Active slipface avalanches on martian sand dunes: *Evidence for a wind-related origin*

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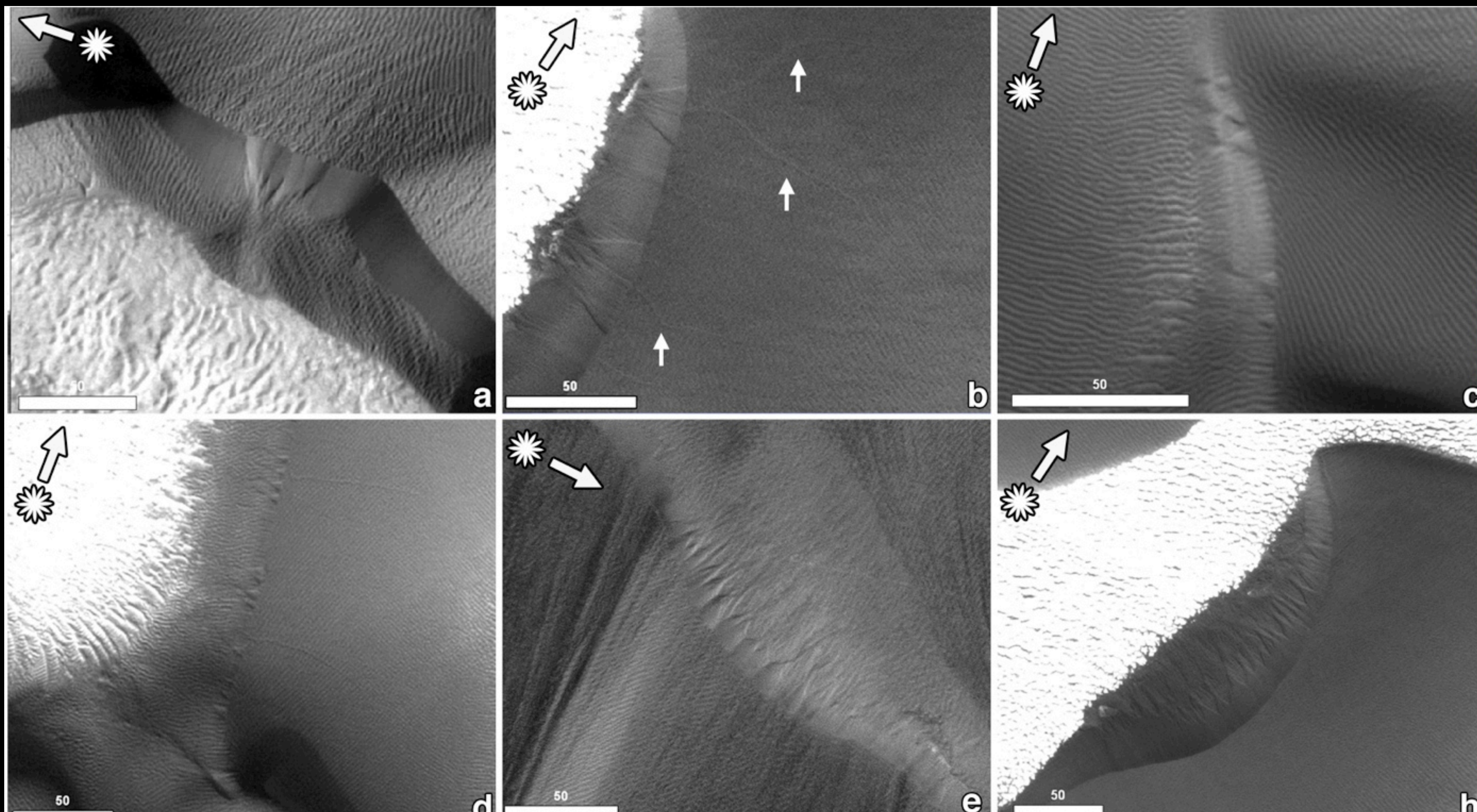
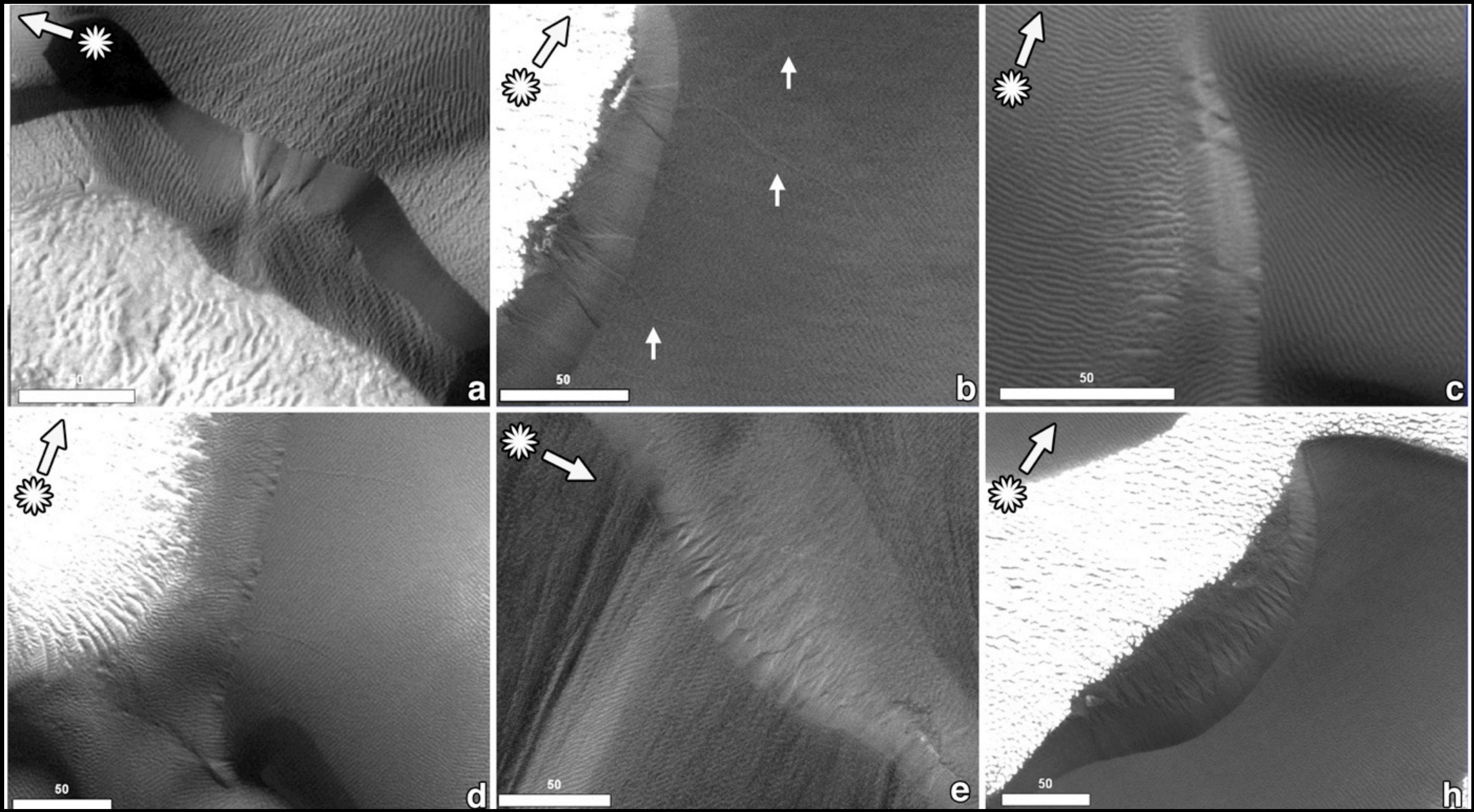


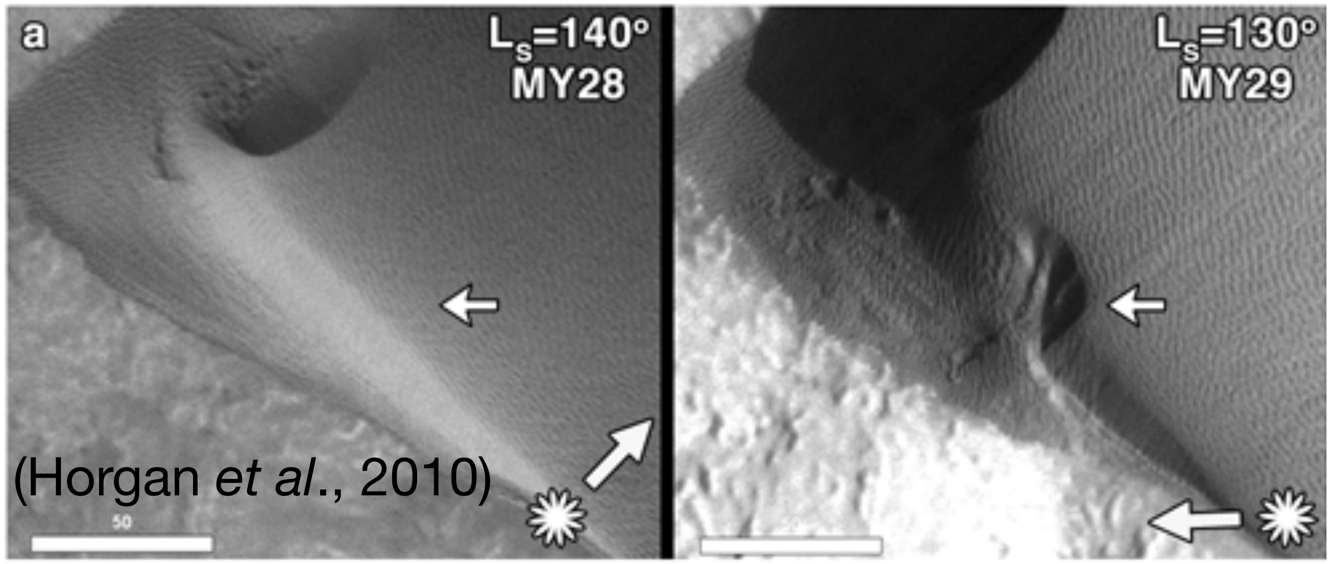
A new class of features modifying sand dunes: Slipface alcoves and fans

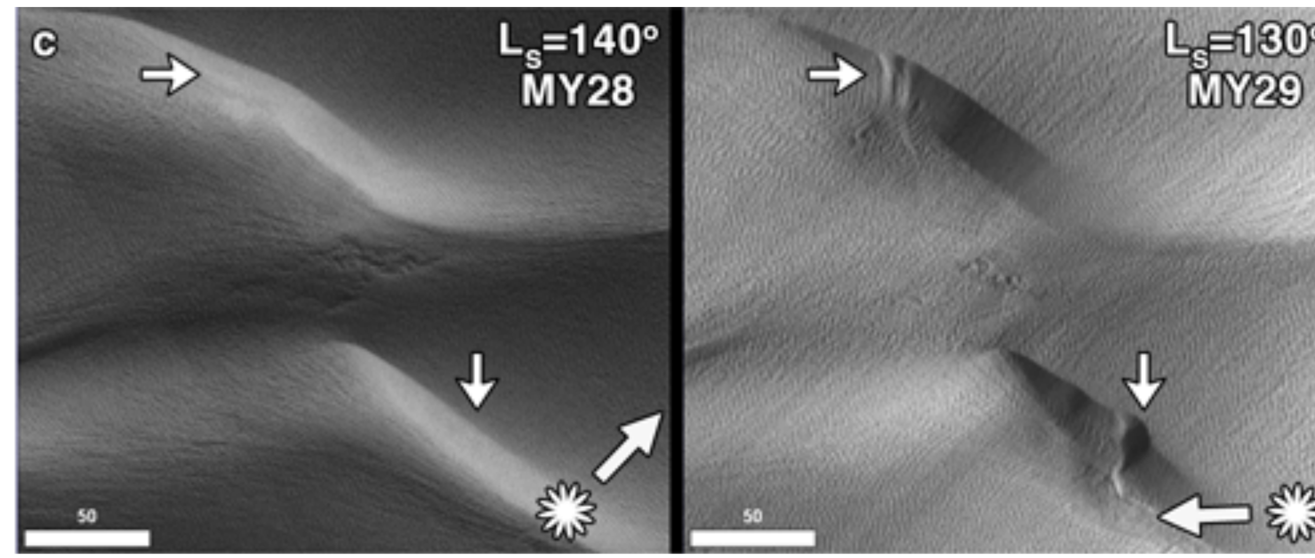
(Horgan *et al*., 2010; Hansen *et al*., 2011; Horgan *et al*., submitted to GRL)



