Recurring Slope Lineae (RSL) and Mars Planetary Protection

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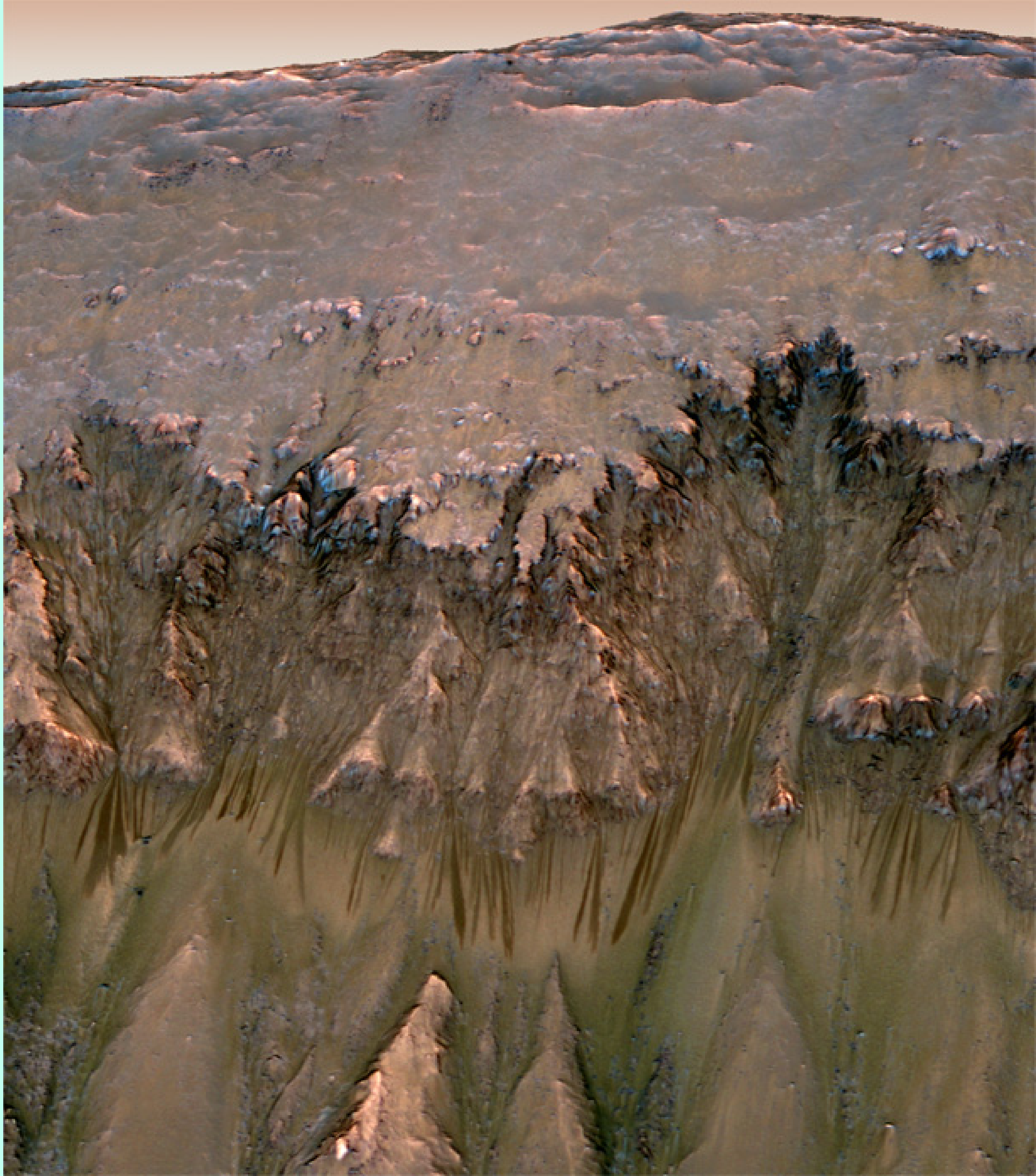


Reprojected view of seasonal flows in Palikir crater

Background

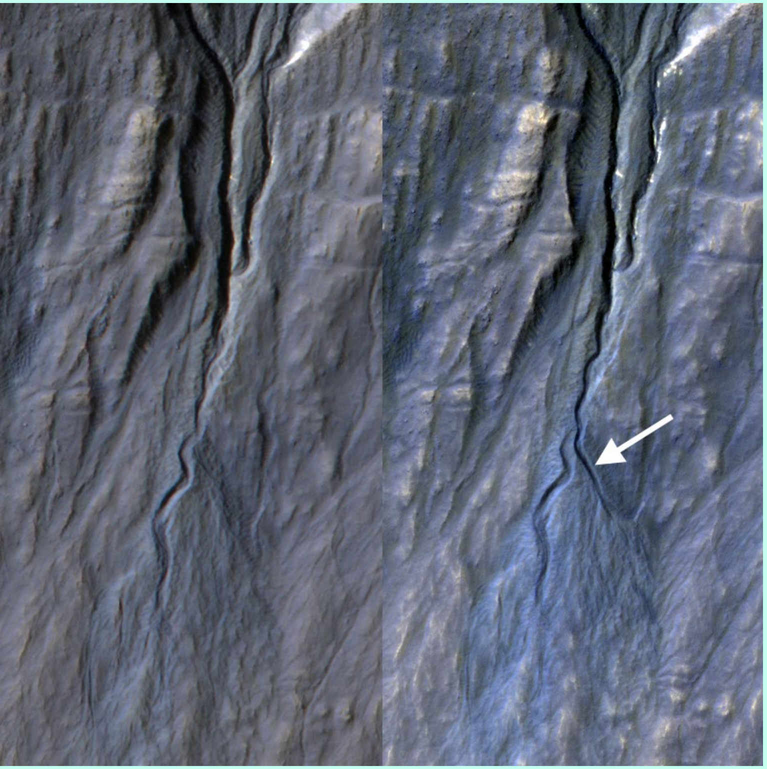
- Mars Reconnaissance Orbiter (MRO) has been observing Mars since 2006
- MRO has a high data rate
- MRO has had consistent observing conditions:
  - ~320 x 250 km orbit, ~3 PM local mean solar time
- MRO has routine off-nadir pointing to targets of interest
  - Enables stereo imaging and frequent repeat coverage under similar lighting to monitor changes
- The High Resolution Imaging Science Experiment (HiRISE) images the surface from 0.25-0.32 m/pixel scale
  - 3 colors in narrow central strip
- CTX (5-6 m/pixel) finds larger-scale surface changes
- CRISM (0.4-4 microns) provides compositional data
- **This combination gives MRO unprecedented capability for understanding present-day surface processes.**

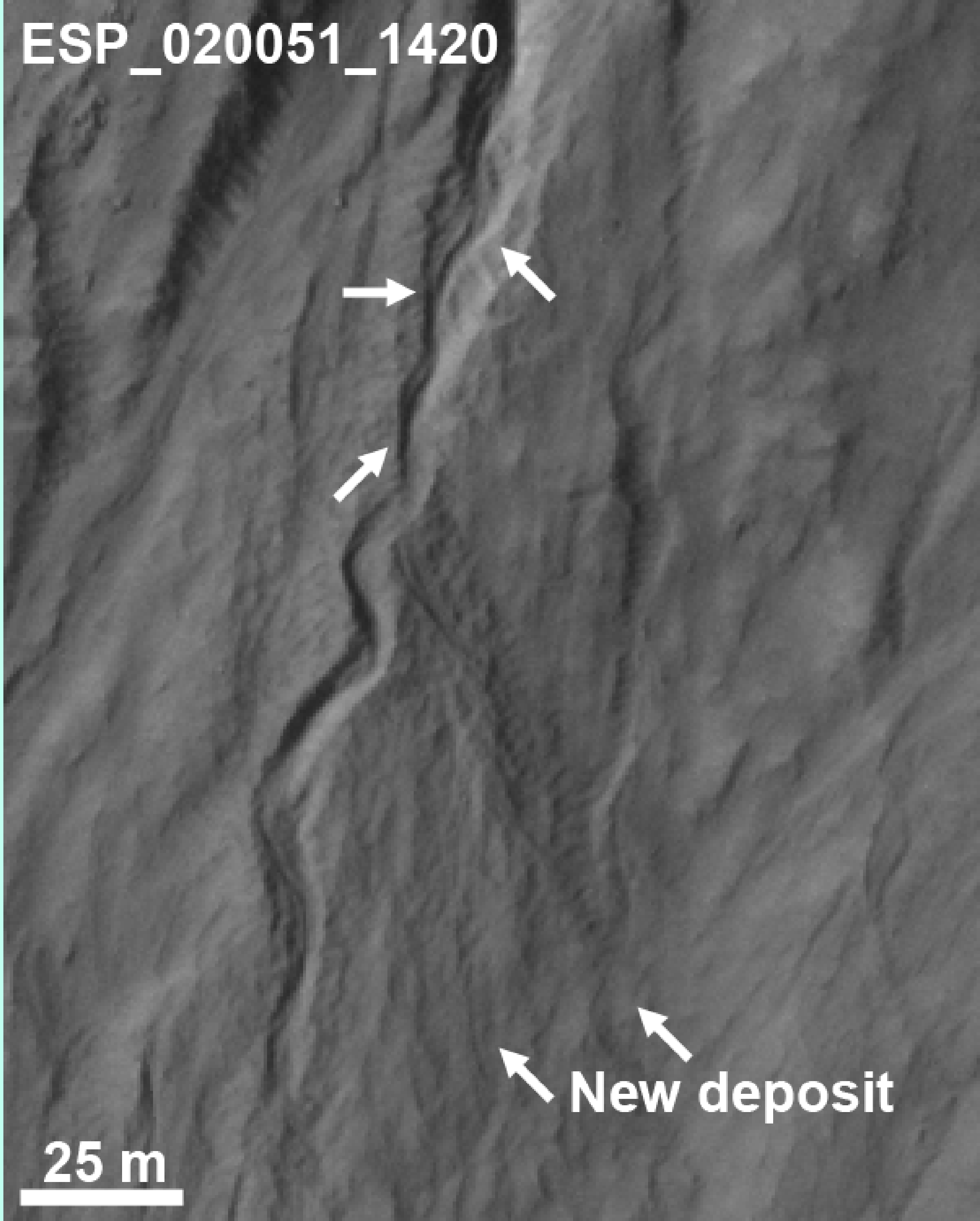
Present Day Gully Formation

- Subsequent to the MOC discovery 20 years ago, many workers concluded that the gullies formed by flowing water, most likely in a different, recent climate.
- HiRISE has monitored active gully sites to look for changes and seasonal activity.
- Substantial ongoing gully activity including channel incision--gullies are forming today.
- Distinct seasonality--most activity correlates with seasonal CO_2 frost. Too cold for liquid water.

