cloudy and diffuse → dense and concentrated



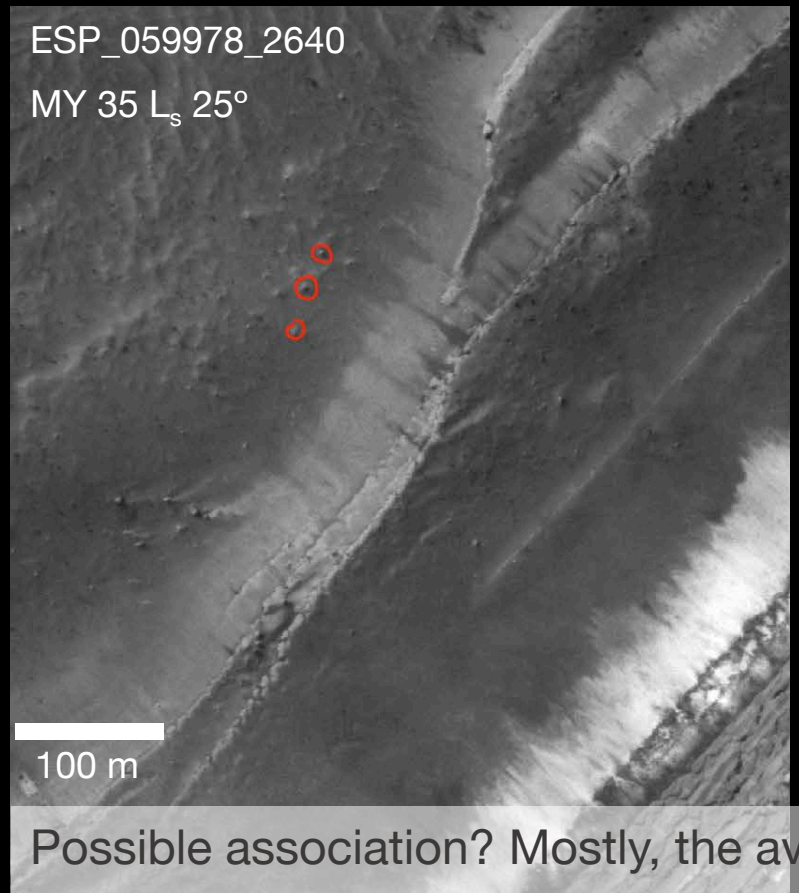


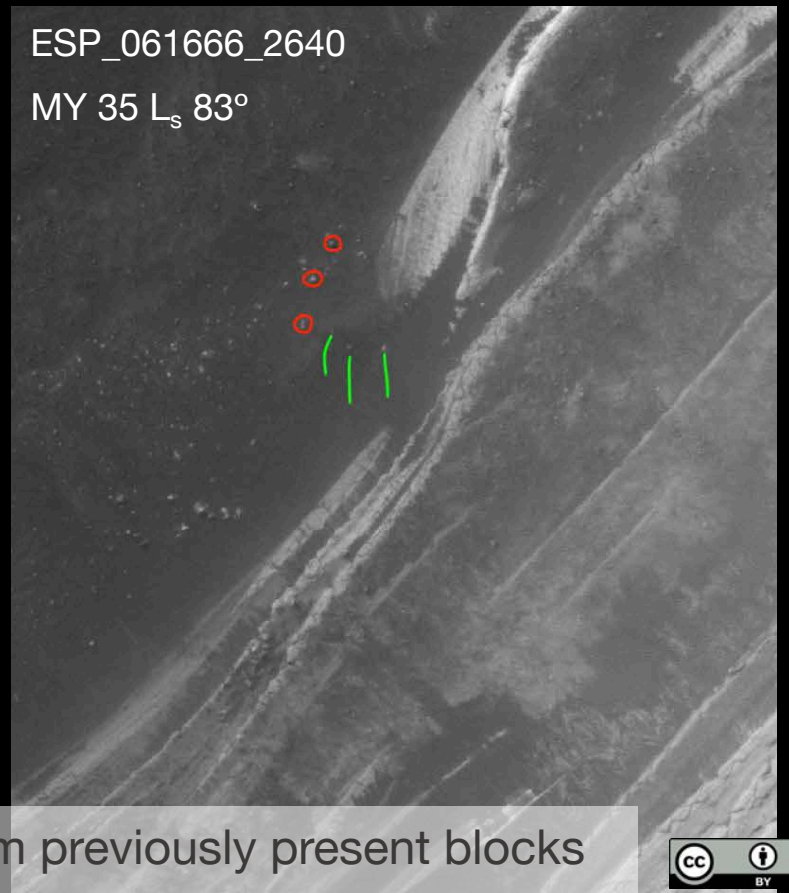
Mass wasting and debris

Numerous new ice blocks have been identified at the base of the scarps (Russell et al. 2014, *8th Mars*)

