Three-dimensional imaging of the Martian polar ice caps from orbit with the MRO Shallow Radar sounder

The Shallow Radar (SHARAD) on the Mars Reconnaissance Orbiter

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with

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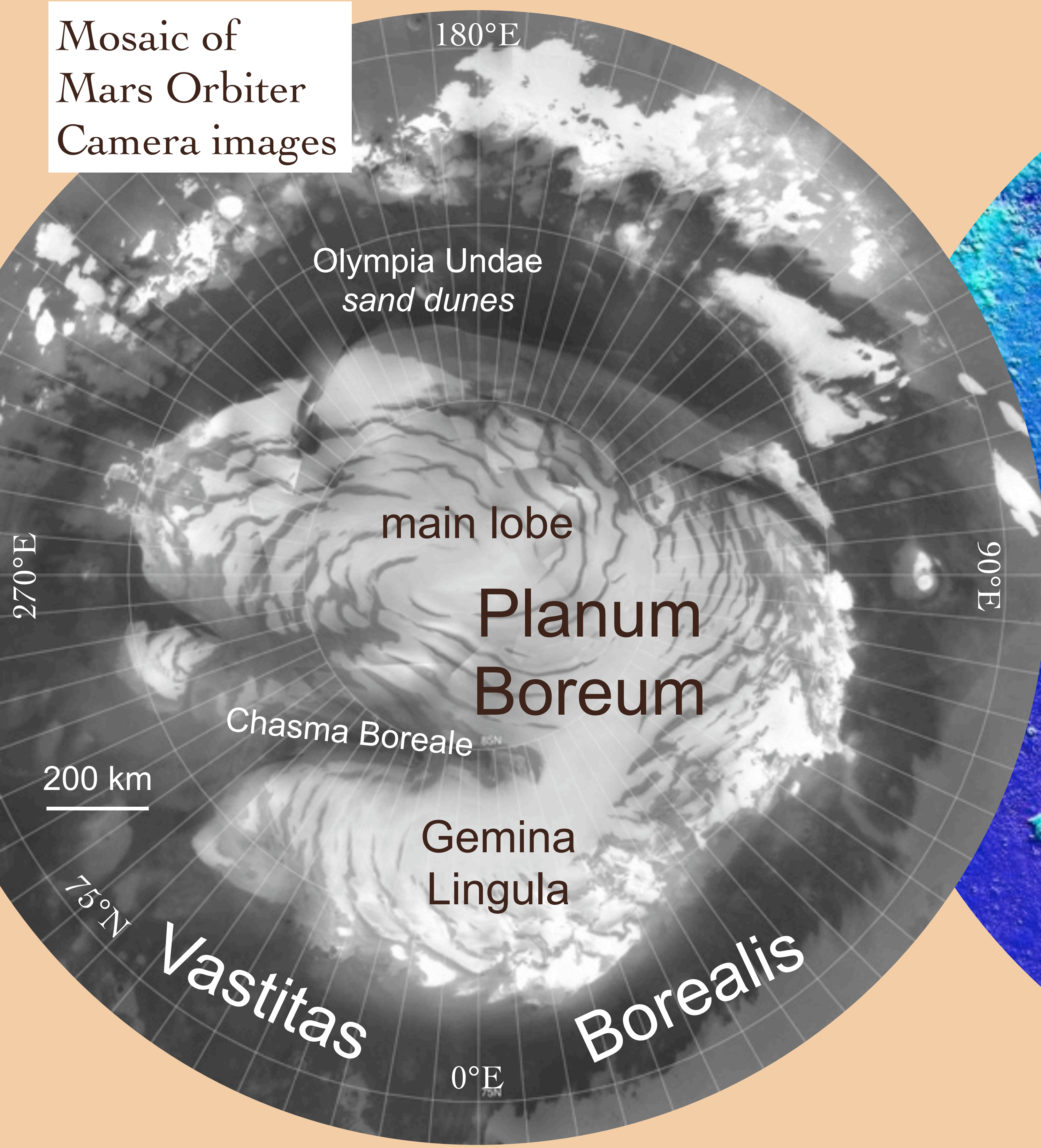
Image credit: NASA/JPL

