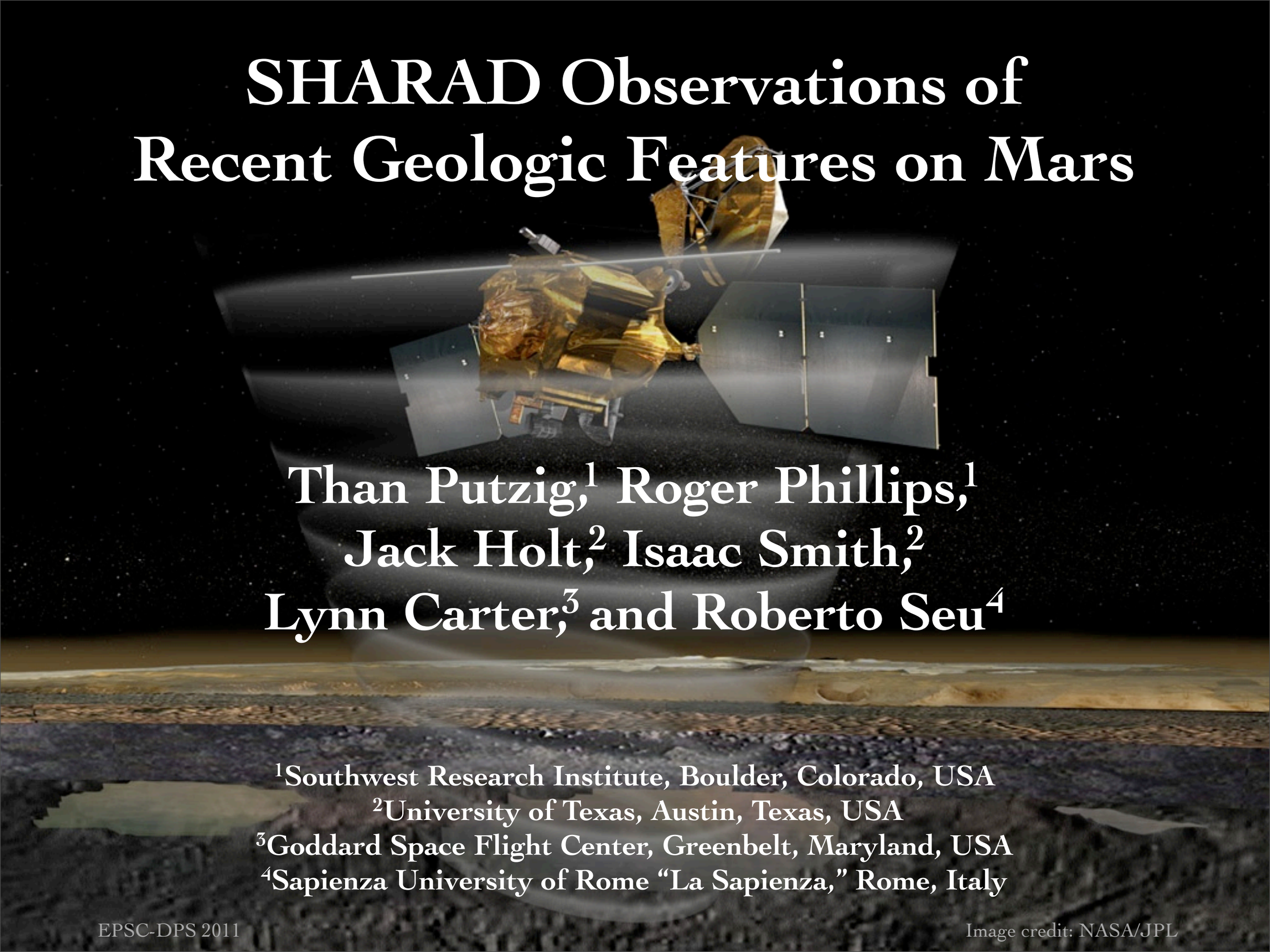
SHARAD Observations of Recent Geologic Features on Mars



Than Putzig,[1] Roger Phillips,[1]
Jack Holt,[2] Isaac Smith,[2]
Lynn Carter,[3] and Roberto Seu[4]

[1]Southwest Research Institute, Boulder, Colorado, USA
[2]University of Texas, Austin, Texas, USA
[3]Goddard Space Flight Center, Greenbelt, Maryland, USA
[4]Sapienza University of Rome "La Sapienza," Rome, Italy

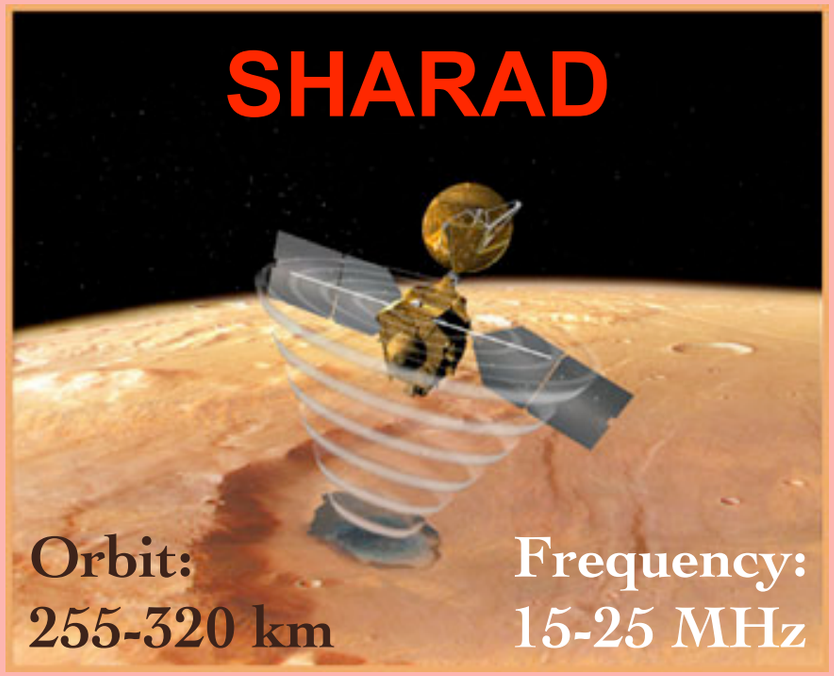
EPSC-DPS 2011

Image credit: NASA/JPL

Outline

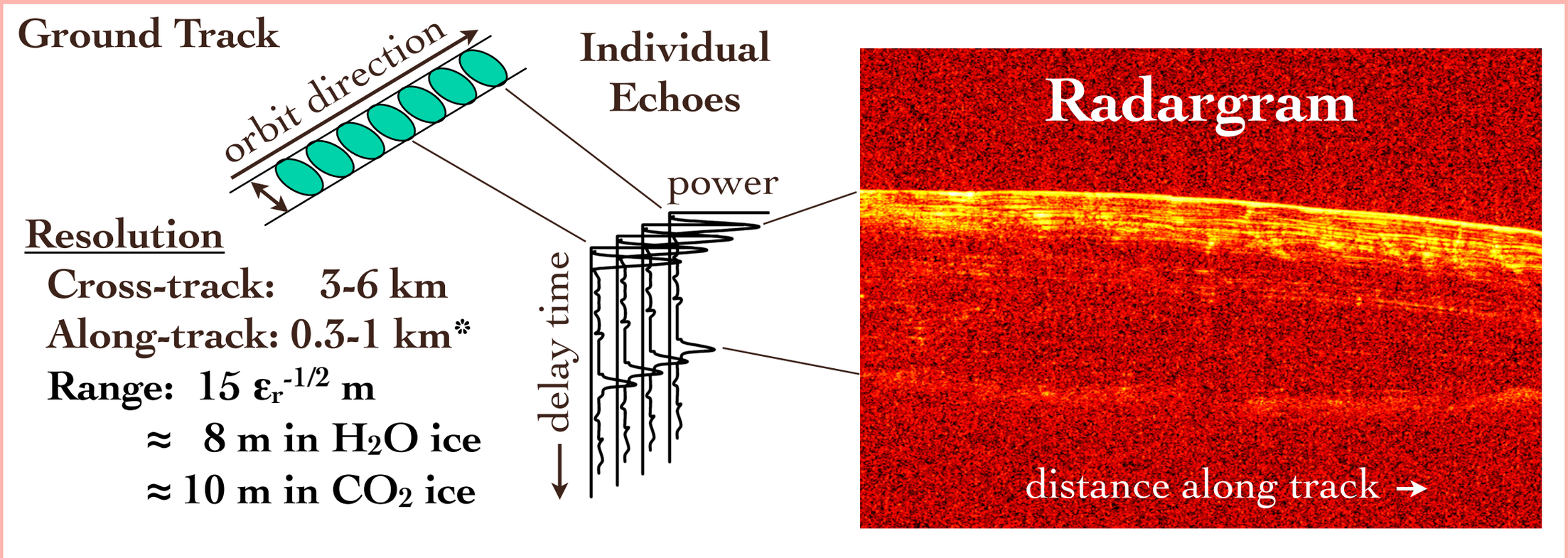
- Overview of SHARAD instrument and its results
- **Planum Boreum:** H_2O ice layers and structures
- **Planum Australe:** Discovery of a large CO_2 ice deposit in the near subsurface
- **Mid-latitudes:** Detections below lobate debris aprons, volcanics, and sedimentary layers
- Conclusions and Acknowledgments

MRO's Shallow Radar sounder



Primary Objective

Map subsurface dielectric interfaces and interpret them in terms of the occurrence and distribution of expected materials, including rock, regolith, water, and ice.



Resolution

Cross-track: 3-6 km

Along-track: 0.3-1 km*

Range: $15\ \varepsilon_r^{-1/2}$ m

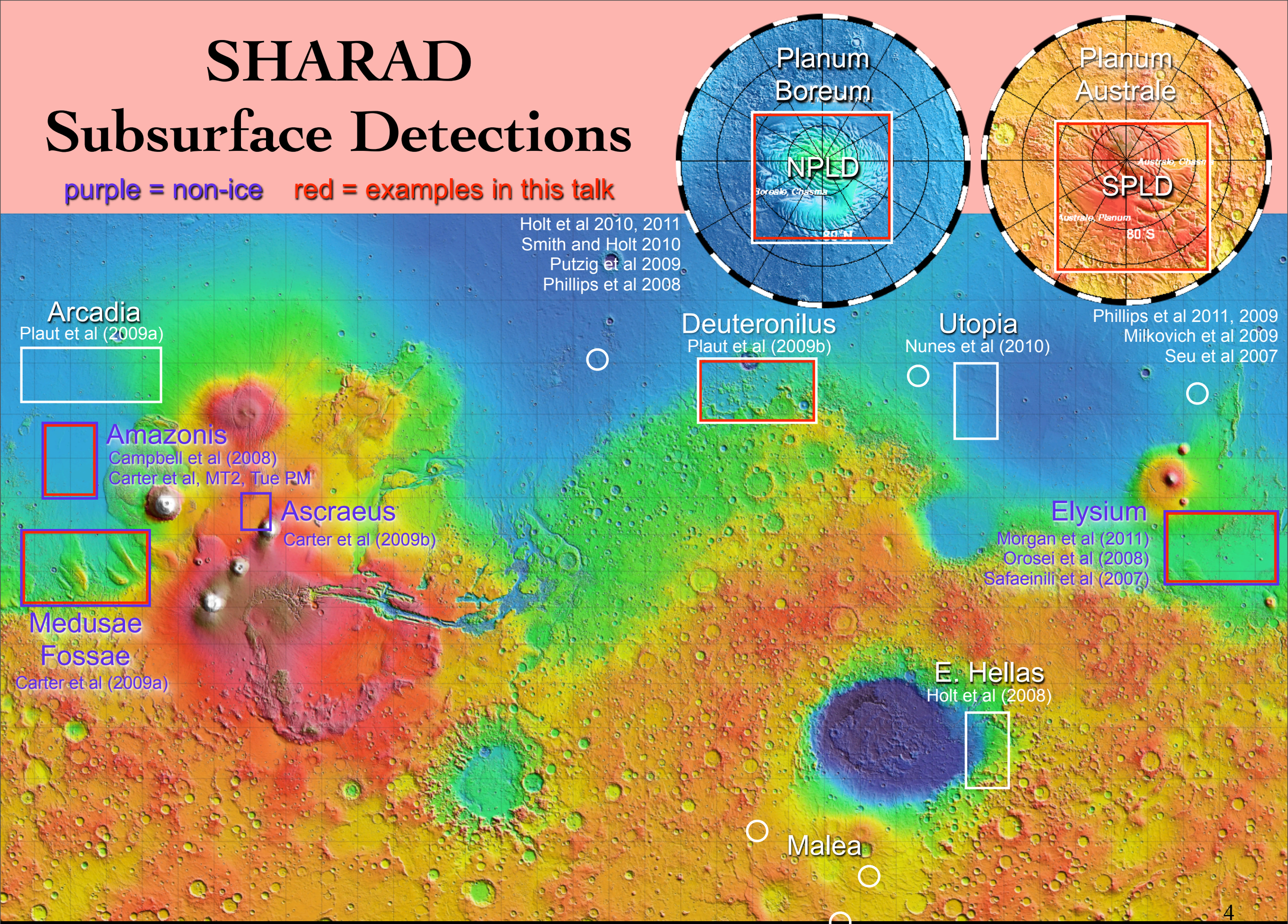
≈ 8 m in H_2O ice

≈ 10 m in CO_2 ice

* Along-track resolution is improved using synthetic aperture radar (SAR) processing techniques

SHARAD Subsurface Detections

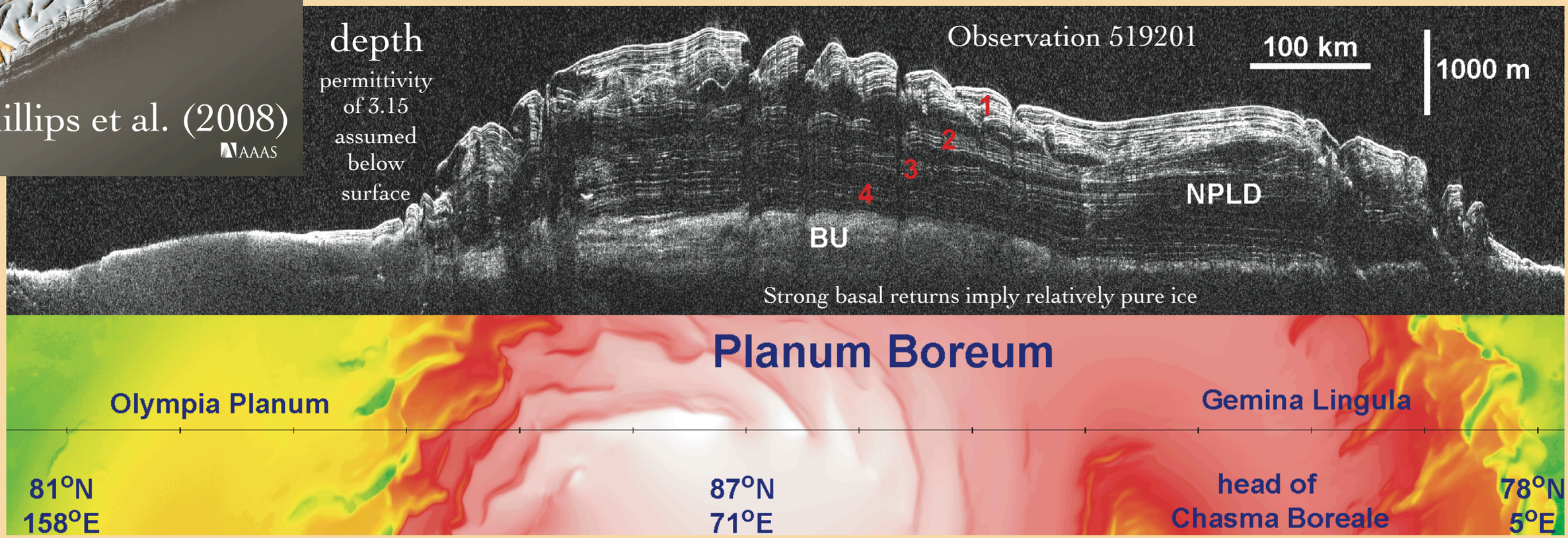
purple = non-ice red = examples in this talk



○ = pedestal craters (Nunes et al., 2011)

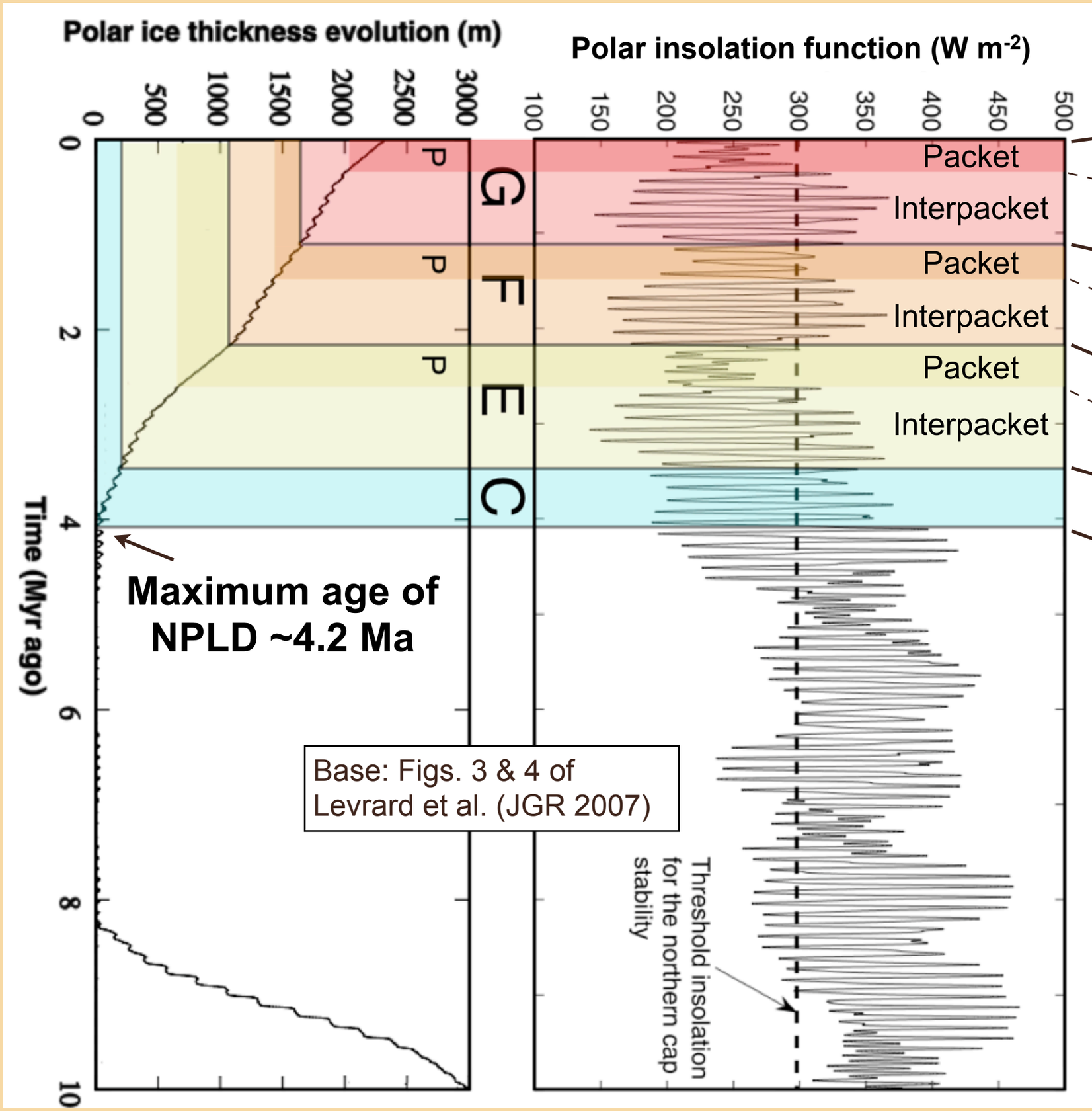
Basemap: NASA/MOLA Science Team

SHARAD has revealed the internal structure of Planum Boreum

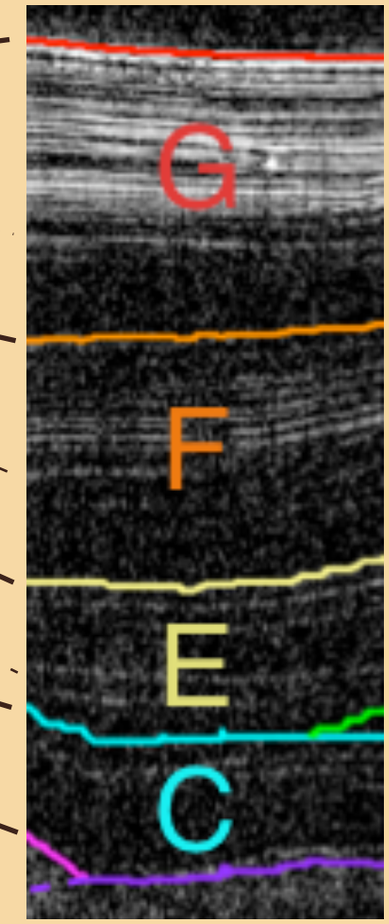


- Packet structure is found throughout the NPLD
- Basal Unit is rarely layered, occasionally seen below Olympia Planum, mostly missing beneath Gemina Lingula
- **Flat basal boundary has ~ 0 flexure ⇨ very low heat flow**

