Testing possibilities at Earth analogues

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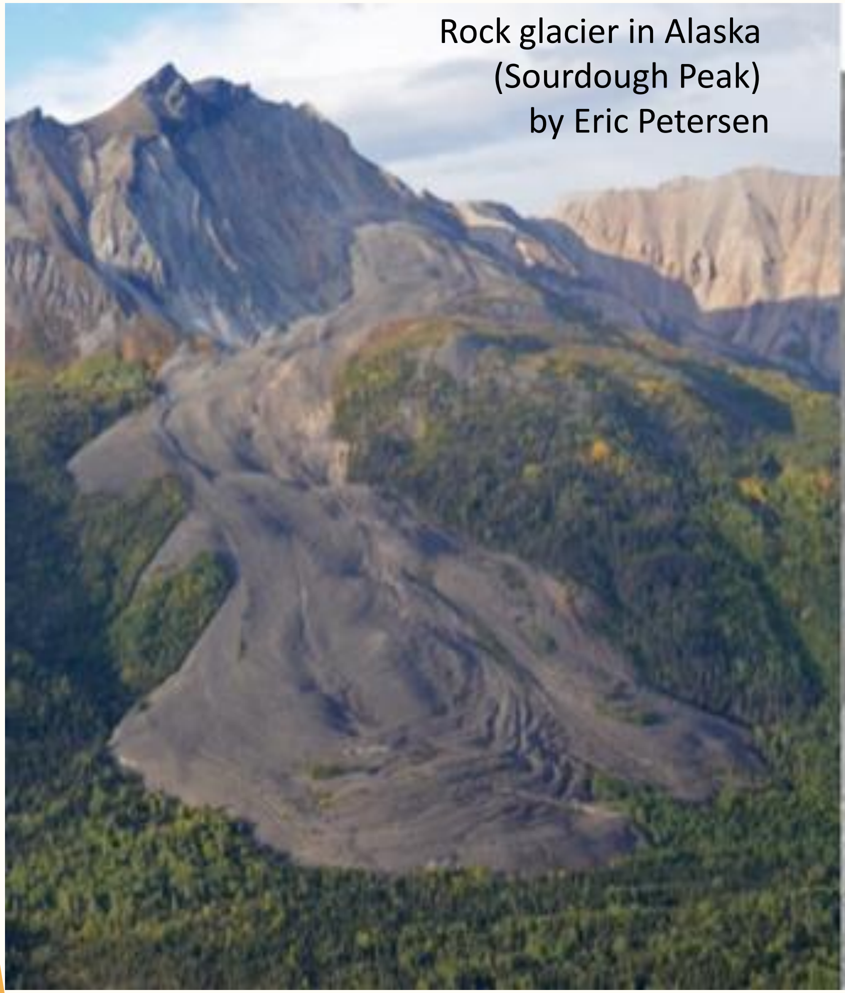
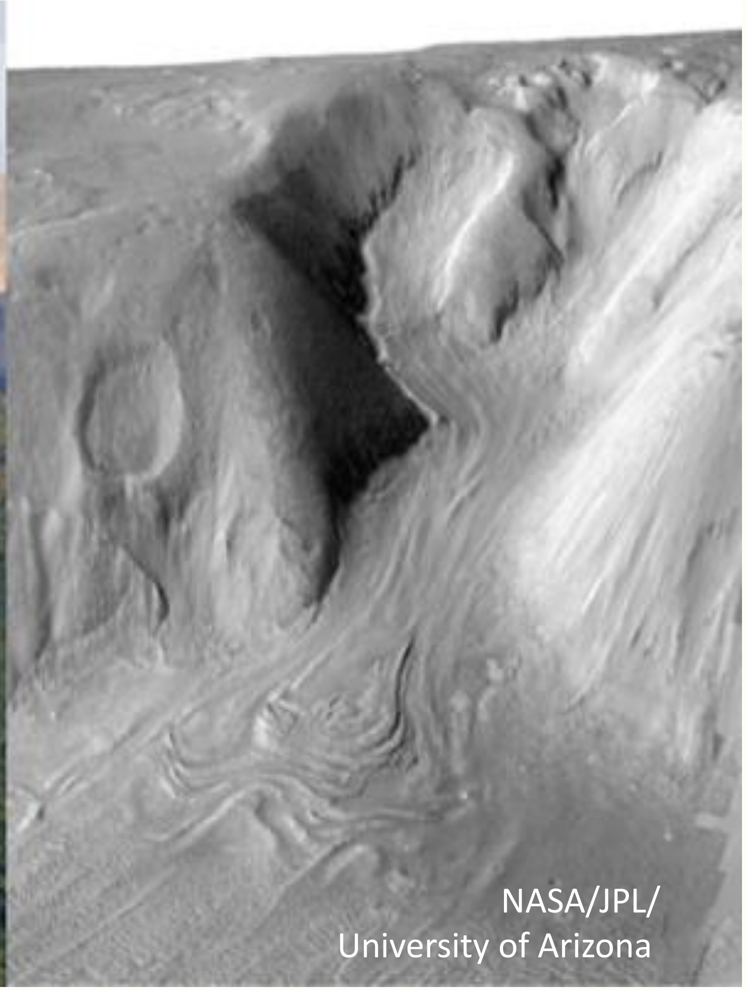
Field tests

- Small-scale testing: ice/rock interfaces (terrestrial glaciers)
- Full-scale testing: water table, geological interfaces, environmental conditions, etc.(Moroccan Sahara)

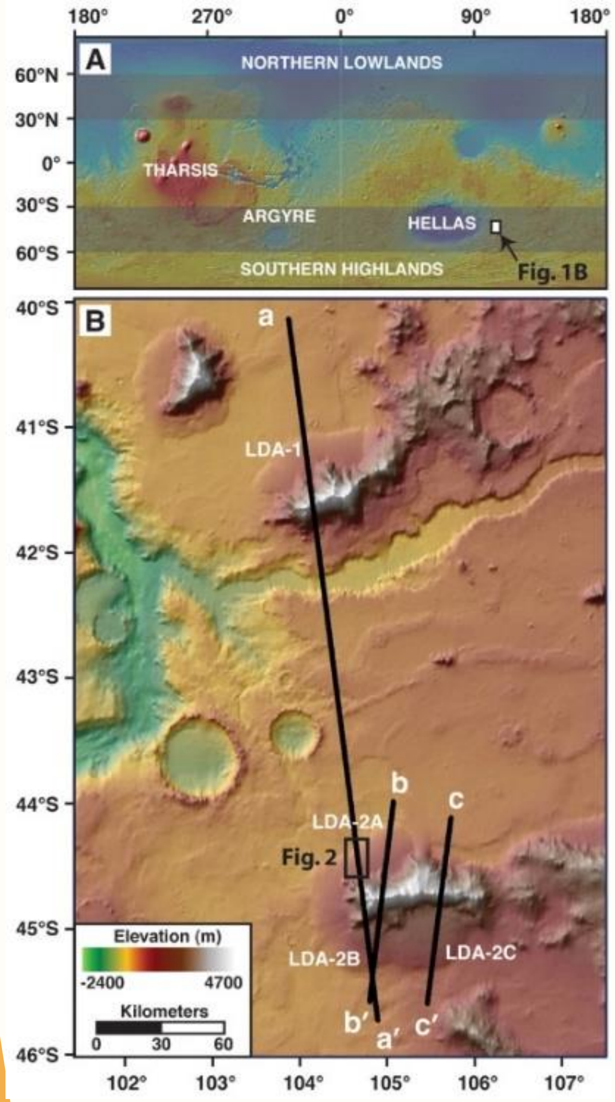
Viscous flow features (VFFs) on Mars mid-latitudes and their importance