→Mass wasting rate of 0.1 – 0.3 m^3/MY per meter of scarp length (Herkenhoff et al. 2020, *7th ICMPSE*; Fanara et al. 2020, *Icarus*)

However, no new blocks have been directly associated to an avalanche-like event





Possible association? Mostly, the avalanches seem to clear dust and sand from previously present blocks

Catalog of events on Discovery scarp

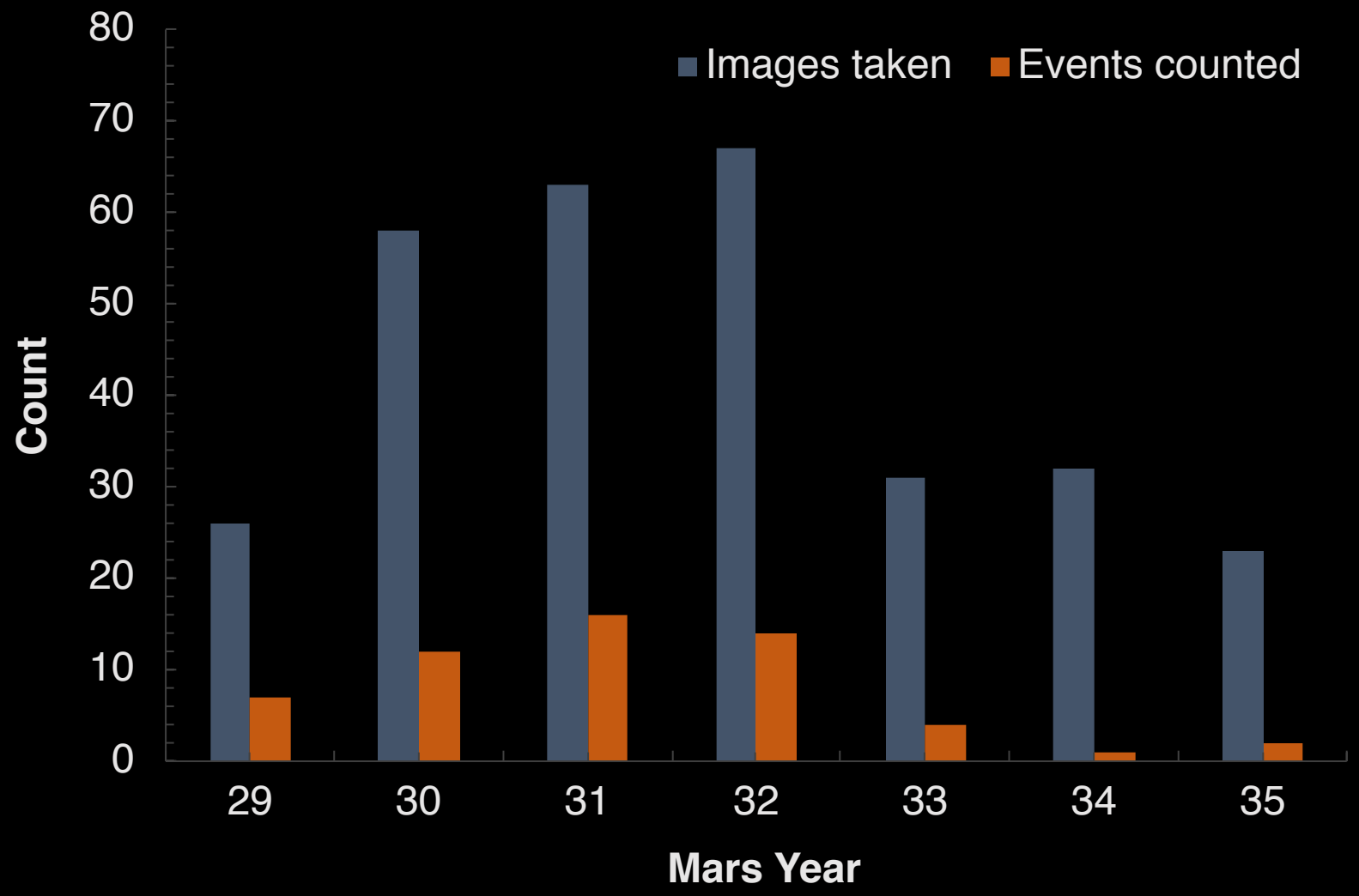
A total of **57 events** caught in action over 7 years