Correlation of radar units to climate cycles



Base: Figs. 3 & 4 of Levrard et al. (JGR 2007)

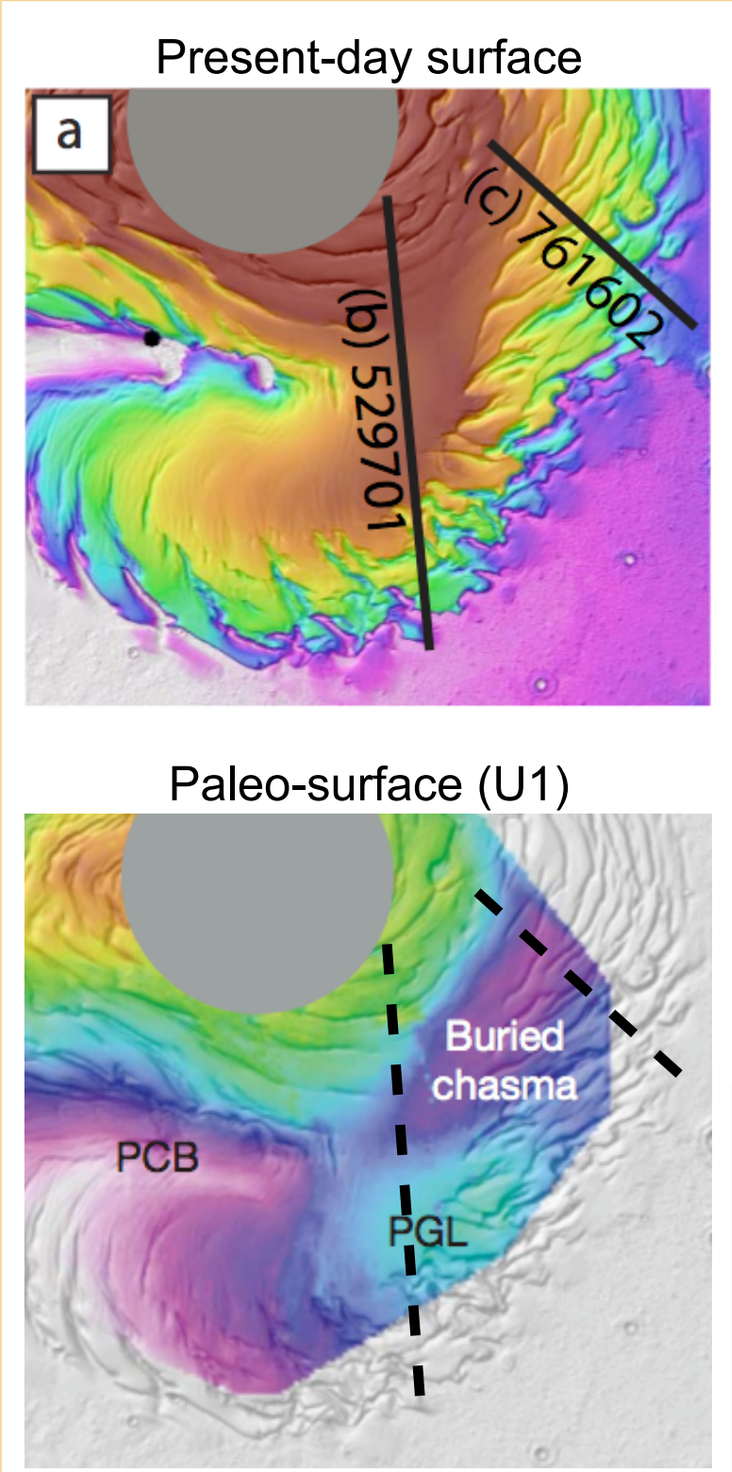


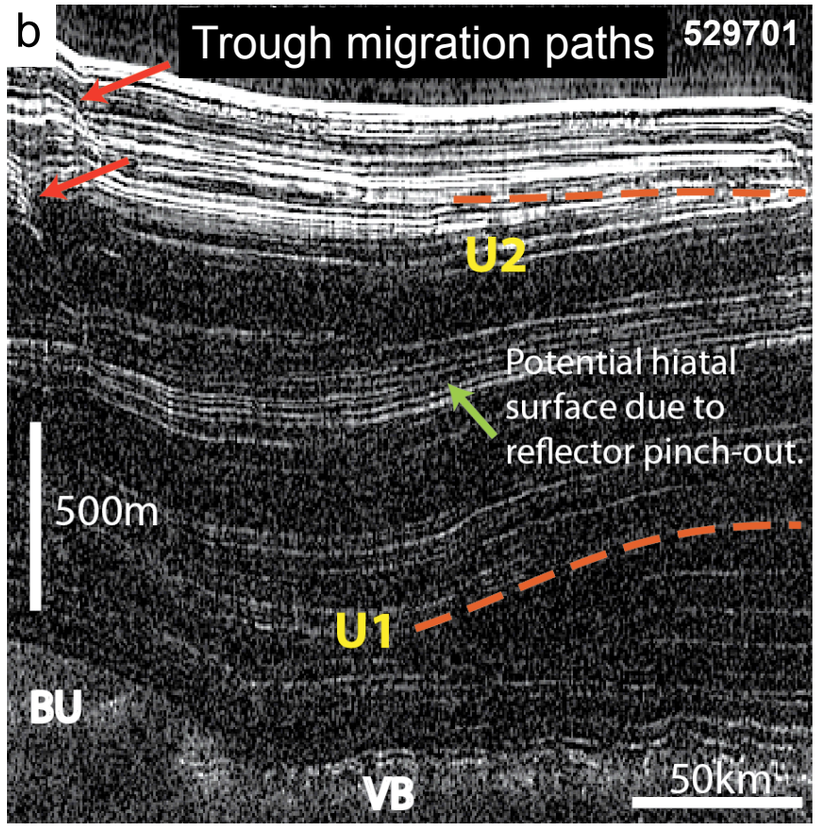
Strongly layered packets may correspond to periods with **low amplitude in the variation of insolation** — the present era, ~1.3 Ma, and ~2.4 Ma.

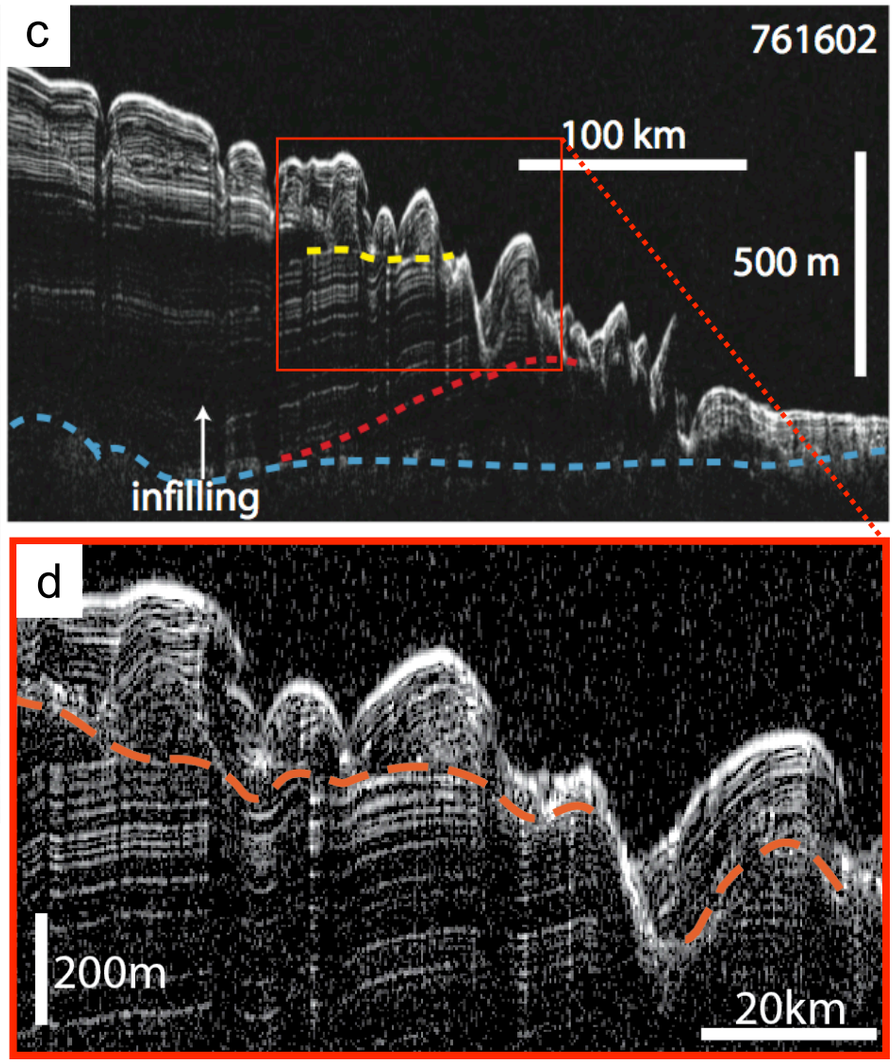
Putzig et al. (Icarus 2009)

NPLD stratigraphic complexity

Unconformities: erosion and depositional variations







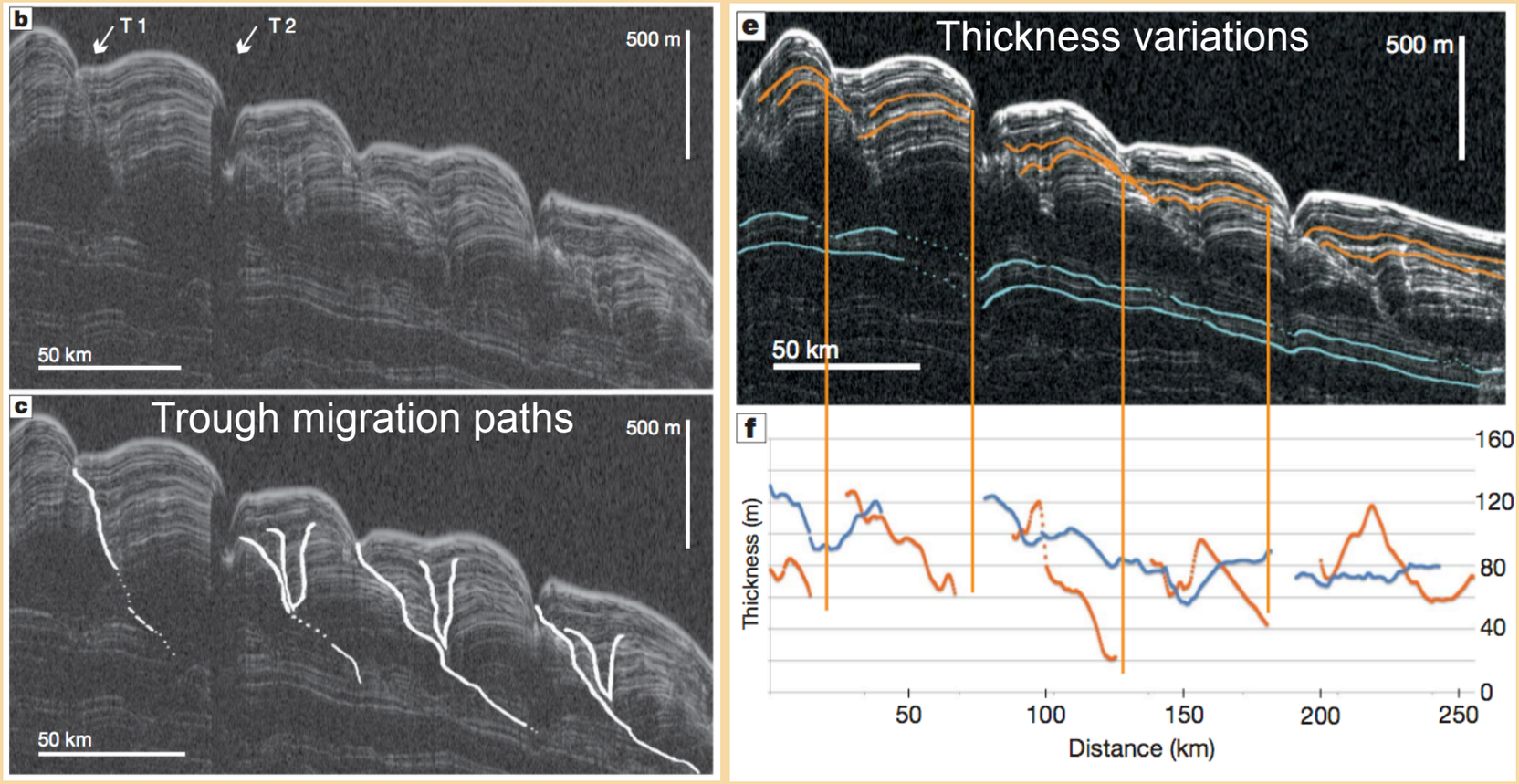
Holt et al. (Nature 2010);
Holt et al. (4th Mars Atmos. Wksp. 2011)

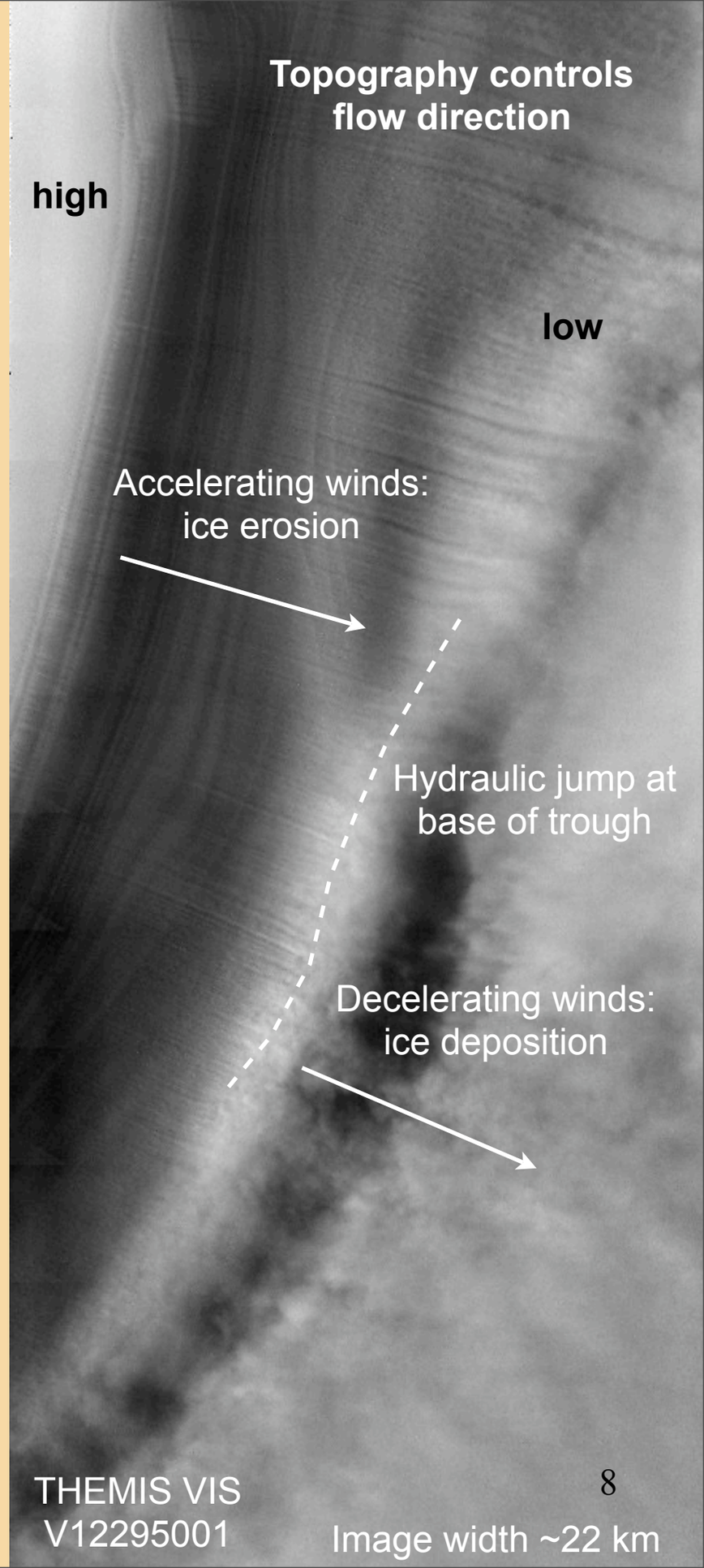
- Thickness variations may reflect locally variable deposition rates.
- Eastern paleo-chasma was completely infilled by later deposition.
- Shallow unconformity likely a major erosional surface.

Trough migration paths

- Analysis of SHARAD data shows that troughs are active, migrating bedforms of H_2O ice.
- Katabatic winds erode ice from lee slopes and deposit it on stoss slopes, resulting in layers that are thickest just downwind of the troughs.
- Surface imagery suggests that active migration occurs from spring into early summer, when CO2 frost is gone and winds are strongest.