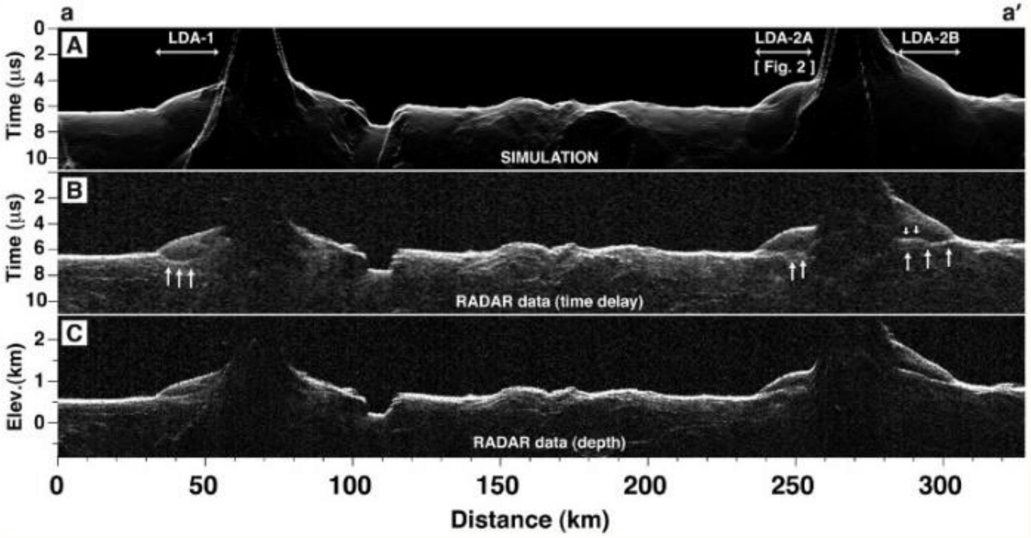

Rock glacier in Alaska
(Sourdough Peak)
by Eric Petersen

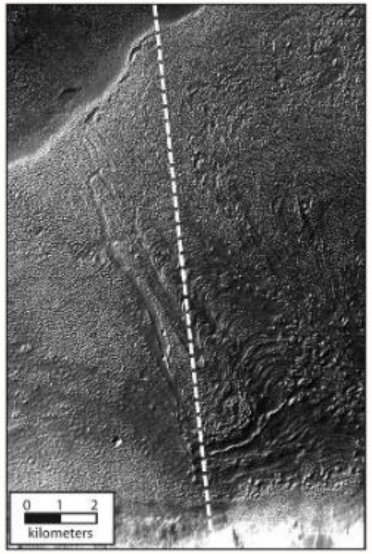

NASA/JPL/
University of Arizona

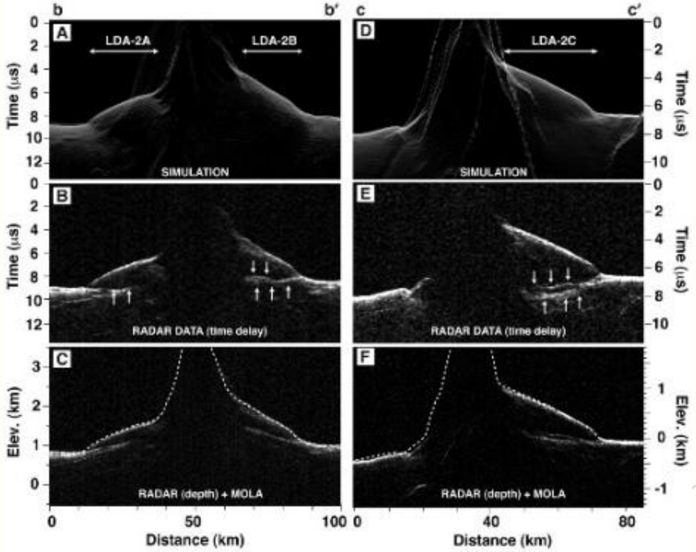
Rock glacier in Dolomites
(San Pellegrino Pass)

VFFs on Mars – rock glaciers or debris-covered glaciers (DCG)? Investigations with radars







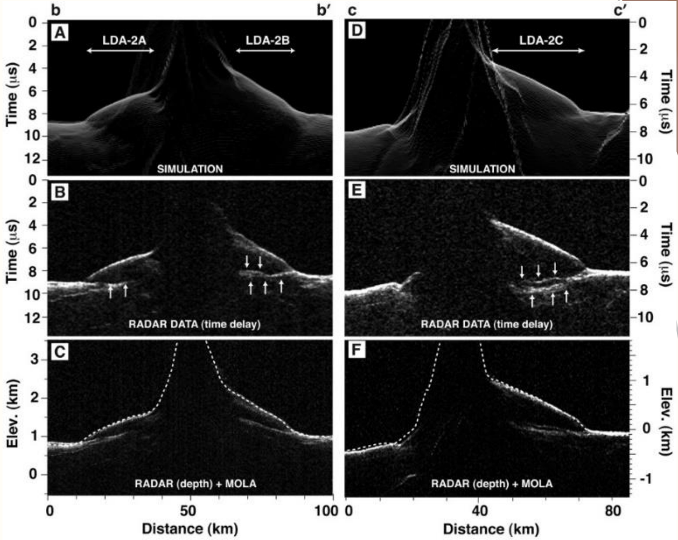


SSHARAD → pure water ice (>80%)

below insulating rocks

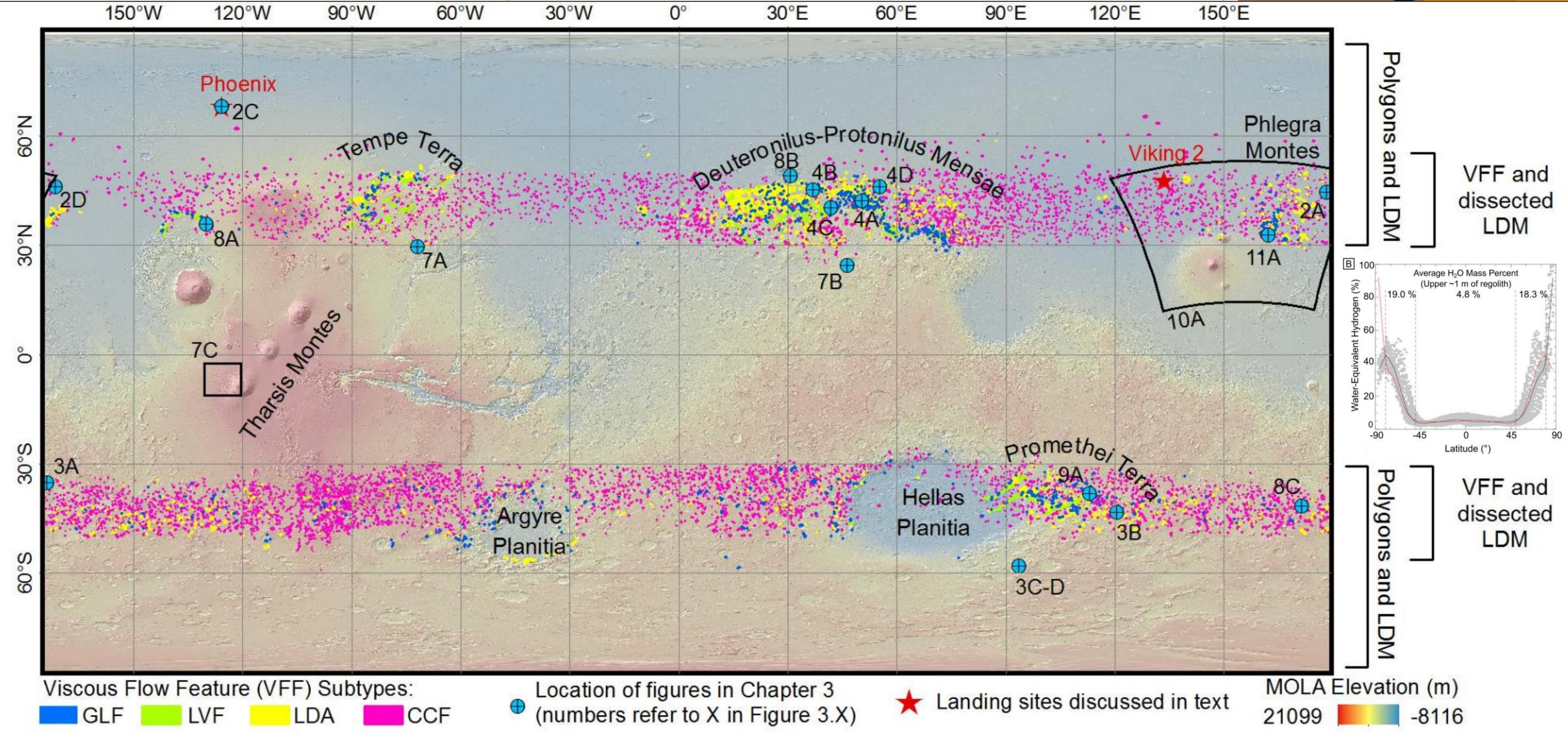
The thickness of debris-cover

- minimum dust thickness at GLF #947 located in the north wall of Crater Greg, eastern Hellas, → some dm (Hubbard et al., 2011)
- recent impact → ~clean ice at a depth of 1-10 dm (Byrne et al., 2009; Dundas and Byrne, 2010)
- permafrost → prevents dead-ice melting if the debris-cover > active layer