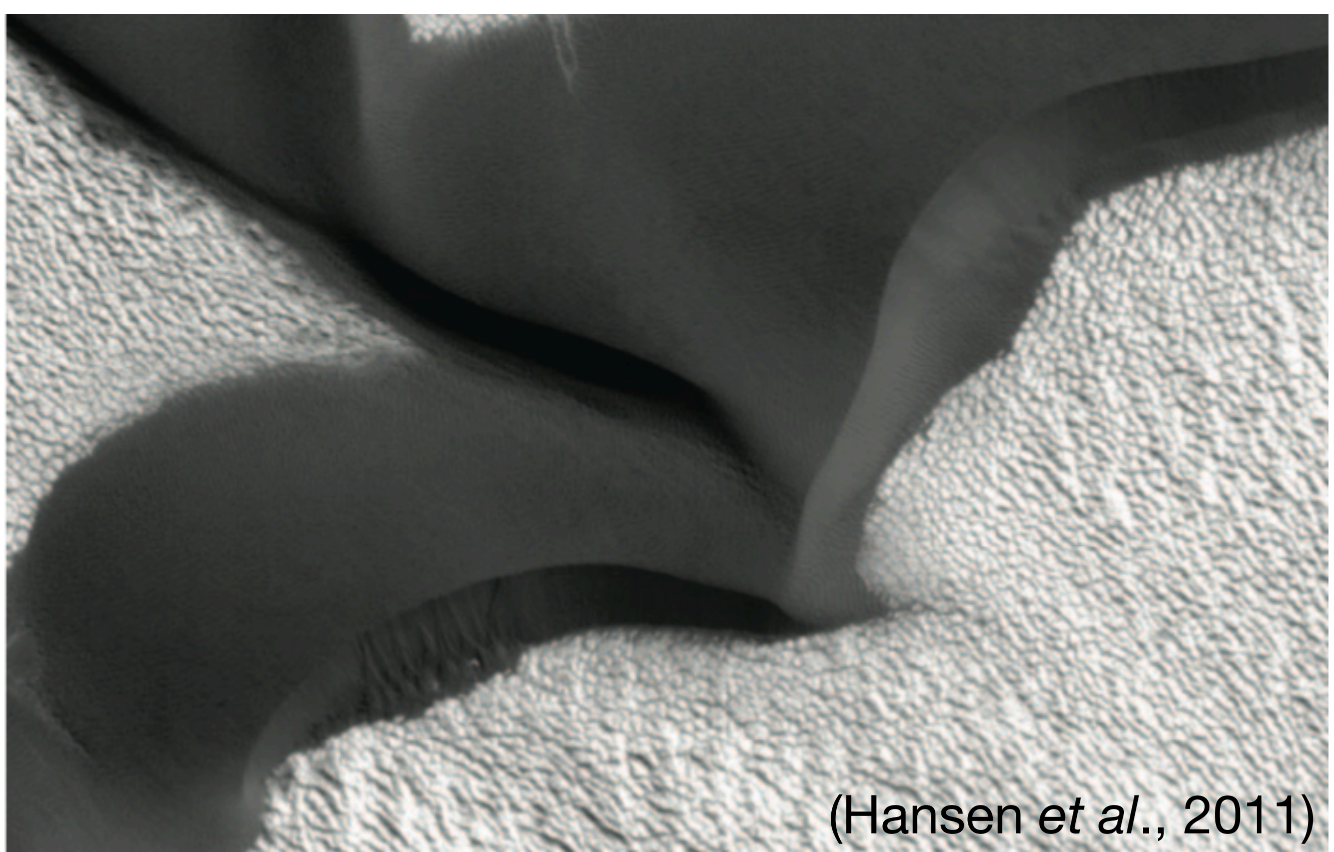
These are active features, observed forming between consecutive years.

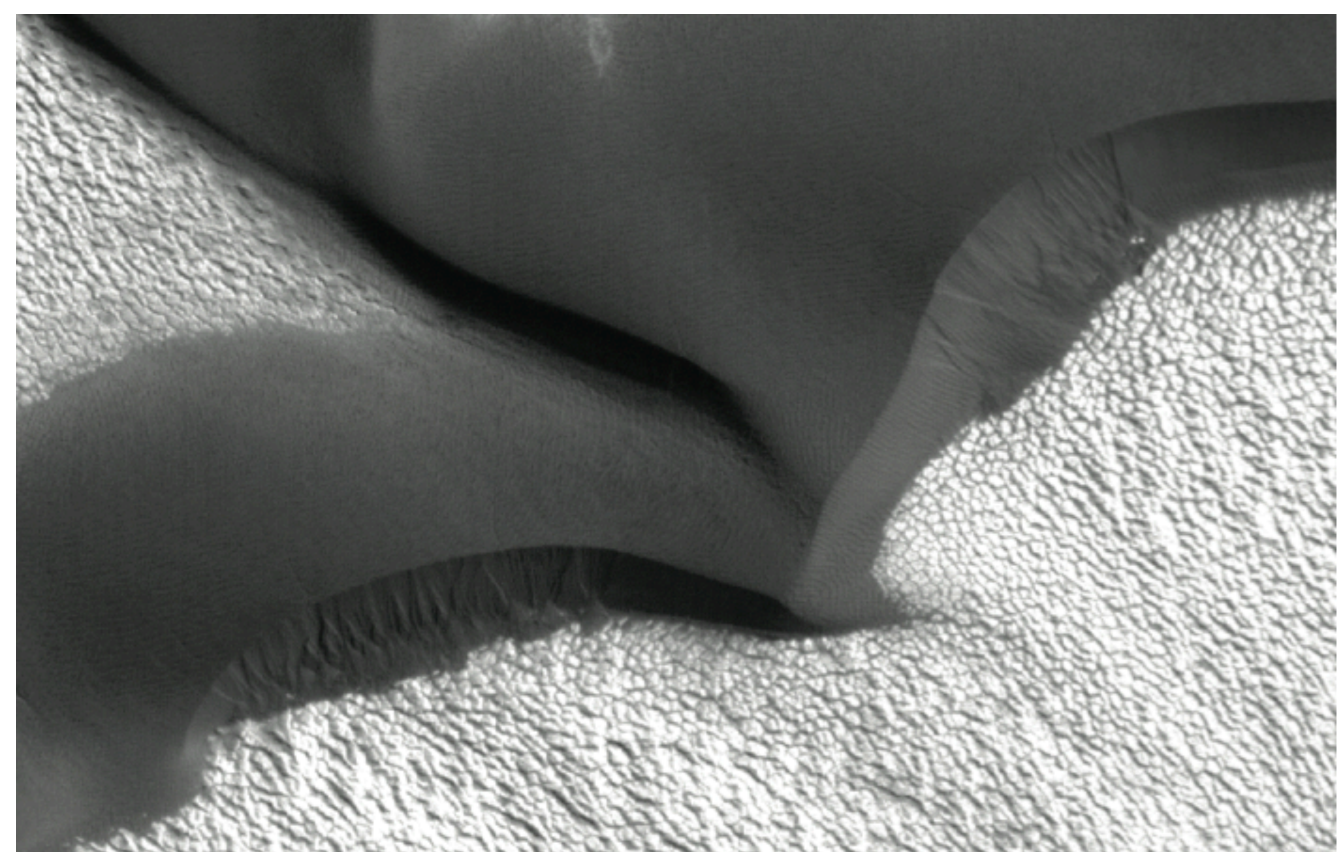
A few new alcoves in Chasma Boreale formed between summers of MY 28-29





Abundant alcoves in Tenuis Cavus formed between summer MY 29 and spring MY 30





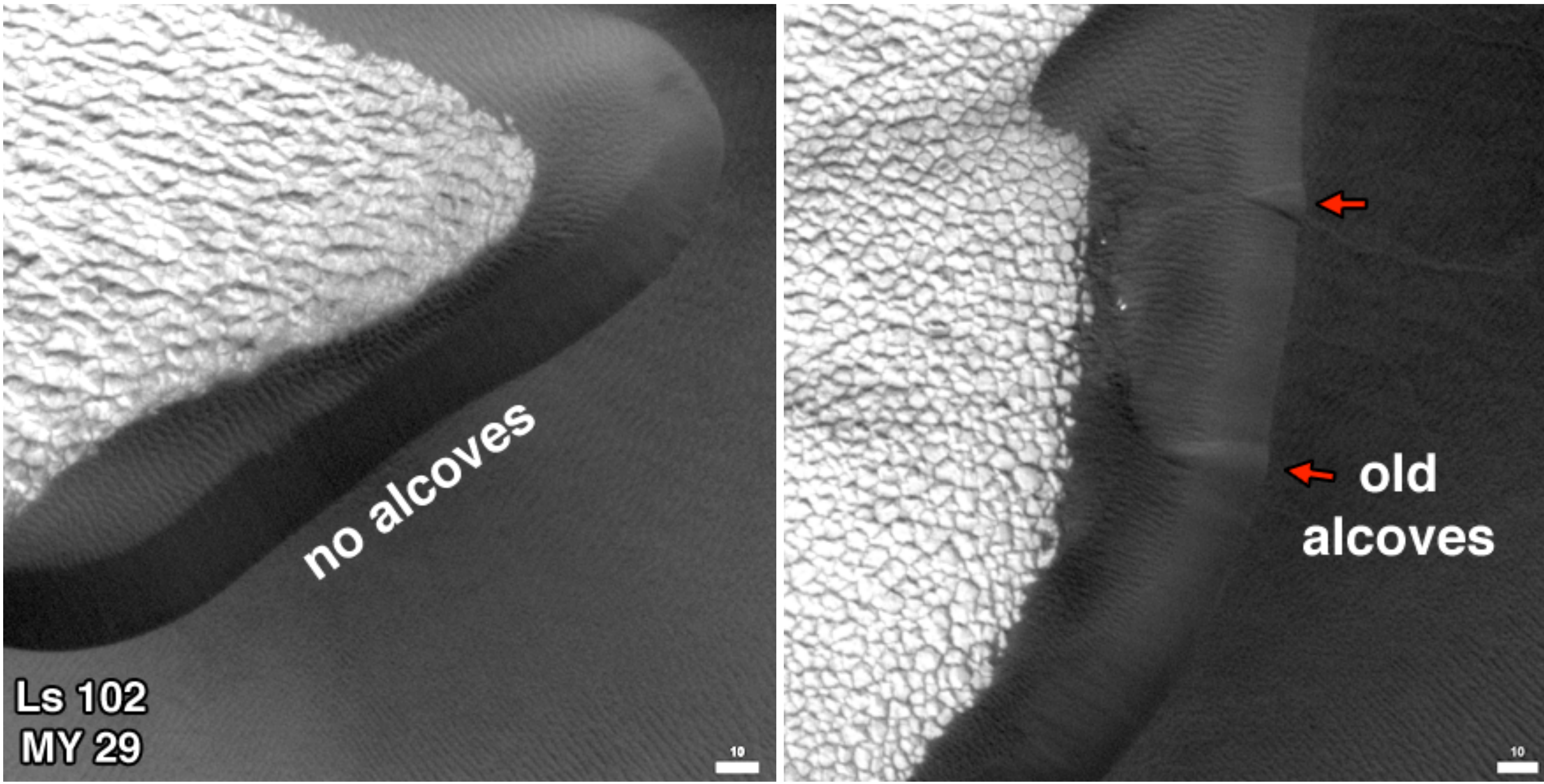
When and why did the mass wasting that formed these features occur?

New alcoves are co-located with earliest sites of CO_2 sublimation and associated mass wasting

(Hansen *et al.*, 2011)

This would seem to imply a genetic relationship - but which came first?

Evidence for presence of new alcoves underneath CO2 frost



(Horgan *et al.*, submitted to *GRL*)

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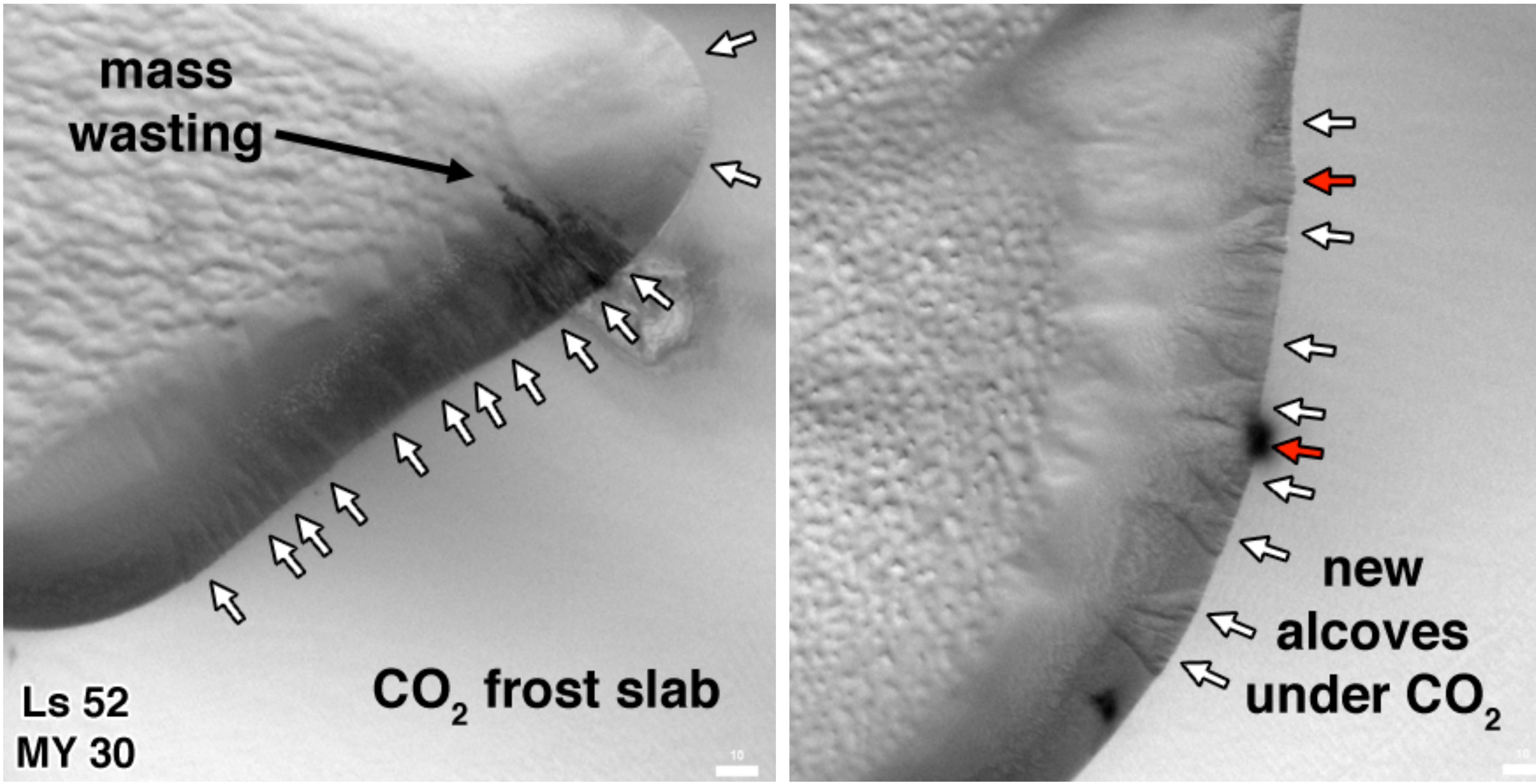