Dundas et al., 2010; Diniega et al., 2010; Dundas et al., 2012

New channel incision; curving channels do not require liquid



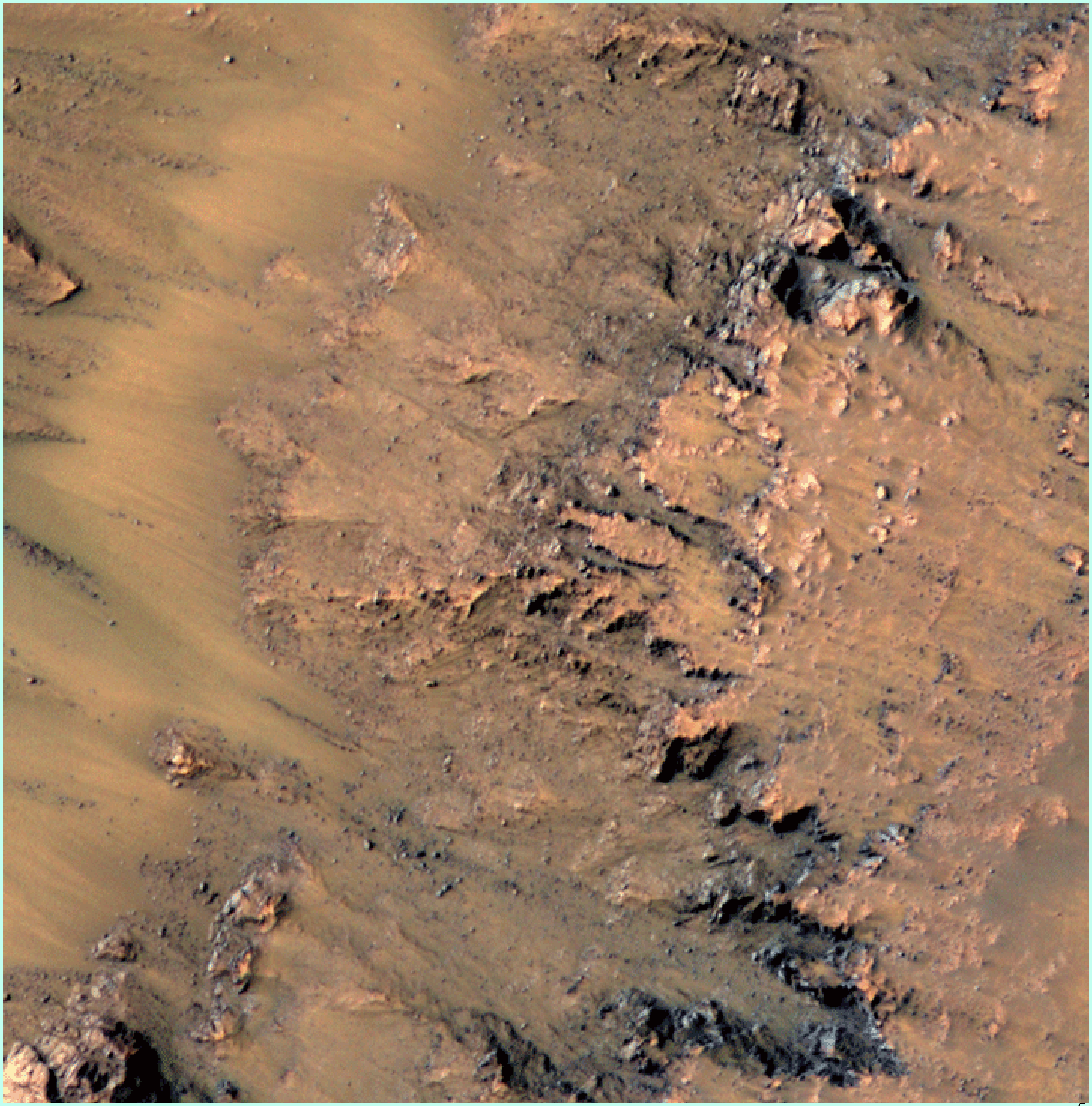


Seasonal Flows on Warm Martian Slopes

(McEwen et al., Science, 5 Aug 2011)

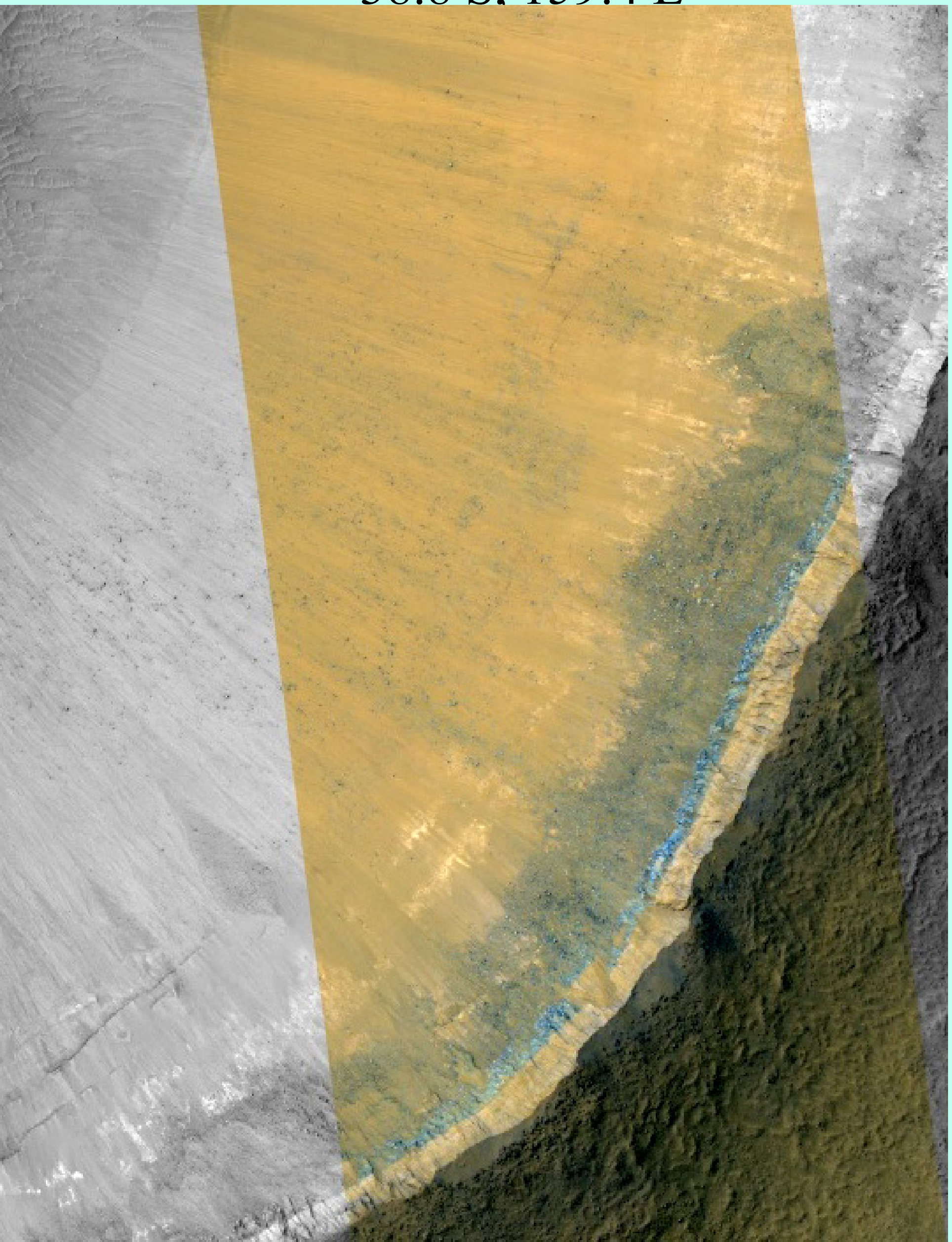
What we knew in 2011:

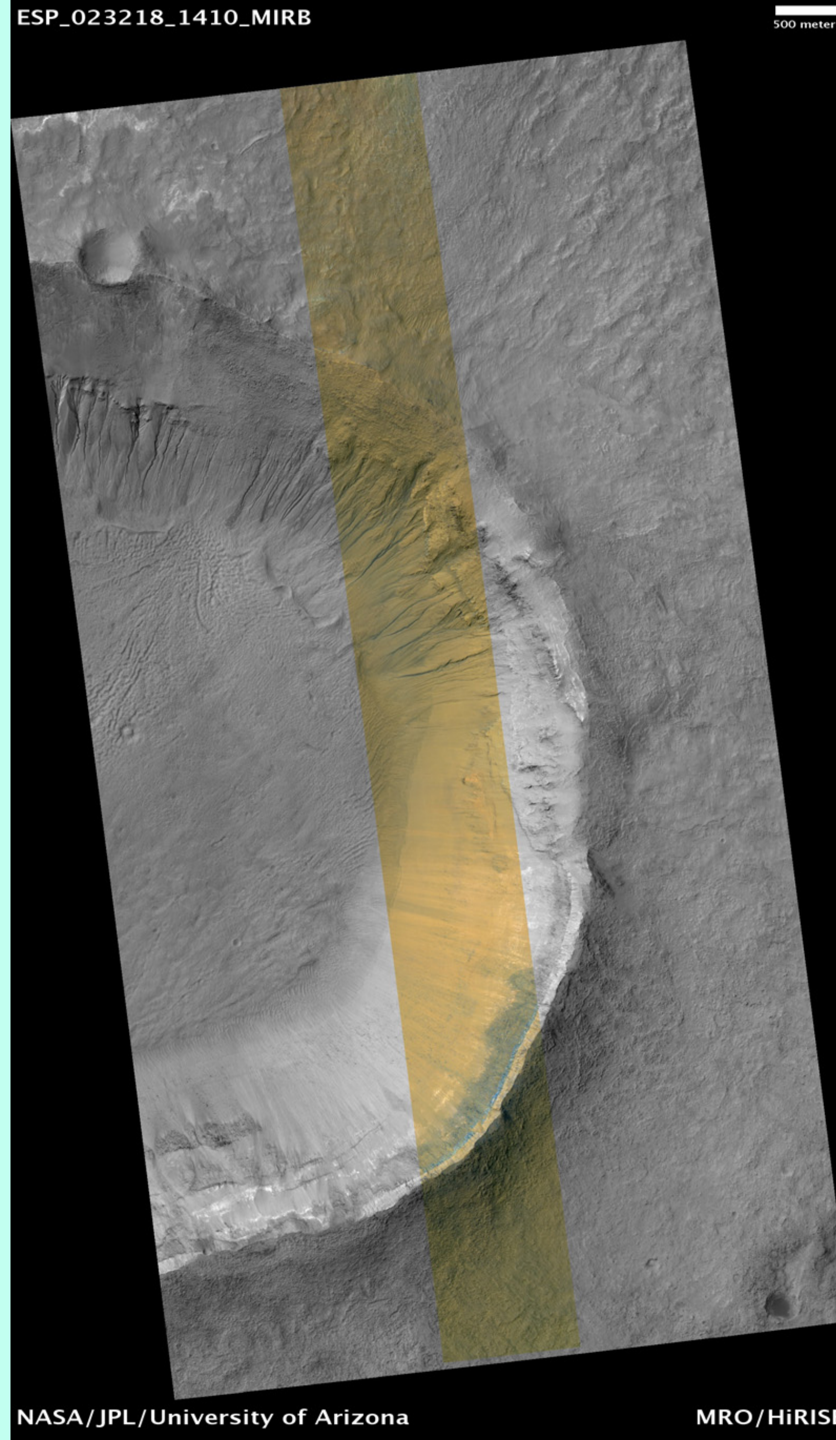
* Recurring Slope Lineae (RSL) are narrow (0.5-5 m), dark markings on steep slopes (>25°)
* Concentrated in southern hemisphere (32°S to 48°S), favoring equator-facing slopes.
* Form and incrementally grow in late spring to summer, then fade or disappear in late summer to fall.
* Reform at nearly same locations in multiple Mars years.
* Extend downslope from bedrock outcrops or rocky areas; often associated with small gullies.
* RSL active when and where peak temperatures > 250 K.
* Mechanism not understood, but seepage of brines fits the observations.