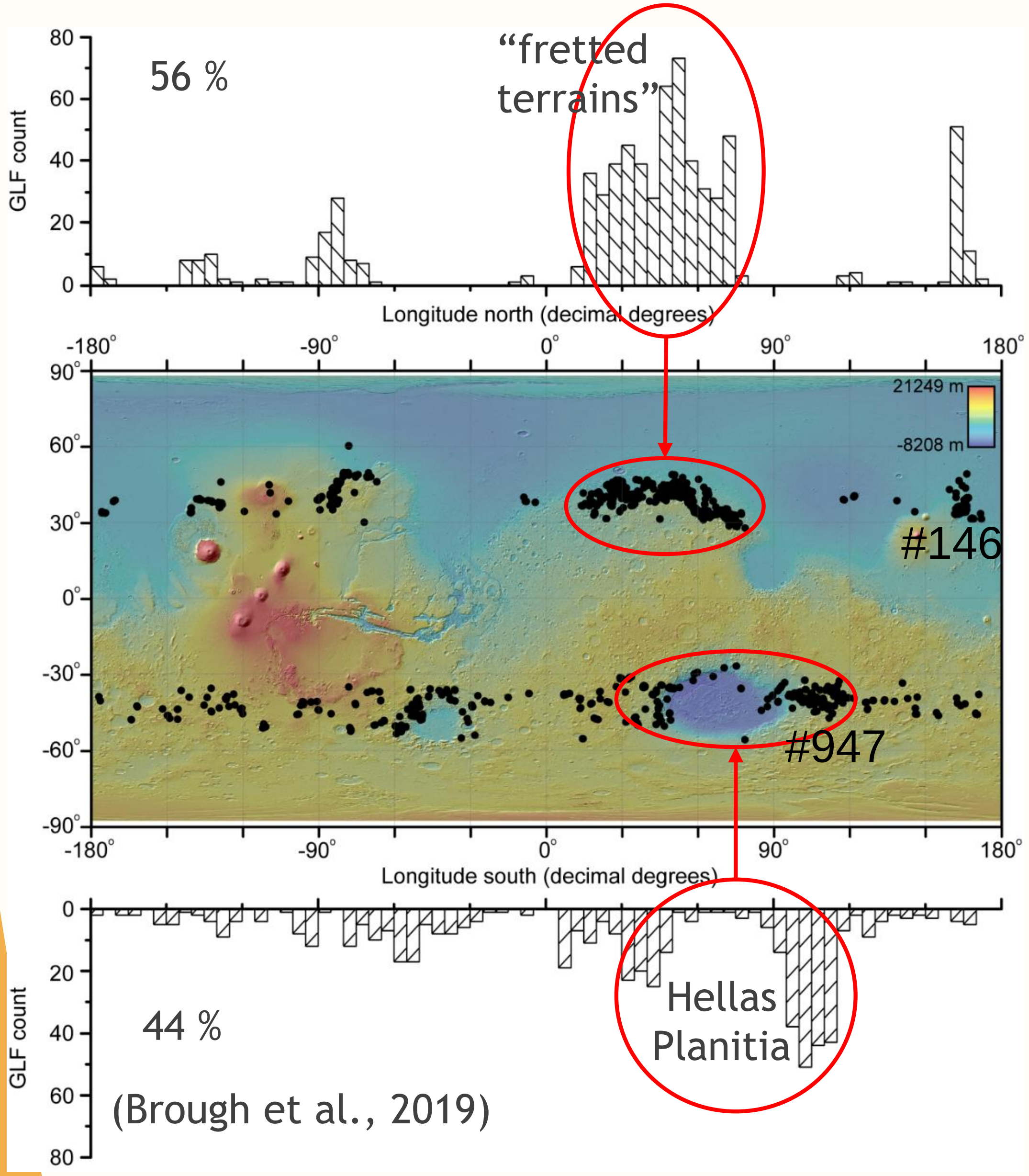


FlyRADAR

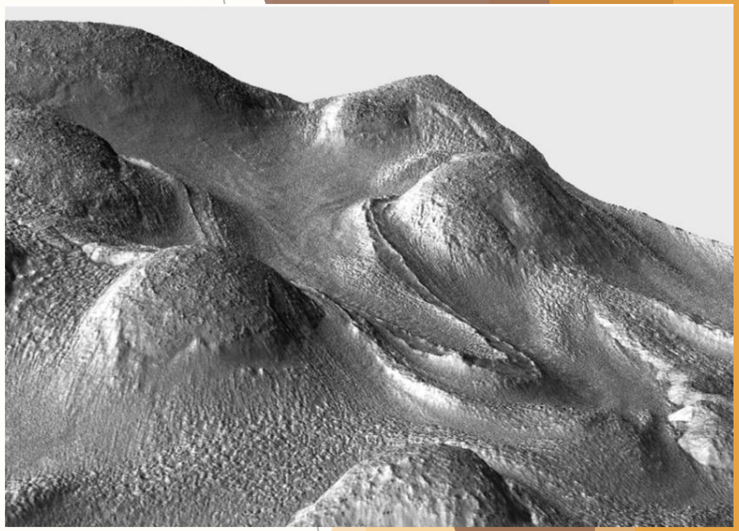
VFFs – relict non-polar ice reservoirs on Mars

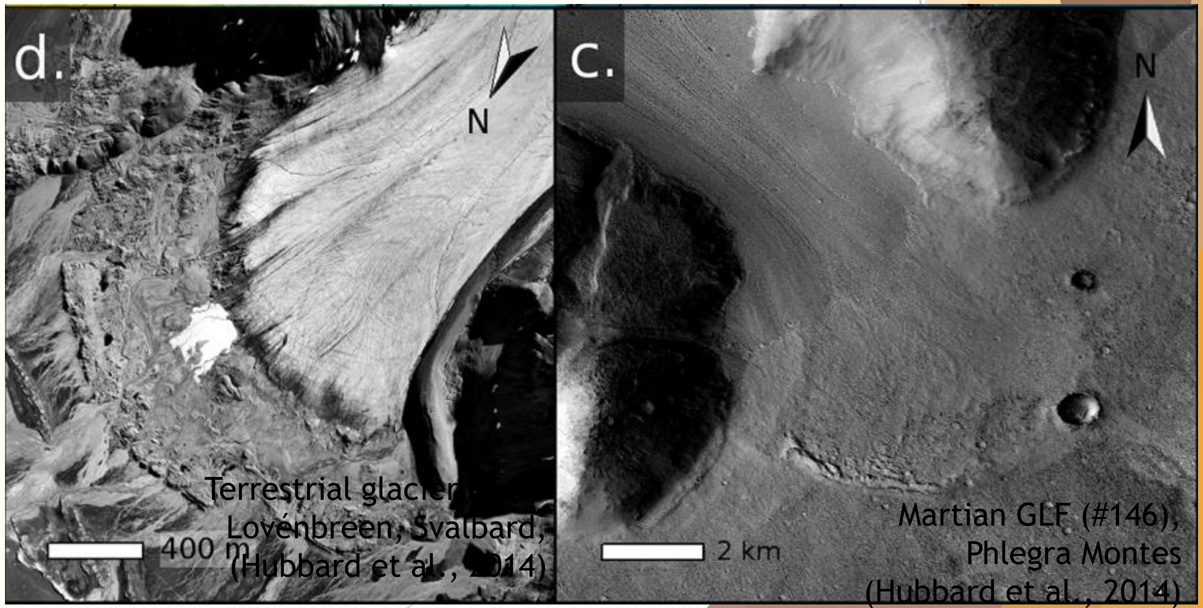


Glacier-like forms (GLFs)



- Latero-terminal ridges at a typical martian GLF (#947), Crater Greg, Promethei Terra (Hubbard et al., 2014)



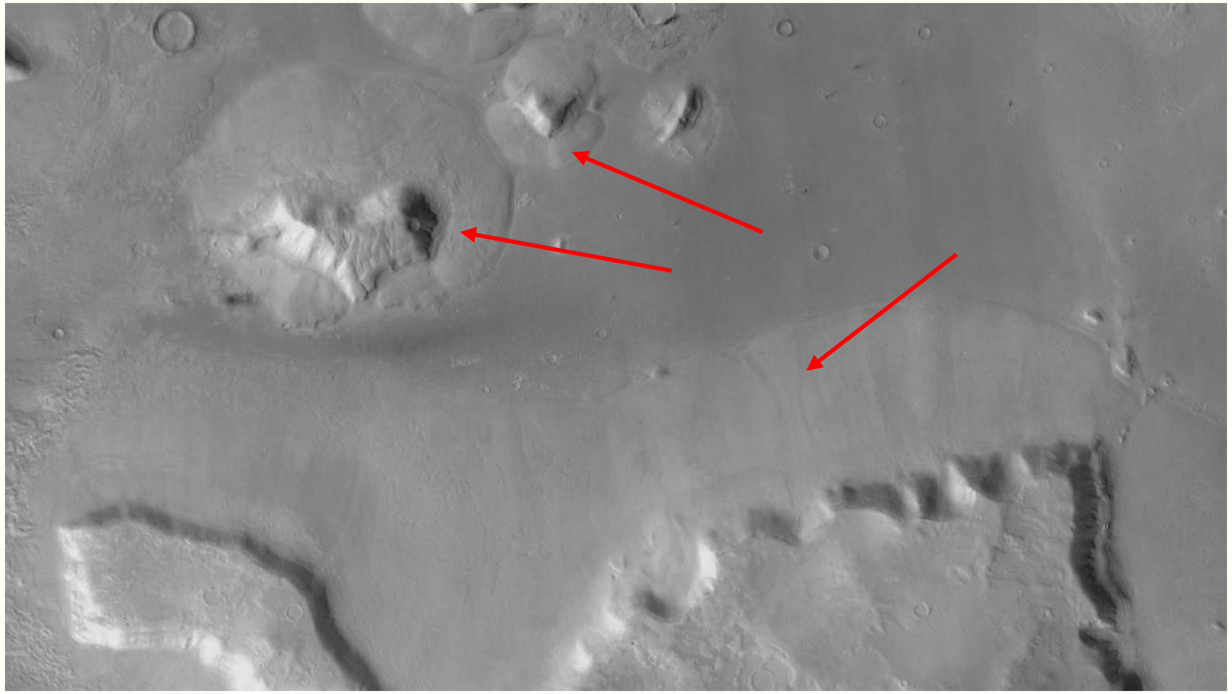


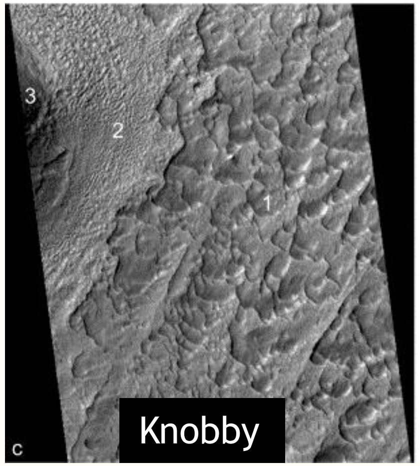
Lineated valley fill (LVF)