Outline

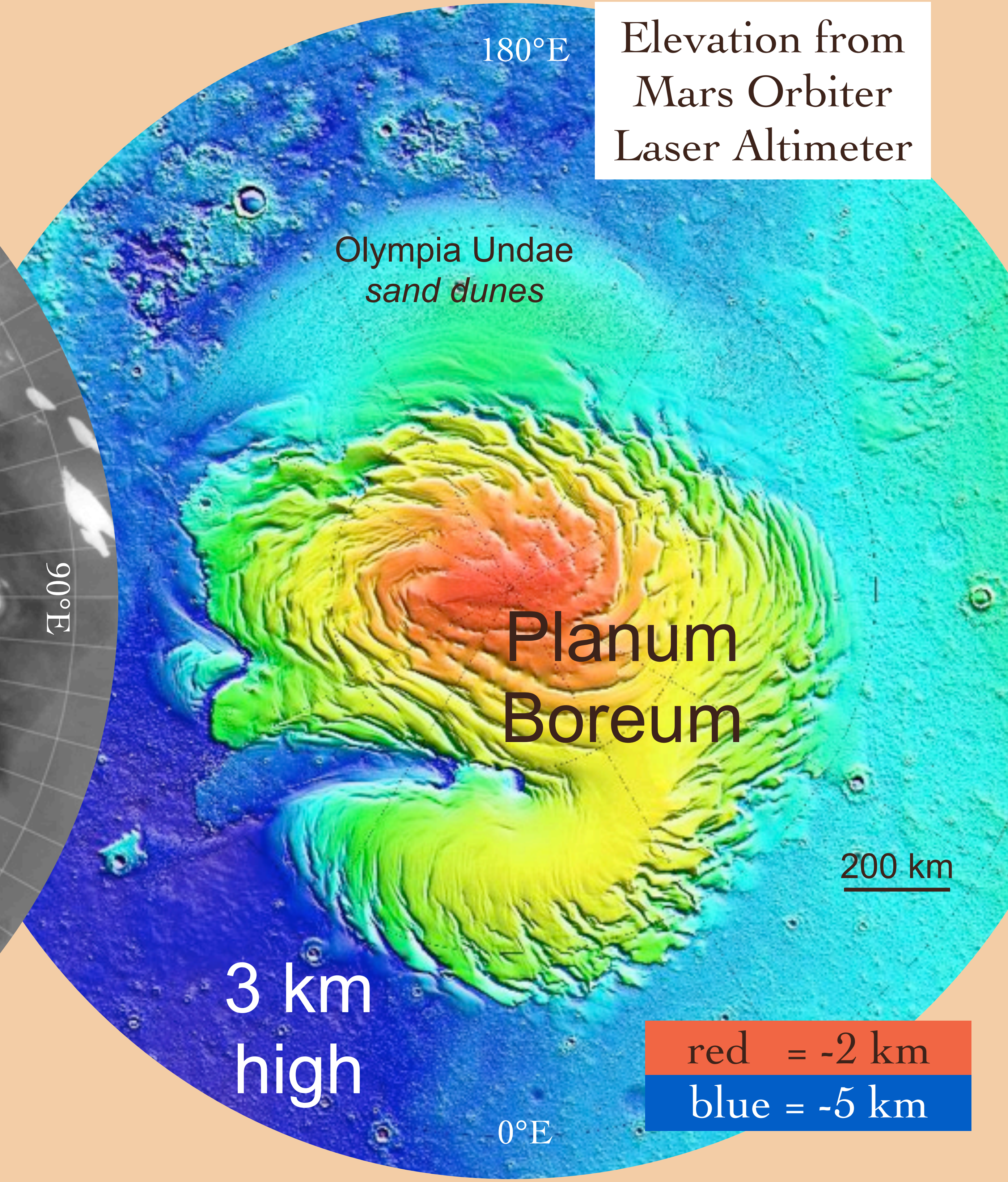
- Overview of Martian north polar region and the SHARAD instrument.
- Summary of polar science results from the collection of 2-D radargrams.
- First results for 3-D processing of the north polar data volume.
- Future plans and Conclusions.

The North Polar Region of Mars

Bright, high-standing ice-rich deposits cut by layer-exposing troughs and surrounded by basaltic dunes.