Smith and Holt (Nature 2010)

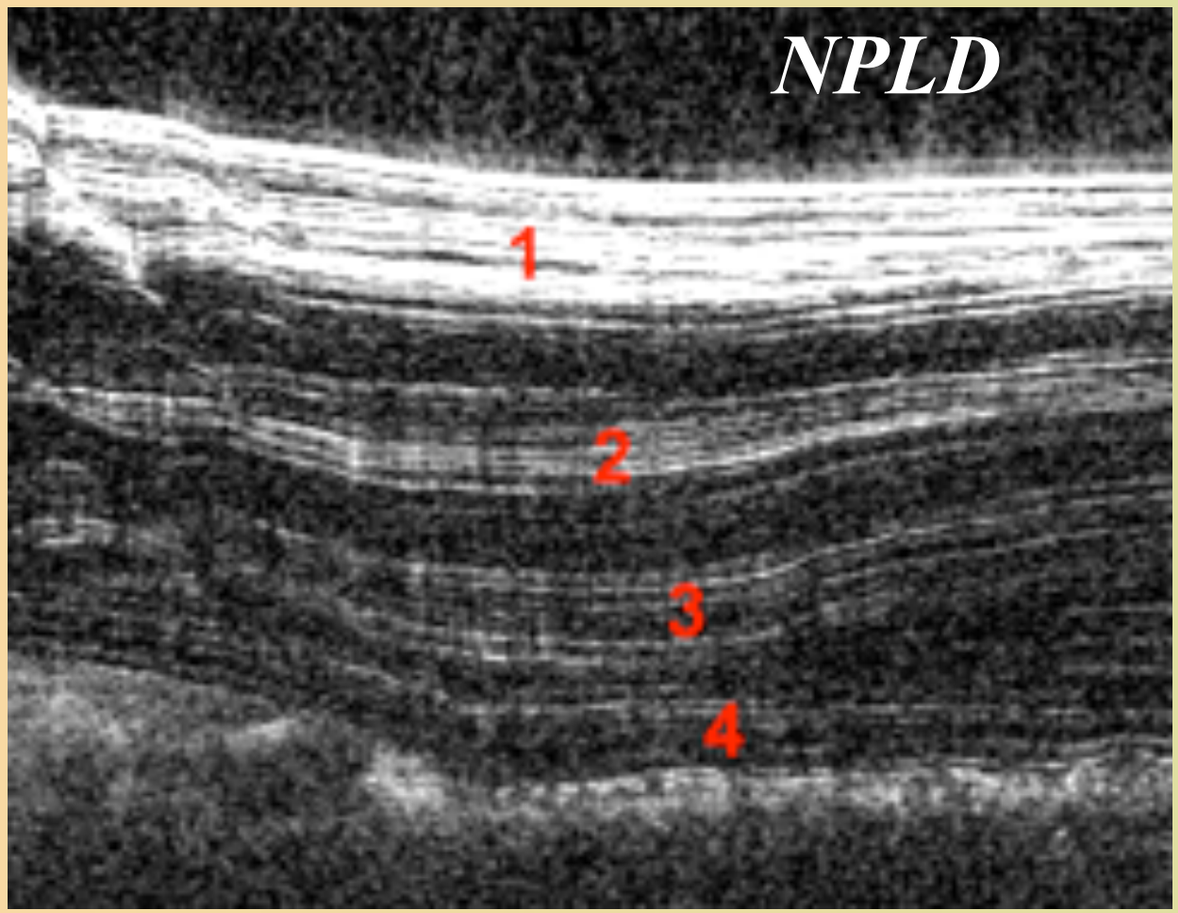


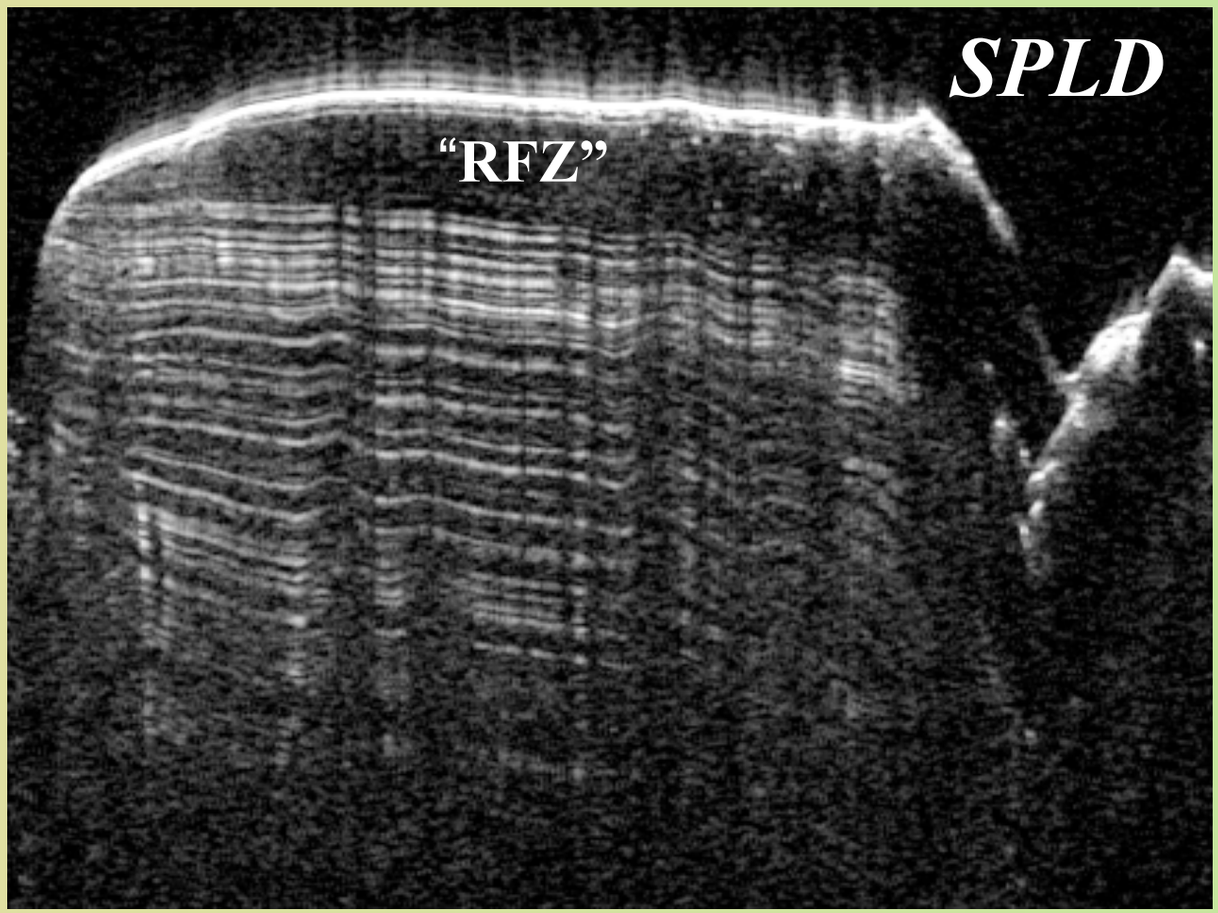


Mars Polar Radar Stratigraphy

Planum Boreum: Image is ~1700-m section of NPLD radar stratigraphy in Gemina Lingula, showing packet/inter-packet structure. **Well-defined radar layering is <u>pervasive</u>.**

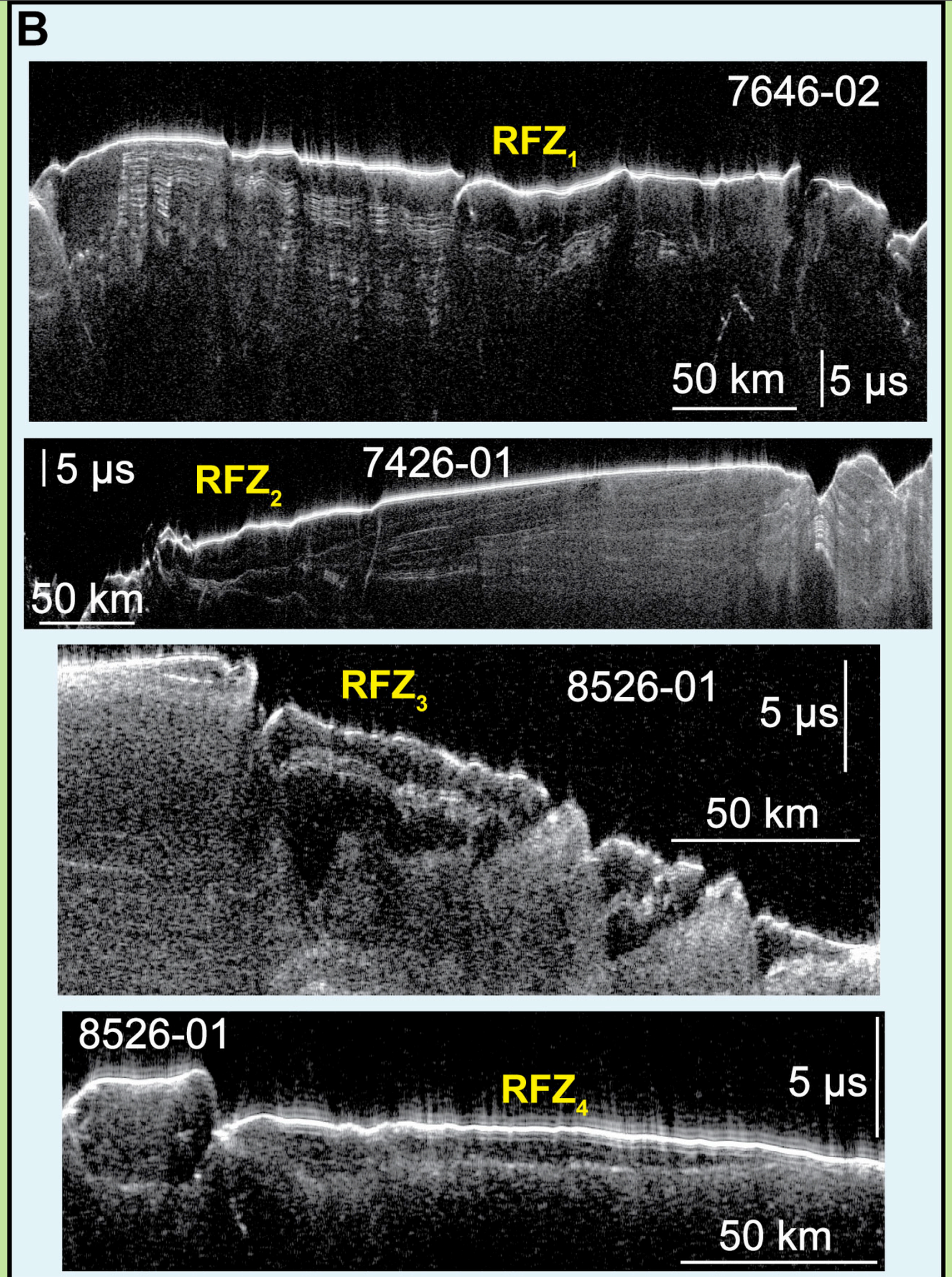
Planum Australe: Image is ~800-m section of SPLD radar stratigraphy in Promethei Lingula. **Well-defined radar layering is <u>rare</u>. Peculiar reflection-free zones occur near surface.**



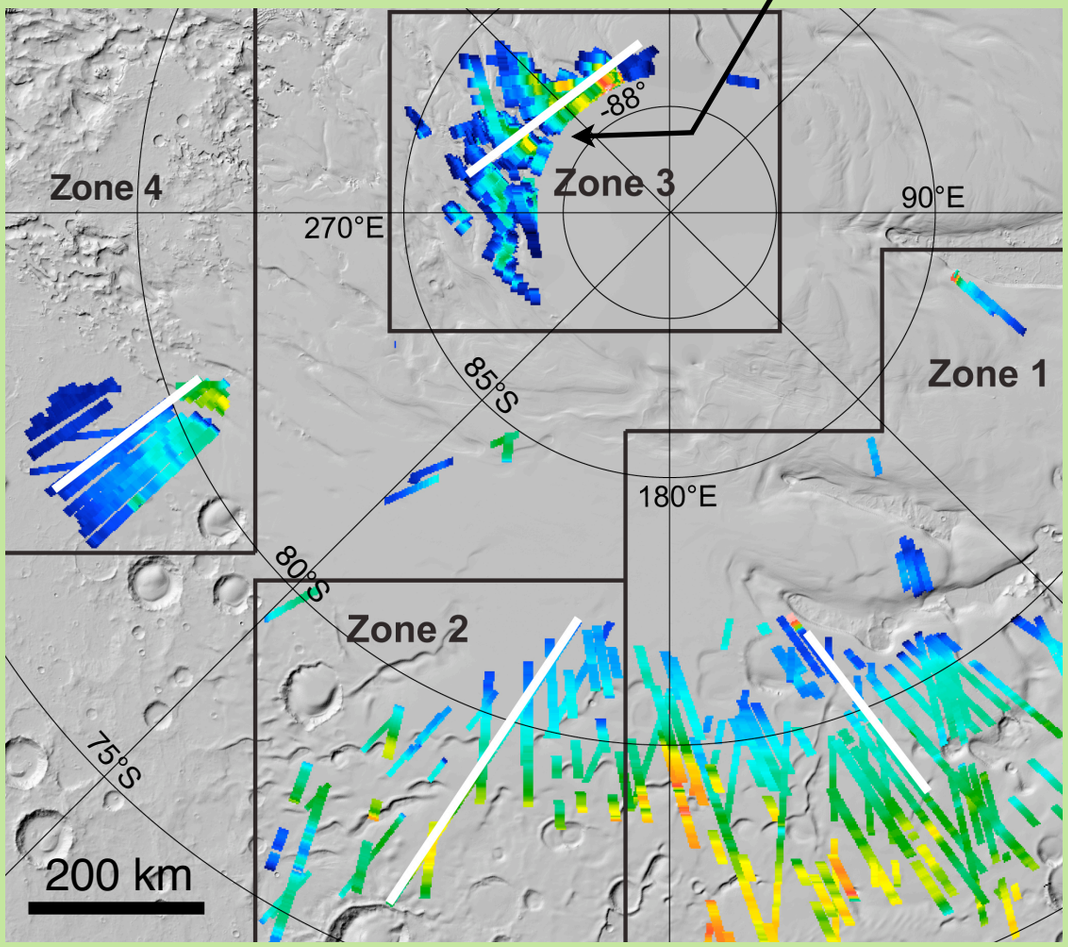


Phillips et al. (Science 2008)

Reflection Free Zones in the SPLD mapped by SHARAD

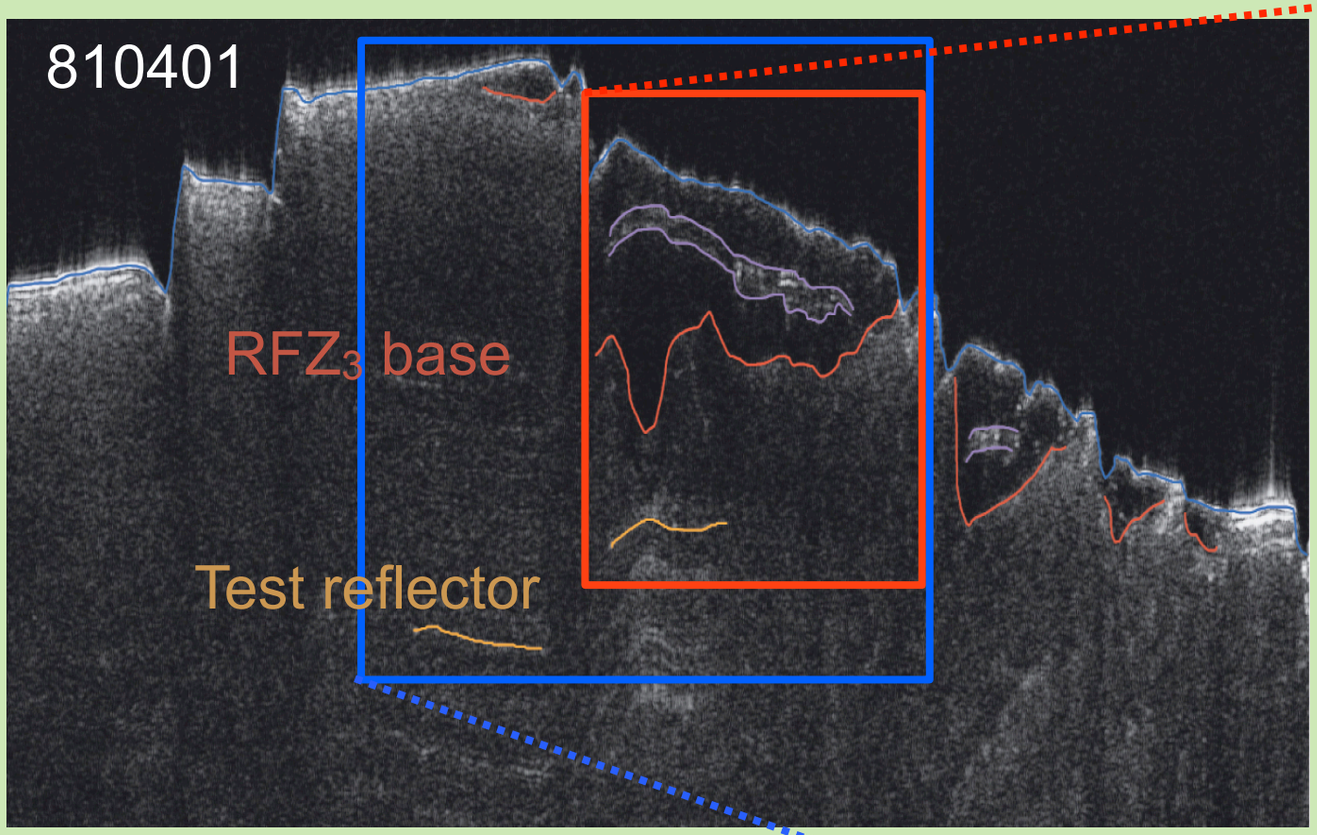


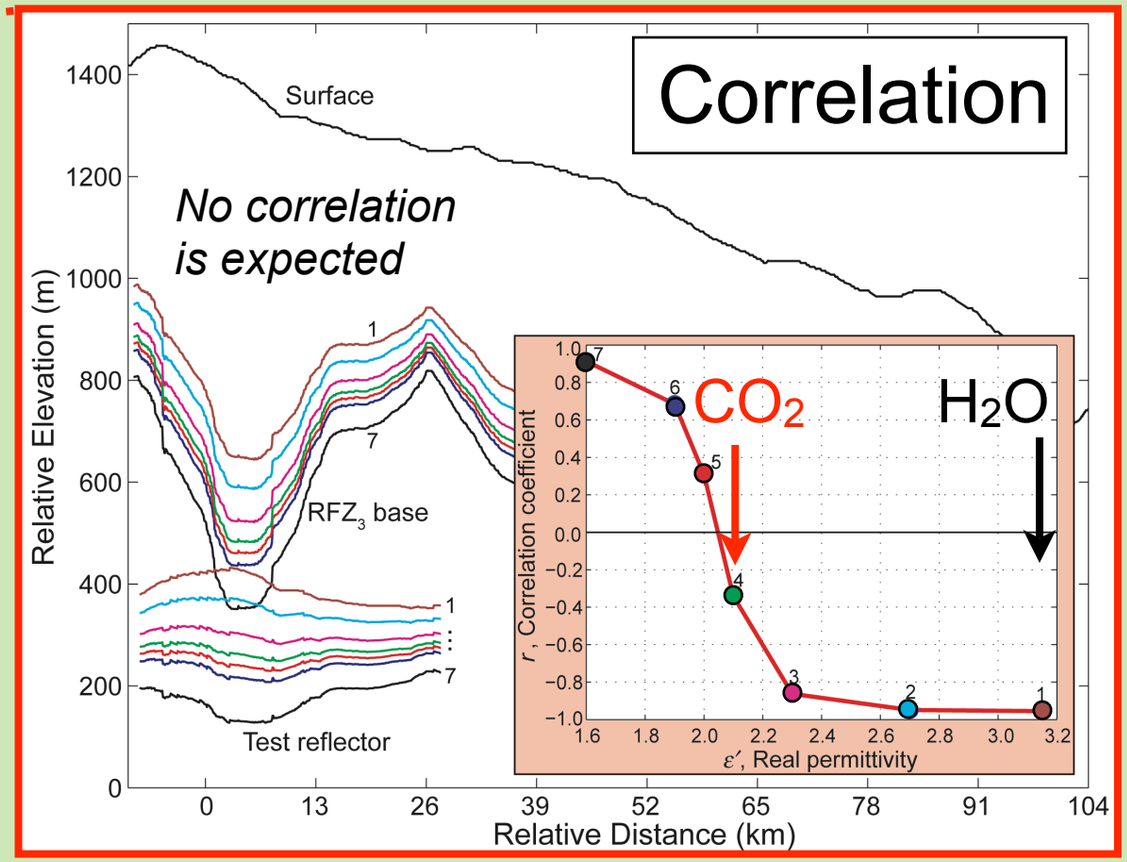
RFZ_3 coincides with locale of the South Polar Residual Cap of CO_2 ice