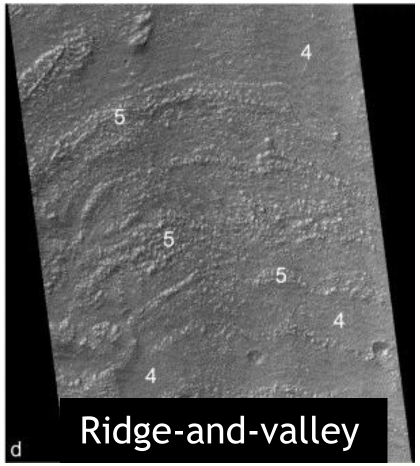
LVF morphologies that suggest past flow:

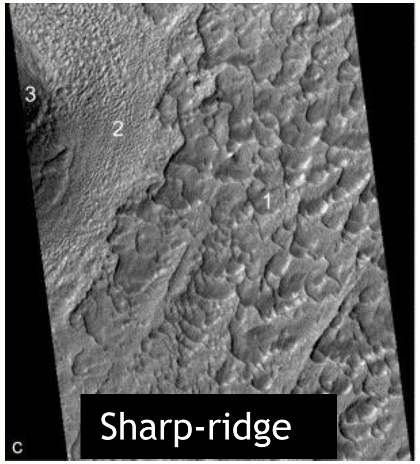
- valley-parallel lineations (Kochel and Peake, 1984)
- valley-transverse arcuate ridges that point downvalley
- down-valley deflection from mass wasting of confining valley walls
- a lack of evidence for lateral flow deflection of trunk LVF where they cross the mouths of tributary valleys containing contributory valley fill (Lucchitta, 1984)

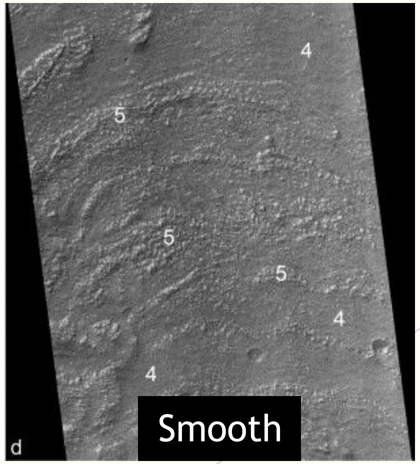
Lobate debris aprons (LDA)