NASA/JPL/Malin Space Science Systems



NASA/MOLA Science Team

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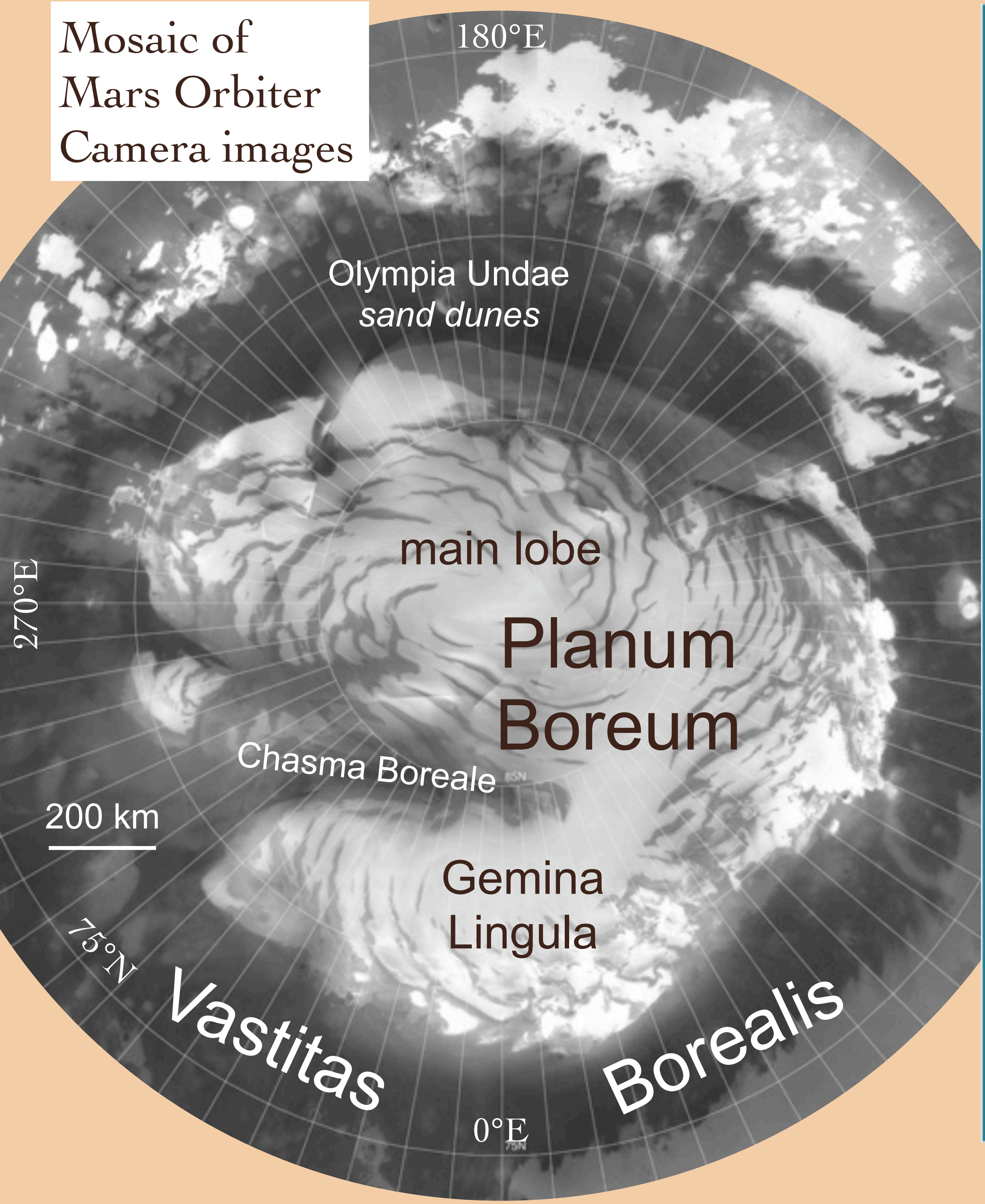
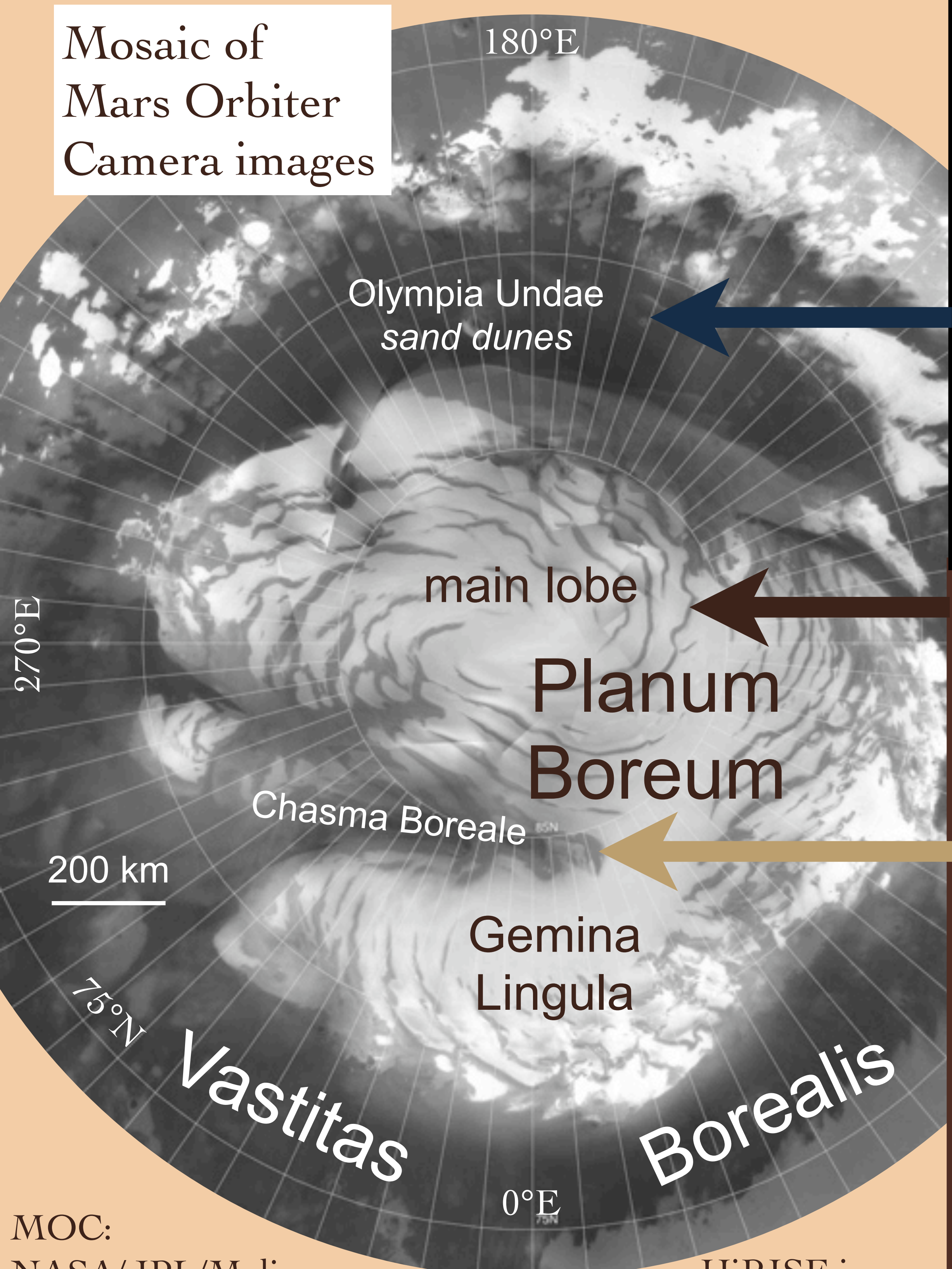