Phillips et al. (Science 2011)

Correlations and Offsets of Reflectors

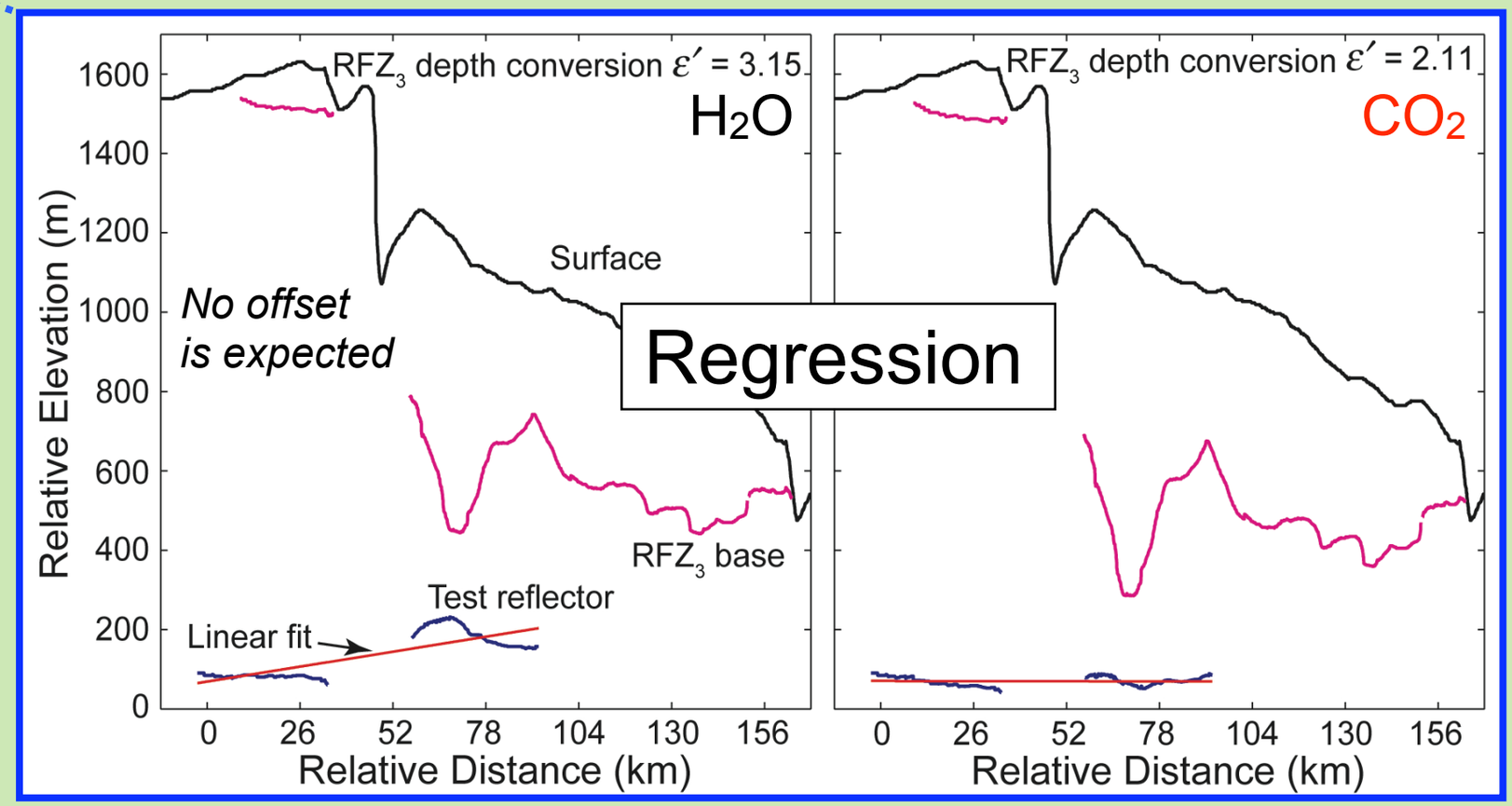




Dual depth-correction analyses reveals that the material in RFZ_3 is most likely to be CO_2 ice!

Other RFZs less likely to be CO_2 ice, but their geometries preclude this type of analysis.

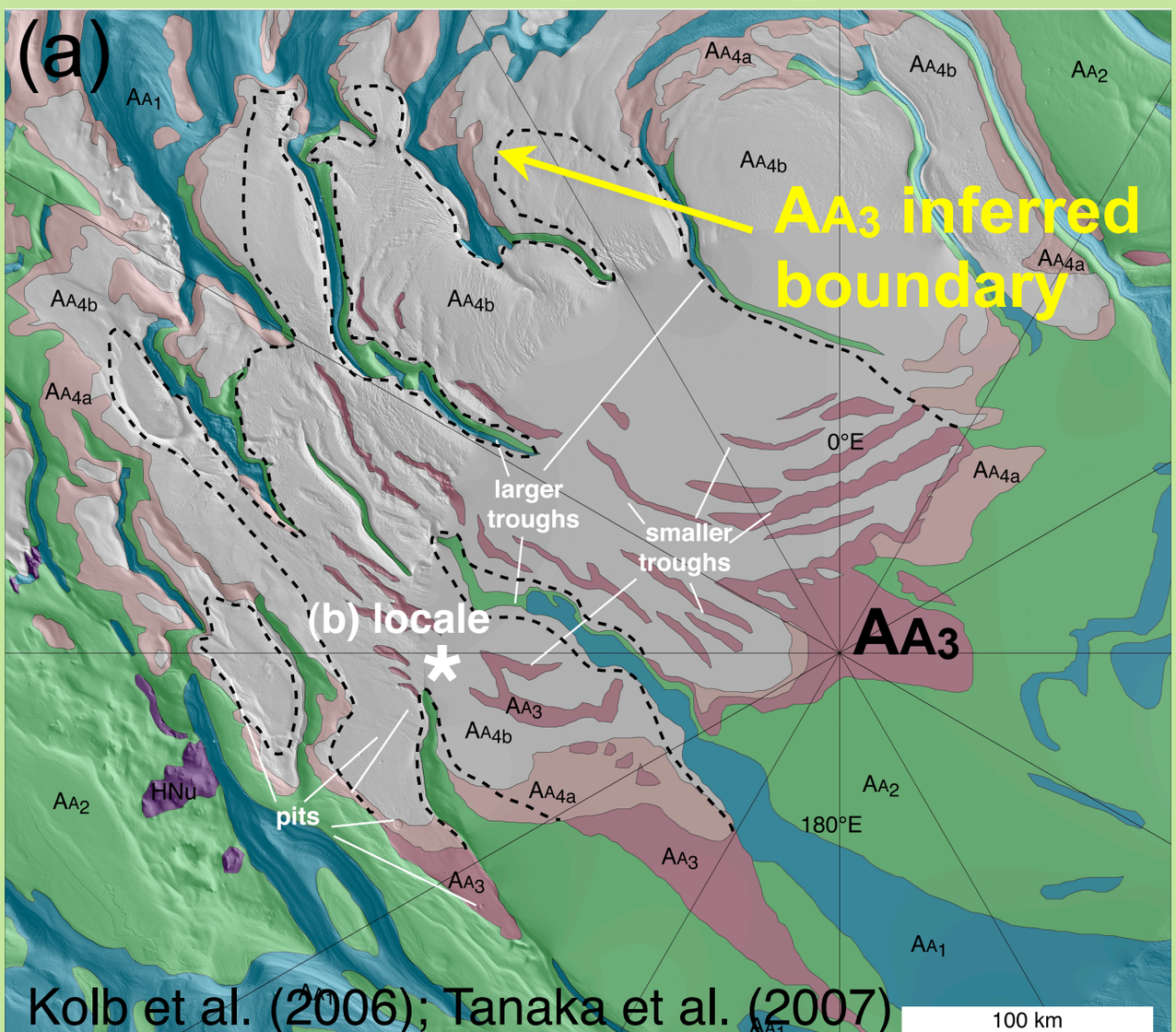
Phillips et al. (Science 2011)



Geologic unit AA_3

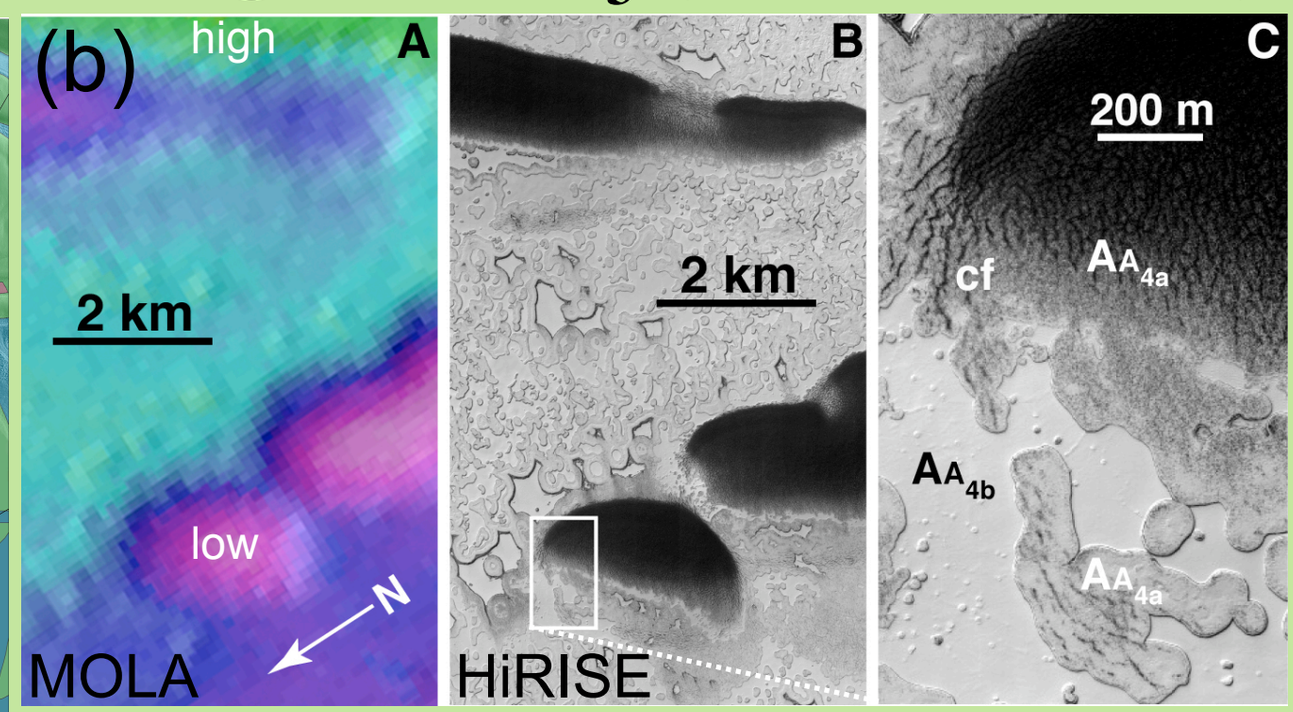
- SPRC (AA_{4a}+AA_{4b}) overlies **AA_3**, which occurs only at SPLD summit and unconformably overlies older units.
- Small troughs and isolated pits cut into AA_3 show evidence of collapse, suggestive of sublimation of volatiles - mostly likely CO_2.

Geologic Map



Kolb et al. (2006); Tanaka et al. (2007)

Troughs in AA_3 (~87°S, ~268°E)

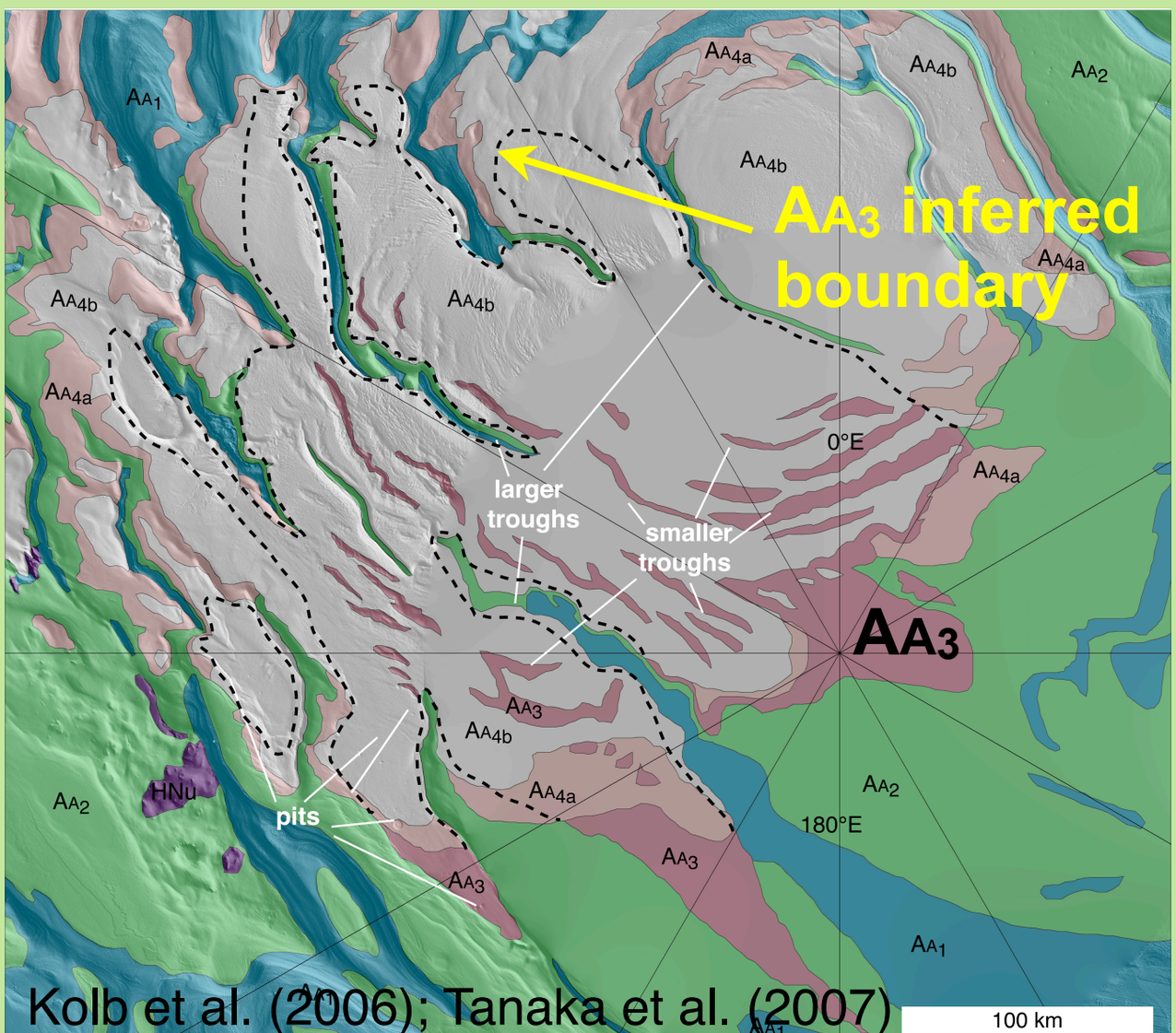


Phillips et al. (2011)

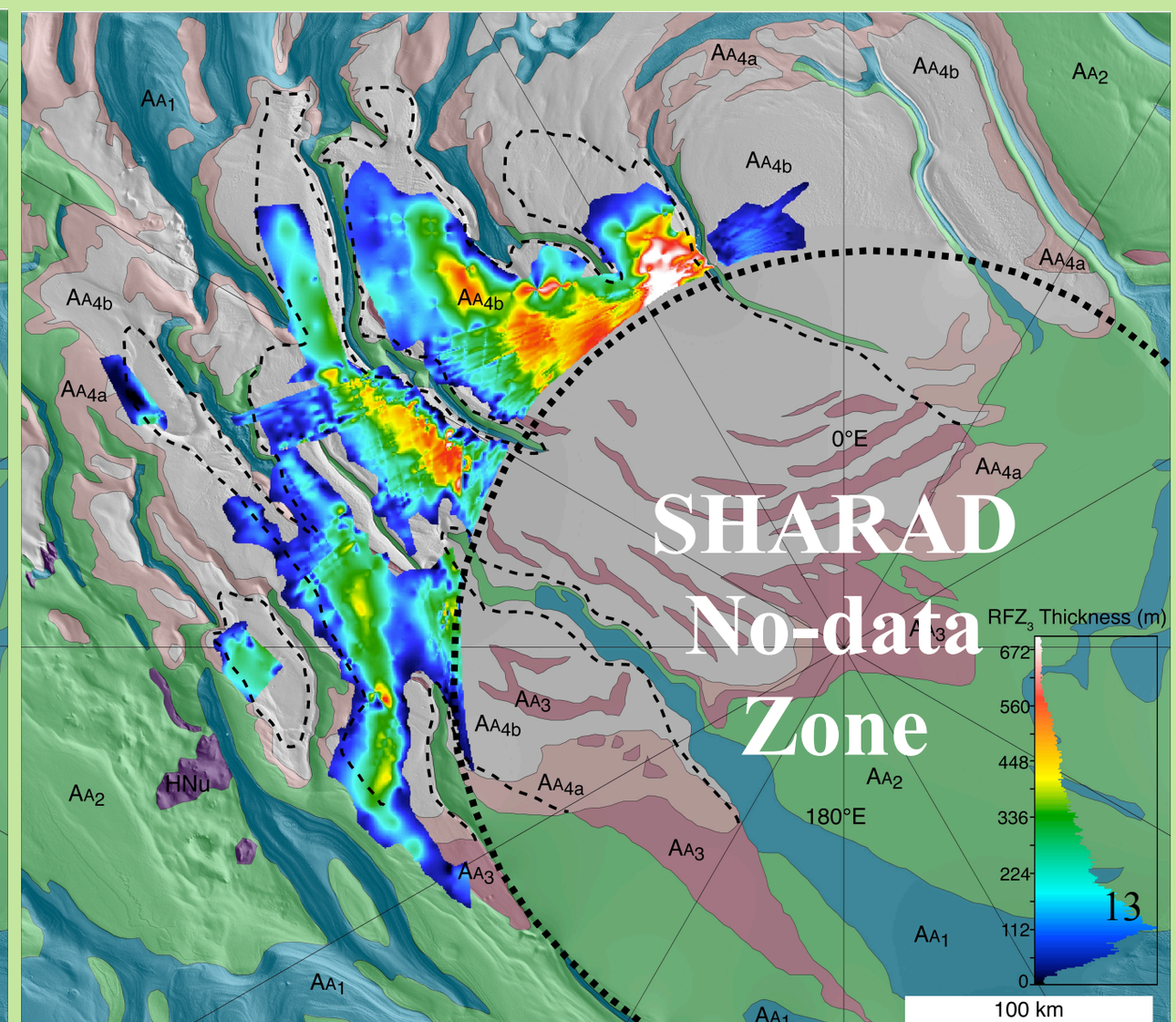
- **Both MOLA data & HIRISE image suggest trough modification through collapse and pit formation.**

RFZ_3 coincides with geologic unit AA_3

- SPRC (AA_{4a}+AA_{4b}) overlies **AA_3**, which occurs only at SPLD summit and unconformably overlies older units.
- Small troughs and isolated pits cut into AA_3 show evidence of collapse, suggestive of sublimation of volatiles - mostly likely CO_2.
- RFZ3 falls predominantly within the mapped bounds of AA_3.