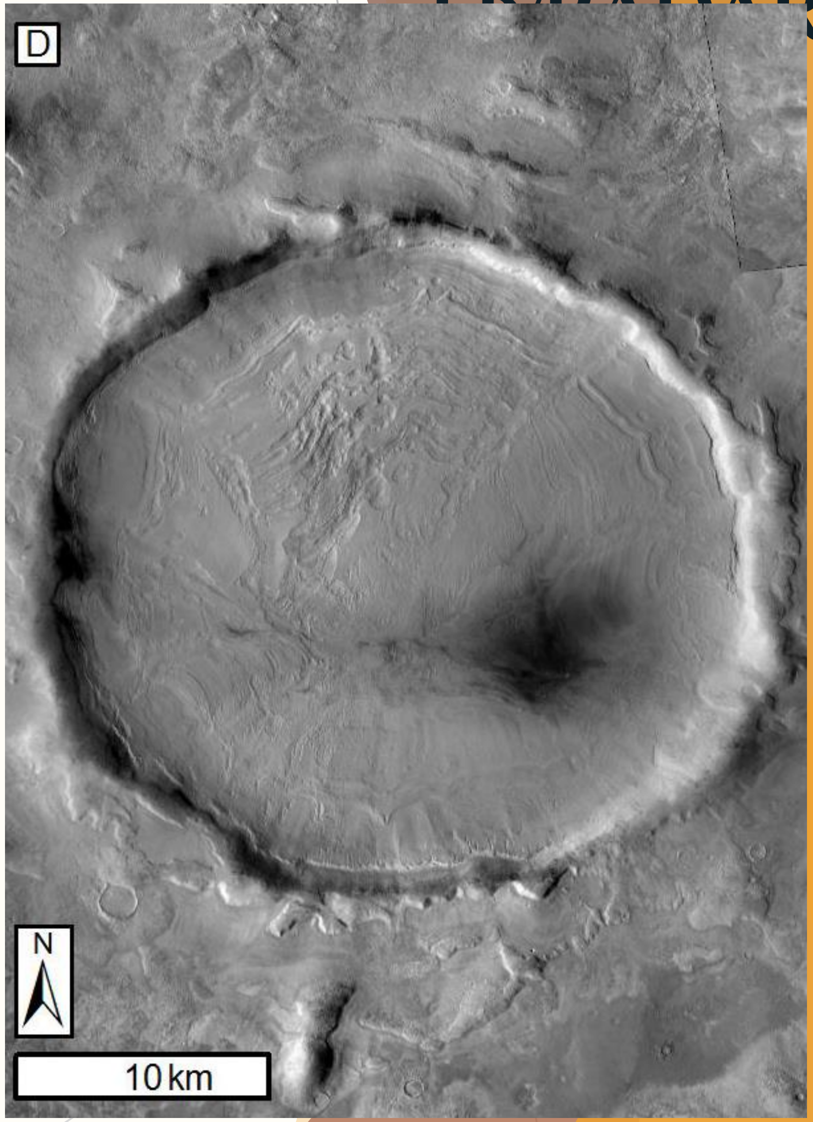




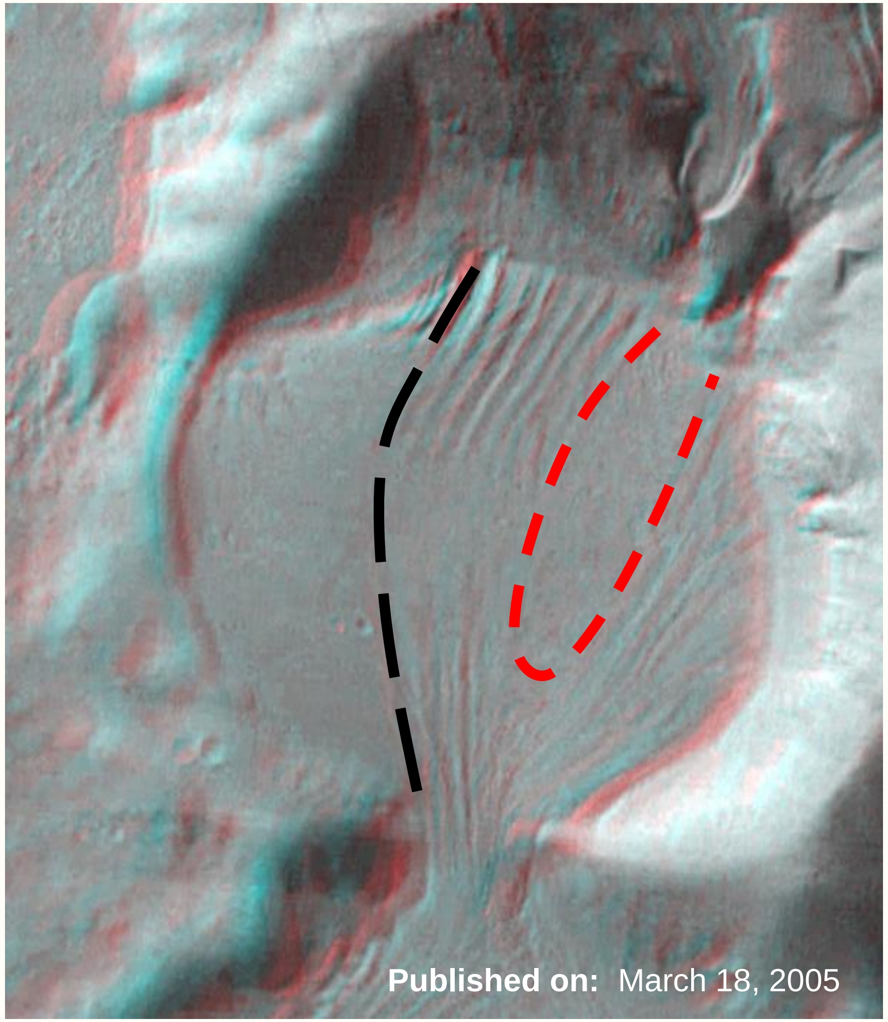


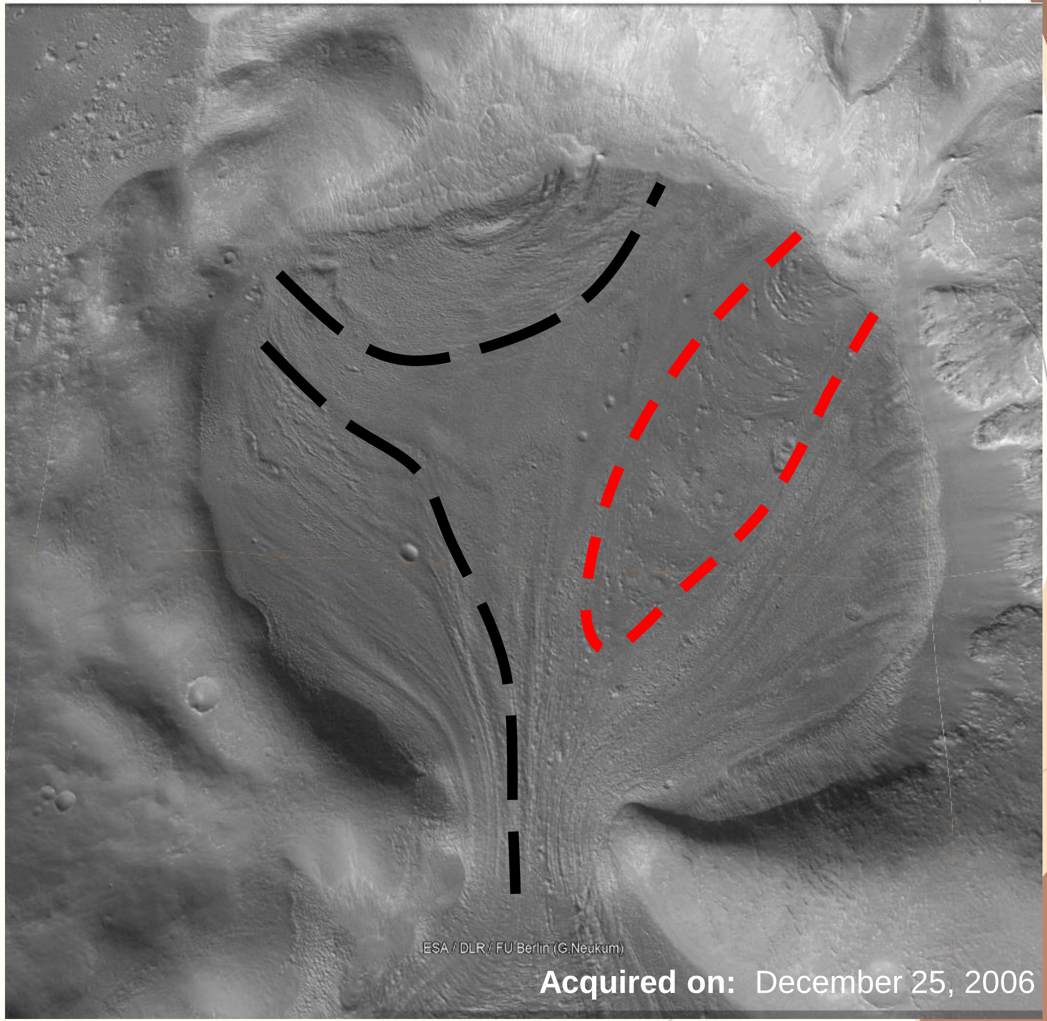
Concentric crater fill (CCF)

- The dielectric constant is generally very low (<5) → high ice content, or even pure ice (Castaldo et al., 2017).
- At ± ~45–60° lat. - covera impact crater floors. Concentric ridges on CCF →past flow from the rims to the centres.
- At ± ~25–45° lat. – only from their pole-facing walls, similar appearances to lobate debris aprons (Dickson et al., 2012).

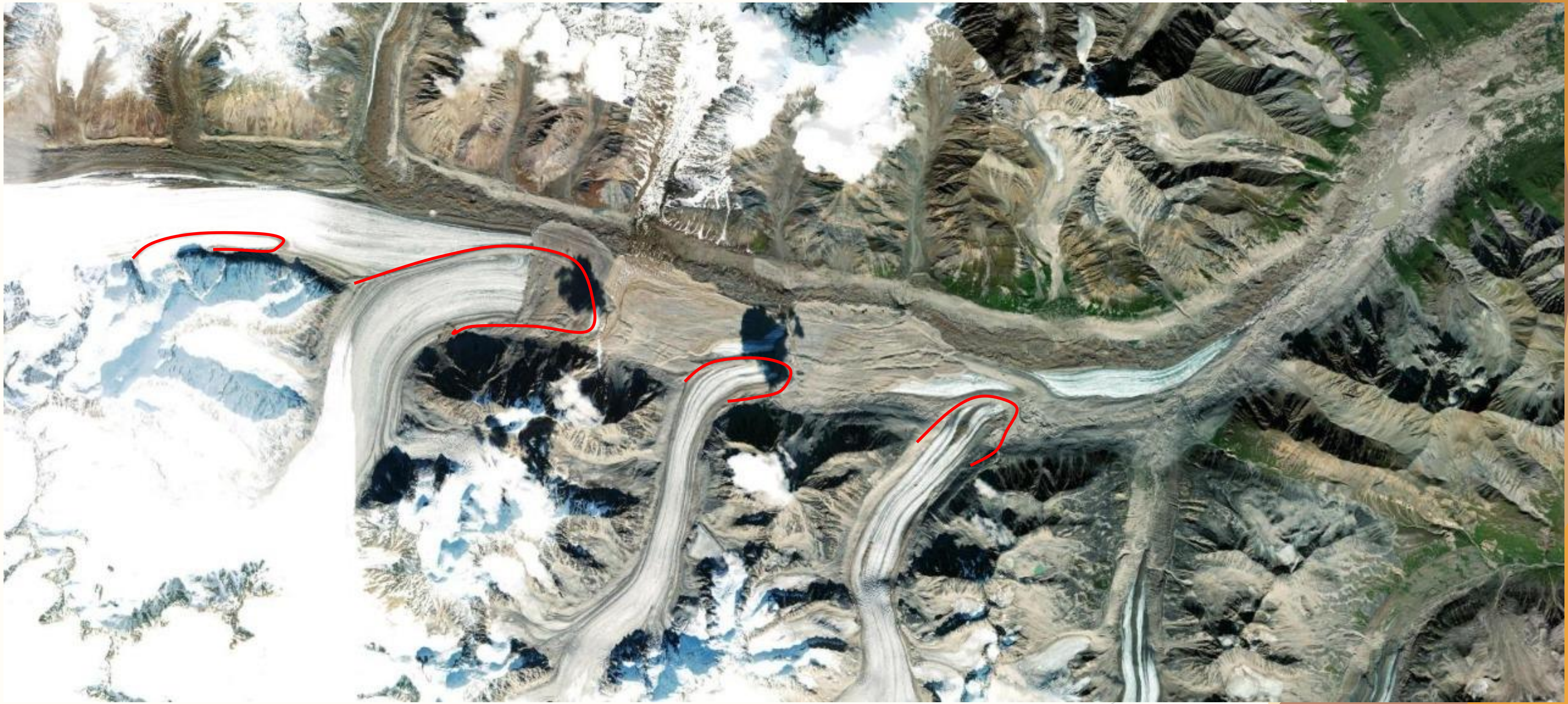


„Recent" (?) surface changes and "looped" features → looed moraines from tributary glaciers?





“Looped” moraines: geomorphic evidence for glacier surging



Terrestrial analogues for FlyRadar tests

FlyRADAR

- Rock glaciers (**completely debris coverage**, low content of pure ice, up to 30%): Dolomites, Alps
- Debris-covered glaciers with large covered area (lower part of the glacier in the ablation zone is **mostly covered by debris**): Miage Glacier, Alps
- Ice-cored moraines with limited melting due to conservation of ice (partly relict) in permafrost (much pure ice and good **preservation of relict ice**): Mer de Glace, Alps
- Completely **debris-covered glaciers by ash fall** (much pure ice, good): Valley of Ten Thousand Smokes area, Alaska
- **Pleistocene massive ground ice** - possible glaciers buried by sedimentation (much pure ice, good preservation of relict ice by permafrost, completely debris coverage, **but not on land** surface): Beaufort Sea coast

Specific experiences by GPR from earlier surveys

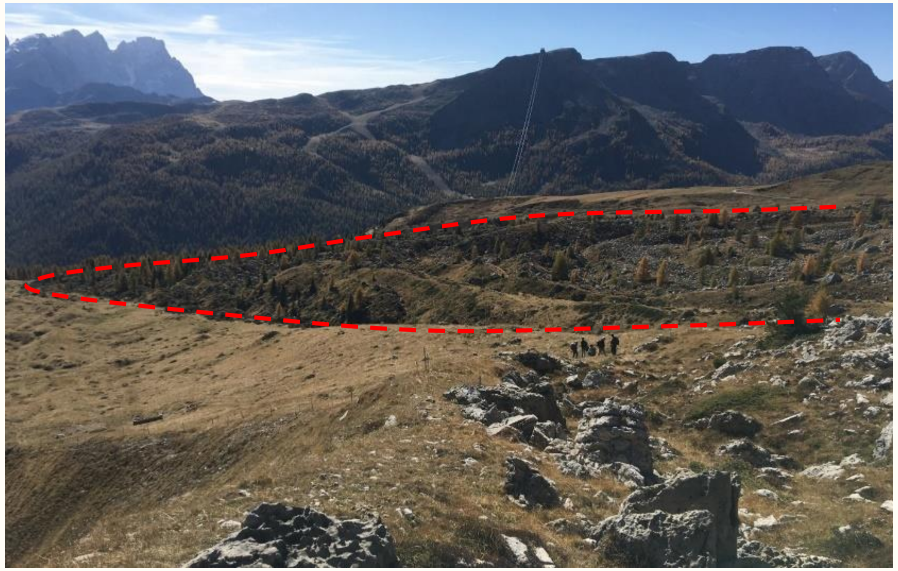
- frequency 50 MHz - 2 GHz (100-200 MHz)
- presence of ice
- embedded rocky grain layers
- small amount of liquid water
- often no liquid phase
- liquid phase was easily observable
- elevated conductivity → loss signal strength
- but moisture content is lower on Mars
- heterogeneity → increase diffraction, noise
- conductive areas absorb microwaves