Corozal Crater

38.8 S, 159.4 E

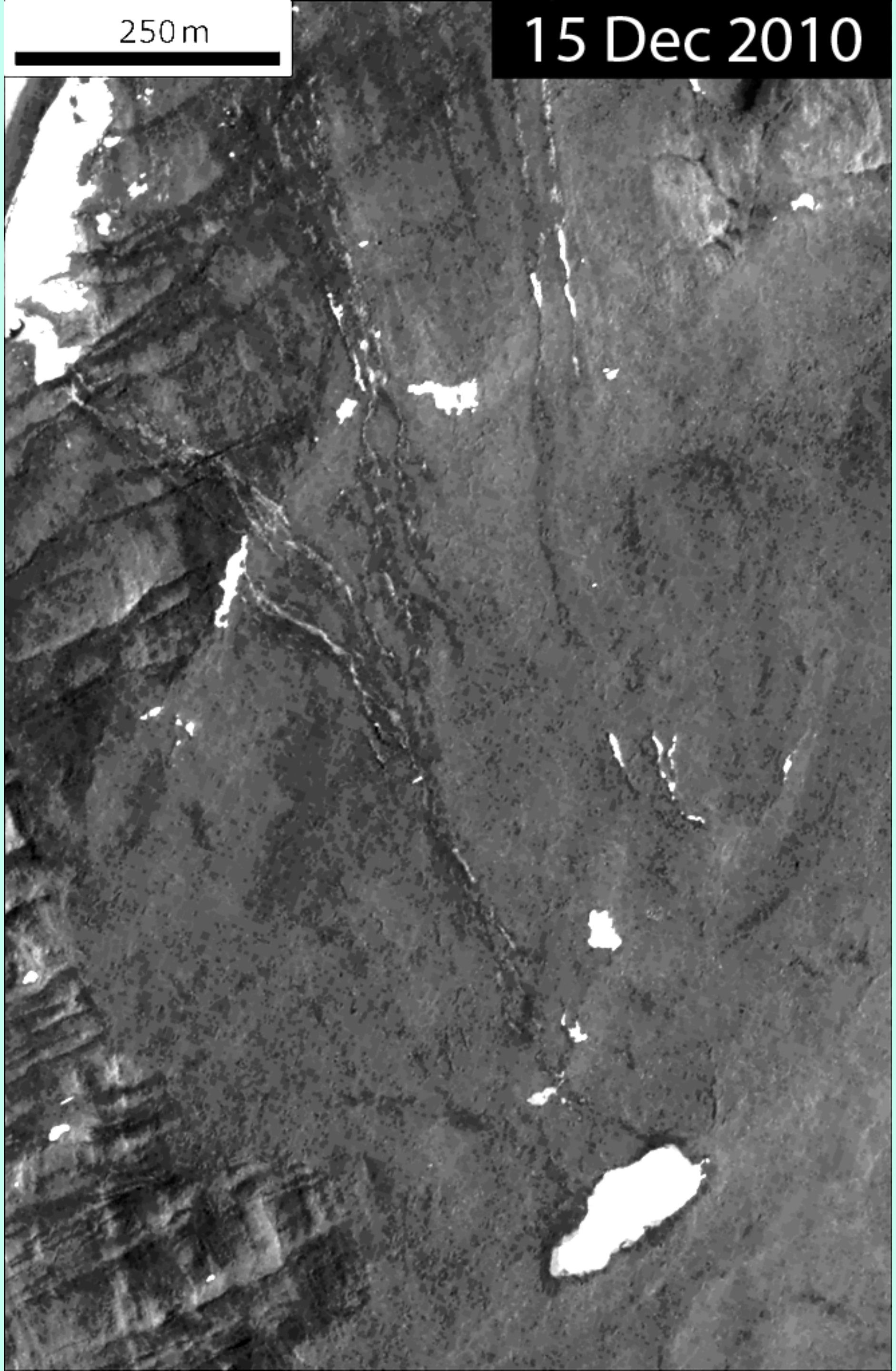




Water Tracks in Antarctica

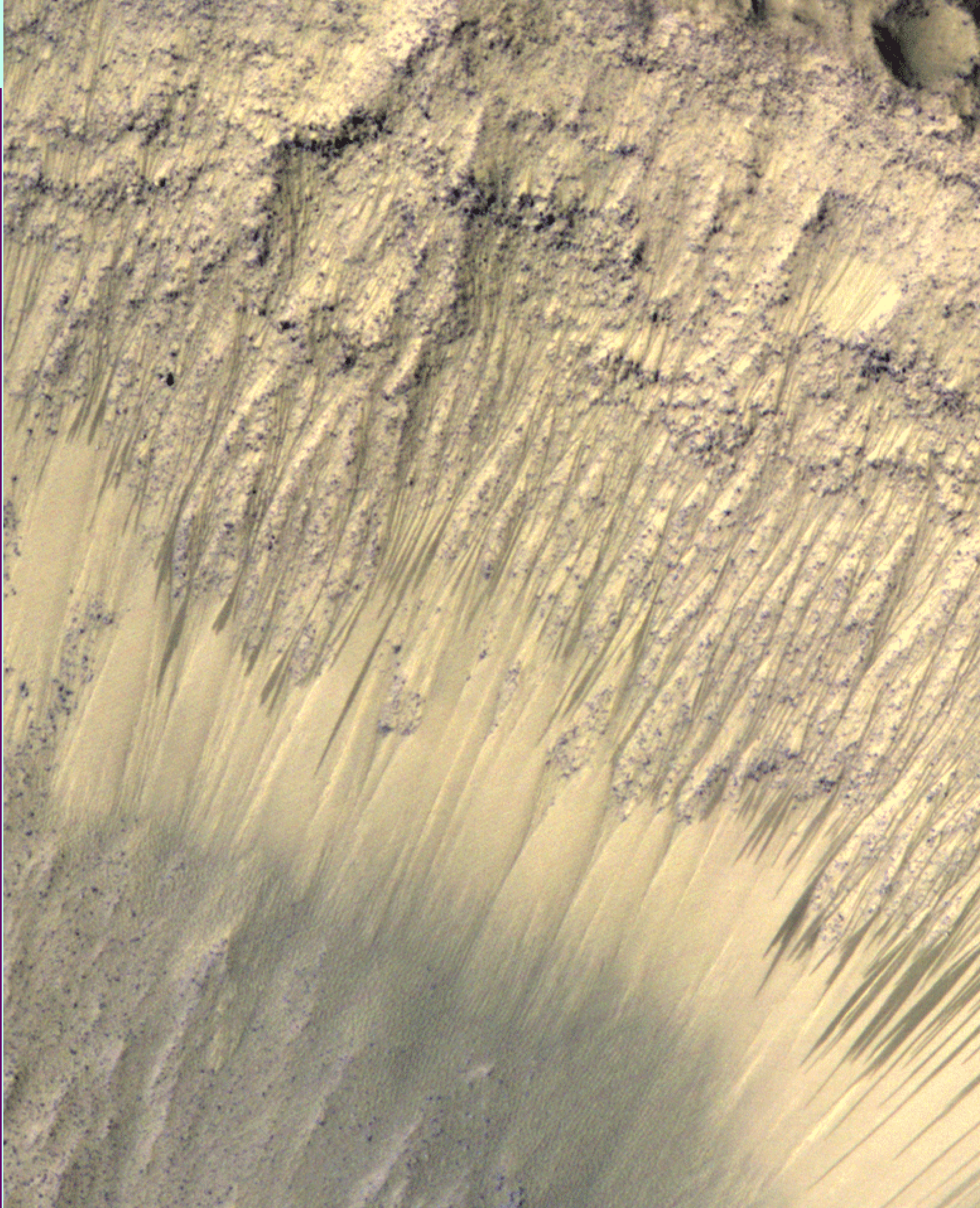
Form initially by deliquescence of atmospheric water (Levy, 2012).

Don Juan Pond never freezes due to salt concentration.