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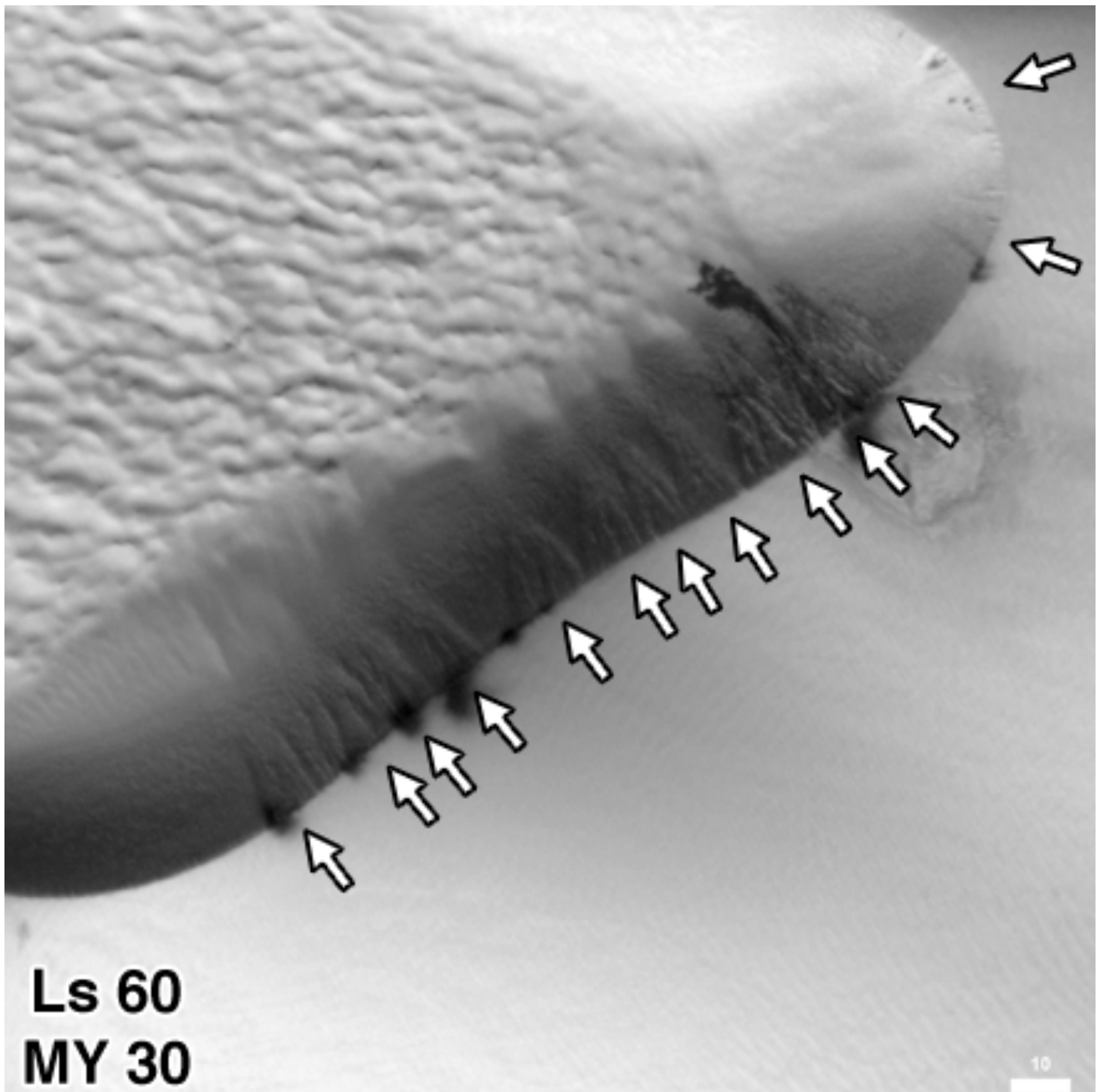

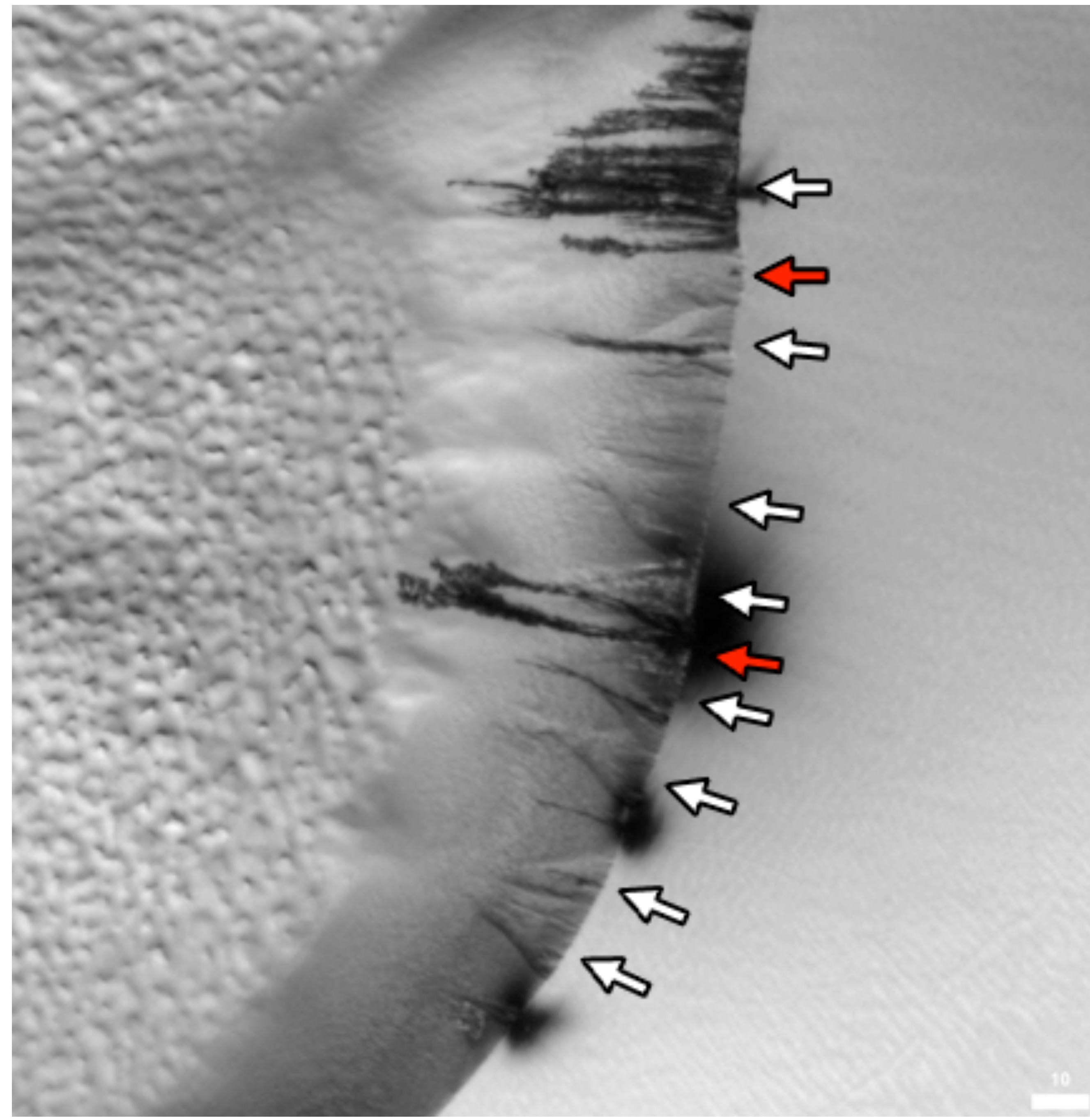

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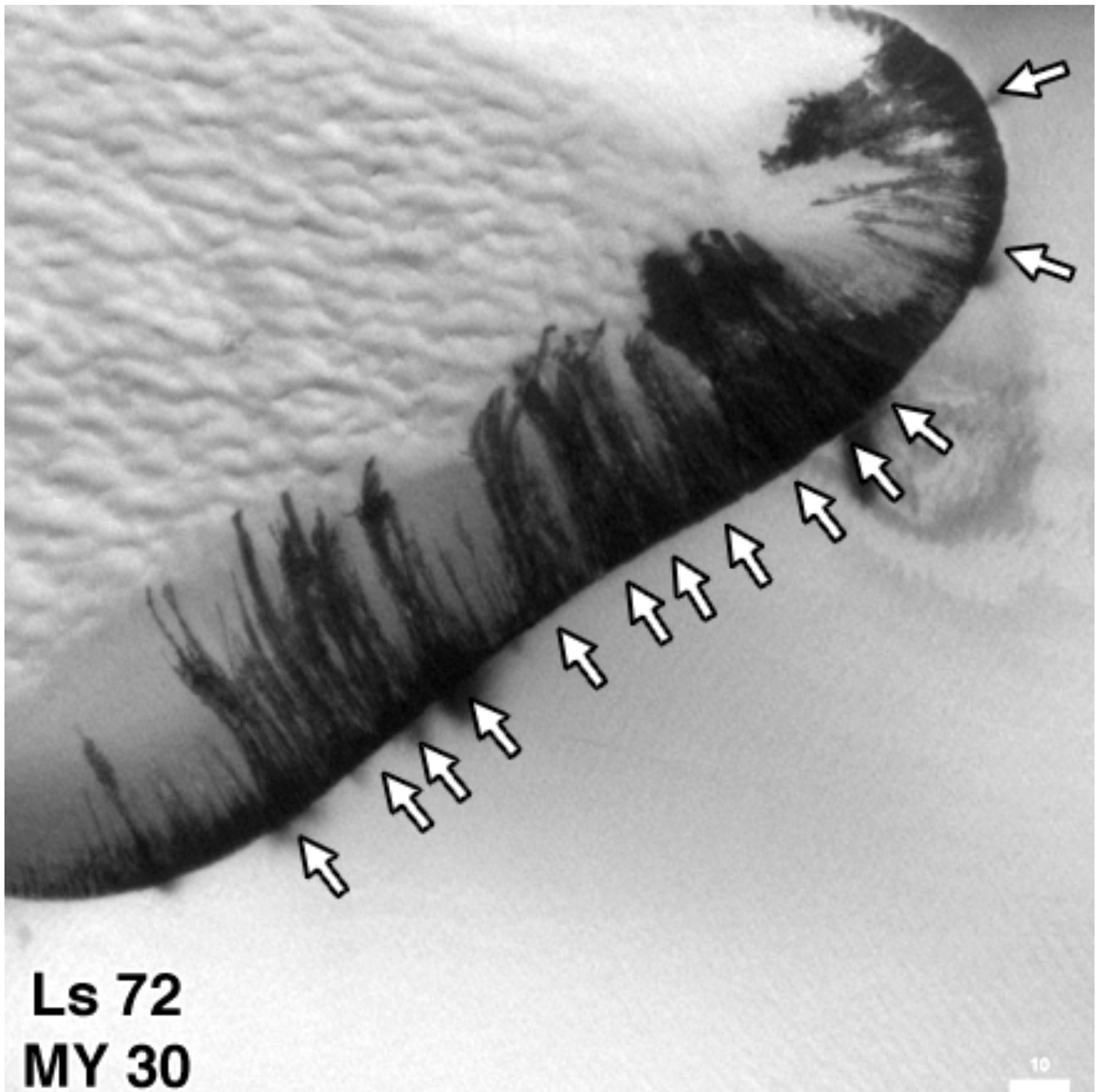