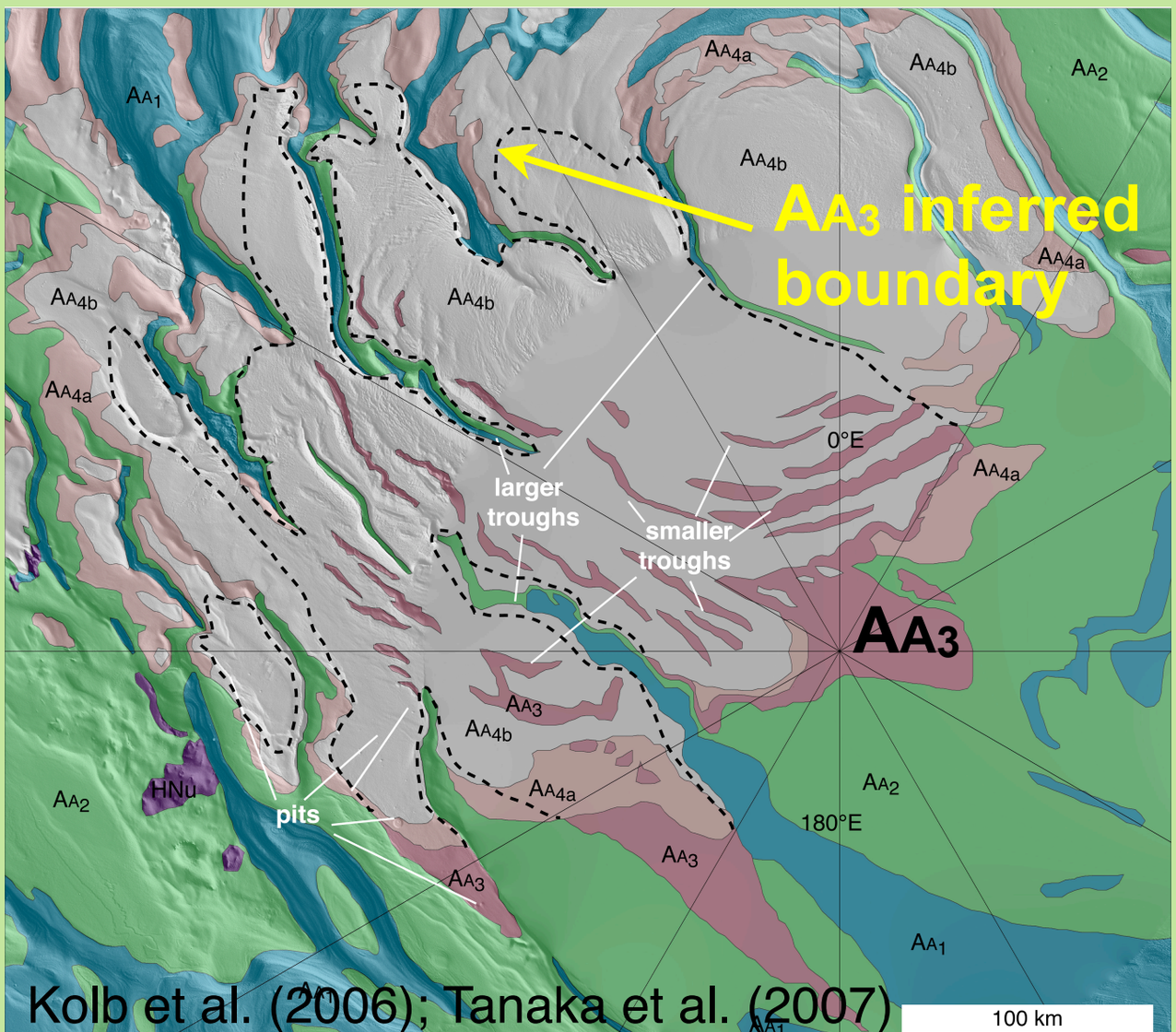


Kolb et al. (2006); Tanaka et al. (2007)

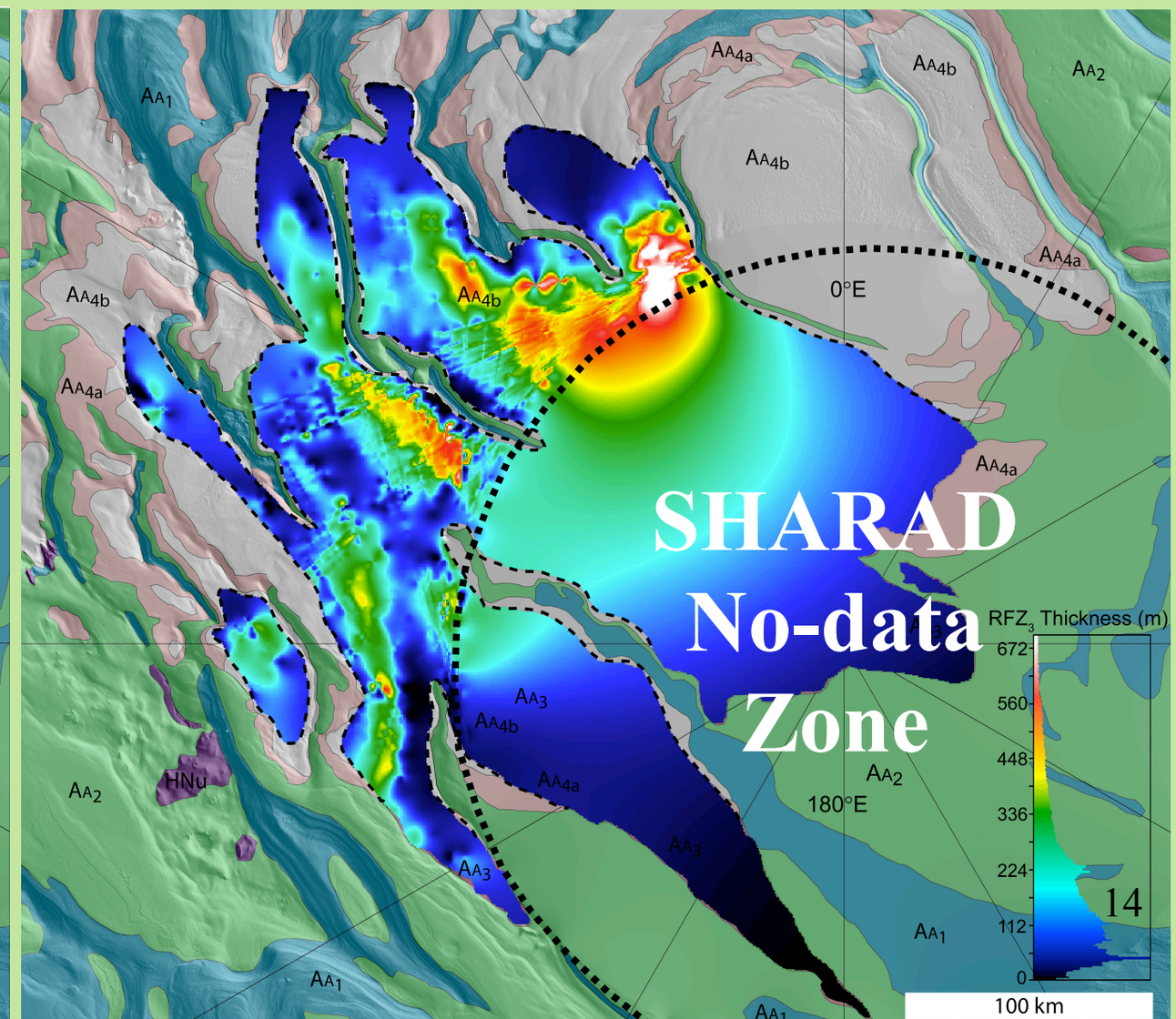


RFZ_3 coincides with geologic unit AA_3

- Extrapolated RFZ_3 volume is 30× SPRC and equates to **4–5 mbar (~80% of present value of 6–7 mbar).** If sublimated at high obliquity (e.g., ~0.6 Ma), initial GCM modeling suggests that:
  - ➪ Surface liquid water would likely be stable many more places.
  - ➪ More frequent and intense dust storms are likely.



Kolb et al. (2006); Tanaka et al. (2007)

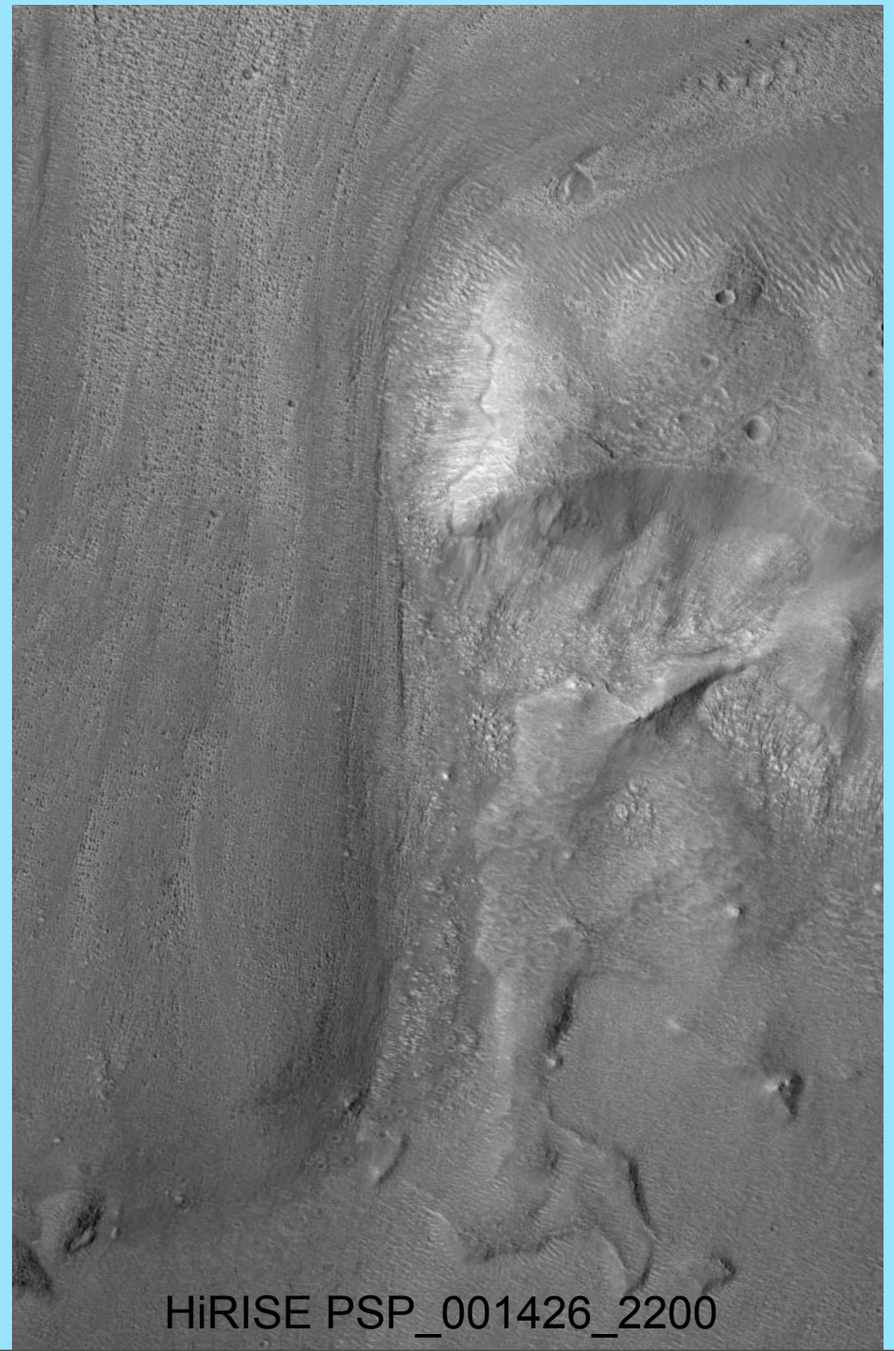


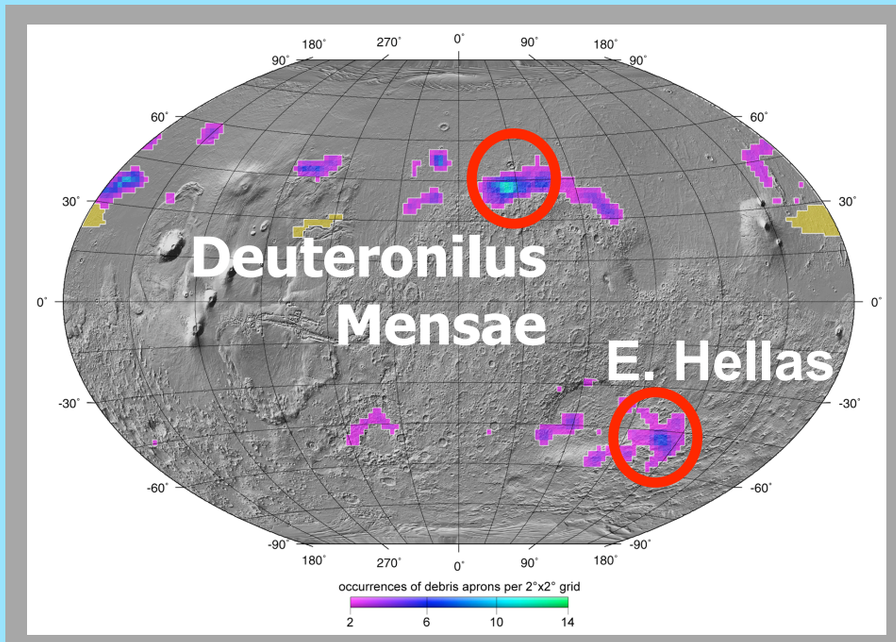
Lobate Debris Aprons

Morphology suggests ice as a component, but amount is debated. End members:

- **~ 10%: ice-lubricated debris flow**
- **~ 95%: debris-covered glaciers**

Deuteronilus Mensae

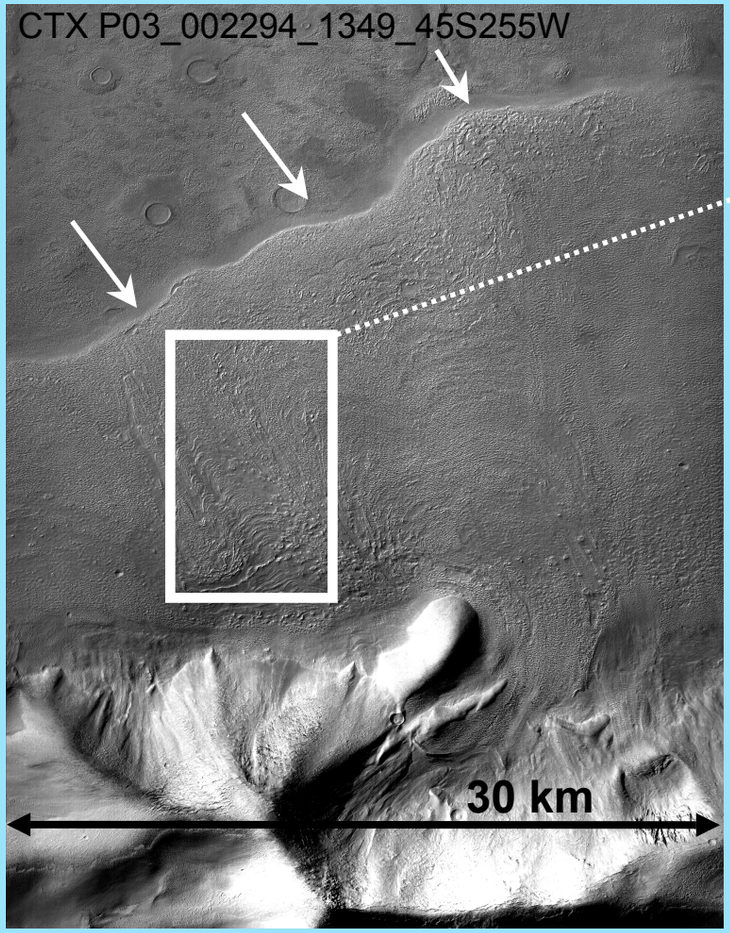


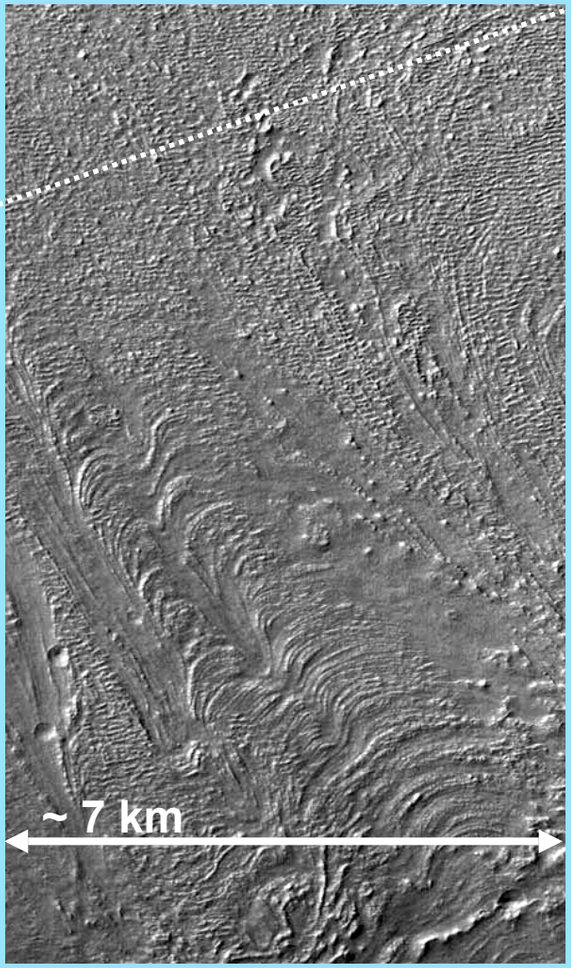


Global distribution

Hauber et al. (2008)