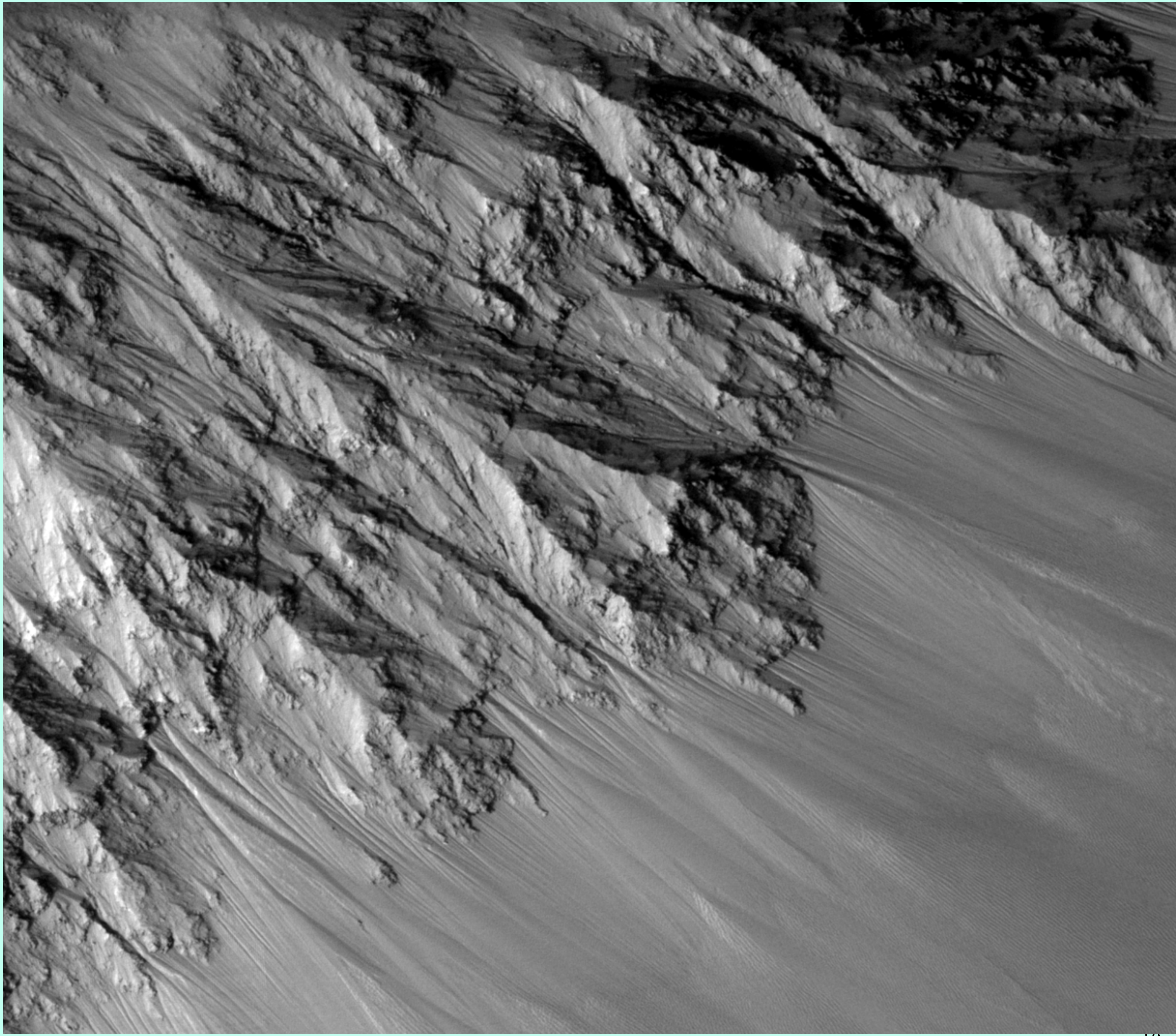


What we knew in 2014:

- RSL also concentrated in Valles Marineris (VM) on all slope aspects, plus in a few other equatorial and N hem. regions
- In VM they form and grow in N spring/summer on N-facing slopes, S spring/summer on S-facing slopes, then fade or disappear when inactive (not necessarily colder season)
- May be active most of year on E- and W-facing slopes
- Recur in multiple Mars years.
- Extend downslope from bedrock outcrops or rocky areas; often associated with “small” gullies.
- Longer RSL in VM, >1 km

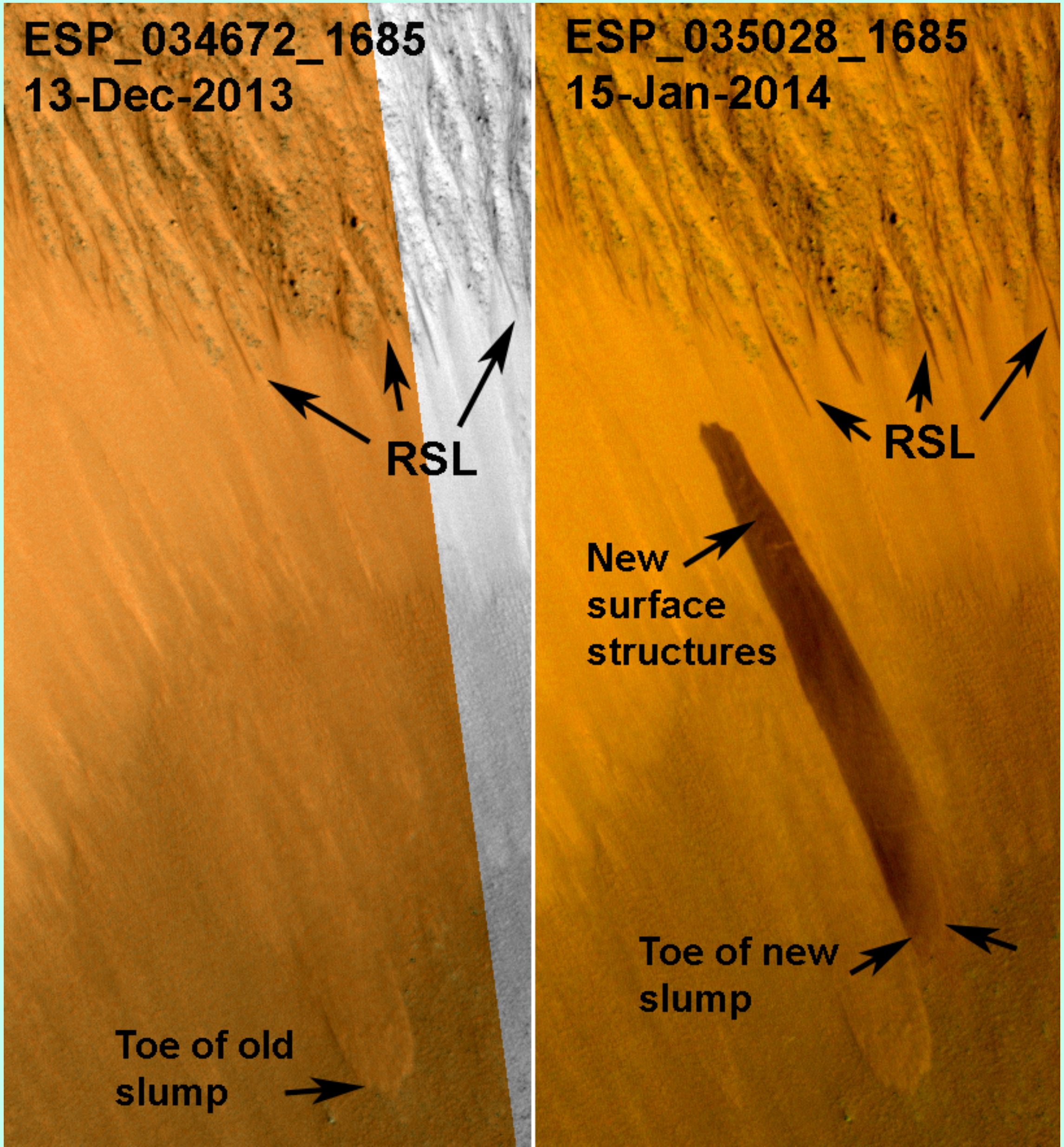


RSL are often associated with small gullies

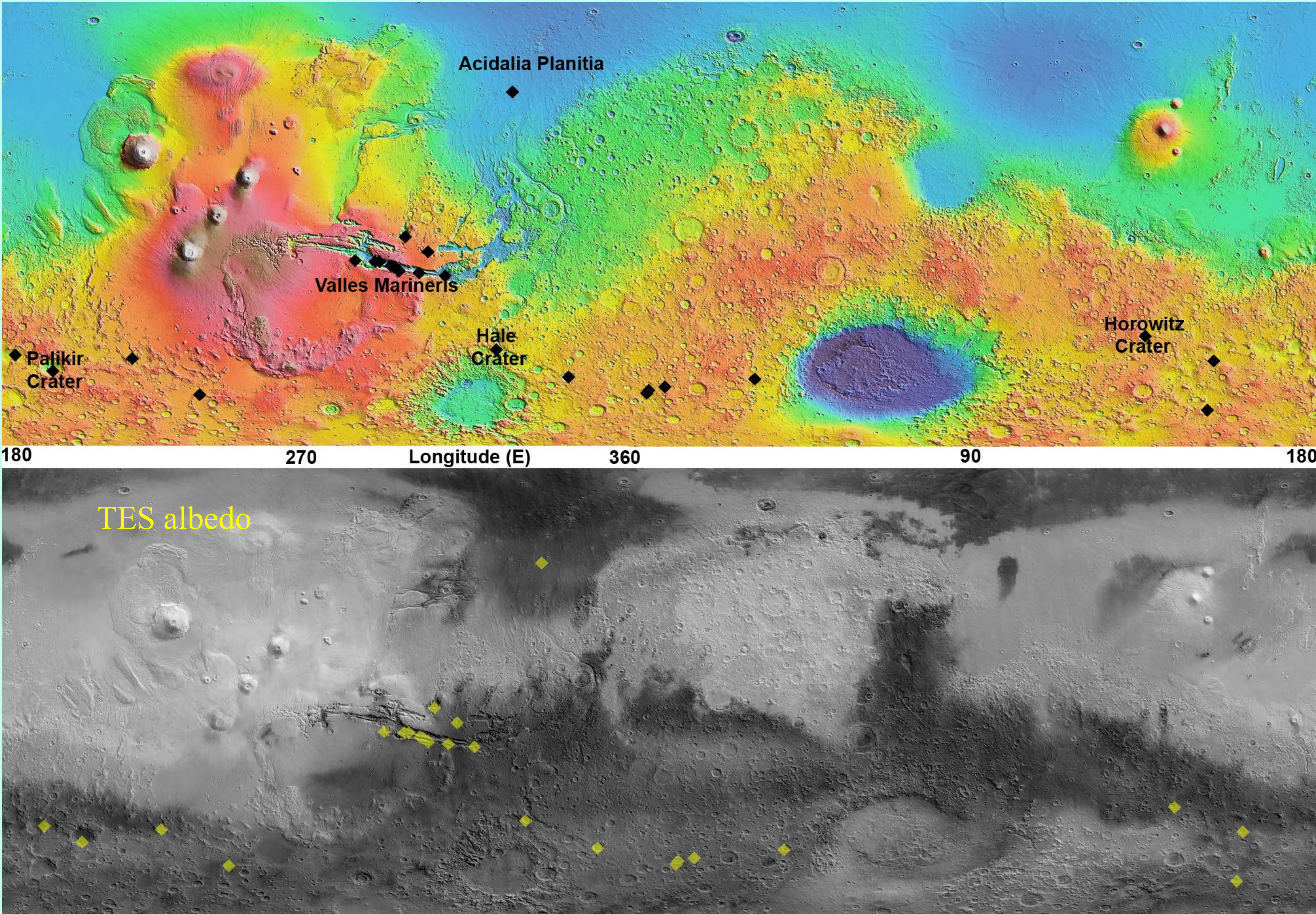


Juventae Chasm

Slumping associated with RSL first seen inGarni crater on the floor of Melas Chasm (34672_1685 and 35028_1685)



2013 Map of "fully confirmed" RSL sites
(observed incremental growth, fading, and recurrence of many (>10) flows on a slope)