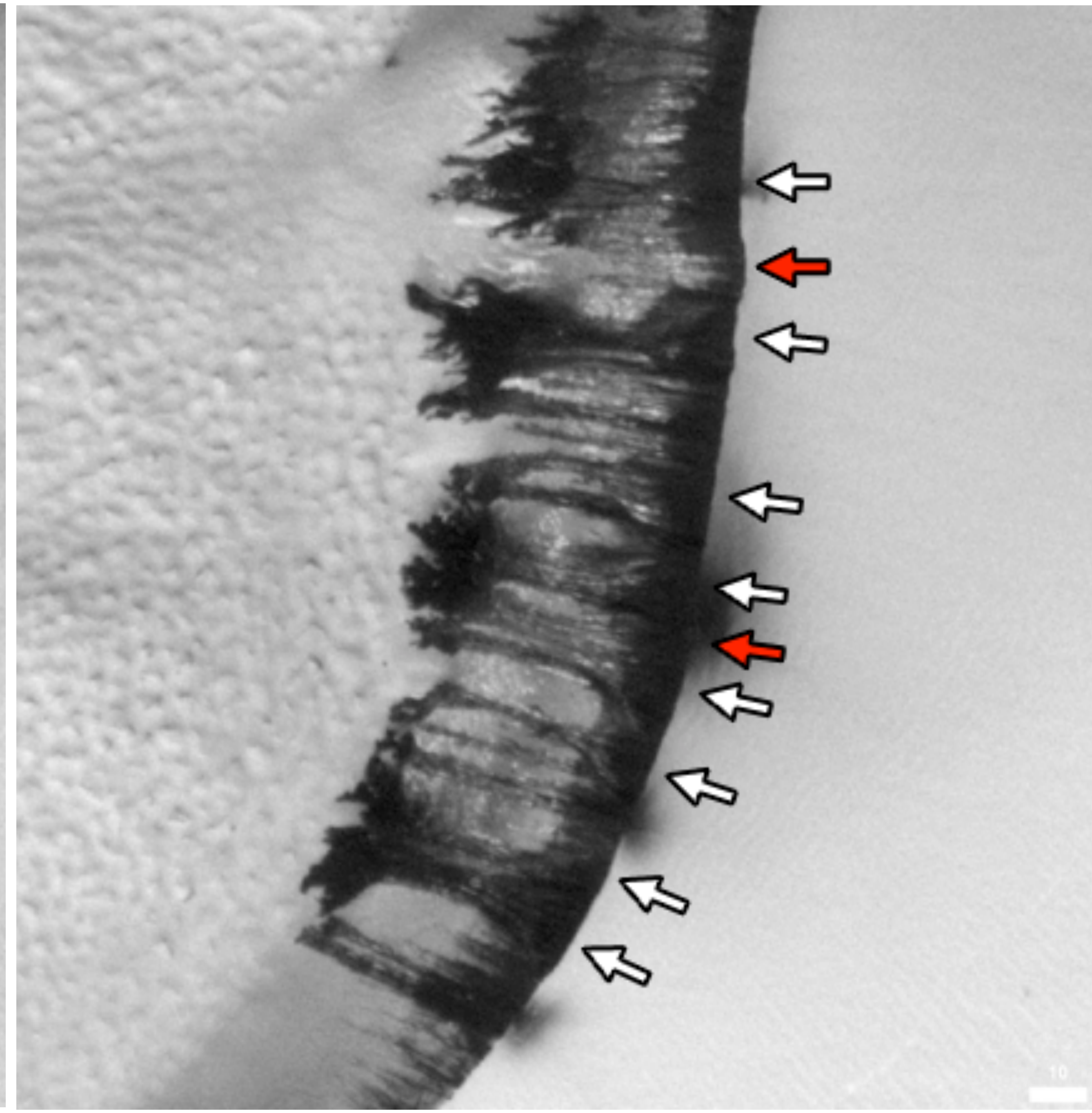

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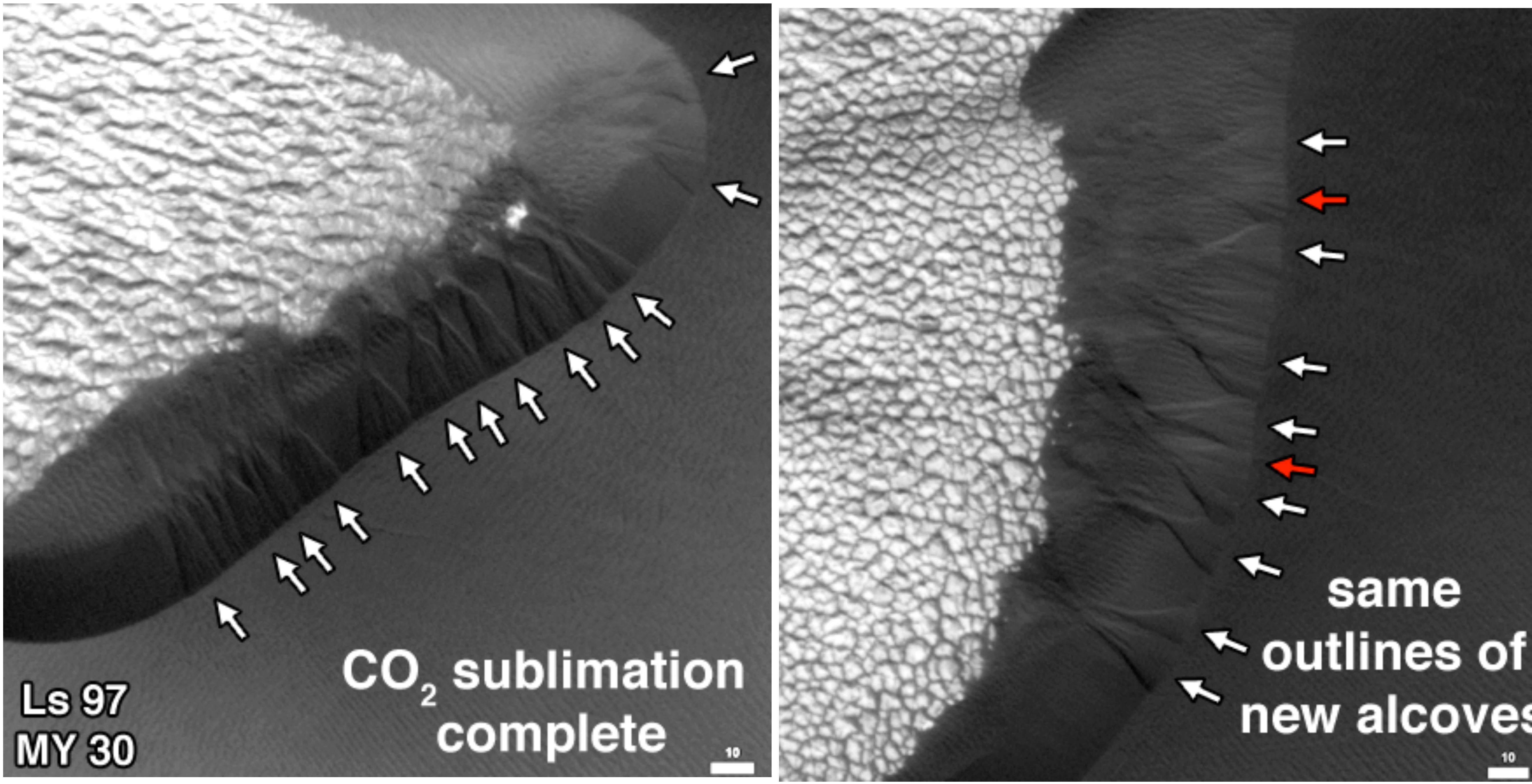
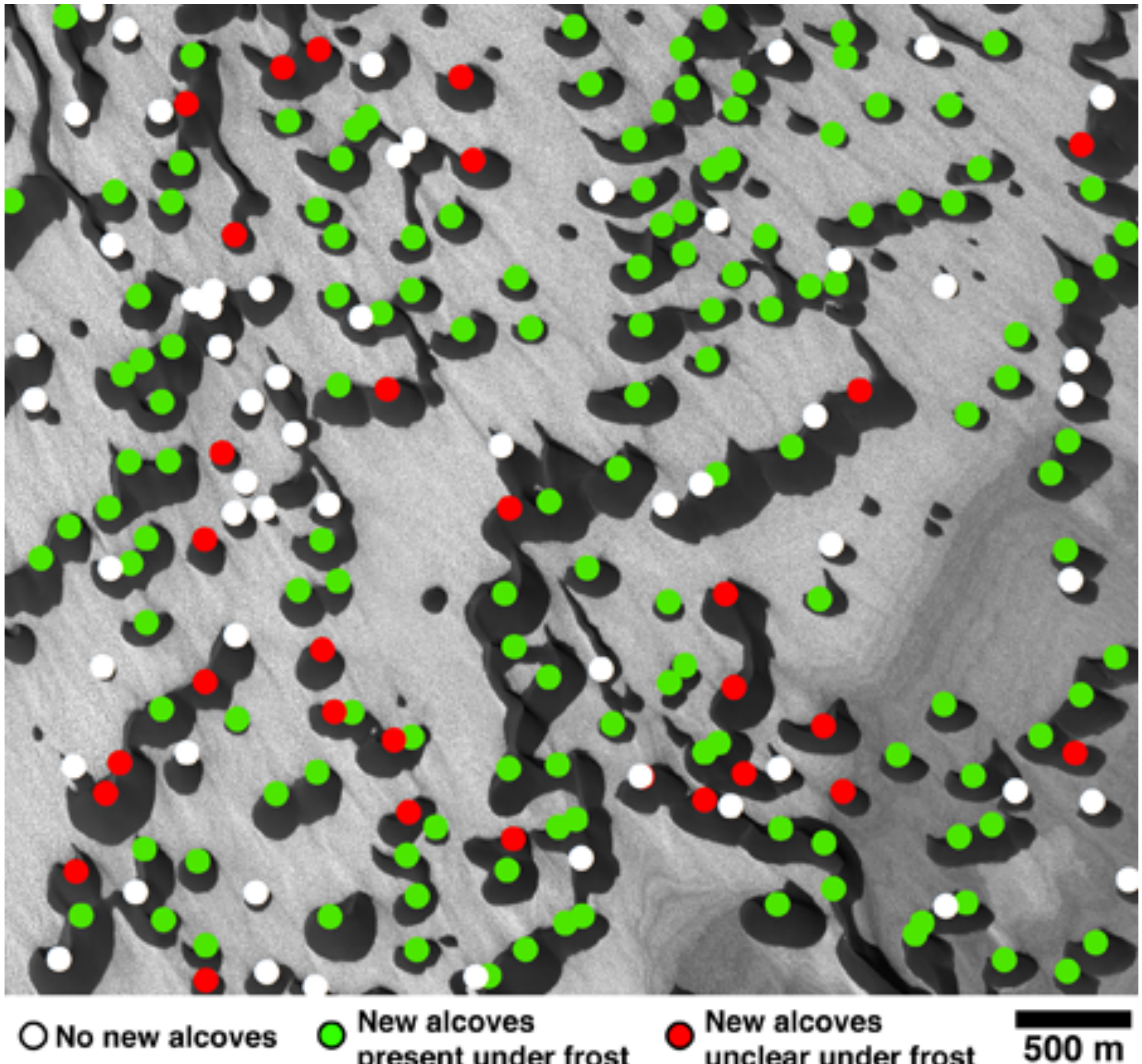
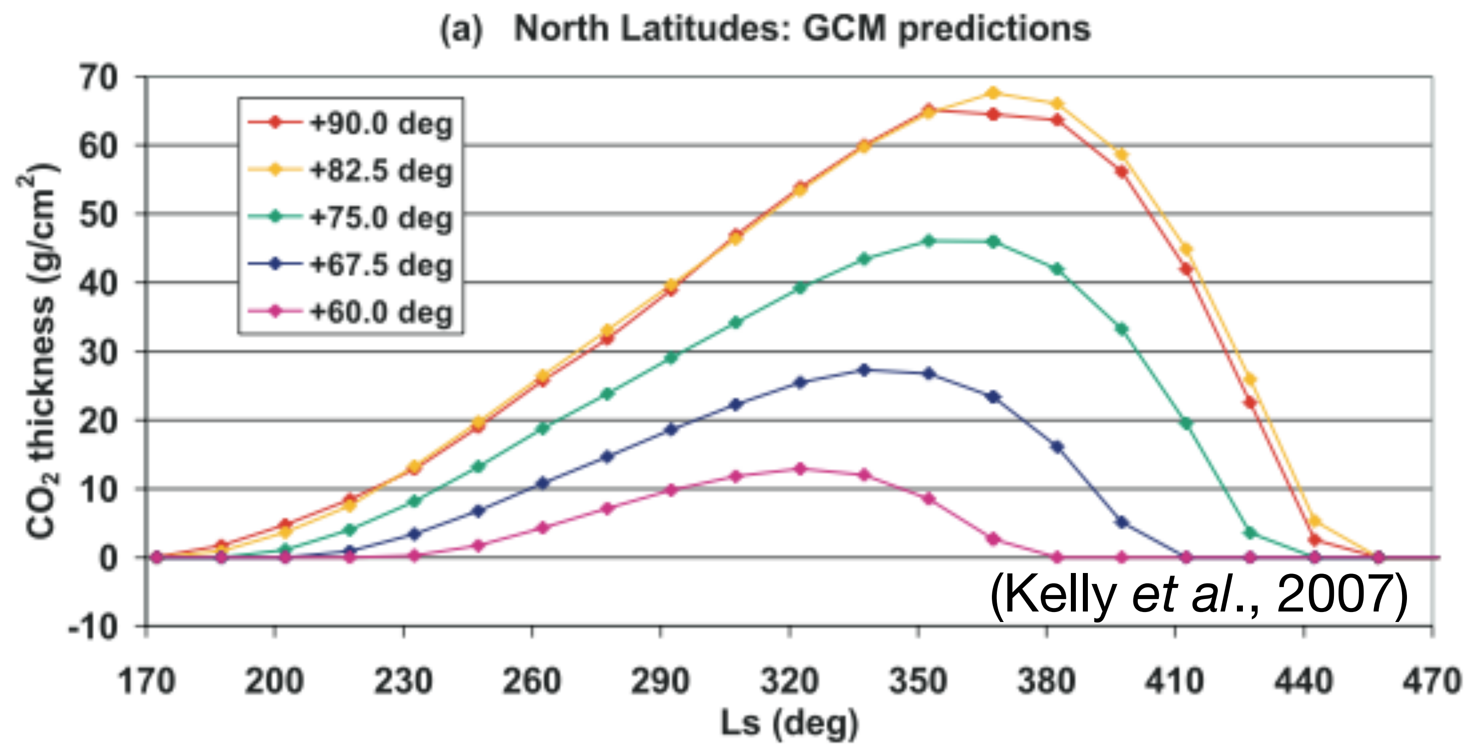