Some observational bias in the annual catalog due to drop in monitoring frequency in MY 33 – 35:

- Average of 8 events per year captured
- Average of 14 events per year captured between MY 30 – 32

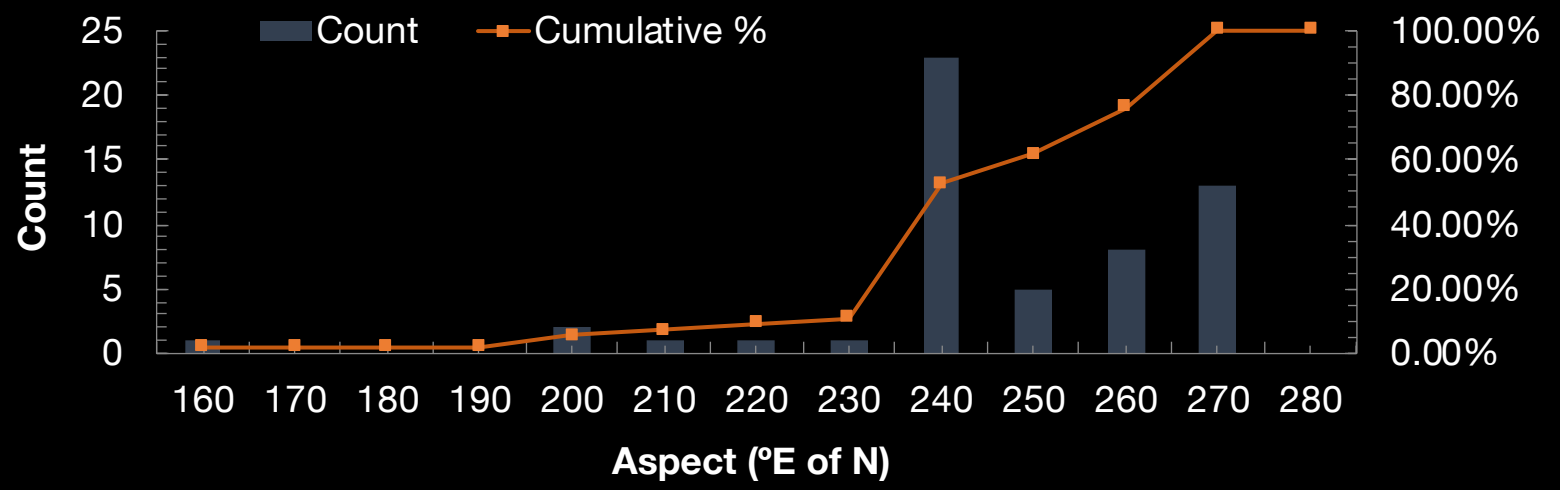
Images in which events are detected contain on average 2 events