Global compilation of RSL sites and candidate sites

D.E. Stillman et al./Icarus 285 (2017) 195–210 197

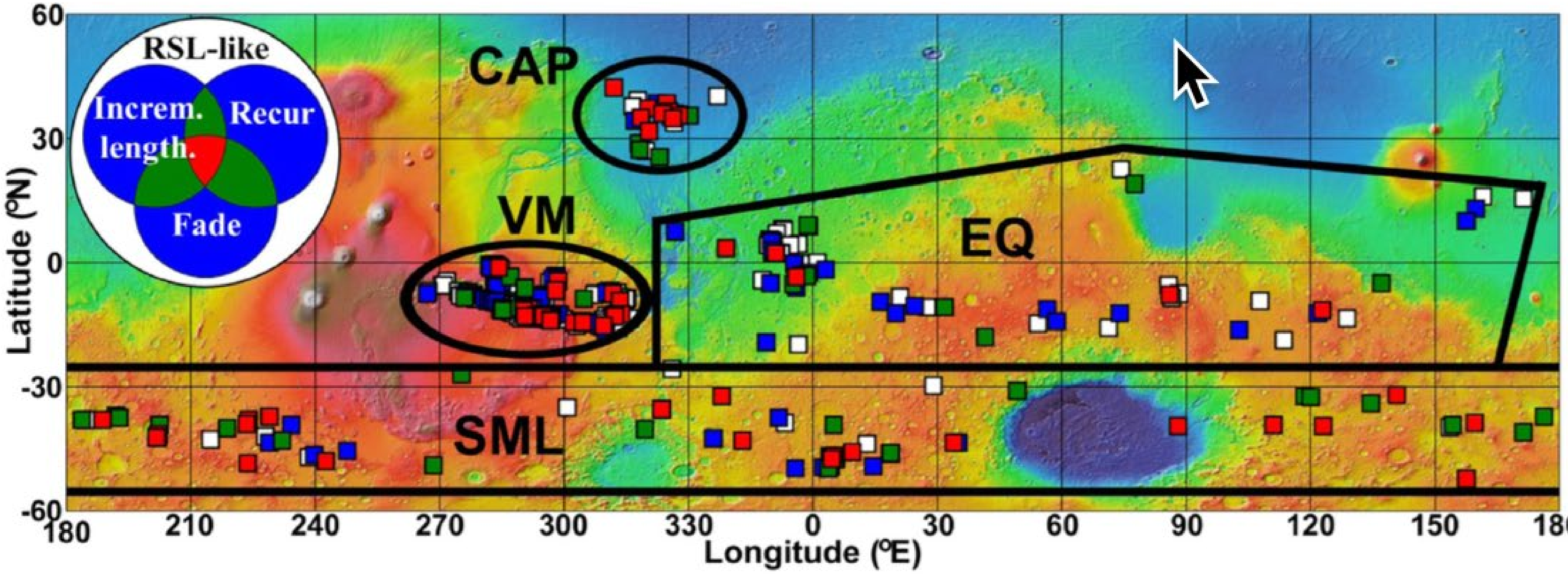


Fig. 1. Global distribution of RSL sites and the four RSL regions from 60°N to 60°S. Background is shaded relief Mars Orbiter Laser Altimeter (MOLA; onboard Mars Global Surveyor) colorized elevation.

Prior to MY34, there were at least 748 confirmed, partially 95 confirmed, or candidate RSL sites (Stillman, 2018)

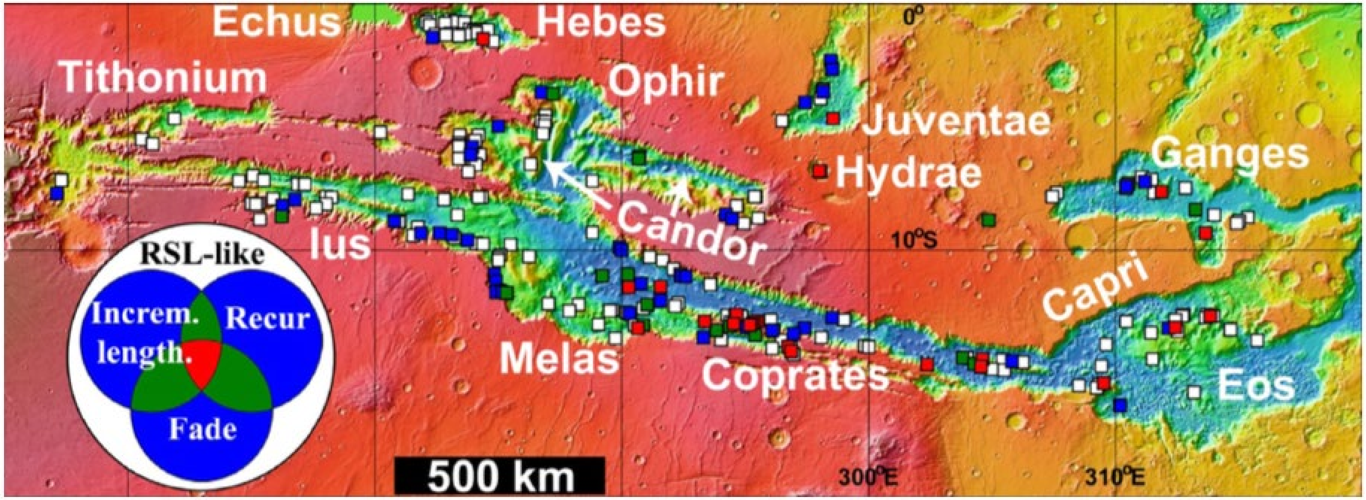
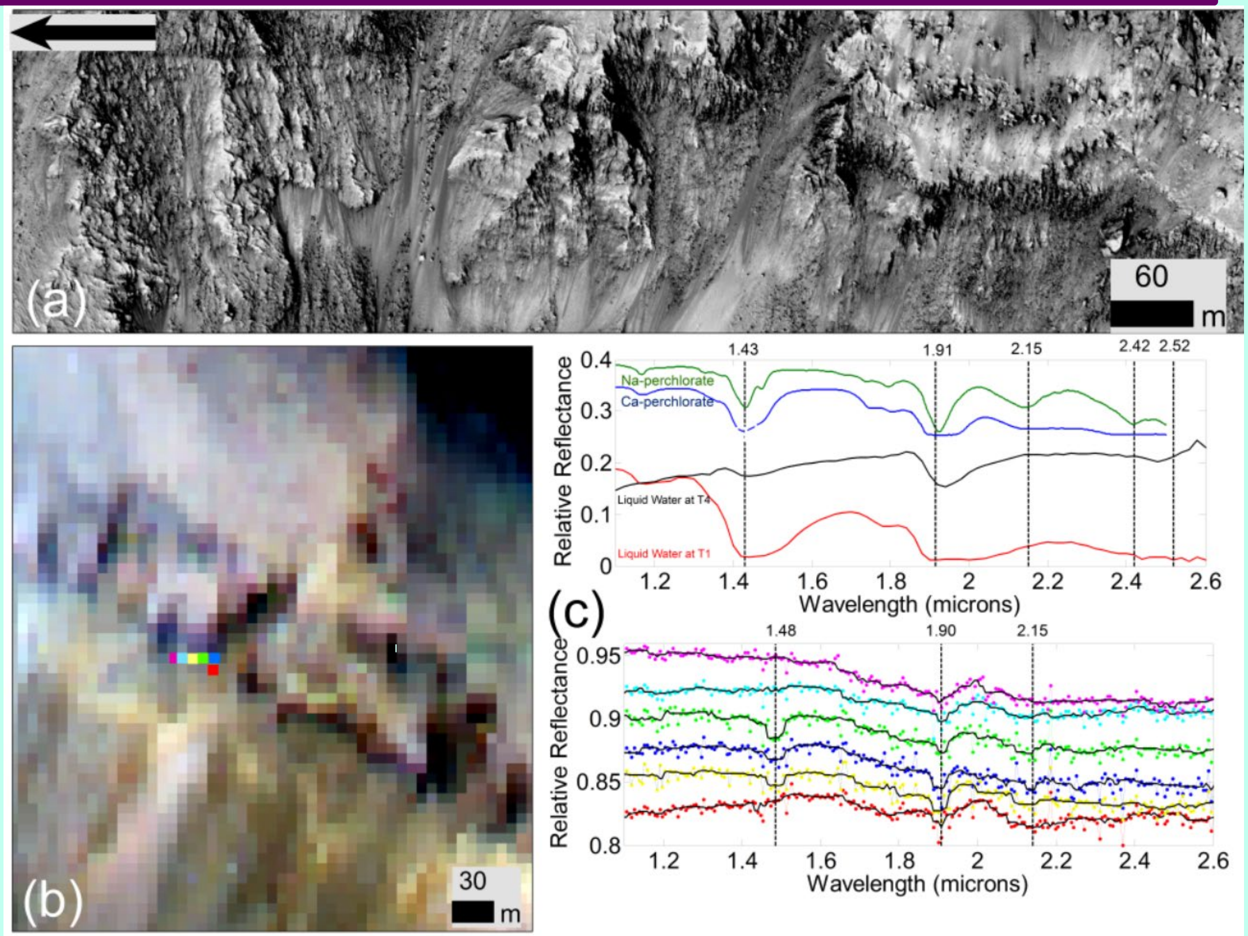


Fig. 2. Valles Marineris RSL are found in every major canyon except Echus. Background is shaded relief MOLA colorized elevation.

CRISM Results for RSL

- RSL fans have ferric and ferrous absorptions that deepen when RSL are active (Ojha et al. 2014)
  - Multiple interpretations
- Hydrated perchlorates at some RSL sites (Ojha et al., 2015)
  - Lots of news media attention

Update: Absorptions at 1.9 and 2.15 microns are data processing artifacts (Leask et al. 2018)



Palakir crater

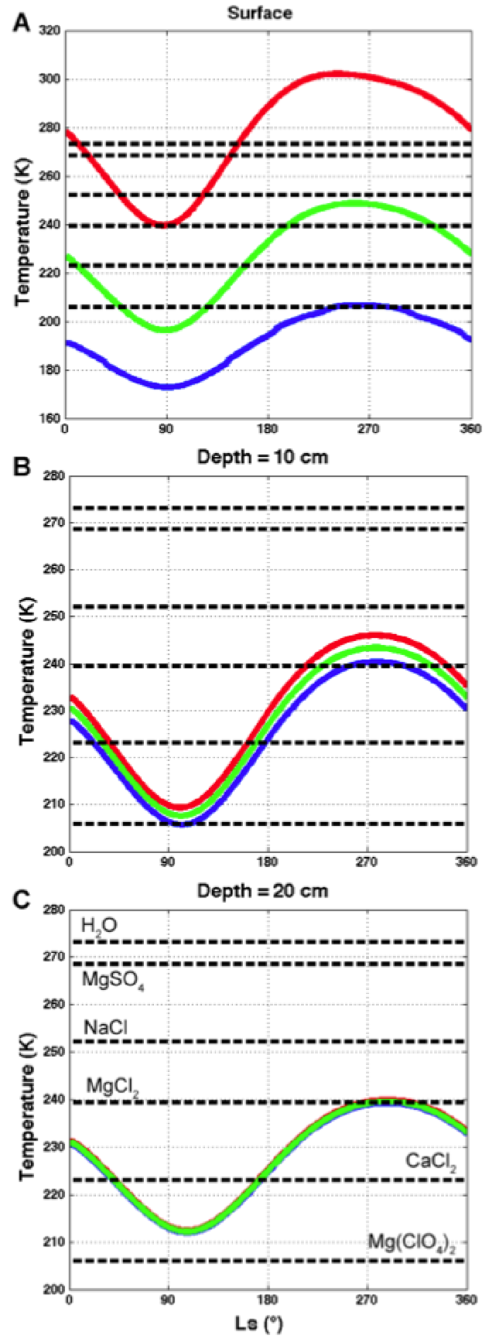
Melting frozen brines from a past climate

(Chevrier and Rivera-Valentine, 2012)

Model explains a number of observations for mid-latitude RSL

Peak RSL activity corresponds to peak Ts in shallow subsurface, not at the surface

Problem: Hard to explain how ice could still be present in equatorial regions, or on equator-facing slopes in mid latitudes.