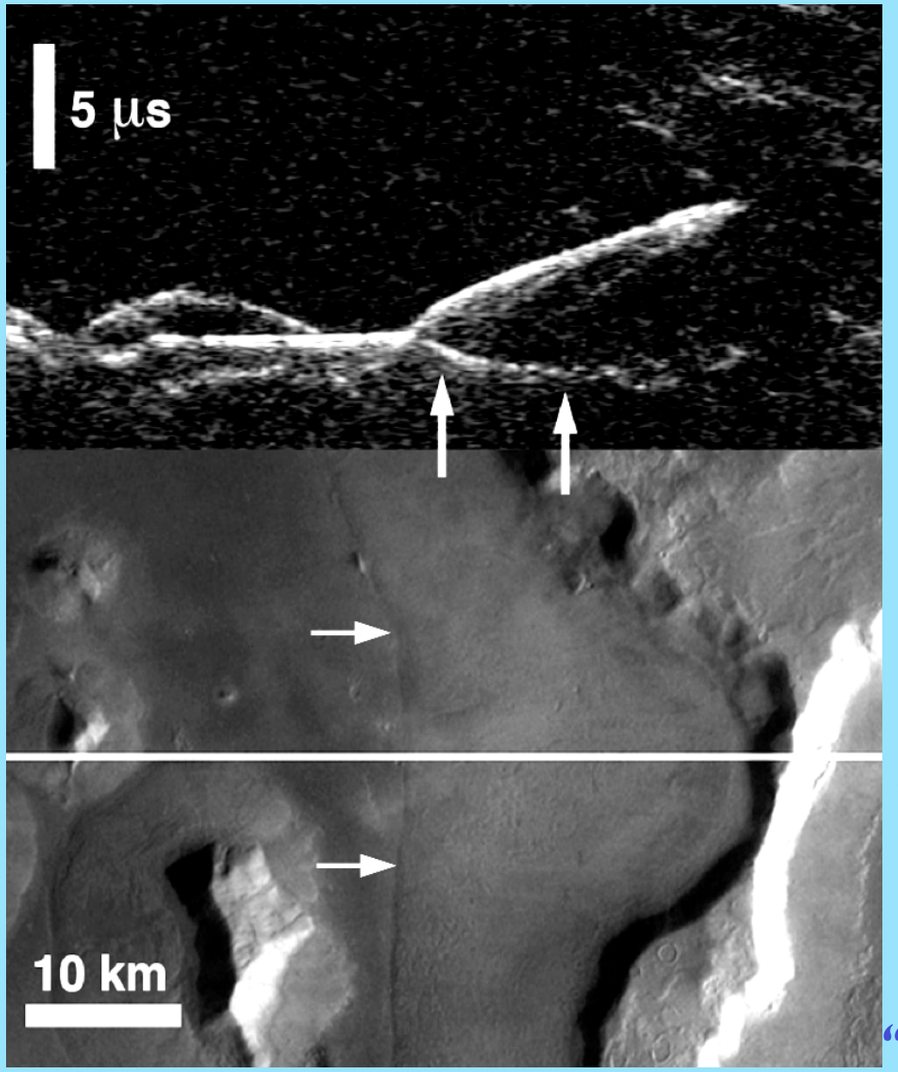
Eastern Hellas region





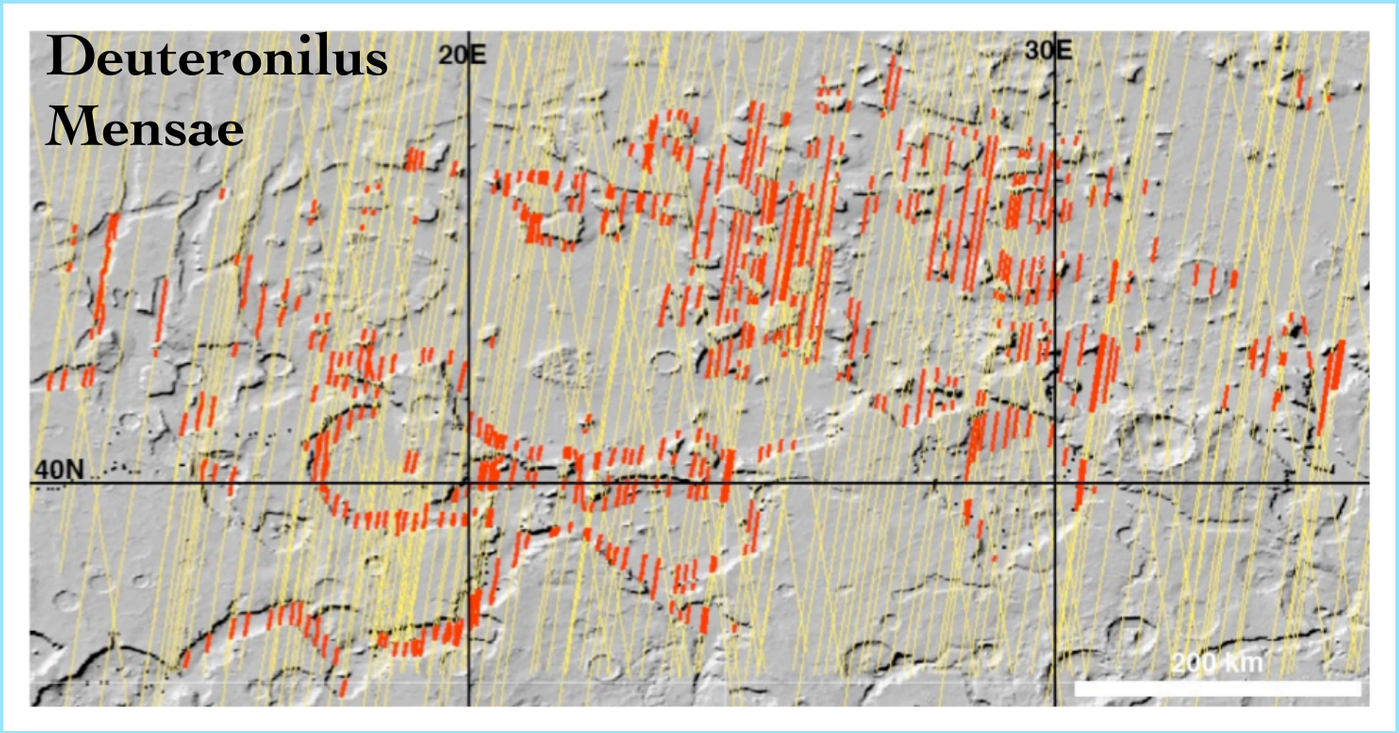
See Holt et al. (Science 2008)

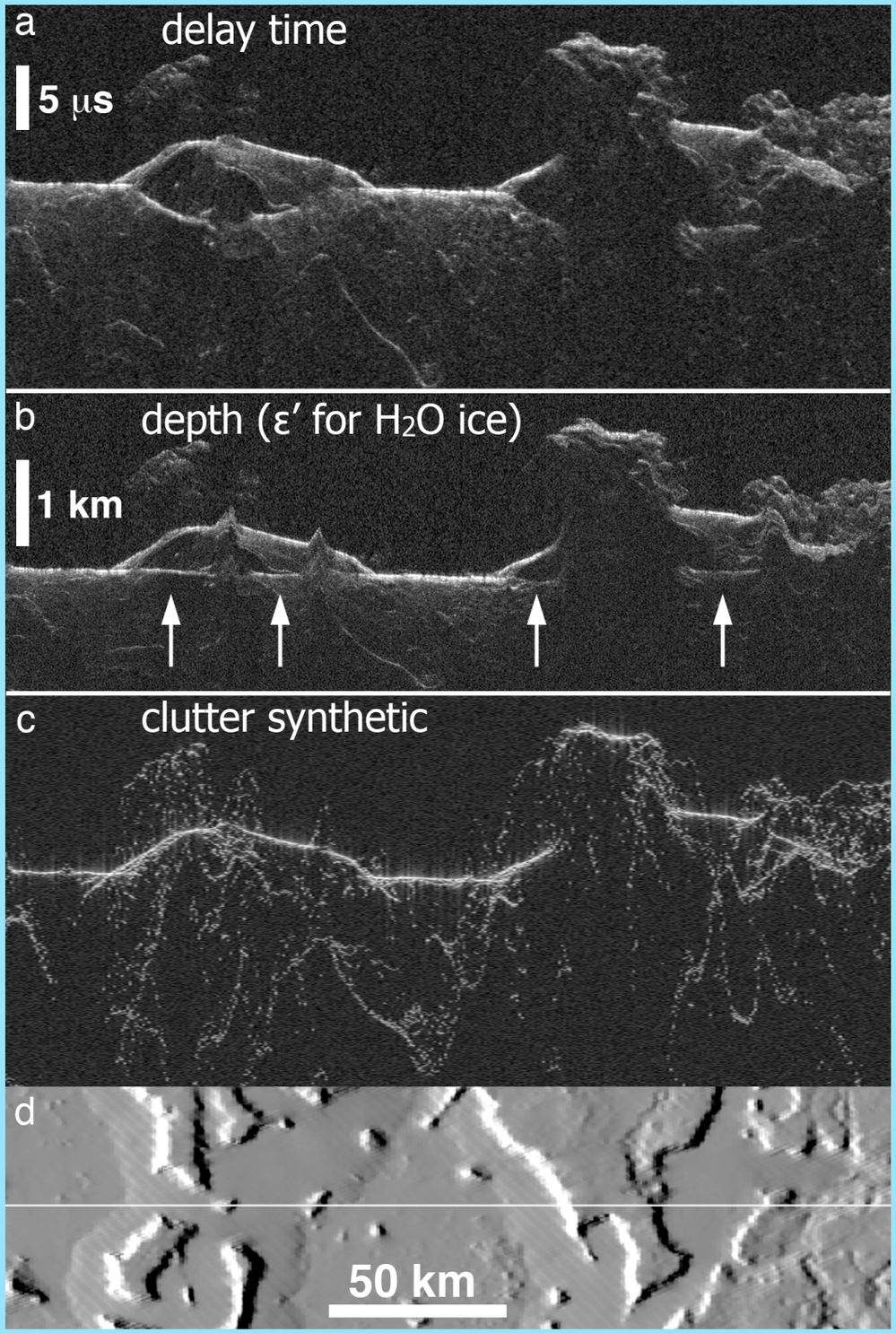
SHARAD results strongly support debris-covered glacier hypothesis



LDAs are established as remnants of mid-latitude glaciation

Mapped detections (in red below) are widespread and include LDAs and "lineated valley fill".

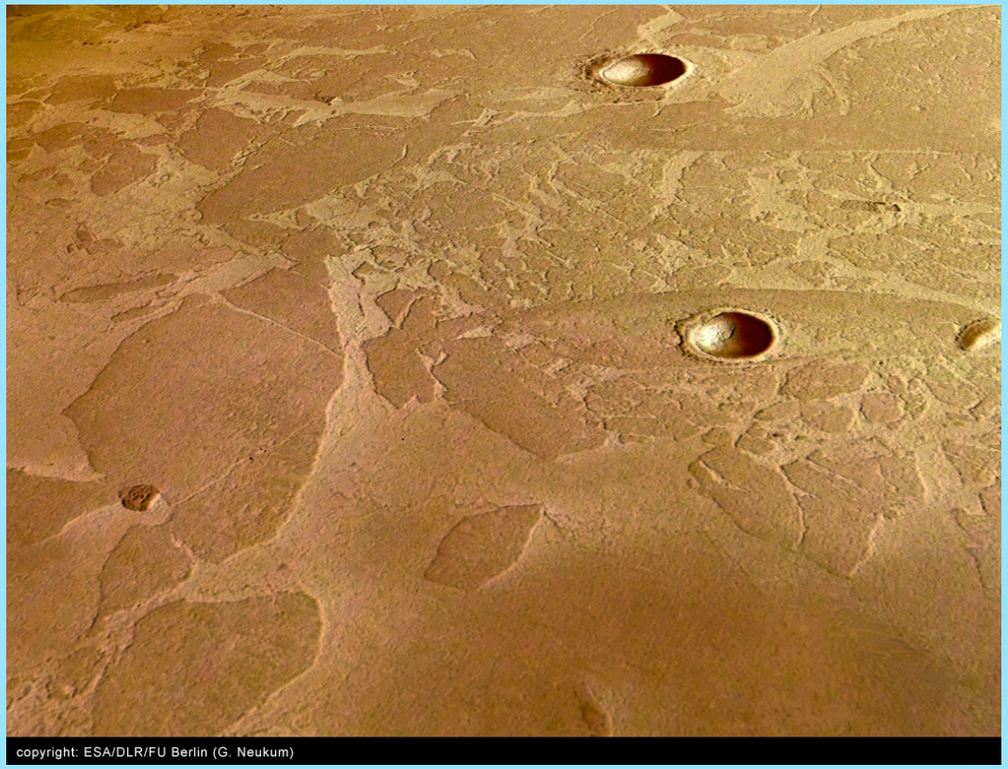


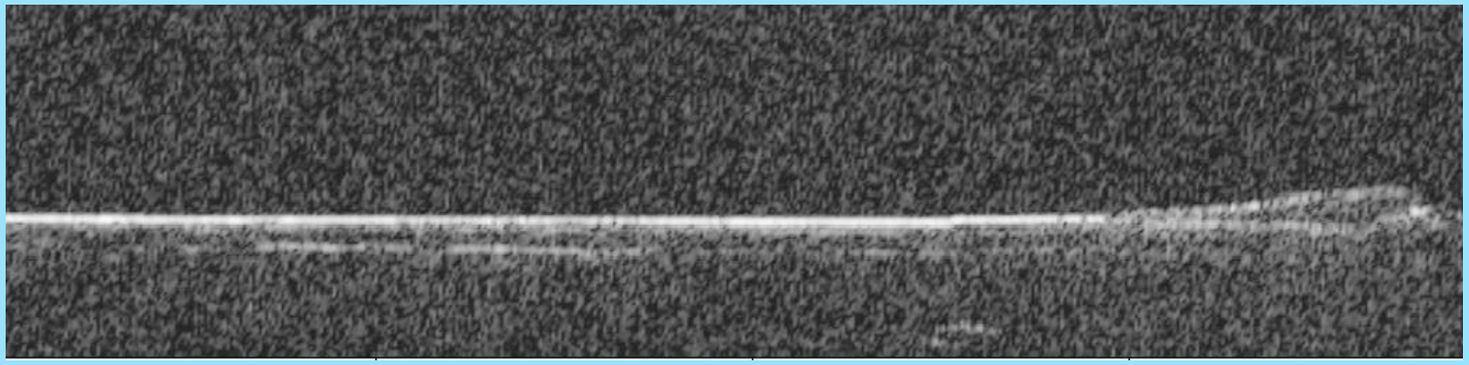


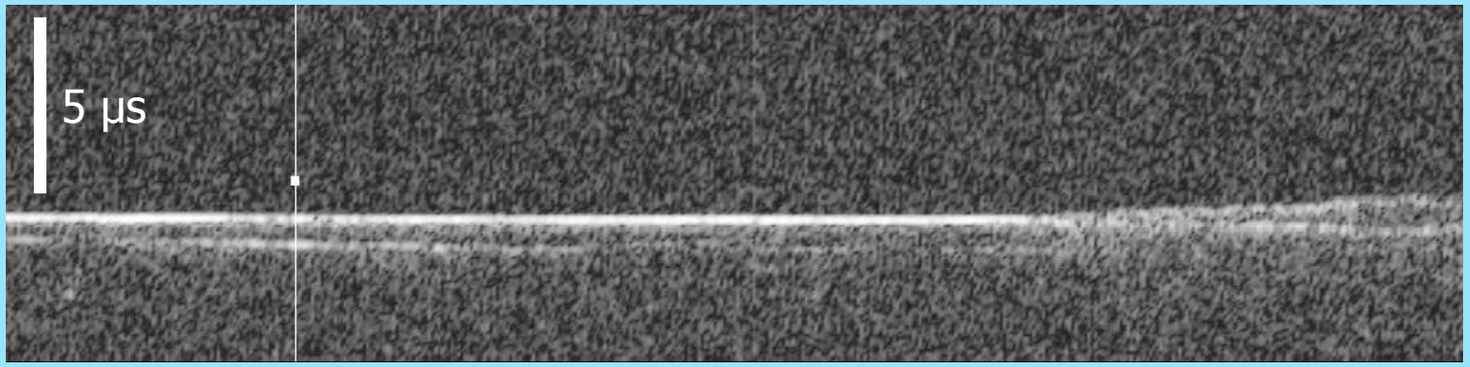
Plaut et al. (GRL 2009; LPSC 2010)