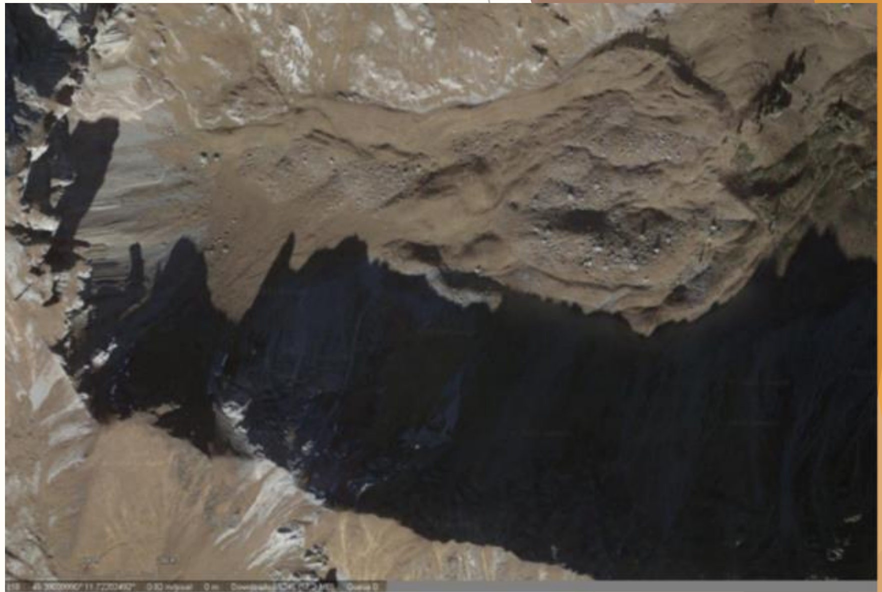
Target name, type	Used GPR, frequency	Observed ice characteristics	Observed liquid water characteristics	Reference
Permafrost in Alaska and Dry Valleys of Antarctica	50 - 100 - 400 MHz	Stratigraphy of permafrost. -Dry Valleys: Stratified silts, sands and gravels of low or little ice content, virtually no water. Glacio-fluvial or glacio-lacustrine origin(a1) -Alaska: Frozen sands with possible presence of water probably even within the body of the permafrost(a2)	Water table at depths of 20–35 meters produced strong reflections (Alaska). Wet sediments may reflect high rates of attenuation in the signal. The contrast in dielectric properties between frozen and unfrozen water undoubtedly causes the stronger diffractions and reflections.	Arcone et al. (2002)
Permanent ice cap on the summit of a stratovolcano (Jamapa Glacier; Mexico)	400 MHz (static point surveying technique)	Ice thickness (ice base/bedrock) along profiles(b)	No liquid water phases were interpreted.	Brown et al. (2005)
Galena Creek Rock Glacier (Wyoming)	100 MHz	Stratigraphy of debris-bounded ice units (nested spoons type)(c)	No liquid water phases were interpreted.	Petersen et al. (2017)
Galena Creek Rock Glacier; Sulphur Creek glacial system (Wyoming)	100 MHz (Sulphur Creek); 50 MHz (Galena Creek)	Internal structure, thickness and purity of the ice(d)	No liquid water phases were interpreted.	Petersen et al. (2020)
Ice-cemented/ice-cored rock glaciers (Gilpin Peak, Colorado; Galena & Sulphur Creek, Wyoming; Sourdough, Alaska)	200 Hz	Glacier geometry and structure. Debris mean thickness measured from GPR (for all of the sites): 2 meters(e1)	A film of meltwater at the debris-ice contact was observed in most of the shallow debris measurement sites(e2)	Meng et al. (2020)
Permafrost tunnel (Fairbanks, Alaska)	1 - 2 GHz (GPR constant offset profiles)	Ice-frozen loess detection (seismic data) displaying relatively large Q values (~80; indicative of low seismic attenuation).	Water-ice content tends to decrease with depth below the floor of Permafrost Tunnel. Overall, large variations were inferred.	Lorenzo et al. (2022)