[*Zent et al.*, 2010]. A soil-ice mixture is assumed to exist at varying depths using the properties from *Kereszturi and Rivera-Valentin* [2012] following the method of *Mellon et al.* [2004]. Surface evaporation rates were modeled using a diffusion-buoyancy equation [*Ingersoll*, 1970], modified to include the effect of water activity [*Altheide et al.*, 2009; *Chevrier and Altheide*, 2008; *Chevrier et al.*, 2009]. Evaporation in the subsurface includes the effects of diffusion-advection in the regolith [*Ulrich*, 2009].

[6] Results were compared to the eutectic temperatures of various salts relevant to Mars: $MgSO_4$ (a_{H2O} = 0.96, T_E = 268.6 K), NaCl (a_{H2O} = 0.82, T_E = 252.2 K), $MgCl_2$ (a_{H2O} = 0.72, T_E = 239.5 K), $CaCl_2$ (a_{H2O} = 0.62, T_E = 223.2 K), $Mg(ClO_4)_2$ (a_{H2O} = 0.55, T_E = 206 K). Magnesium sulfate has been widely observed on Mars [*Gendrin et al.*, 2005], whereas chlorides have been identified in the southern highlands [*Osterloo et al.*, 2008], where the RSL are observed. Finally, perchlorate has recently been identified by the Phoenix lander and magnesium perchlorate exhibits one of the lowest eutectic temperature of all salts [*Chevrier et al.*, 2009; *Hecht et al.*, 2009]. Although this is not an exhaustive selection, we focused on a wide range of water activities and corresponding eutectic temperatures. Most other possible salts have eutectics similar to those studied here. For example, the eutectic of ferric sulfate is very close to Mg-perchlorate, whereas ferrous sulfate's is similar to Mg-sulfate.

3. Results

[7] Latitudes between 30° and 50°S were modeled recording results for depths of 0 (surface) 10, and 20 cm to allow for temperature cycling. Modeled temperatures for equator-facing slopes reach a maximum of ~300 K at 30°S and 270 K at 50°S, while poleward slopes reach only 210 to 180 K respectively (auxiliary material, Figures S1a–S1c). Hence, equator-facing slopes experience maximum temperatures high enough for various salt-ice mixtures to melt, even at depth. Poleward slopes are too cold for seasonal melting to occur except for the lowest eutectics. These results correlate well with observations of RSL on equator-facing slopes, whose surface brightness temperatures were as high as 300 K [*McEwen et al.*, 2011].

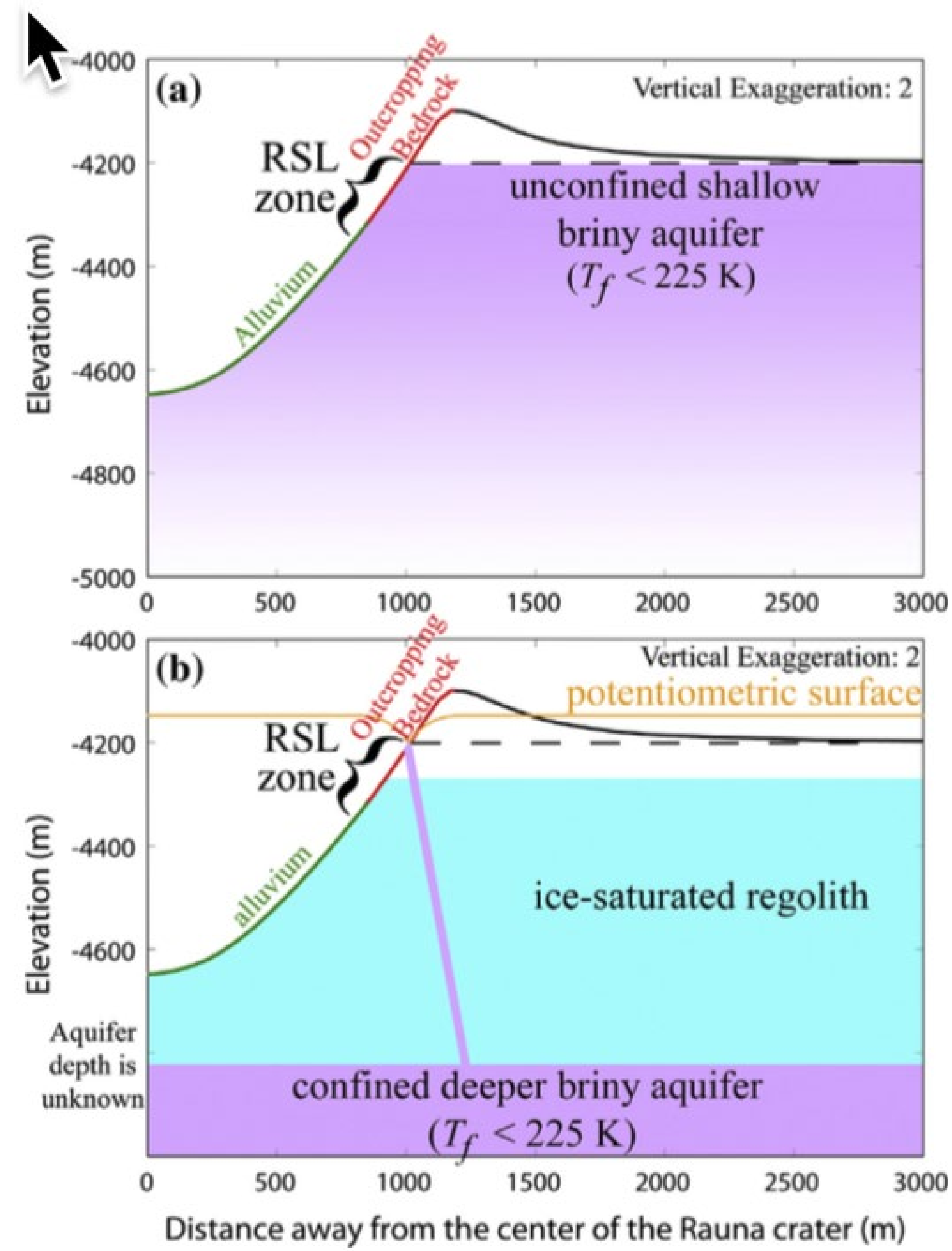
[8] Diurnal variations in surface temperature allow melting and freezing for virtually any brine; however, at lower depths, only $MgCl_2$, $CaCl_2$, and $Mg(ClO_4)_2$ solutions can melt (Figures 1a–1c). Water, $Mg(SO_4)$, and NaCl systems only melt if close to or on the surface. All salt systems are frozen for at least part of the winter, so melting is only a seasonal process, except for some limited diurnal melting on the surface. Most of the confirmed RSL were observed in

Figure 1. Modeled temperatures of surface and shallow subsurface as a function of depth, and solar longitude at latitude 40° south and for a 35° equator-facing slope: (a) surface, (b) 10 cm deep, and (c) 20 cm deep. Figures 1b and 1c were made with ice cemented soil at the given depth. Red: maximum, blue: minimum and green: average yearly temperatures. Horizontal dashed lines represent eutectic temperatures for several salts, from top to bottom: Water (T_E = 273.16 K), $MgSO_4$ (T_E = 268.6 K), NaCl (T_E = 252.2 K), $MgCl_2$ (T_E = 239.5 K), $CaCl_2$ (T_E = 223.2 K) and $Mg(ClO_4)_2$ (T_E = 206 K).

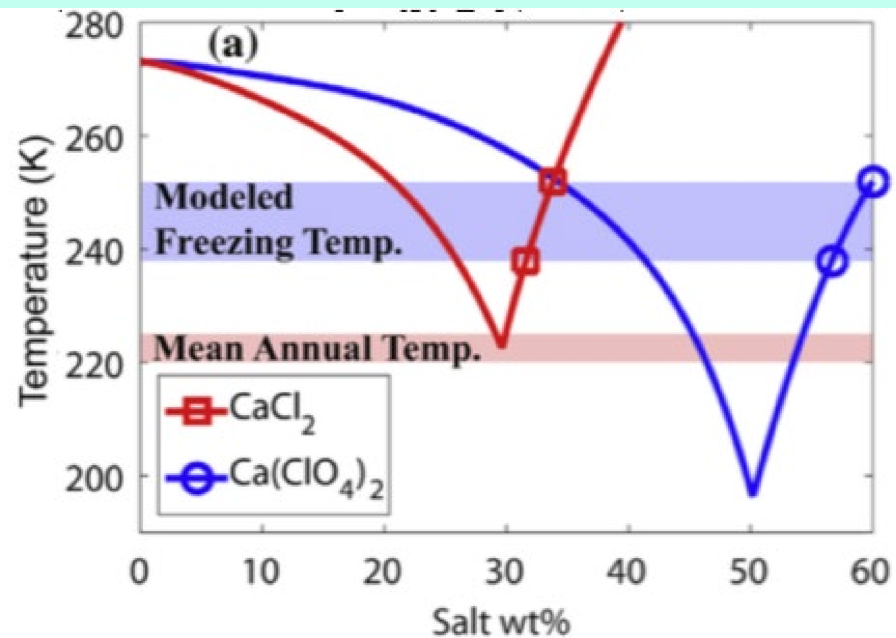
Ice replenished by vapor phase transport (Grimm et al., 2014)