(Horgan *et al*., submitted to *GRL*)

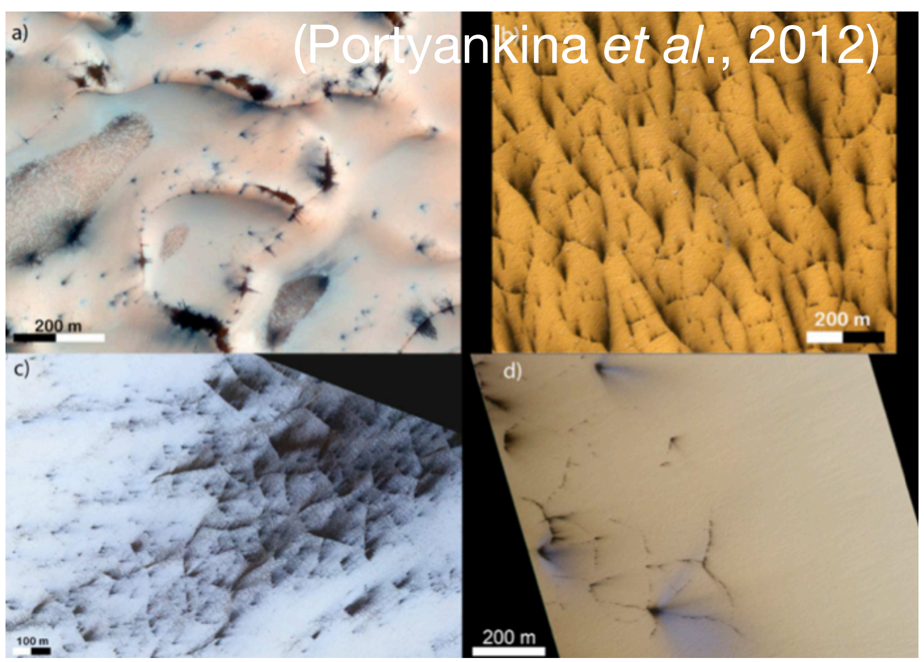
72% of dune slipfaces in this sub-image exhibit new alcoves.
In 80% of those, the alcoves are apparent under the CO_2 frost.

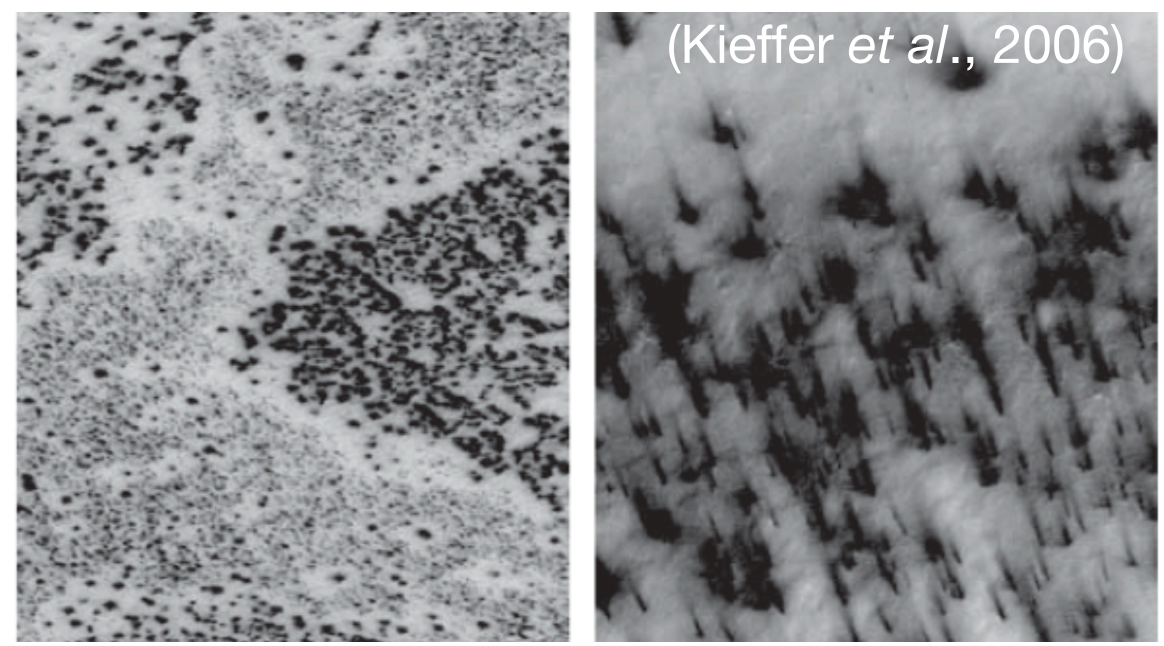


The seasonal CO2 cap is deposited in the fall, and quickly anneals into a solid slab



Evidence: cracks, geysers, transparency, supported by modeling.





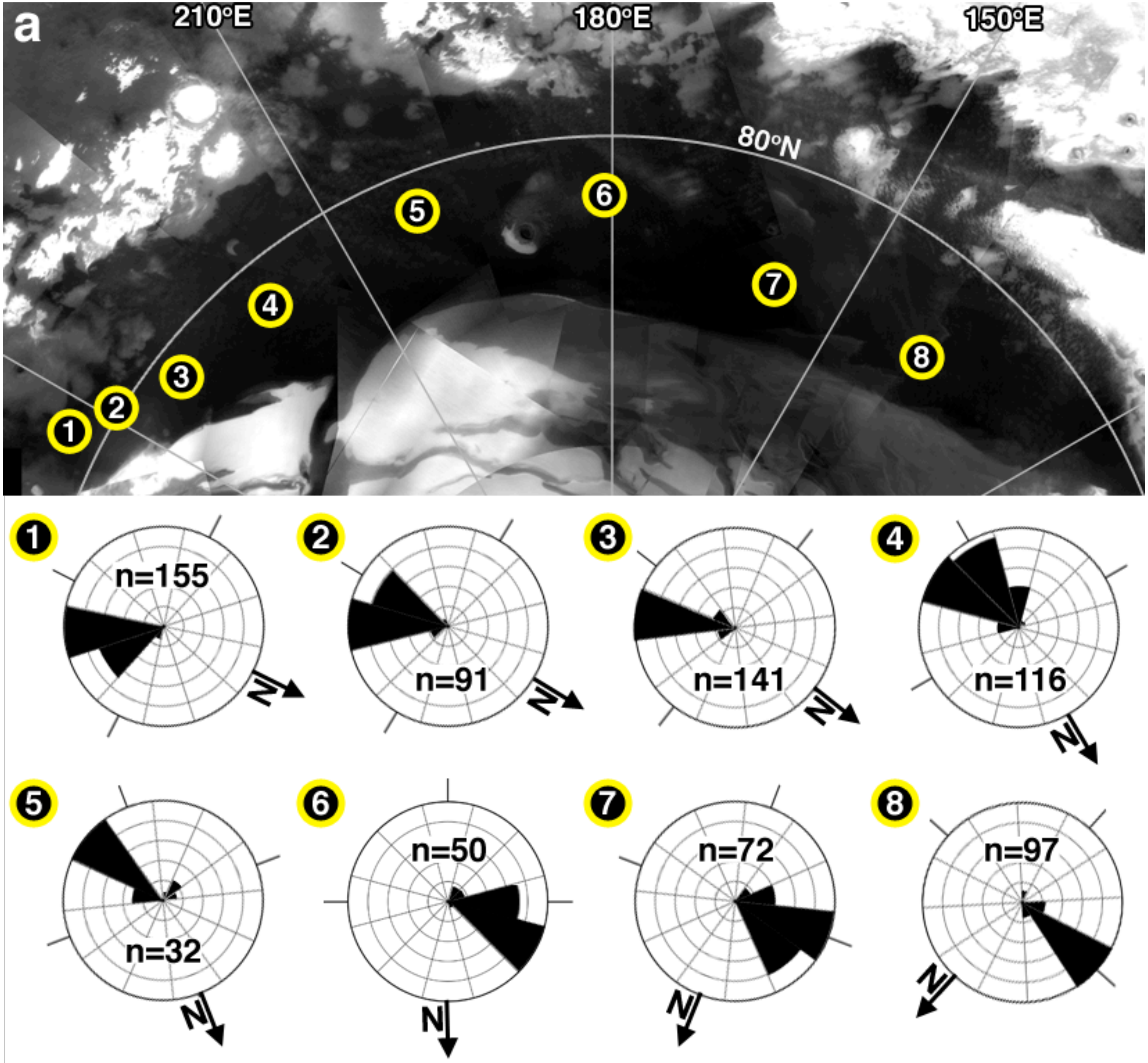
Once the slab forms, not much can happen until it starts subliming in the spring. **Slab formation + imaging constraints = the alcoves must have formed in the mid to late summer.**

The alcoves and fans strongly resemble normal slipface avalanches on terrestrial dunes, **so what about an aeolian origin?**

Grainfall of saltating sand on slipface causes oversteepening, collapse, and run out of sand

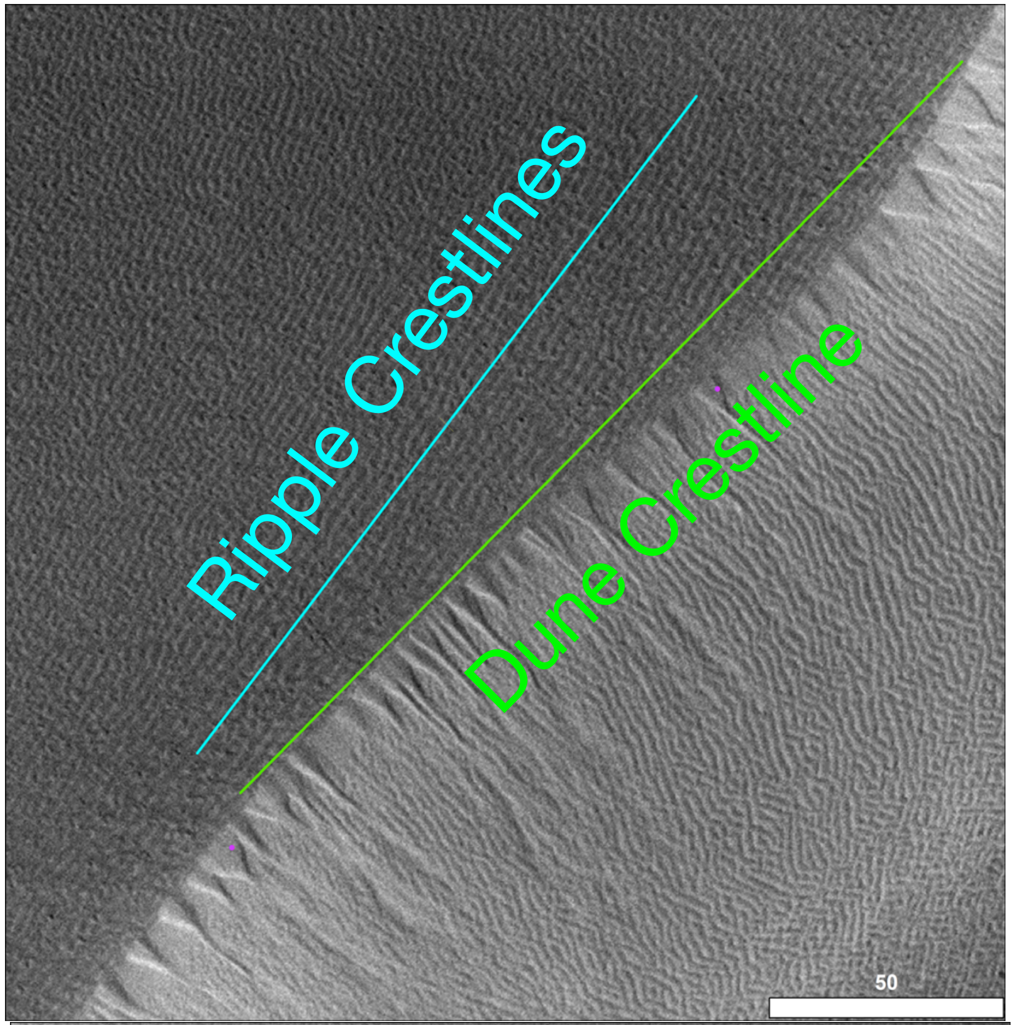
Since saltation on Mars is thought to be driven by strong gusts, this would be consistent with the sporadic nature of alcove formation.