Frequency of events is high:
> ~10 events/year in one scarp

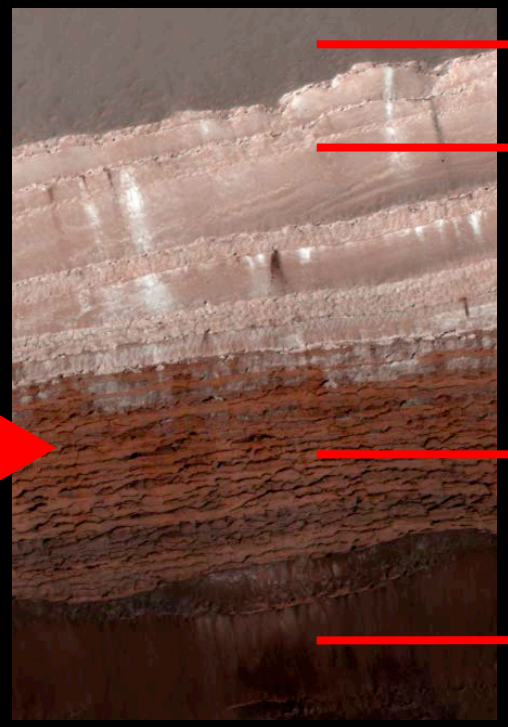


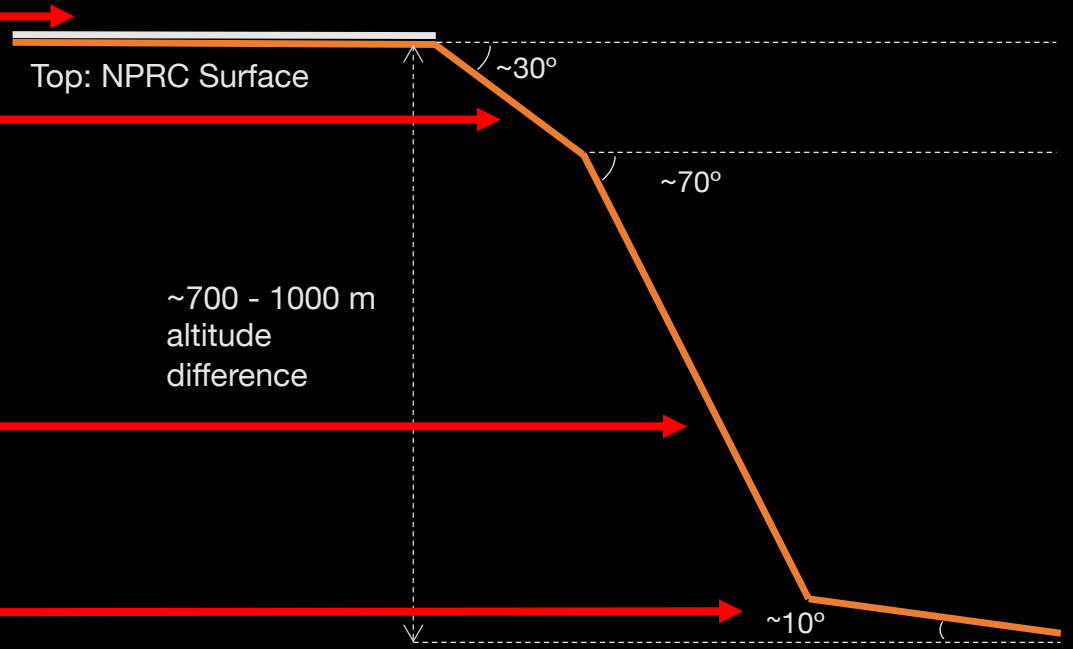
Slope and aspect of walls on Discovery scarp

Events are frequent each year, and tend to occur on SW-facing walls



Most events where initiation is visible appear to start at the steepest sections of the scarp (~50 – 70º)