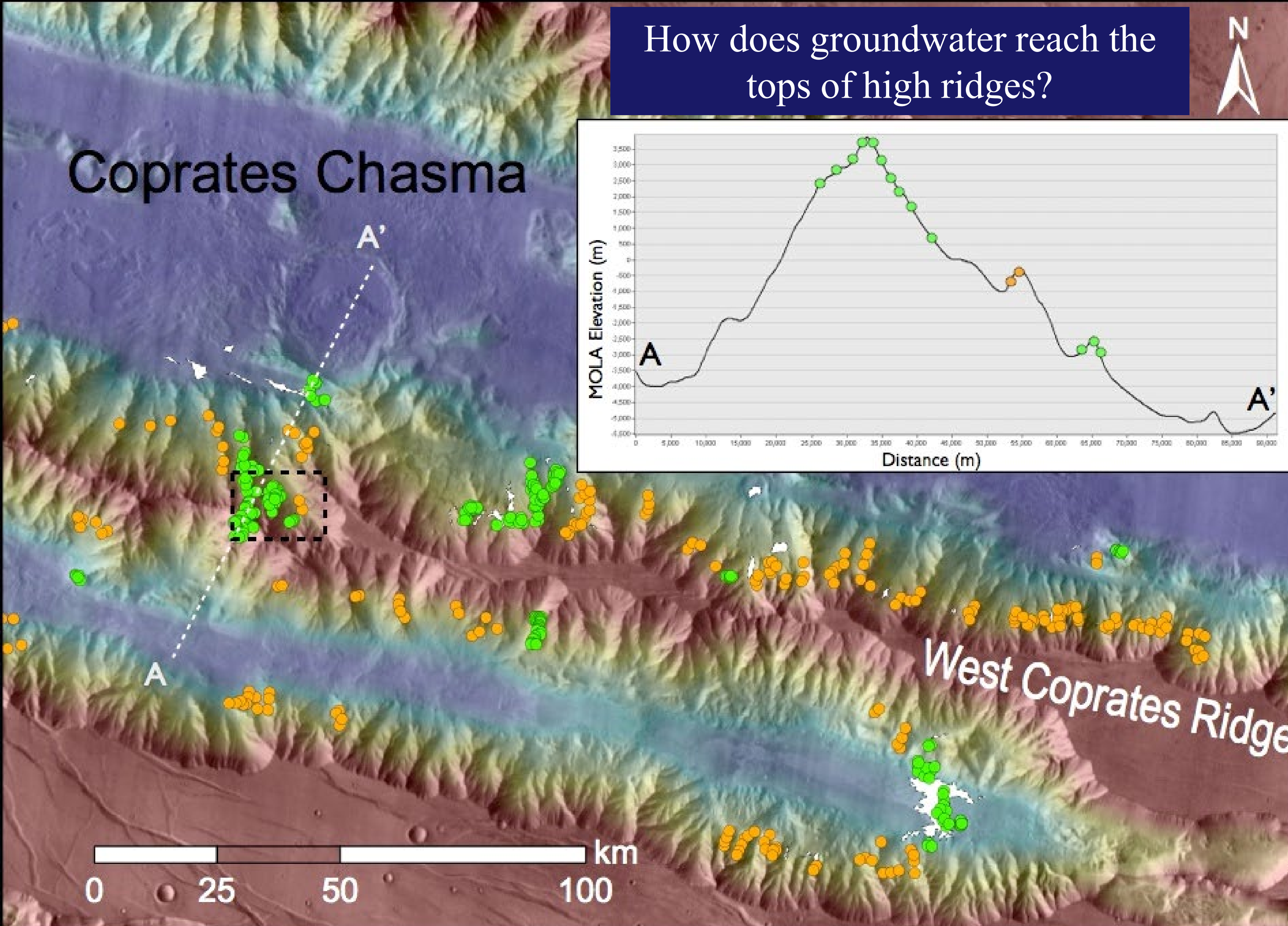
- Annual recharge by vapor cold trapping might be supplied from the atmosphere or subsurface.
  - They explored but did not favor this model
- Problems:
  - Atmosphere is extremely dry
  - Vapor transport in subsurface is extremely slow (Hudson et al.)
    - Cannot recharge yearly if RSL are from seeping water
    - Maybe this would work is RSL are only active for a few years, then take >10^3 years to recharge ice
  - Struggles to explain long RSL given evaporation rate of water at the hottest times

Groundwater Seepage



Stillman et al., 2016:
"the most plausible RSL source is a briny aquifer with a freezing temperature less than or equal to the mean annual CAP surface temperature (220–225 K)."
CAP = Chryse and Acidalia Planitia





HiRISE RSL CTX Potential RSL

Chojnacki

03-13-2015

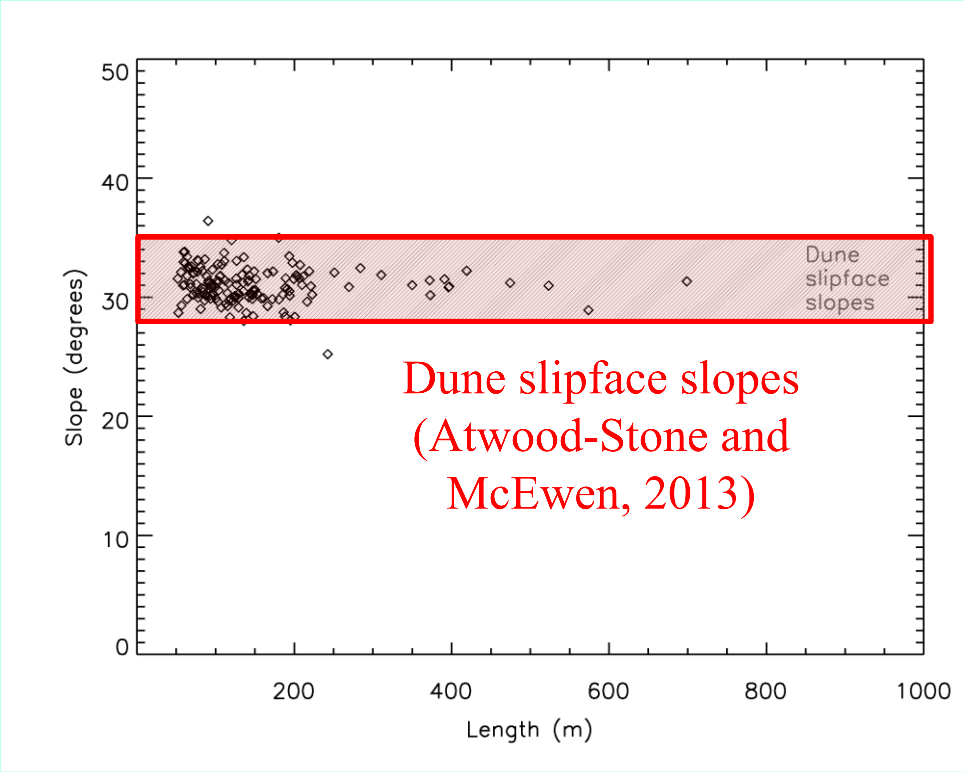
HiRISE

Where could water come from?

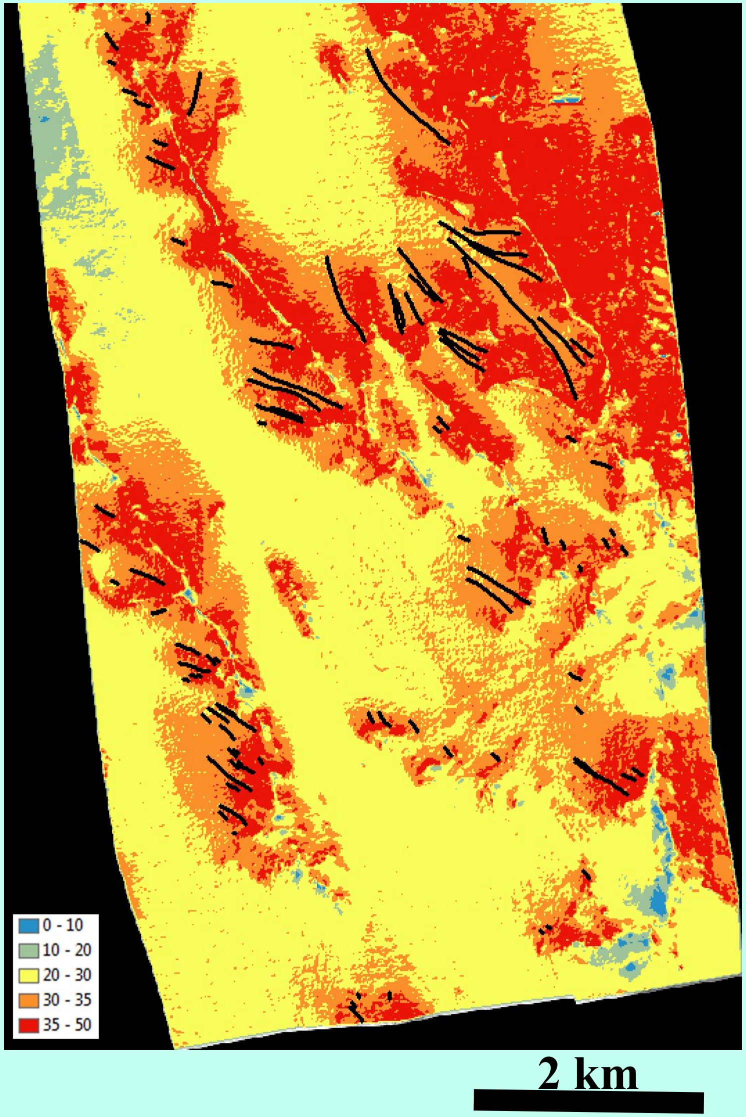
- Water (as a liquid) is extremely limited on Mars today
- Origin of mid-latitude gullies was misunderstood for >10 years after the initial discovery;
- RSL may have also been largely misunderstood for nearly a decade
  - Recent evidence points to dry flows of sand and dust

RSL as granular flows?