(Bridges *et al*., 2012)



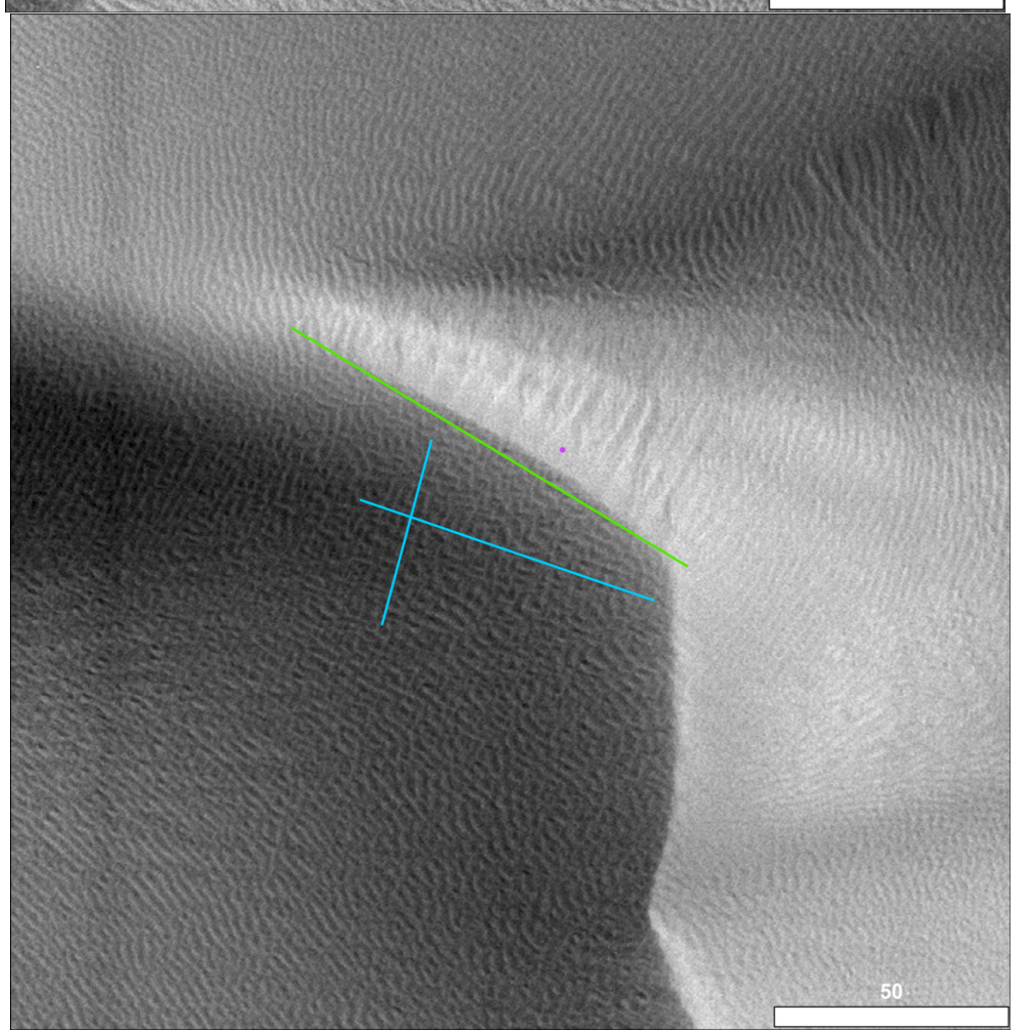
In the largest north polar dune field, the orientation of alcoves is more uniform than dune slipface orientations.

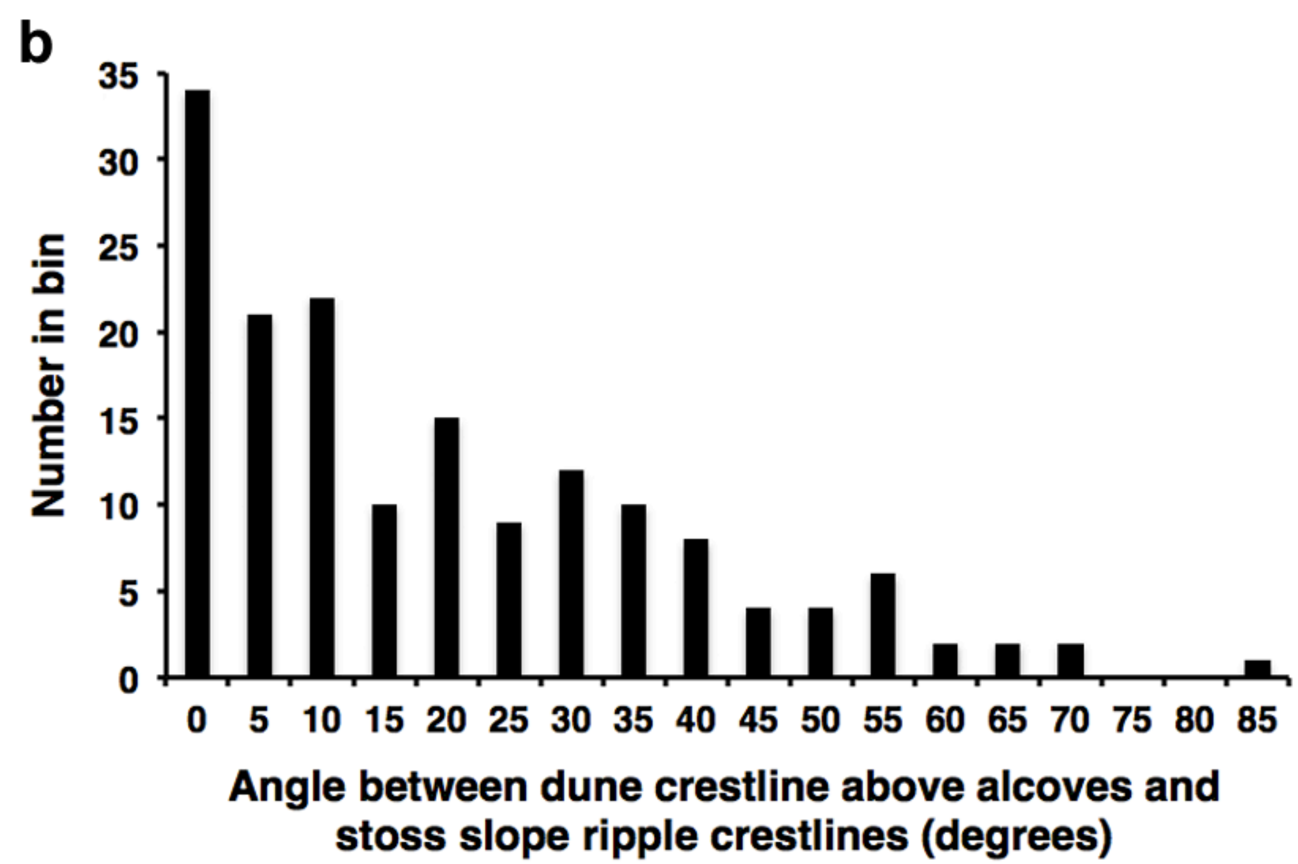
Uniformity is consistent with formation during the most recent wind event(s).



We can use the orientation of ripples to determine the direction of the most recent wind event(s).

For alcove-bearing slipfaces, the ripple and slipface crestlines differ by:
- less than 15° in 46% of the slipfaces
- less than 45° in 84% of the slipfaces

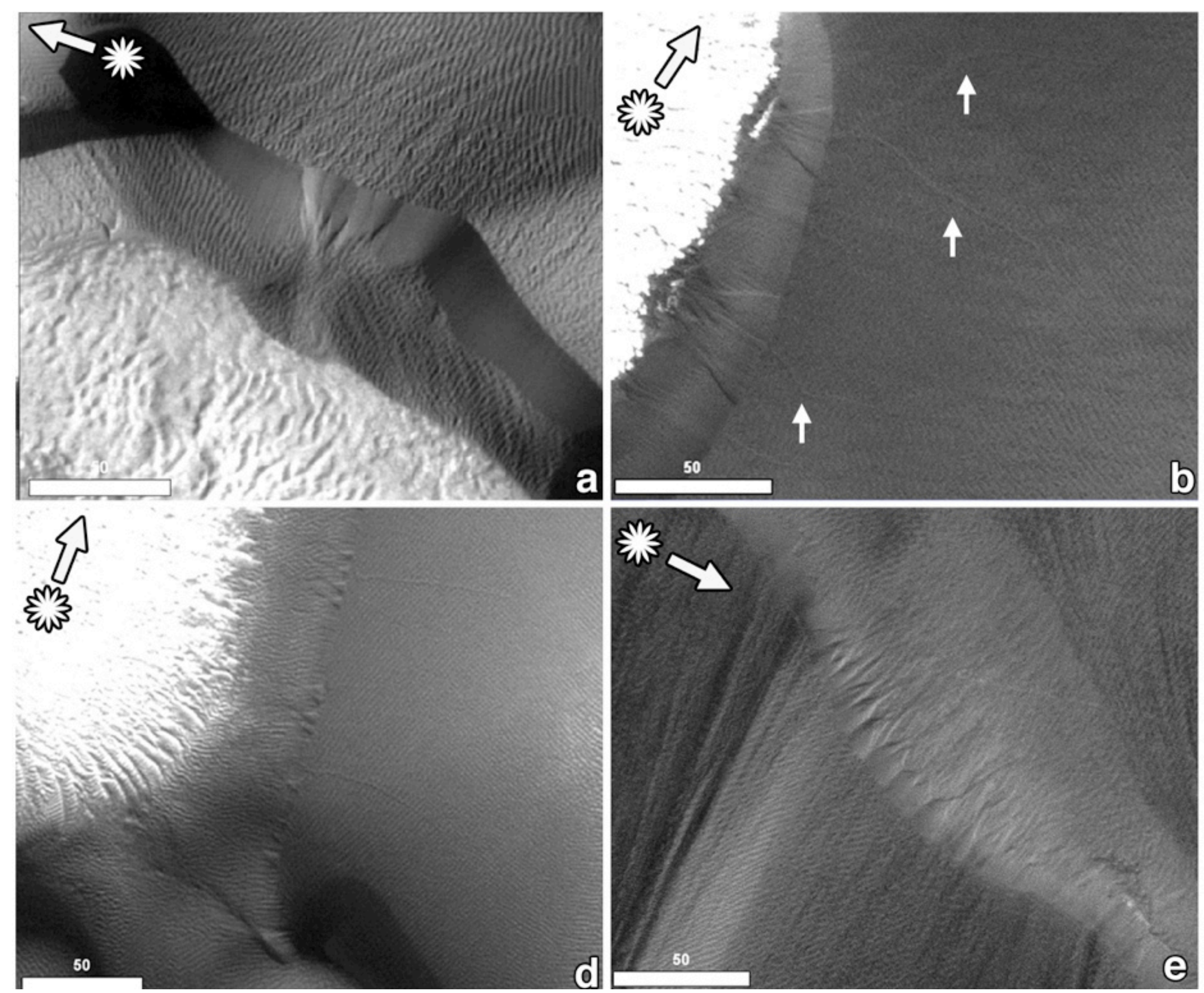




So all the available evidence points to:

- A summertime origin, unrelated to CO2 sublimation
- A genetic relationship between alcoves and aeolian processes
- A morphology consistent with terrestrial slipface avalanches

But there are three critical remaining issues.