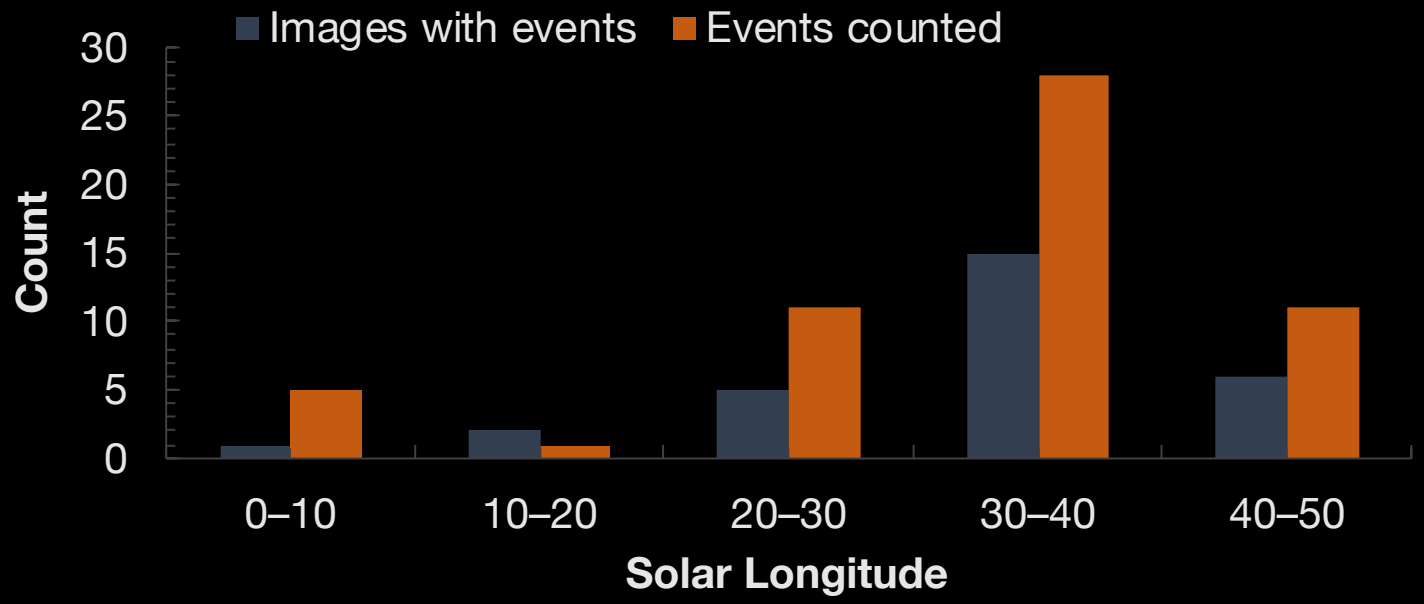




Seasonality of events on Discovery Scarp

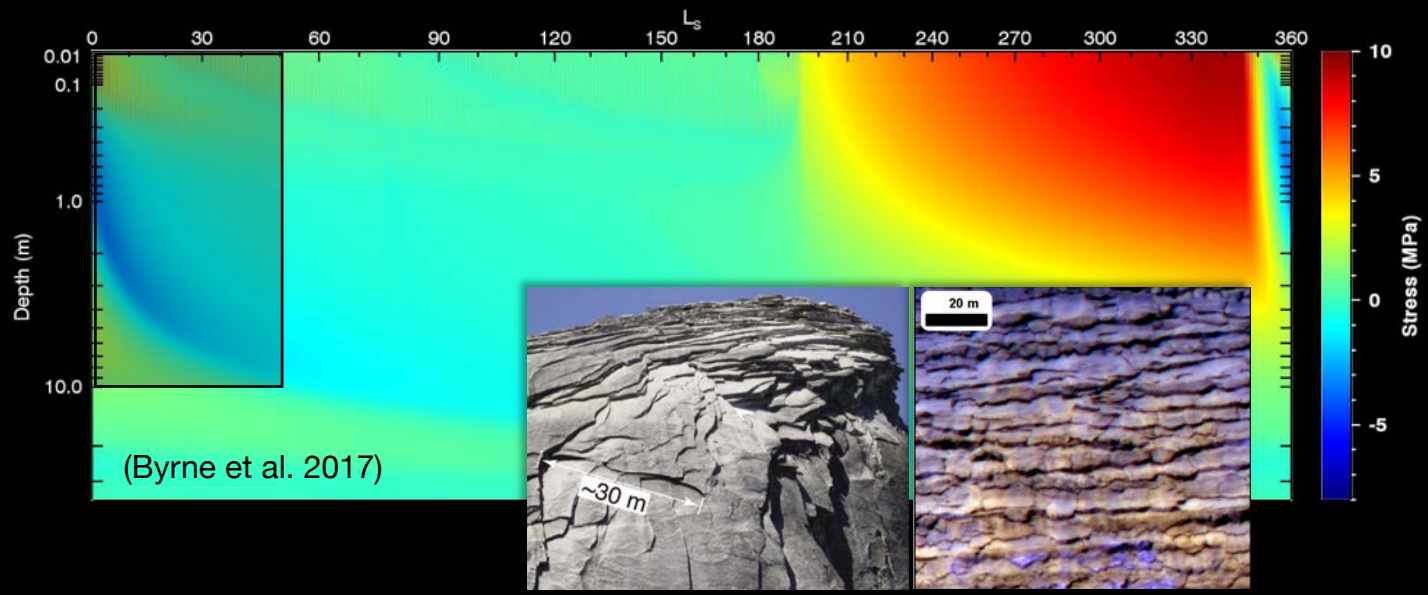
"Avalanche season" is early spring, between L_s 0° – 50° with a peak around L_s 30° – 40°