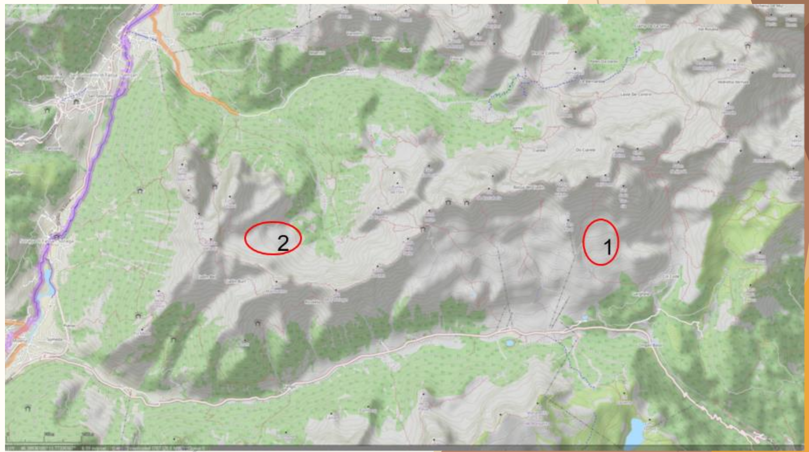
Rock glaciers, Dolomites

2 – Active rock glacier (steep lobe), Rio dei Monzoni

1 – Non active rock glacier, San Pelegrino pass

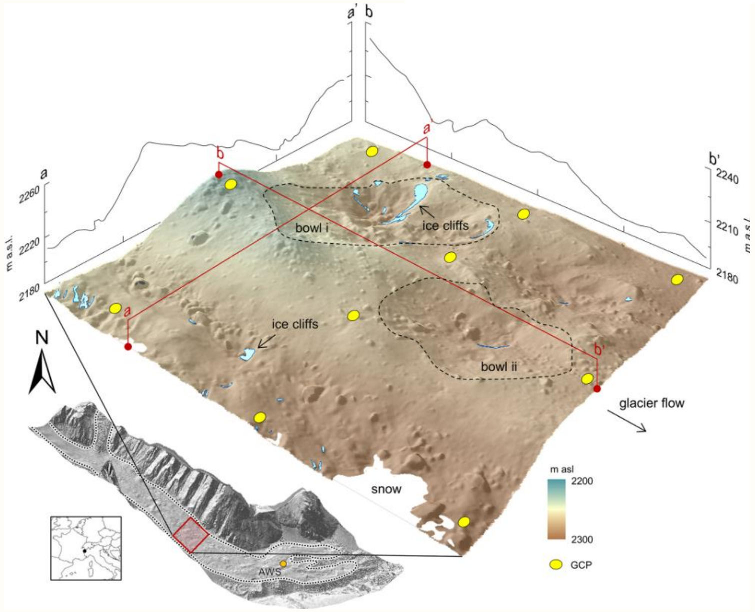


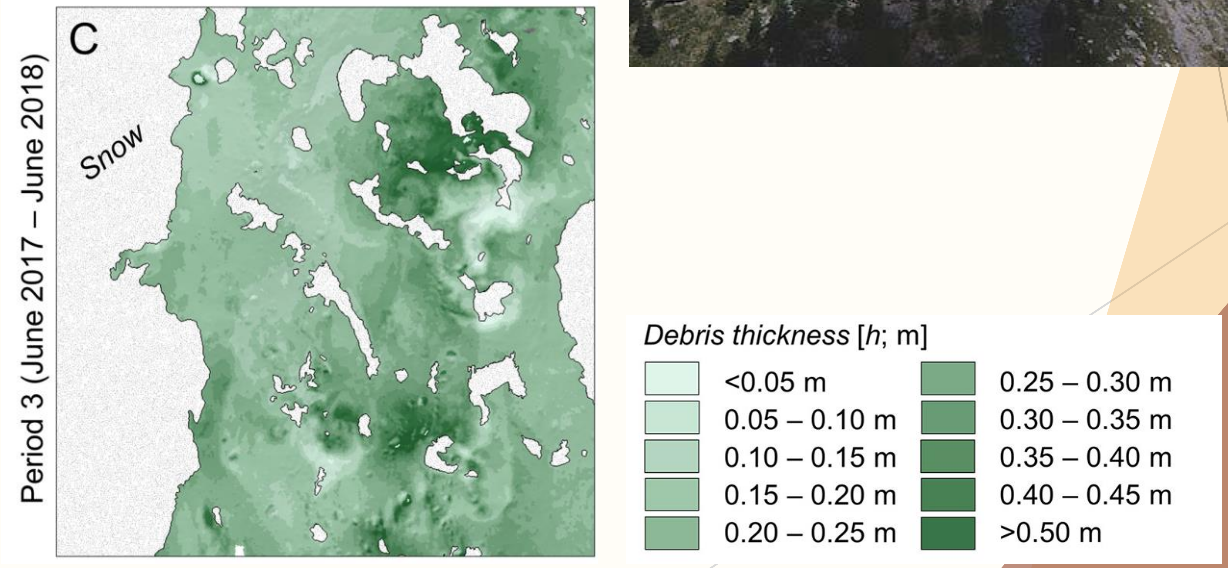




Miage Glacier (Ghiacciao del Miage), Alps

- The largest debris-covered glacier in Europe
- Almost 50% covered by debris





Partly debris-covered glacier, Mer de Glace

Mer de Glace

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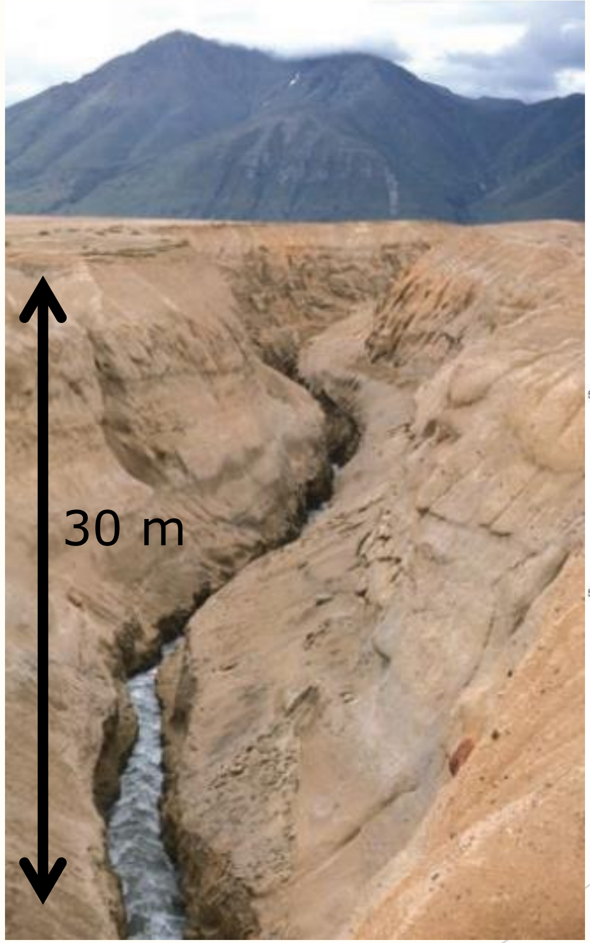
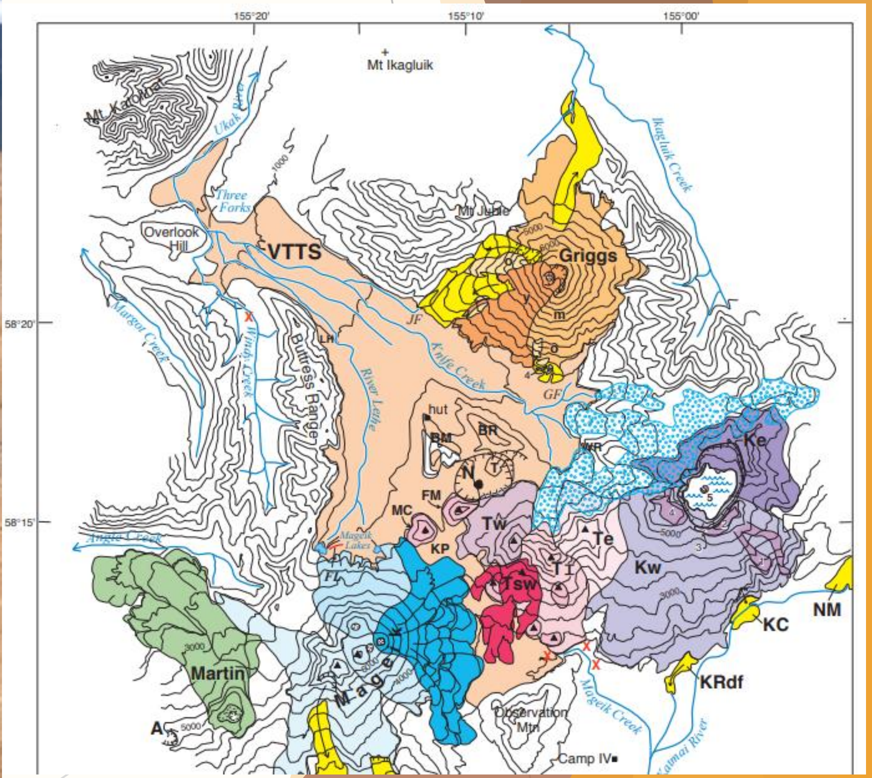
Valley of Ten Thousand Smokes, Alaska

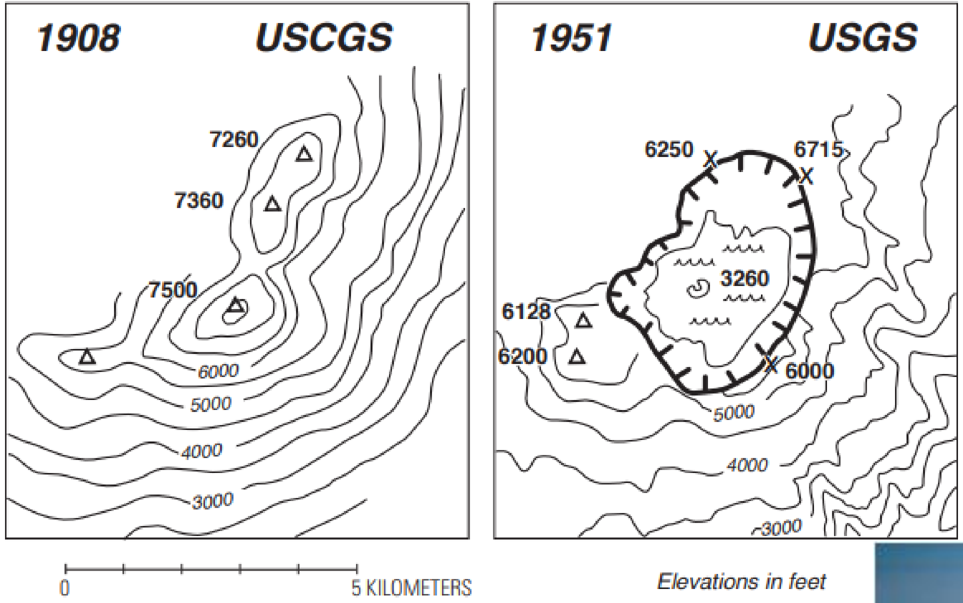
- The 1912 eruption was the largest eruption by volume in the 20th century
- The thickness of ash cover in the valley is up to 200 meters

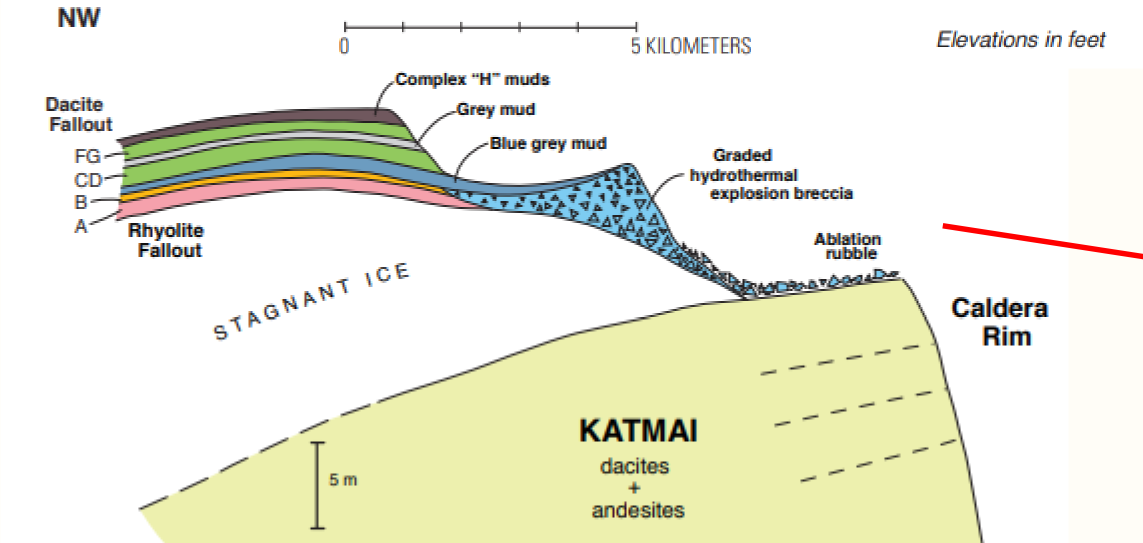
(Hildreth and Fierstein, 2012)