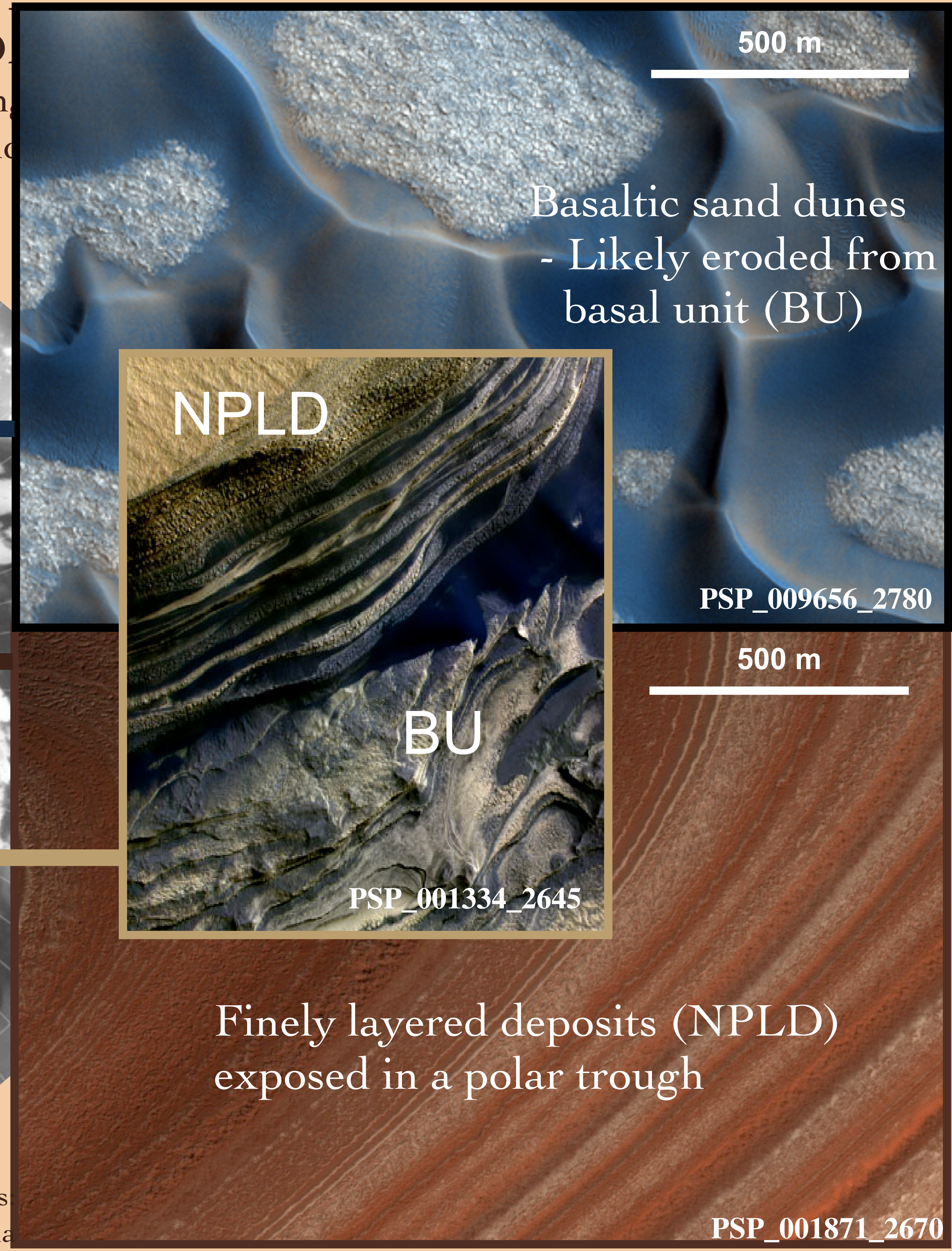
NASA/JPL/Malin Space Science Systems

NASA/MOLA Science Team

The North Po

Bright, high-standin
exposing troughs an





MOC:
NASA/JPL/Malin
Space Science Systems

HiRISE images
NASA/JPL/University of Arizona

As MRO orbits Mars 12 times per day, SHARAD reveals layering within the subsurface.