Events are frequent, seasonal, and tend to occur on SW-facing walls

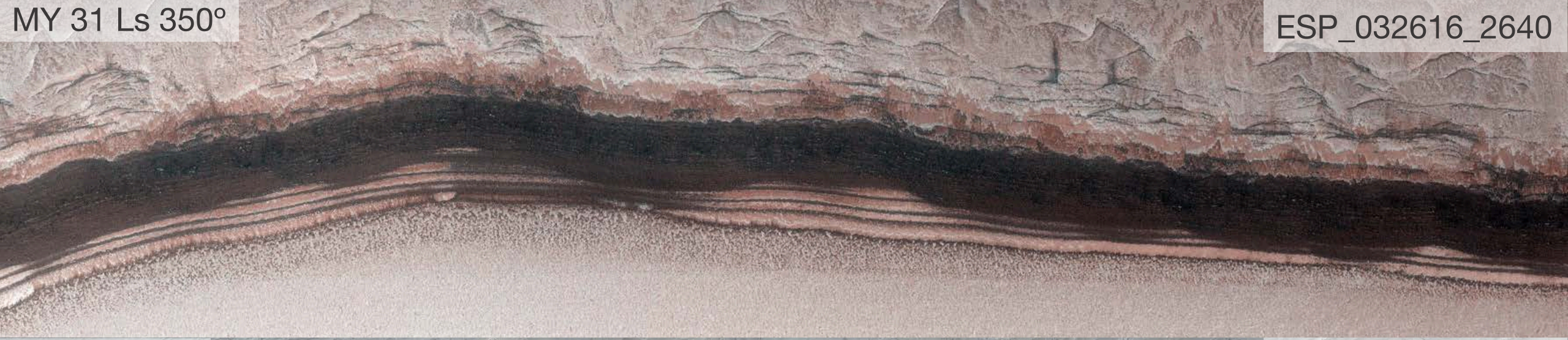


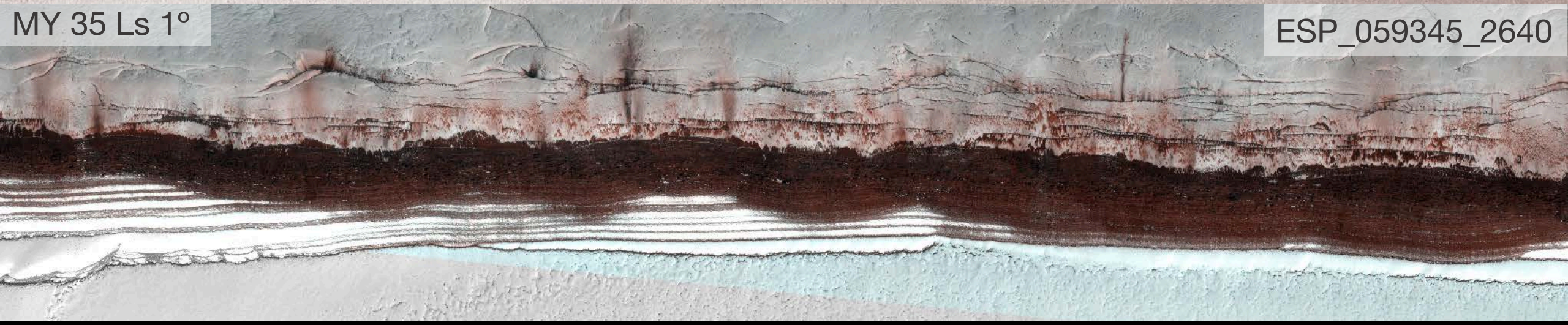
Early spring coincides with:

- Sublimation of seasonal CO_2 ice
  - Sublimation pressure dislodges blocks
- Peak subsurface compressional stresses of the scarp walls (Byrne et al. 2017, *EPSC*)
  - The combination of the outward facing curvature of the scarps and the surface-parallel compressive stresses that peak between Ls 0 – 50° could result in a process similar to exfoliation of granitic domes



→ Possible trigger mechanisms?





Is CO_2 frost sublimation a plausible trigger?

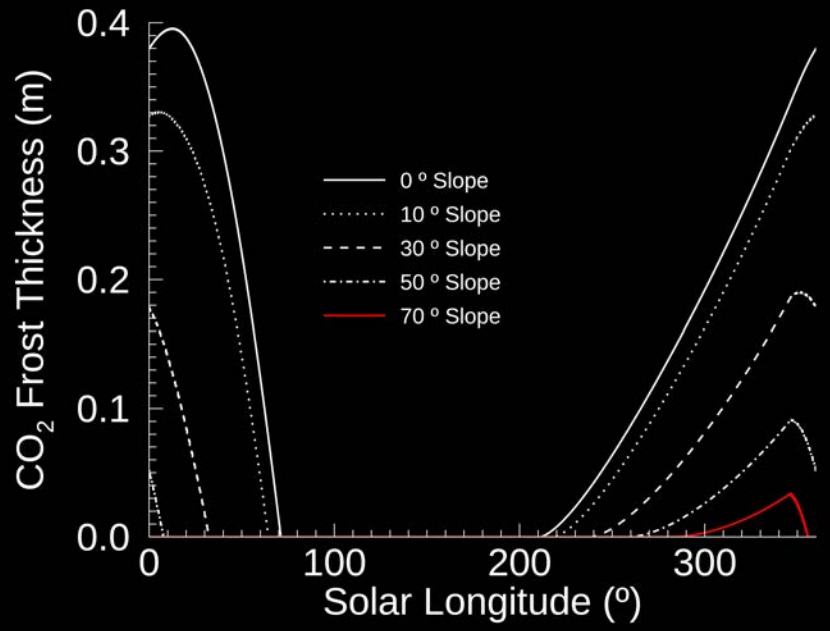
- By L_s 350°:
  - Slopes >60° appear completely defrosted
  - Slopes ~30–40° still frosted