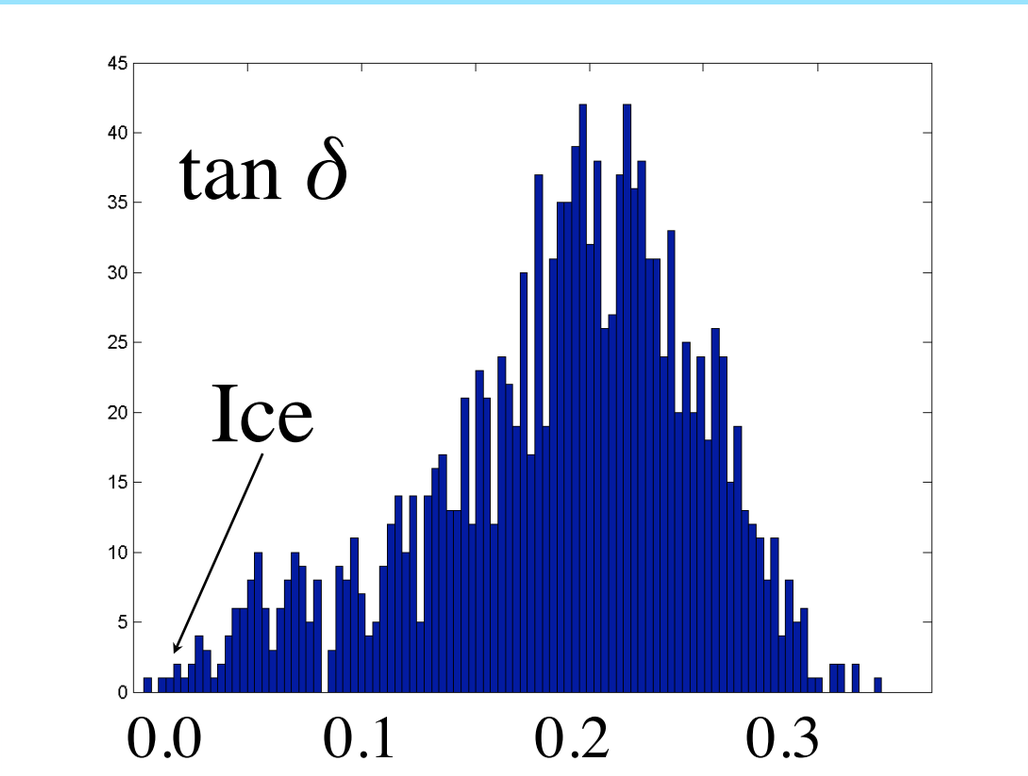
Non-Ice Targets

1. SHARAD shows that Cerberus Palus is not a Frozen Sea







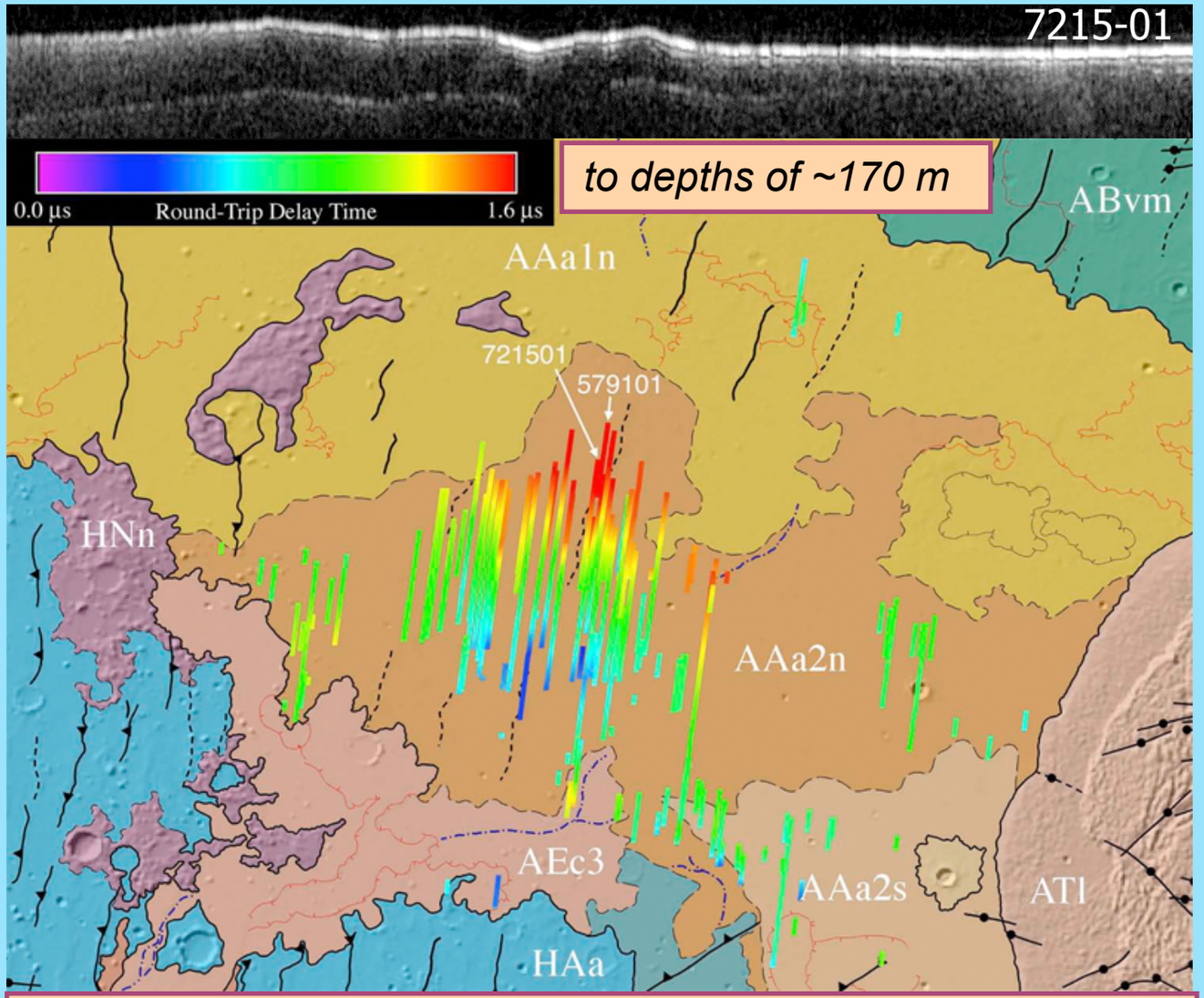


Histogram of **estimated loss tangent** over Cerberus Palus. Most values are > 0.1, and thus **incompatible with pure or dirty ice** in the subsurface.

Orosei et al. (EPSC 2010)

Non-Ice Targets

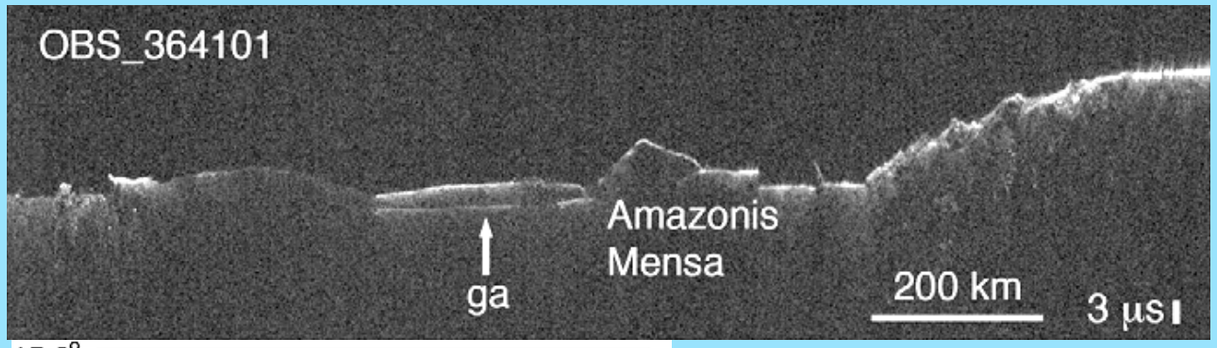
2. Amazonis Planitia

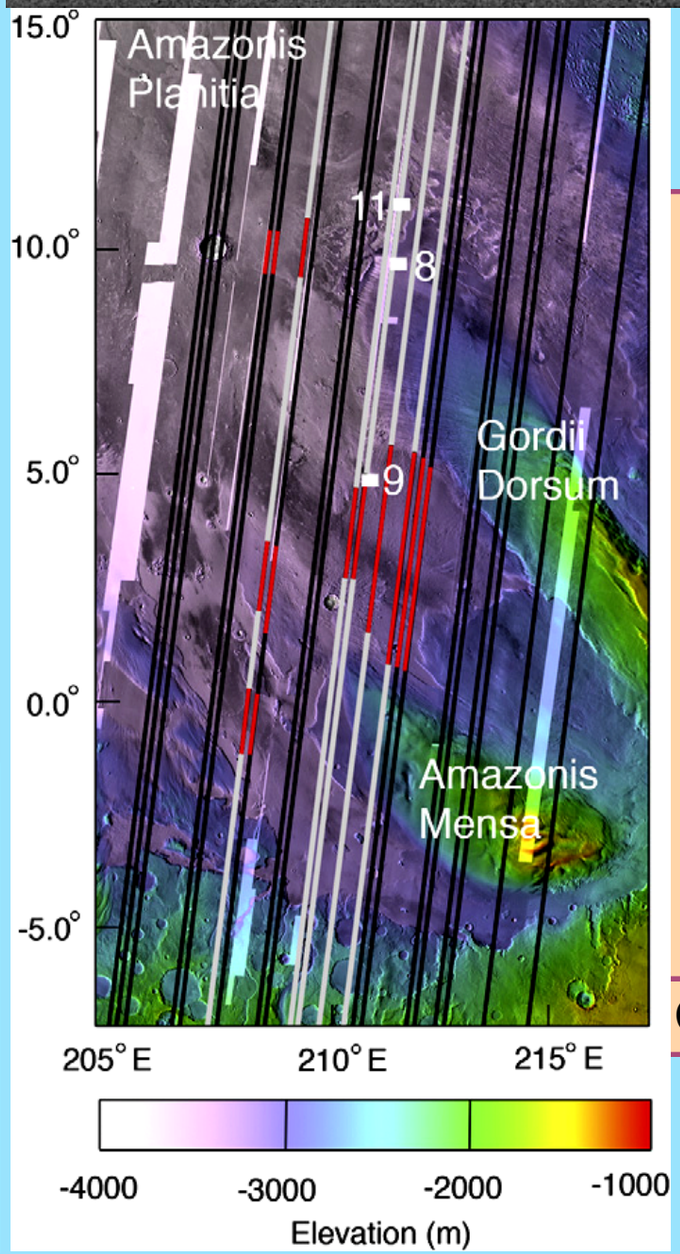


Here, interface marks base of early Amazonian Vastitas Borealis Formation sediments (ABvm) – see Campbell et al. (JGR 2008).

See also Carter et al. (Tue PM) for latest detections to southeast that appear to be from base of mid-Amazonian lava flows.

3. Medusae Fossae





- Reflectors to ~600 m depth.
- ε' ~3, low loss
- no layers (single interface)

➪ **Likely to be a high-porosity material, perhaps pyroclastics?**

Carter et al.(Icarus 2009)

Conclusions

- **Planum Boreum:** H_2O ice layers and structures shed light on heat flow, climate cycles, & recent processes.
- **Planum Australe:** Newfound CO_2 ice deposit may indicate a recent near-doubling of surface pressure.
- **Mid-latitudes:** LDAs are revealed as debris-covered glaciers. Constraining pyroclastics, lava, and sediments helps assess the roles volcanism and fluvial activity.
- All of these features and their evolution over time are closely tied to the climate history of Mars.

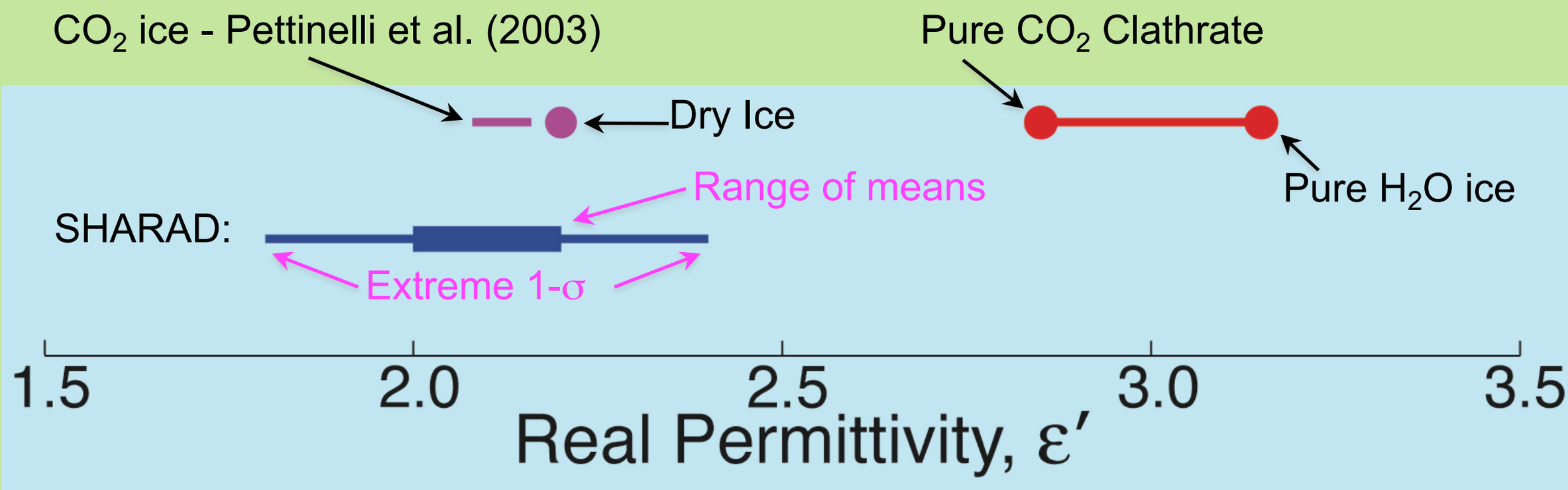
Acknowledgments

Thanks to NASA, ASI (Italian Space Agency), the MRO Project, and the SHARAD Team.

extra slides

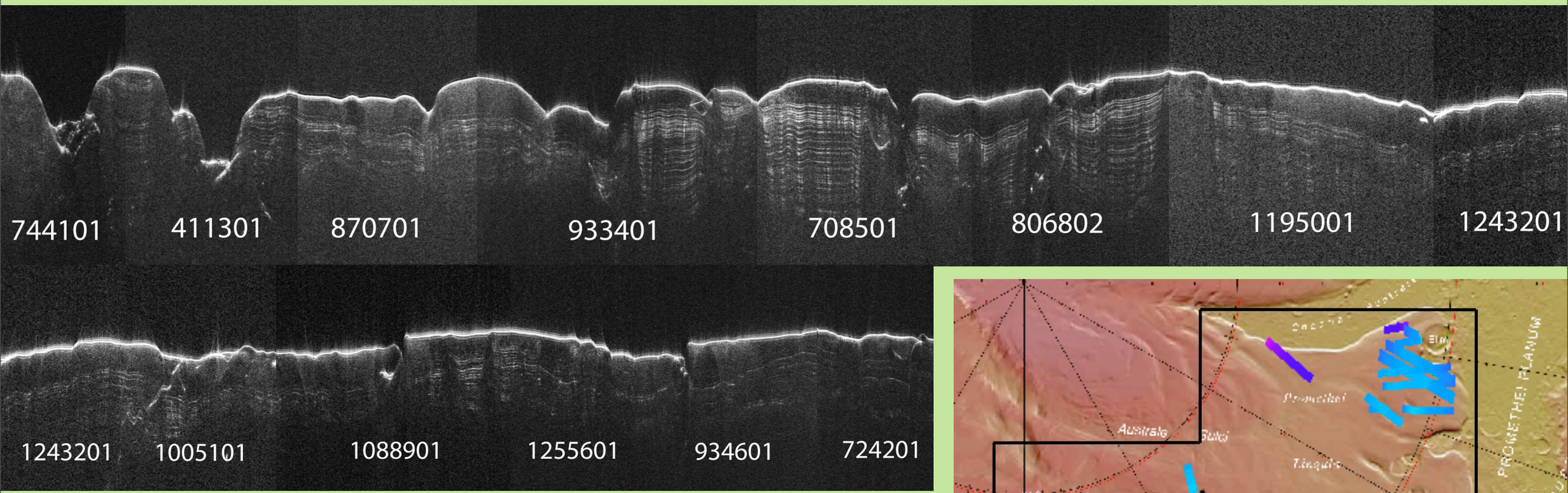
SHARAD Permittivity Results

Results for 41 radargrams using two versions of regression method and four versions of correlation method.

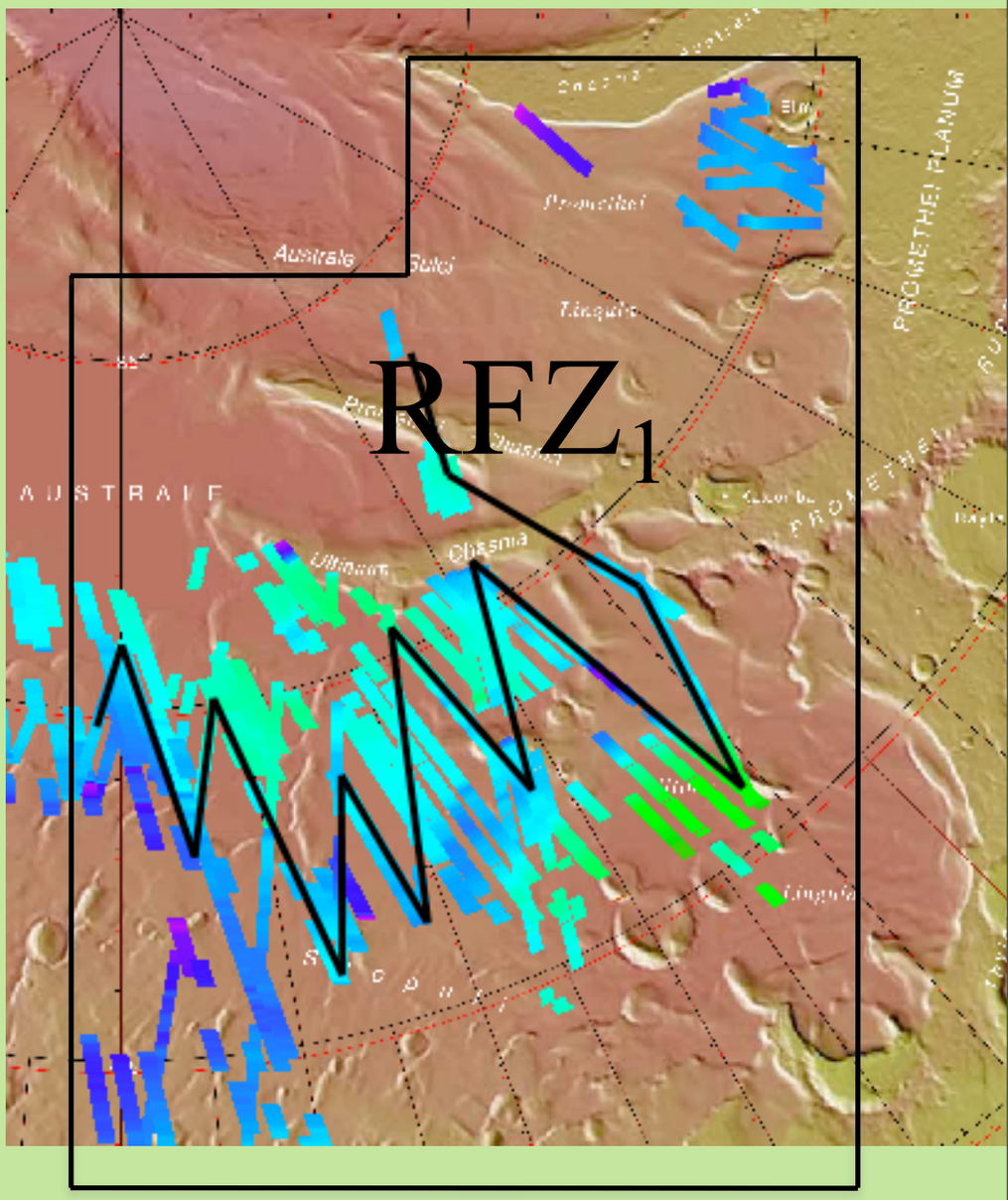


Phillips et al. (Science 2011)

How ‘bout them other RFZs?