(Dundas et al., 2017)

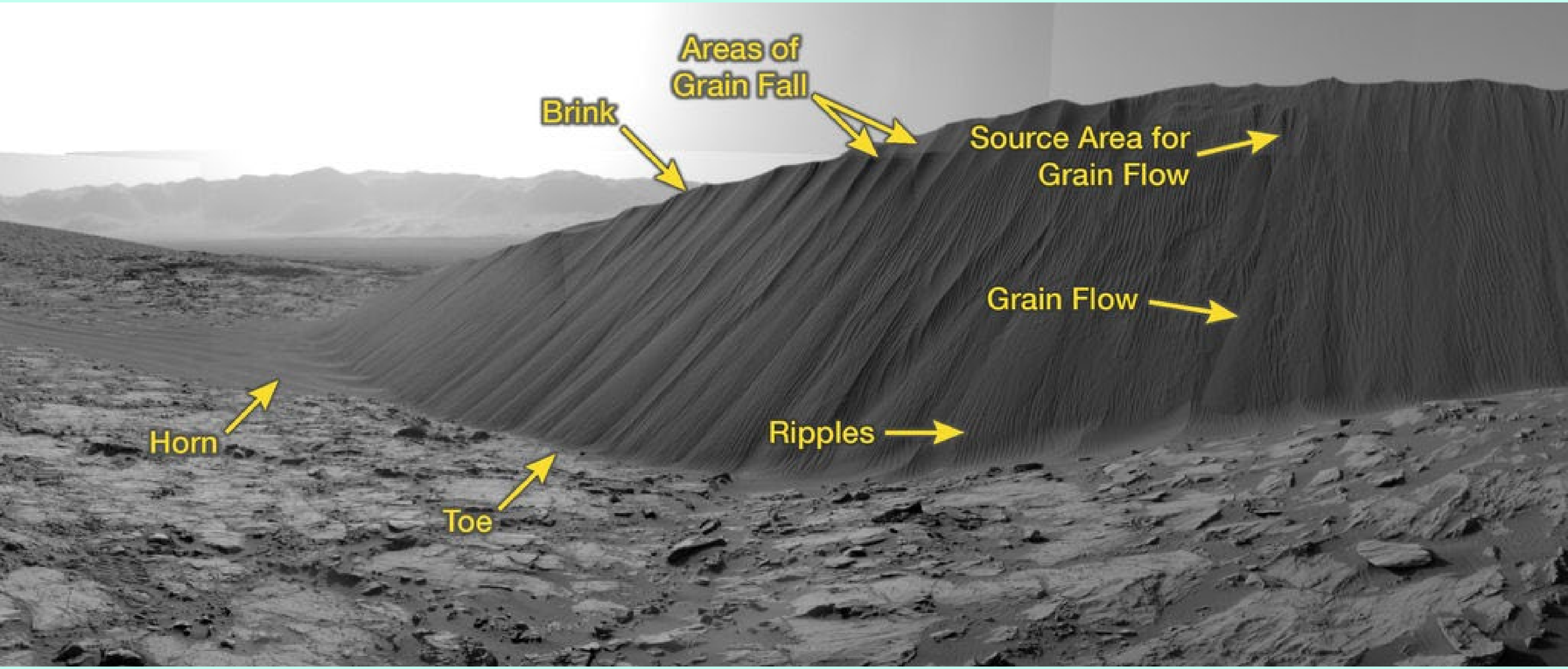


RSL terminal slopes are identical to Martian (and terrestrial) dune slipface slopes.



RSL length controlled by available steep slopes.

Grainflow on Dune slip faces

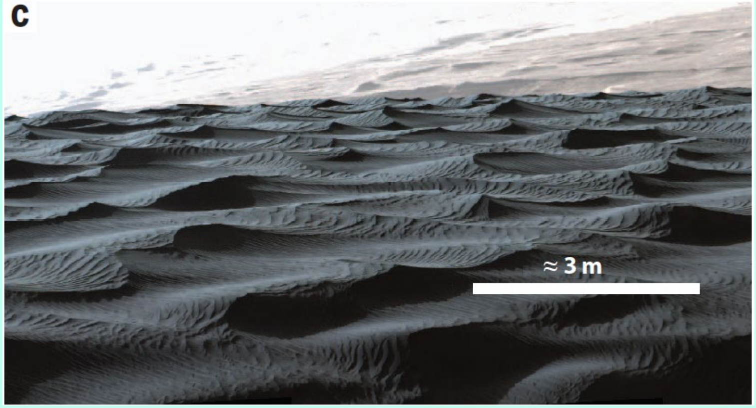


Bagnold dunes images by MSL.

Image: NASA/JPL/MSSS

Recirculating flow

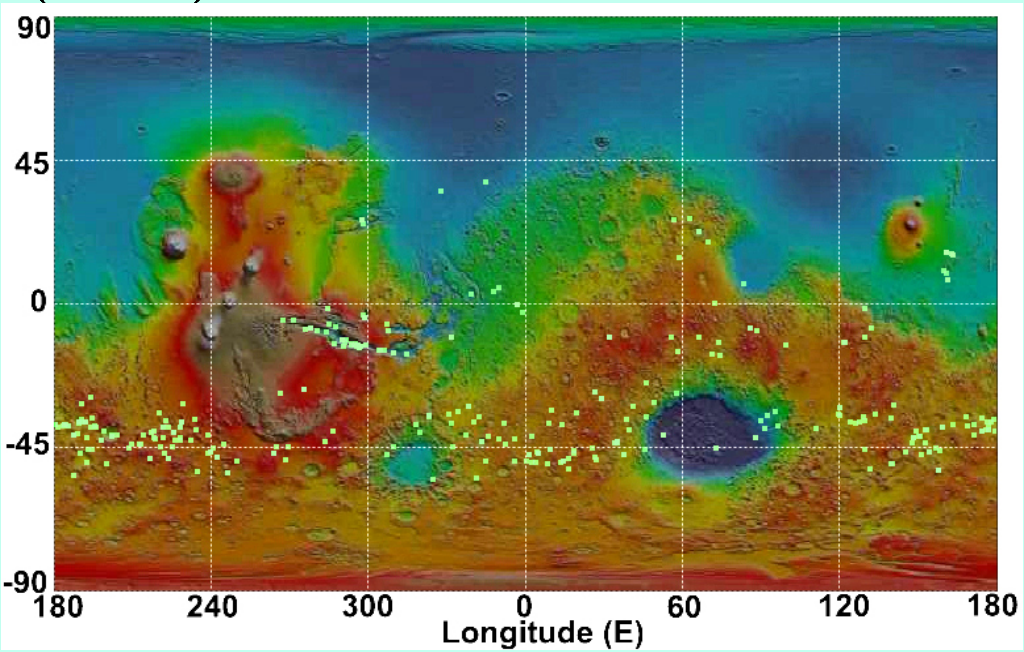
- Observed on some RSL fans (Chojnacki et al., 2016).
- Ripples may be unresolved on other fans.



Lapotre et al., 2016

Mars: Abundant Recurring Slope Lineae (RSL) Following the Planet-Encircling Dust Event (PEDE) of 2018

- Following the great dust storm of 2018, many more candidate RSL were seen than in typical Mars years.
- These RSL sites usually show evidence for recent dust deposition.
- There are clear dust devil tracks in 73% of post-storm images in the southern middle latitudes in the summer, where and when dust devils are most active.
  - The tracks indicate dust lifting, by several mechanisms.
- We suggest that dust lifting processes on steep slopes may initiate and sustain RSL formed from flows of dust (perhaps clumped) and/or sand that is destabilized by dust lifting.
- The otherwise puzzling recurrence and year-to-year variability of RSL activity can be explained by variable yearly dust fallout.



Map of post-PEDE image locations with candidate RSL acquired in MY34, L_s 234-360° (8/2018 to 3/2019). The latitudinal distribution is wider than in prior years within this L_s range. Basemap is Mars Orbiter Laser Altimeter (MOLA) colorized elevation over shaded relief.

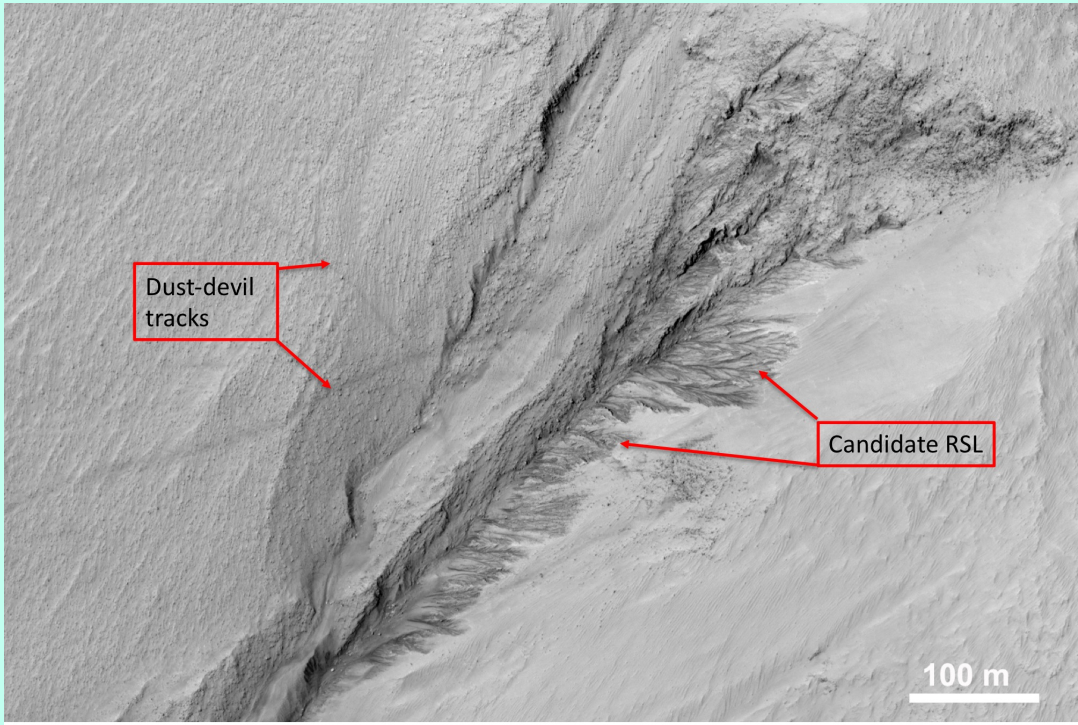
150 RSL sites in southern mid latitudes in MY34, vs 36/yr average in prior MYs.

McEwen et al. (2021), JGR-Planets, doi: 10.1029/2020JE006575

Dust Lifting Mechanisms

Four important dust lifting processes associated with dust devils (Neakrase et al. 2016):

1. Wind entrainment, aided by formation of dust aggregates.
2. Thermo-luminescent lifting, important at low atmospheric pressures (i.e., not effective on Earth).
3. Pressure drop in the core of a vortex (the delta-P effect).
4. Electrodynamics, as the electric forces produced by atmospheric turbulence can be the same order of magnitude as gravitational forces.



Most atmospheric vortices do not produce tracks resolvable from orbit, or even by landers.

Summary and Conclusions

The Scientific Method at Work

- First we discovered something new (RSL)
- Then we formulated multiple working hypotheses
- Then we tested those hypotheses
  - The surviving hypotheses were not our initial favorites
  - None of the wet hypotheses have survived, in my opinion
  - Not ruled out: RSL are dry flows of dust and/or sand triggered by dust lifting processes on steep slopes
    - Warm temperatures favor dust lifting mechanisms

Does this mean RSL can be removed as markers for potential Special Regions?

- Based on the history of studies about martian gullies and slope streaks, wet interpretations will continue to be published for decades

Figure 5. Bright dust devil tracks (black arrows) over candidate RSL in Eos Chasma, observed post-MY34 PEDE (ESP_062917_1640, MY35 Ls 127º).

Terrestrial analog study: tracks are relatively bright because the surface is smoother.