Thermal modeling of the Discovery scarp

Thermal model (based on Dundas and Byrne, 2010, *Icarus*) calculates accumulated CO_2 frost on surface from a 1D energy balance

$$-L_{CO_2}\frac{\partial m_{CO_2}}{\partial t} = Q_{solar} + Q_c + Q_{LWF} - \varepsilon\sigma T^4$$

Free parameters: Slope, Aspect (E° of North), Location, Albedo

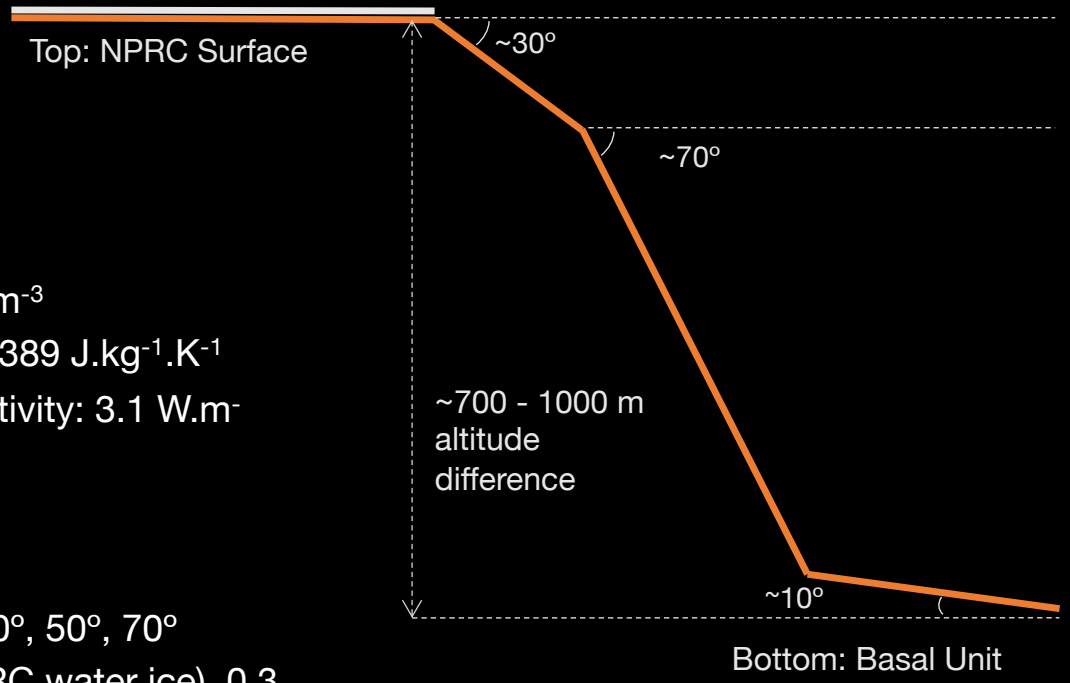


Physical Properties:

- Density: 920 $kg.m^{-3}$
- Heat Capacity: 1389 $J.kg^{-1}.K^{-1}$
- Thermal Conductivity: 3.1 $W.m^{-1}.K^{-1}$
- Orientation: 240°

Varying parameters:

- Slope: 0°, 10°, 30°, 50°, 70°
- Albedo: 0.4 (NPRC water ice), 0.3 (scarp face: dirty ice)