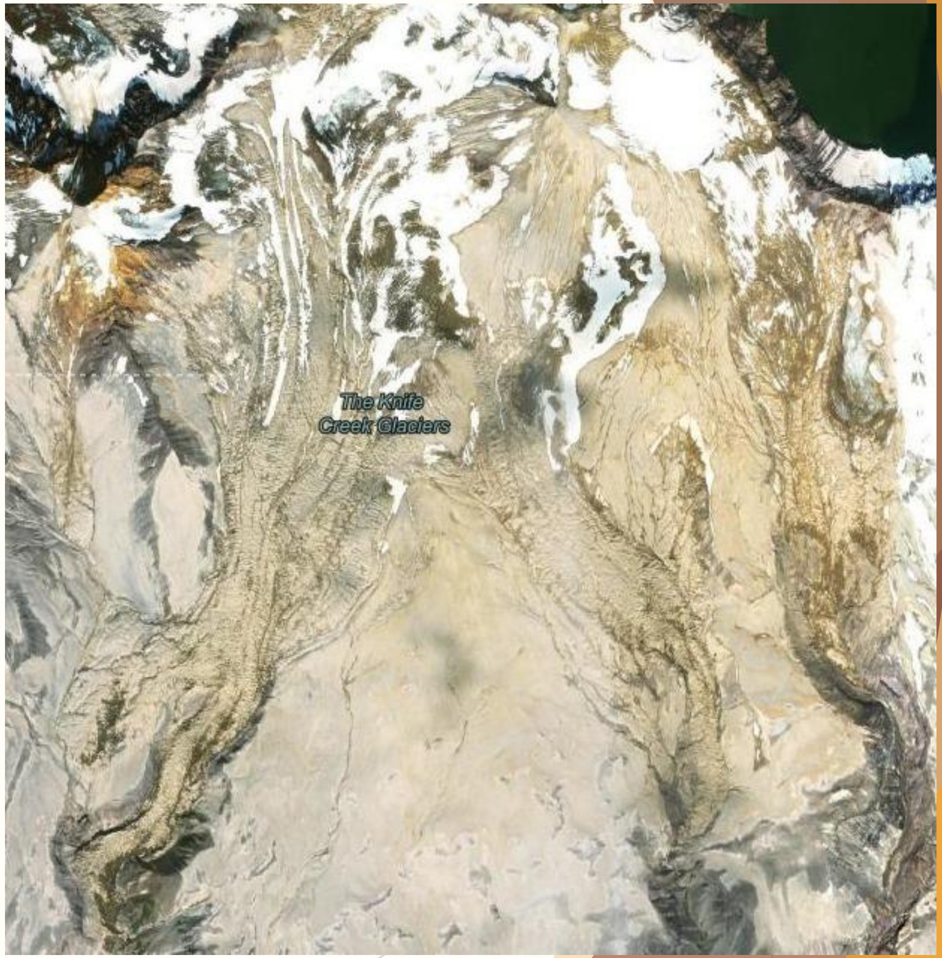
1912 eruption and Mount Katmai caldera collapse, Alaska





(Hildreth and Fierstein, 2012)

Debris- and ash-covered glaciers, Alaska

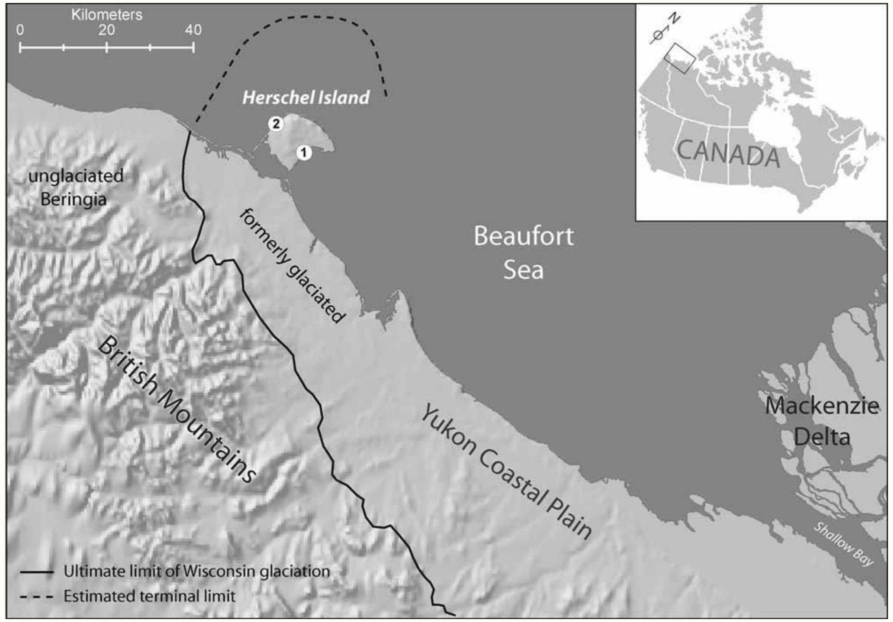


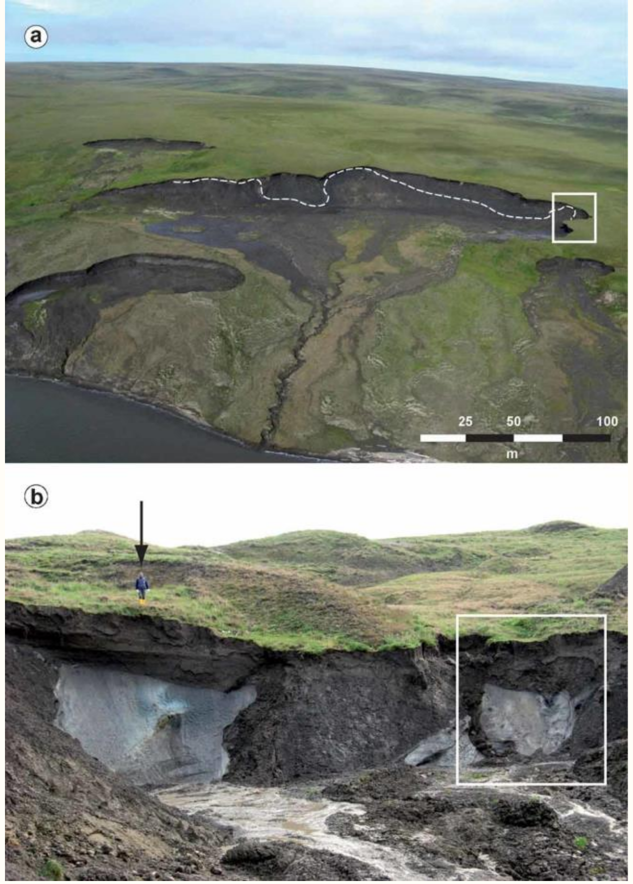
Debris- and ash-covered glaciers, Alaska

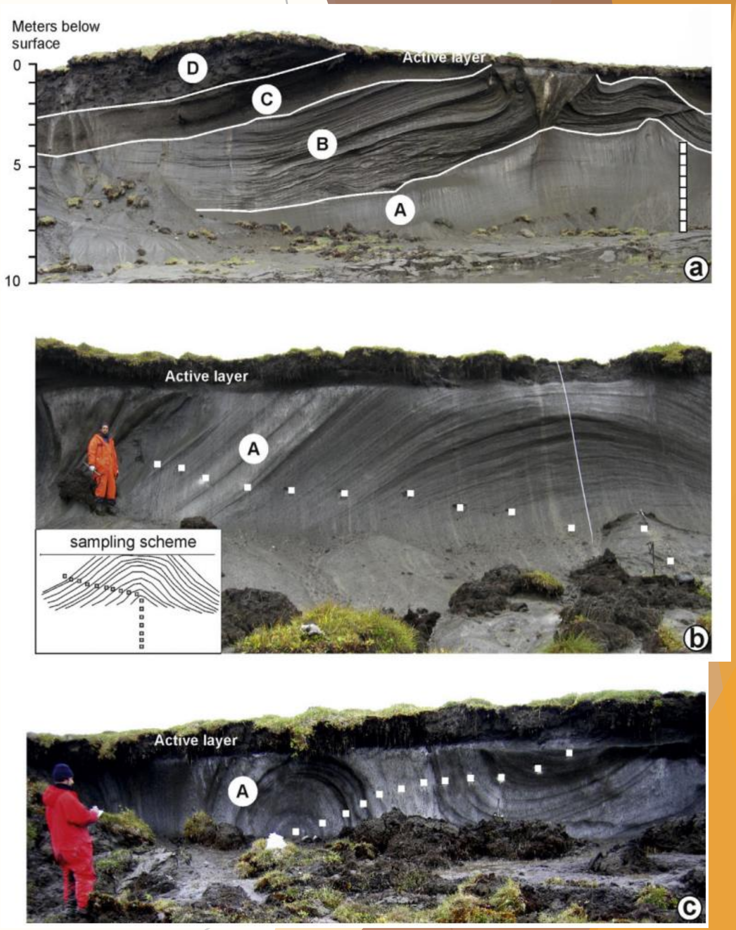
Kennicott Glacier

(Hildreth and Fierstein, 2012)

Pleistocene massive ground ice, Canada







Moroccan Sahara

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