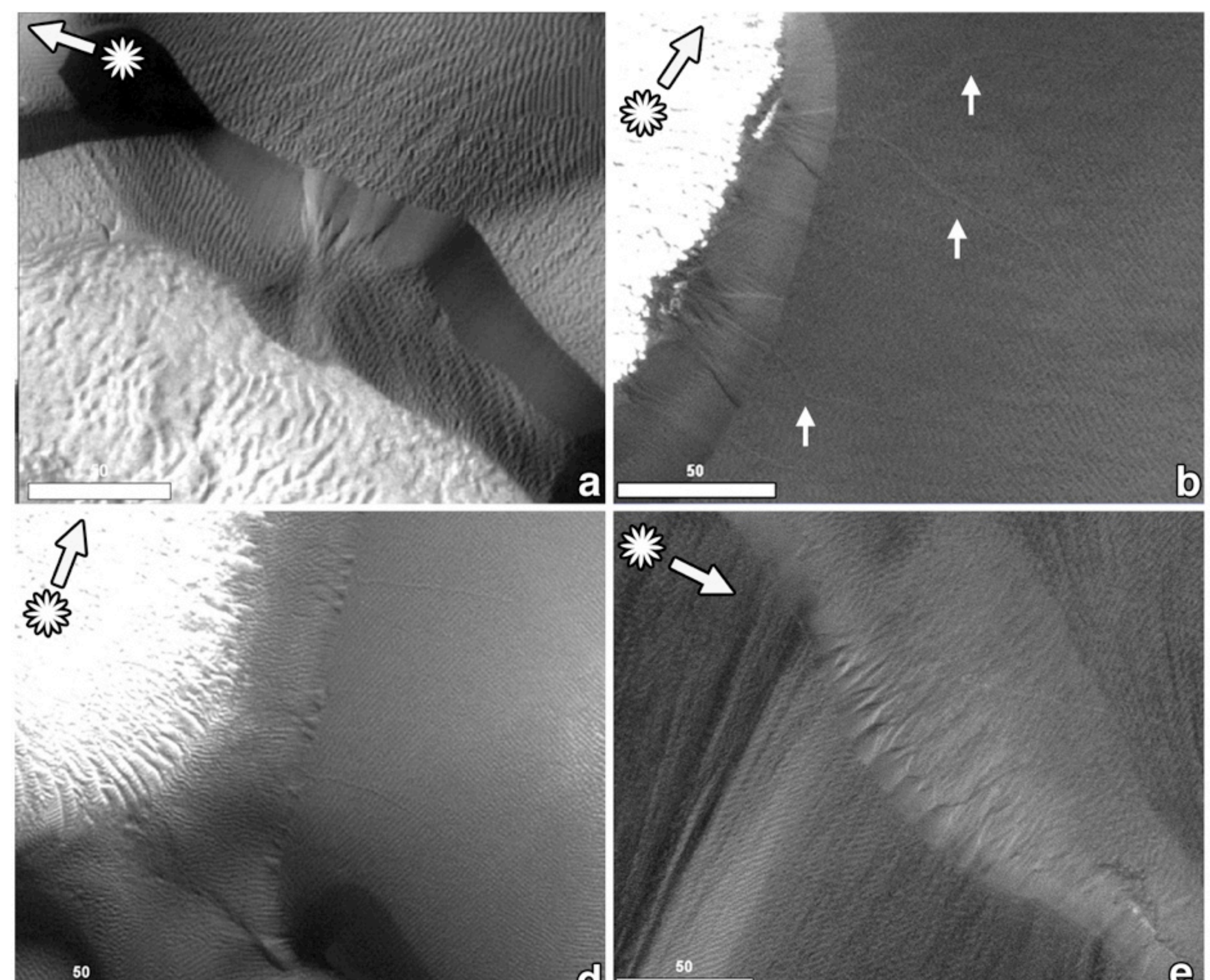


(1) Why are the martian alcoves an order of magnitude larger than terrestrial alcoves?

Spring mass wasting probably contributes significantly to the depth, but the initial width is still huge!

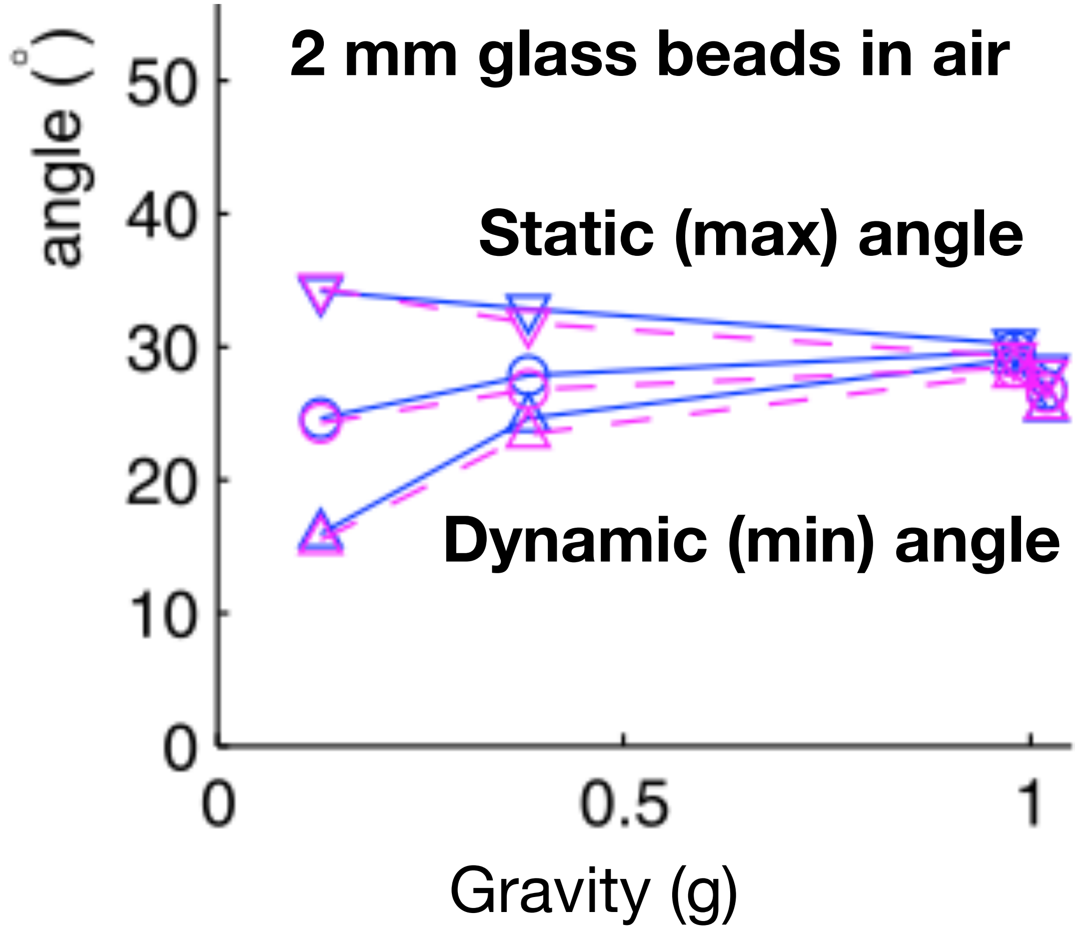
~30 cm wide and a few cm deep

1-15 m wide and ?-1 m deep



Variation in the static and dynamic angles of repose with gravity
(Kleinhans *et al*., 2011)

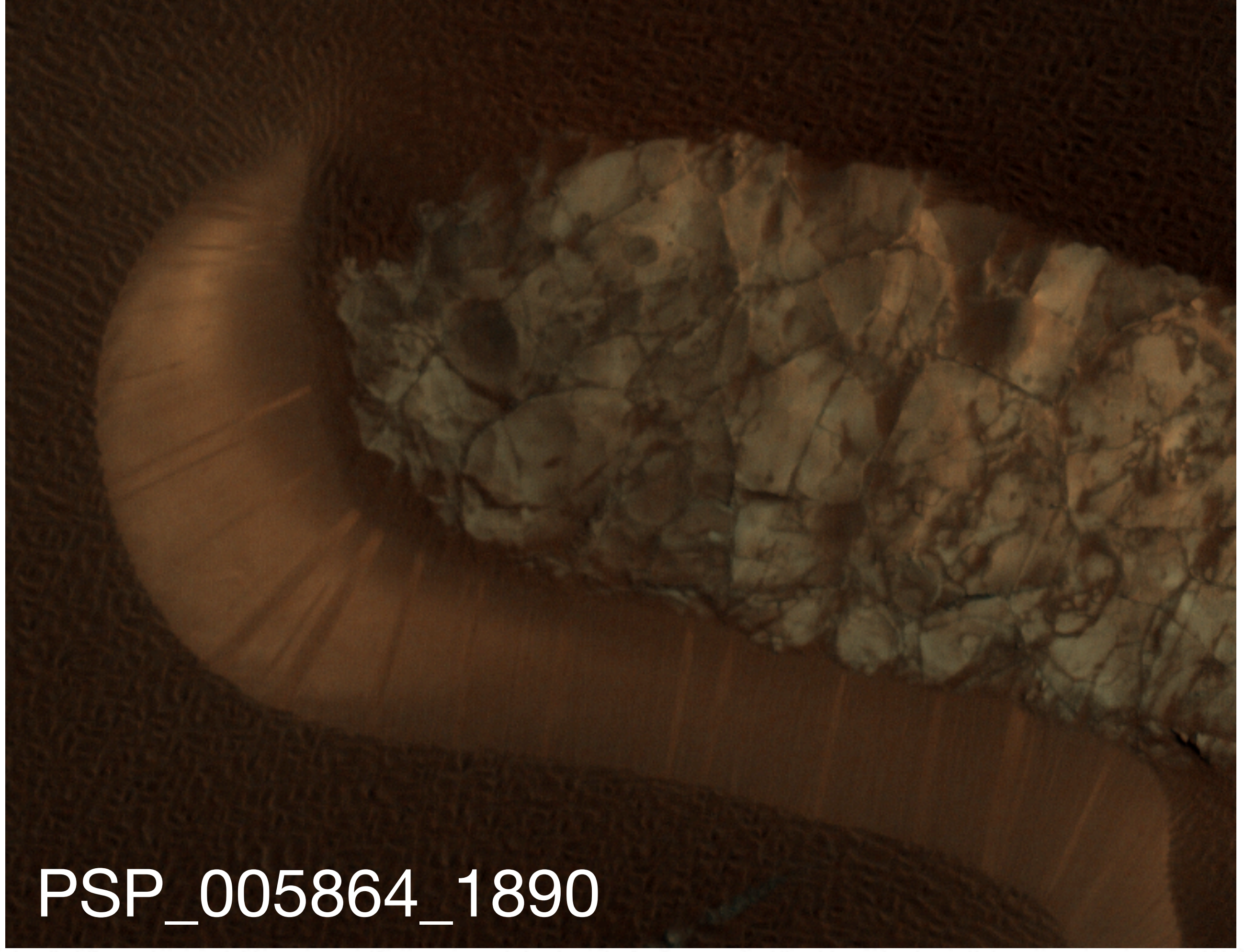
- Centrifuges: the static and dynamic angles of repose are similar and independent of gravity at 1g and up
- Reduced gravity, continuous rotation experiments on parabolic flights with variety of grain sizes, grain roughnesses, and fluids
- **The angles appear to diverge at lower g**, such that the dynamic angle of repose can be 10-20º less than the static angle of repose.
- So it takes a steeper slope to get an avalanche going in lower gravity, but it will run out farther and entrain more materials than on Earth

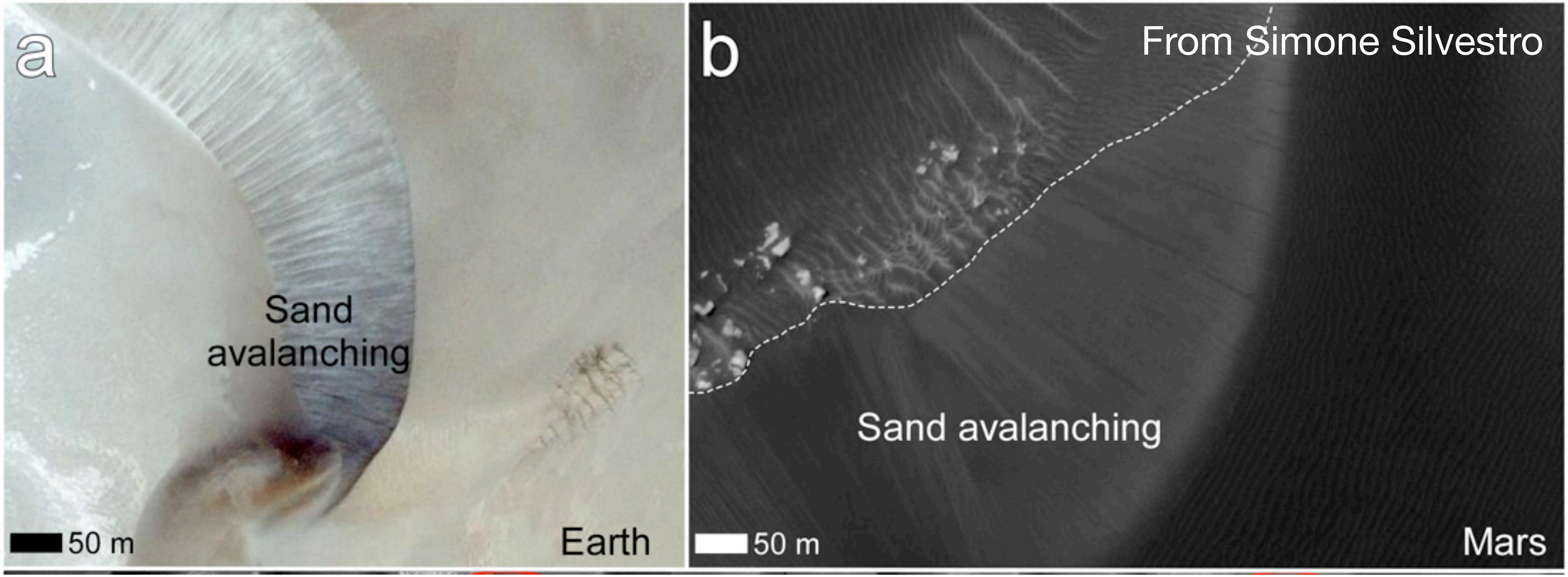


(2) What about slope streaks observed on some martian slipfaces?