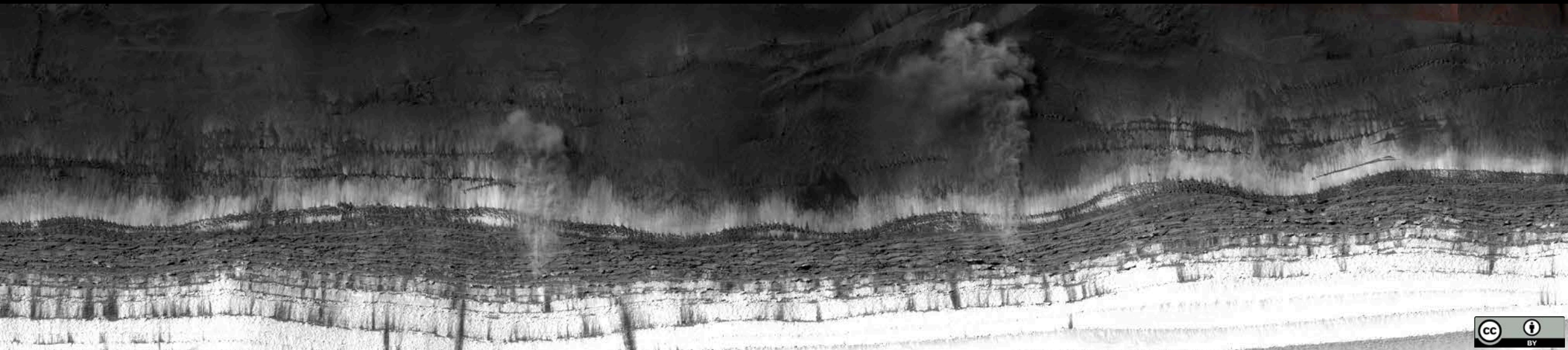
A CO_2-sublimation driven trigger mechanism seems unlikely

Preliminary answers

Q1. Events on the Discovery scarp are frequent, seasonal, and tend to occur on SW-facing walls. Other locations seem to follow the same pattern. Work ongoing.

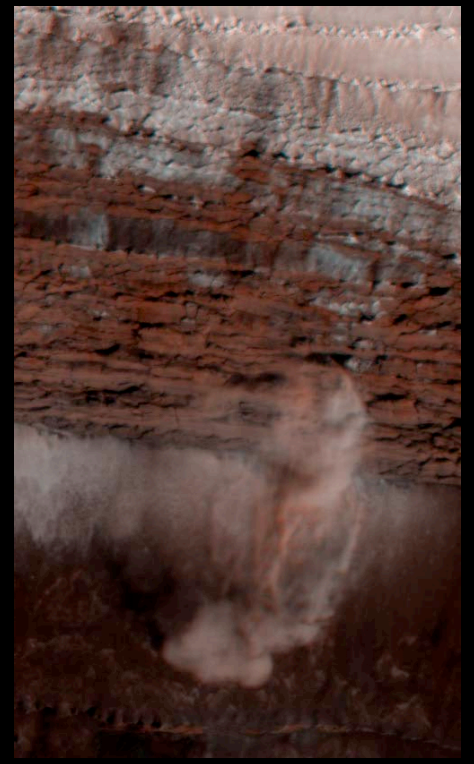
Q2. Although seasonality coincides with springtime frost sublimation on flat surfaces, a sublimation-driven trigger seems unlikely on the frost-free steep slopes where events occur. A more likely mechanism could be exfoliation due to a seasonal peak in surface-parallel compressive stress ~ L_s 0 – 50° (Byrne et al. 2017, *EPSC*). More work to be done.

Q3. These events erode the margins of the NPLD annually, likely acting faster than other processes (e.g. viscous relaxation as in Sori et al. 2016, *GRL*).



Future work

- Complete catalog of every scarp, including detailed slope measurements for events where initiation is visible and size measurements for all events
  - A Convolutional Neural Network (CNN) similar to that of Bickel et al. (this session) was tested with 32 known events as a “training” set. We will apply this CNN to the remaining set of images to expedite the count and dimension measurements of events.
- Further investigate the correlation with the seasonality of compressional stresses (Byrne et al. 2017)
- Work on Q3:
  - Measure speeds of as many events as possible using the timing difference between HiRISE color bands (Russell et al. 2008)
  - Estimate volume and mass of events using terrestrial debris fall/flow models. Are these events dynamically similar to terrestrial powder avalanches? Or rather to terrestrial rock falls?



Highlights

- “Avalanche-like” events occur on the steep margins of Mars’ North Polar Layered Deposits every spring
- So far 57 avalanches have been “caught in action” between L_s 0 – 50° in 7 Mars years of monitoring the Discovery Scarp
- Material is likely to be a combination of water ice and dust. Morphology suggests similarity to terrestrial avalanches; debris suggests similarity to terrestrial rock falls
- Seasonality initially suggested a CO_2-sublimation trigger, but thermal modeling and early imaging shows CO_2 is gone from steep scarps by the time the events occur
- Seasonality of events coincides with peak compressional stresses (Byrne et al. 2017) → appears to be a more likely trigger mechanism