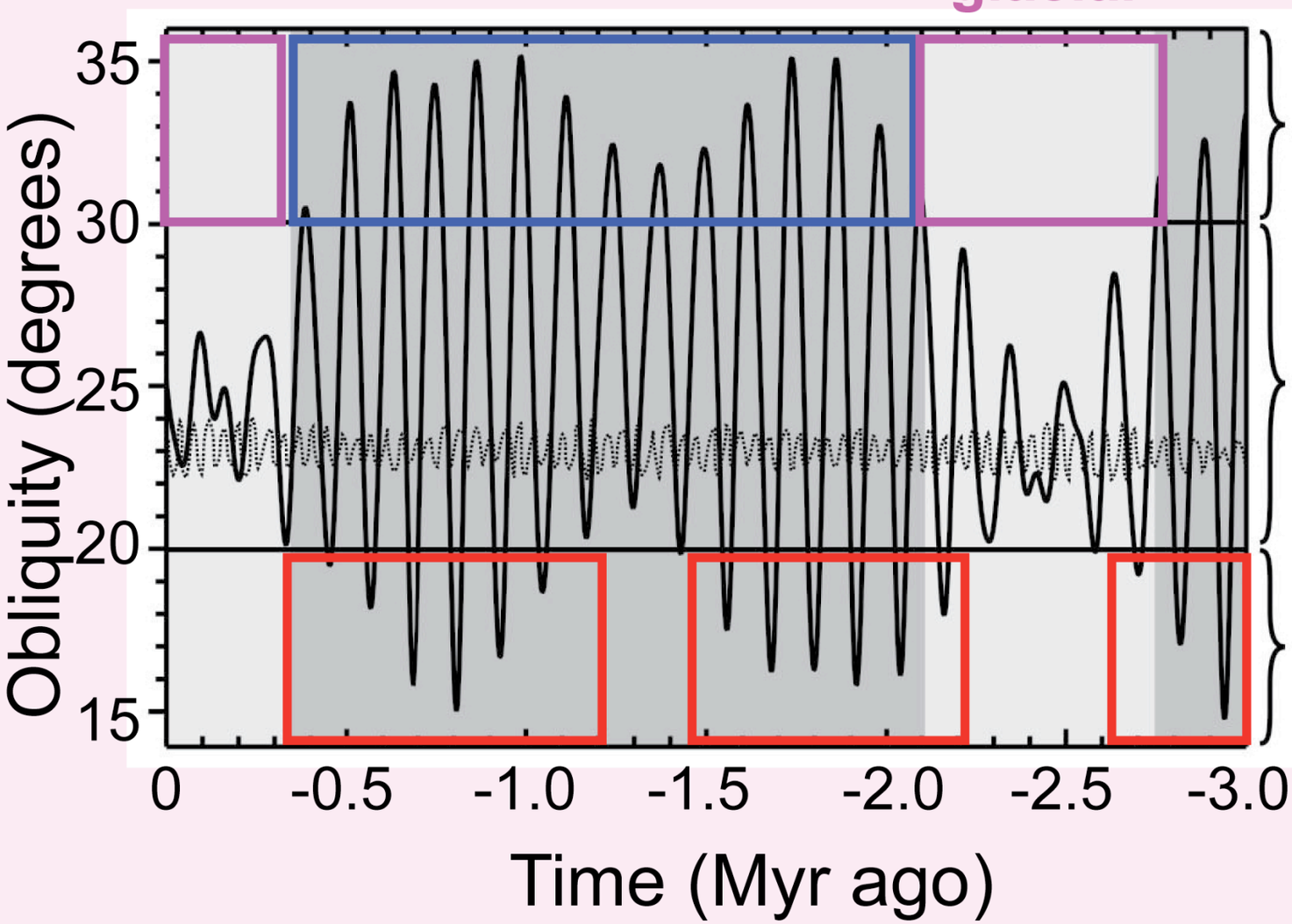
- We tried <u>really</u>, <u>really</u> hard to estimate ε′ in the other 3 RFZs.
- Alas, we failed: lack of rugged lower boundaries.
- Lack of sublimation features associated with other RFZs. But is that strictly true?



When was the ice emplaced?

Accumulation at mid-latitudes.
Net removal at polar caps.
Mid-latitude Ice Age

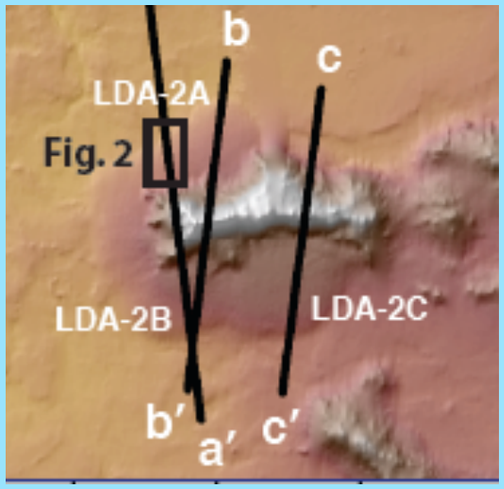
LDAs remain.
Inter-glacial



Moderate accumulation of cap.

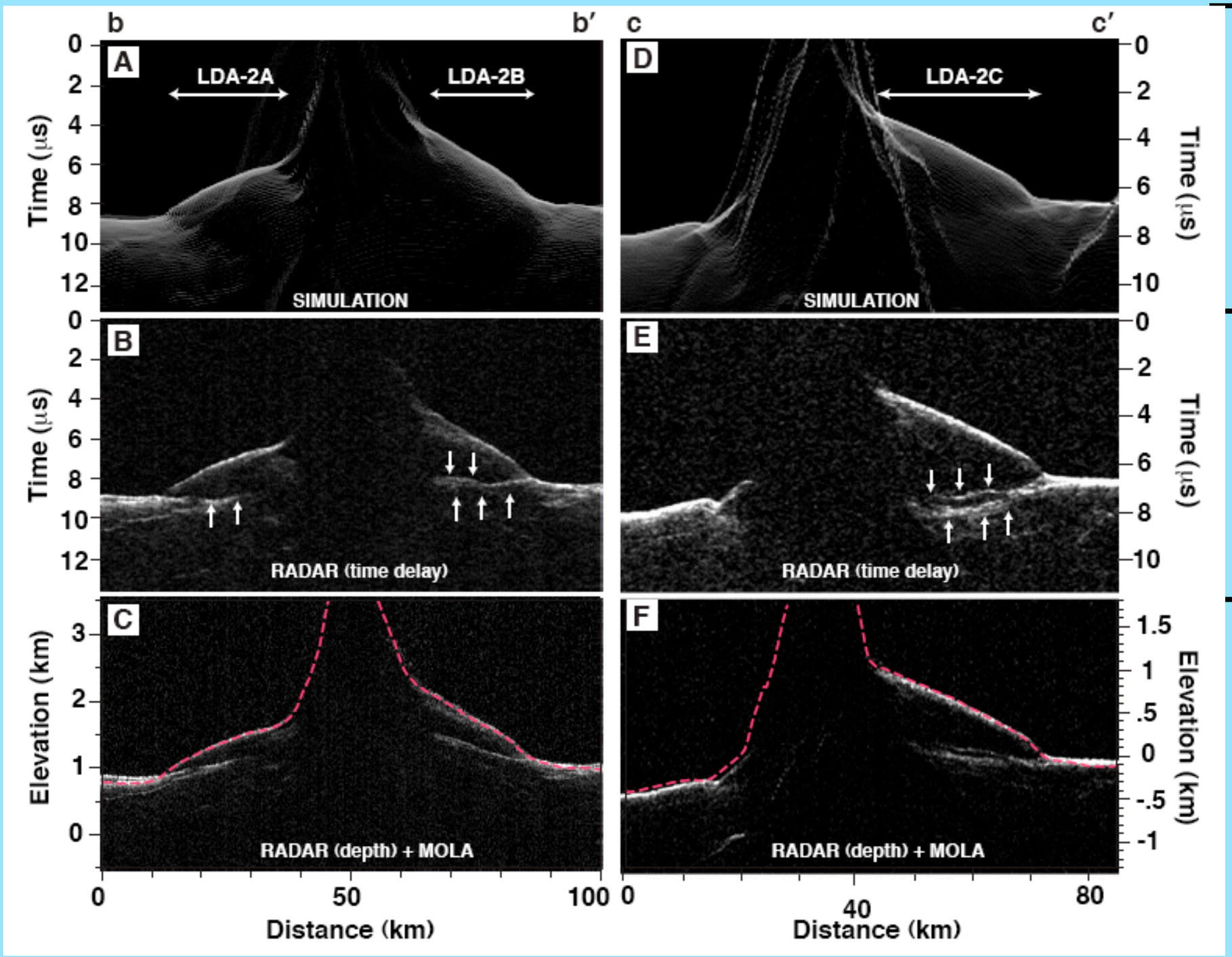
Intense accumlation of ice cap & liitle dust transport to poles.
Interpacket regions form.

Modified from Head et al. (2003)



SHARAD results strongly support debris-covered glacier hypothesis

Eastern Hellas



Critical Step: Modeling of surface clutter (based on MOLA topography)

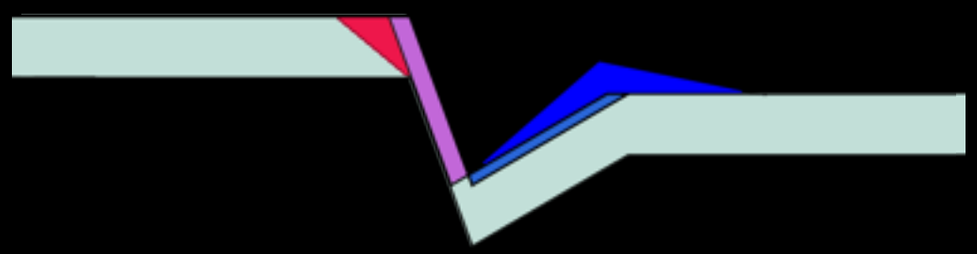
SHARAD data:

- **Radar transparency**.
- Little interior scattering.
- Losses similar to ice, PLD.
- Possible thin basal layers.

Depth-converted SHARAD data with MOLA surface

Holt et al. (Science 2008)

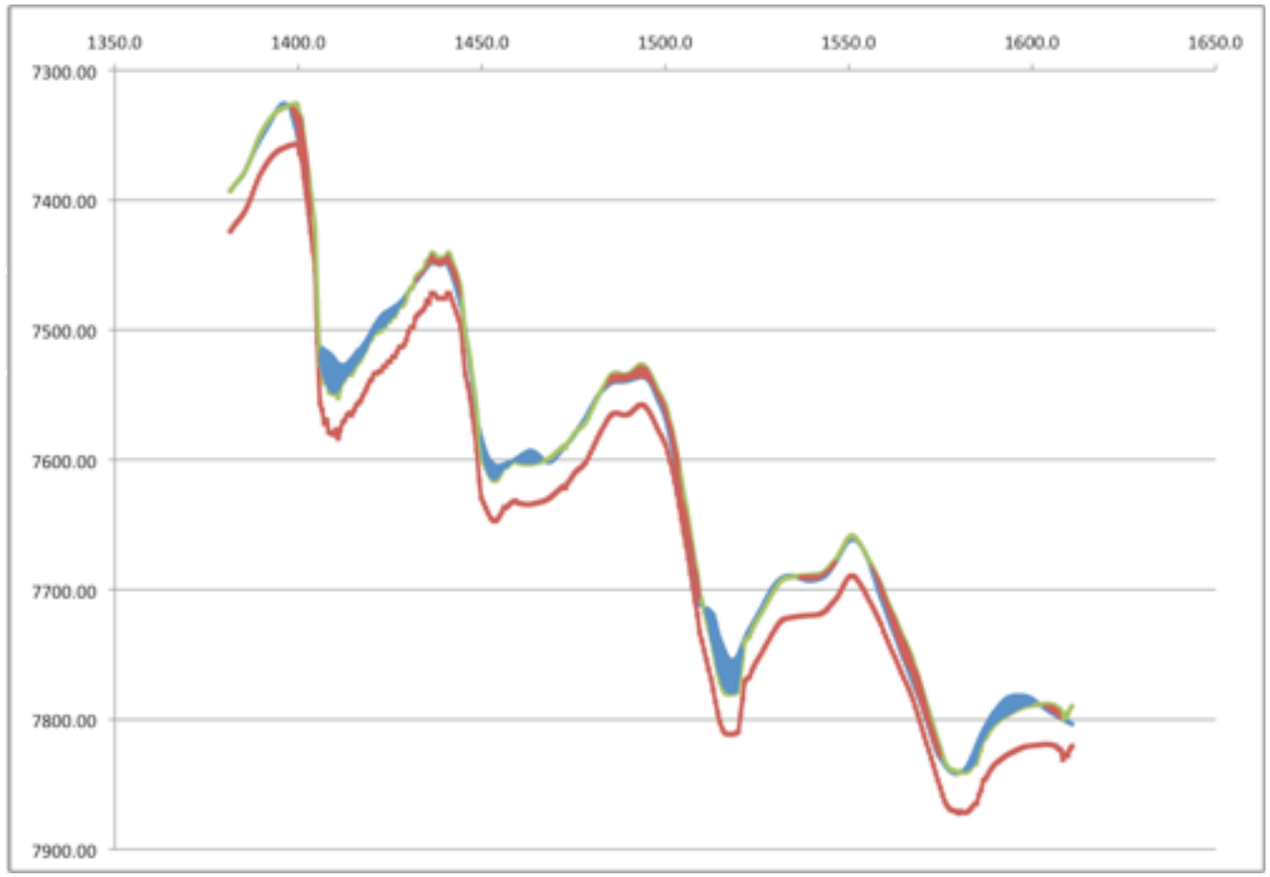
NPLD Troughs

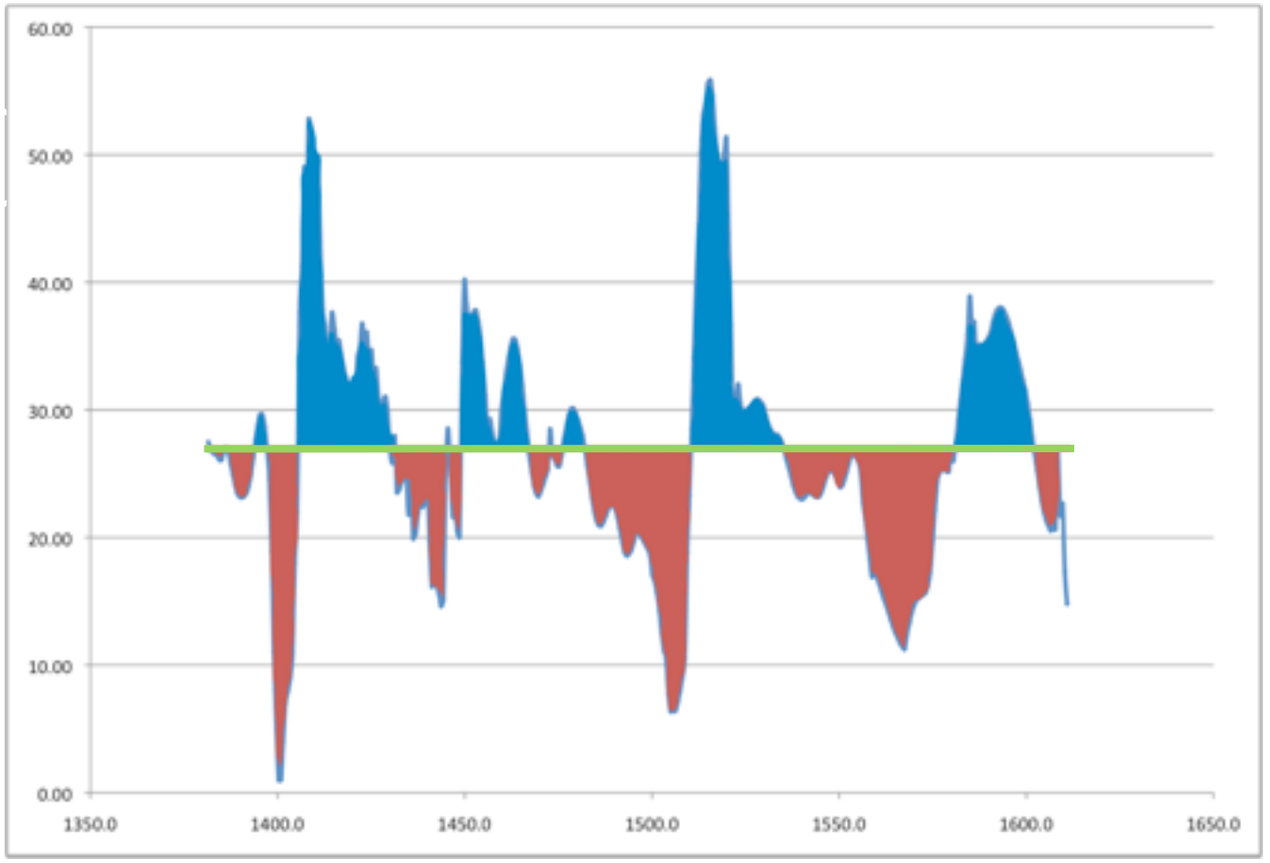


Length (km) 229
Average thickness (m) 27

Area km^2 6.184

Communication between troughs is minimal

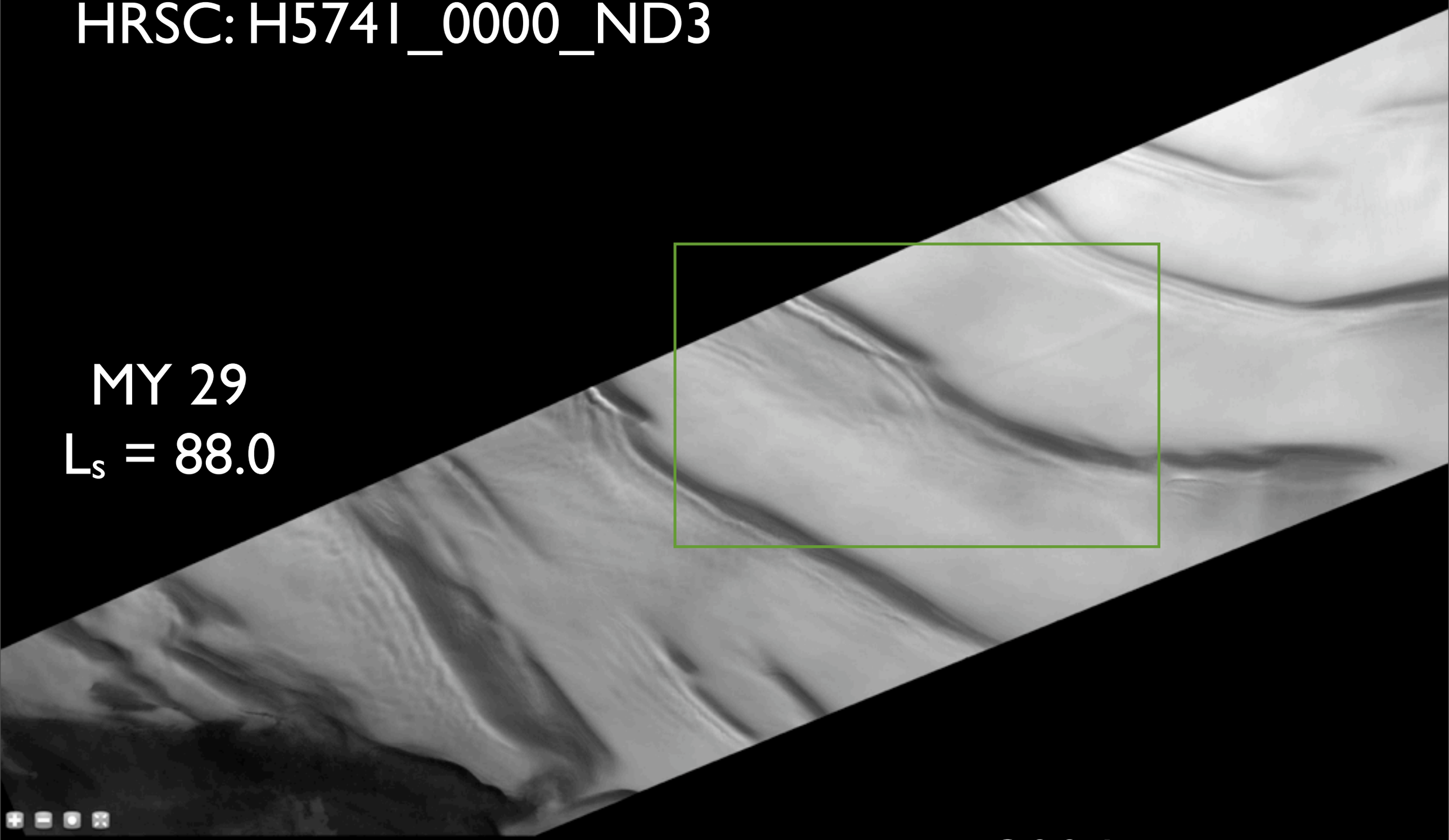




Along Track (km)

NPLD Troughs

HRSC: H5741_0000_ND3



MY 29

L_s = 88.0

~300 km

NPLD Troughs