Interpreted as grain flows due to strong similarity to terrestrial counterparts (Fenton, 2006; Silvestro *et al*., 2010)

Appear to be fundamentally different features than large alcoves + fans



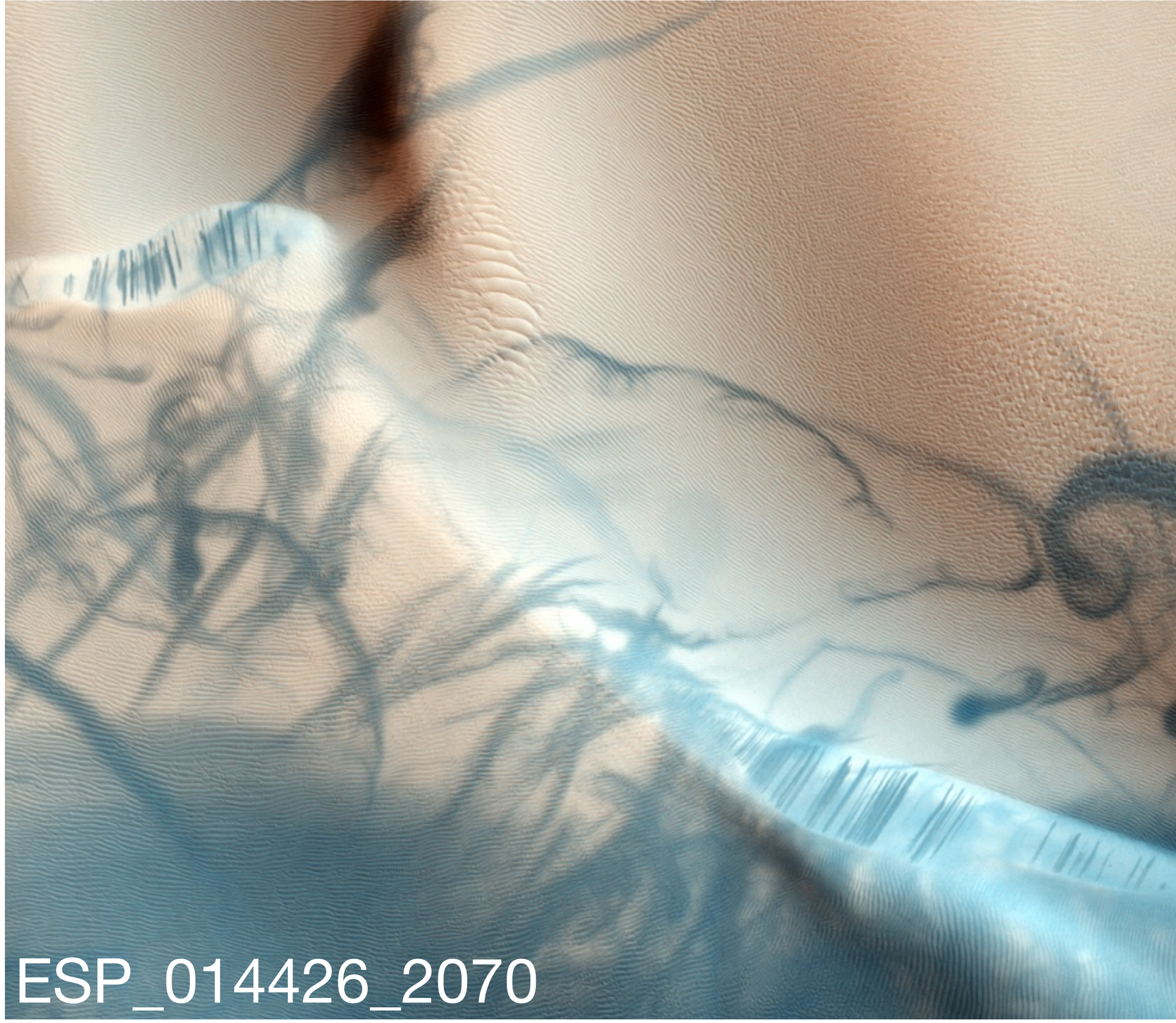


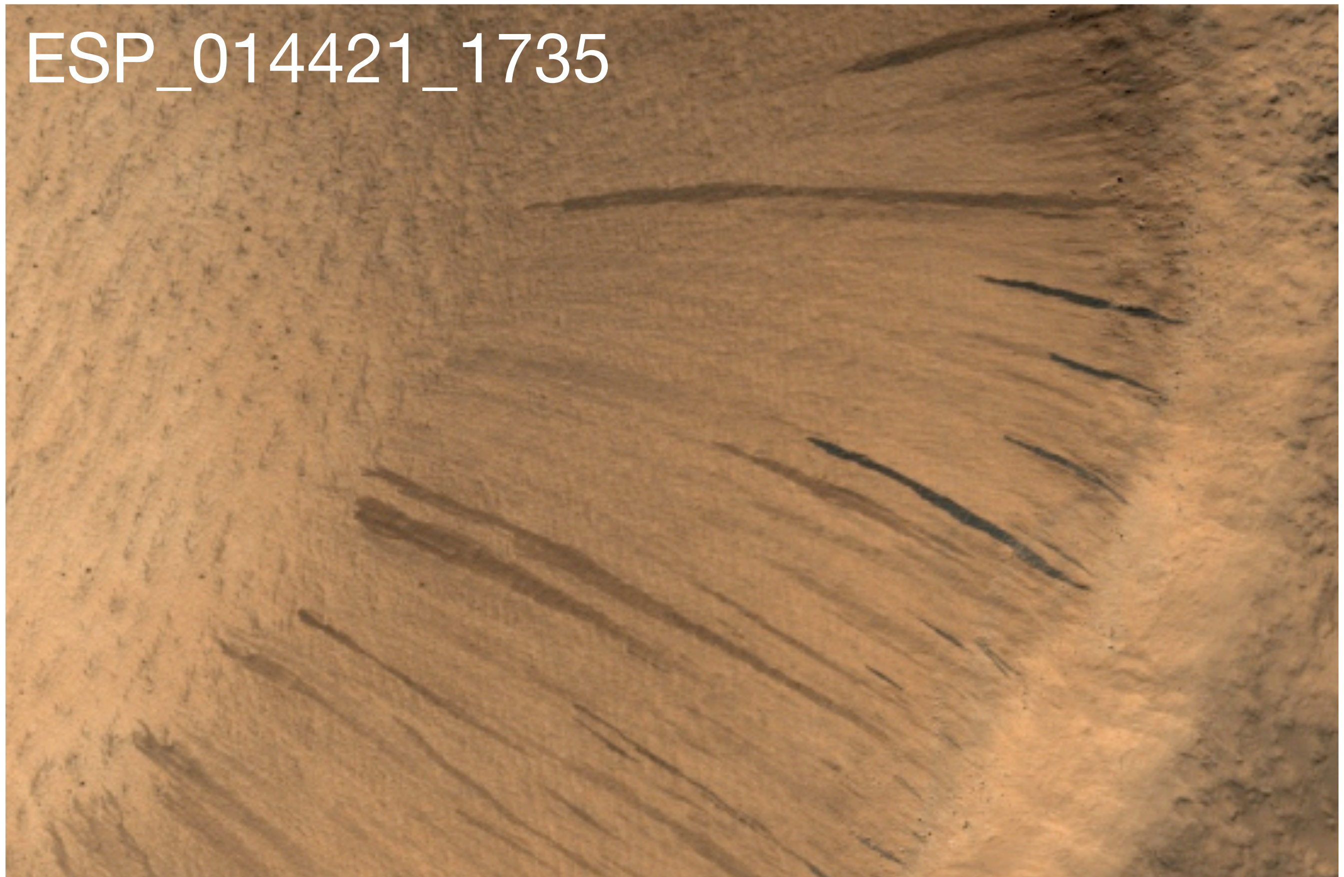
Slope streak properties:

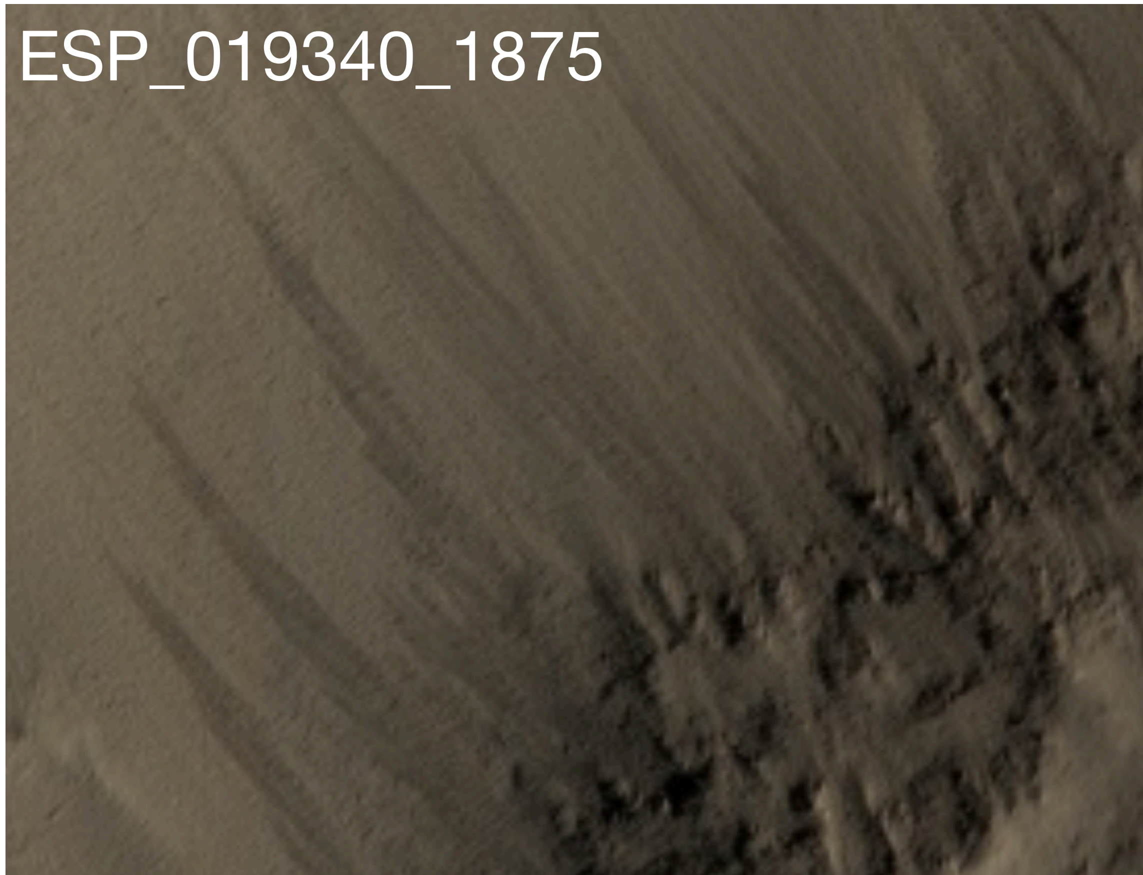
- Apparent due to albedo contrast, no morphologic signature
- Often have bright termini
- Sometimes associated with dust devils
- Similar to dust avalanches on other slopes (Sullivan *et al*., 2001)

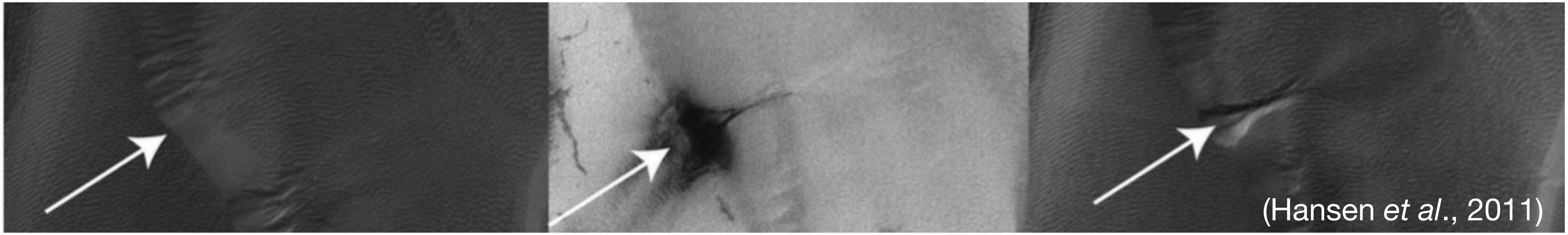
Hypothesis: Dust avalanches triggered by dust devils, other turbulence, or grain fall.

But, this is somewhat ambiguous.









(3) Why are the new alcoves sites for early CO2 sublimation in the spring?

- This would occur if the new alcoves have different thermal properties
- **Hypothesis:** Surface of dunes is indurated
- Surface induration is supported by morphologic features, widespread presence of sulfates (Horgan *et al*., 2010)
- Recent avalanche sites expose un-indurated interior, have a lower thermal inertia, and so warm up faster in the spring.
- **Test:** Multi-year monitoring of sublimation timing on existing alcoves

Conclusions

- Slipface avalanches must have formed in mid to late summer - inconsistent with CO2-related origin
- Timing, orientation, and morphology are consistent with a wind-related origin
- **Hypothesis: Form due to aeolian oversteepening and avalanching**

- Open questions:
    - Why are the martian alcoves larger than terrestrial counterparts?
    - What is the relationship between alcoves and smaller slipface streaks?
    - Why are new alcoves associated with early springtime mass wasting?

- Slipface avalanches are present outside the north polar region, and could be used as tools for identifying the most active dune fields