Animation credit: NASA/JPL-Caltech/University of Rome/SwRI

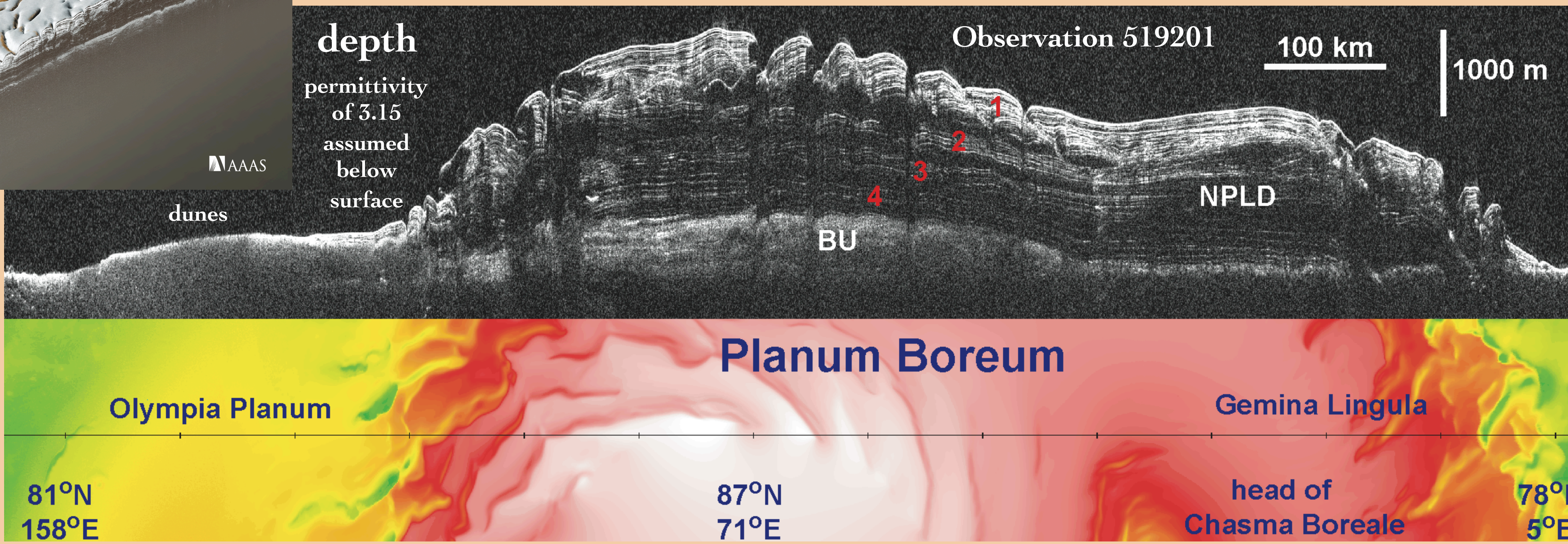
Orbit altitude: 255 to 320 km

Wavelength: 15 m (~9-m vertical resolution in ice)

Transmitted sweep: 15 to 25 MHz

Lateral resolution: 3 to 6 km (0.3 to 1 km inline with SAR)

In 2007, SHARAD began revealing the internal structure of the NPLD

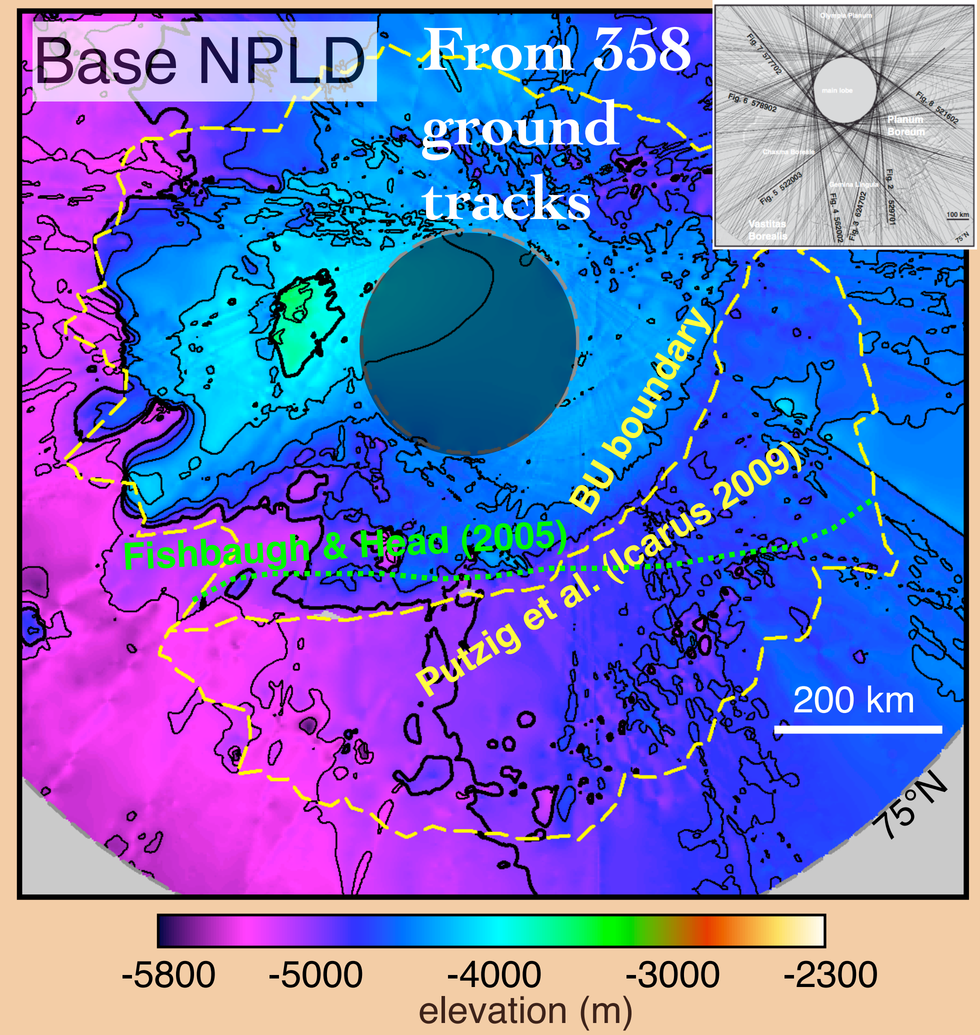


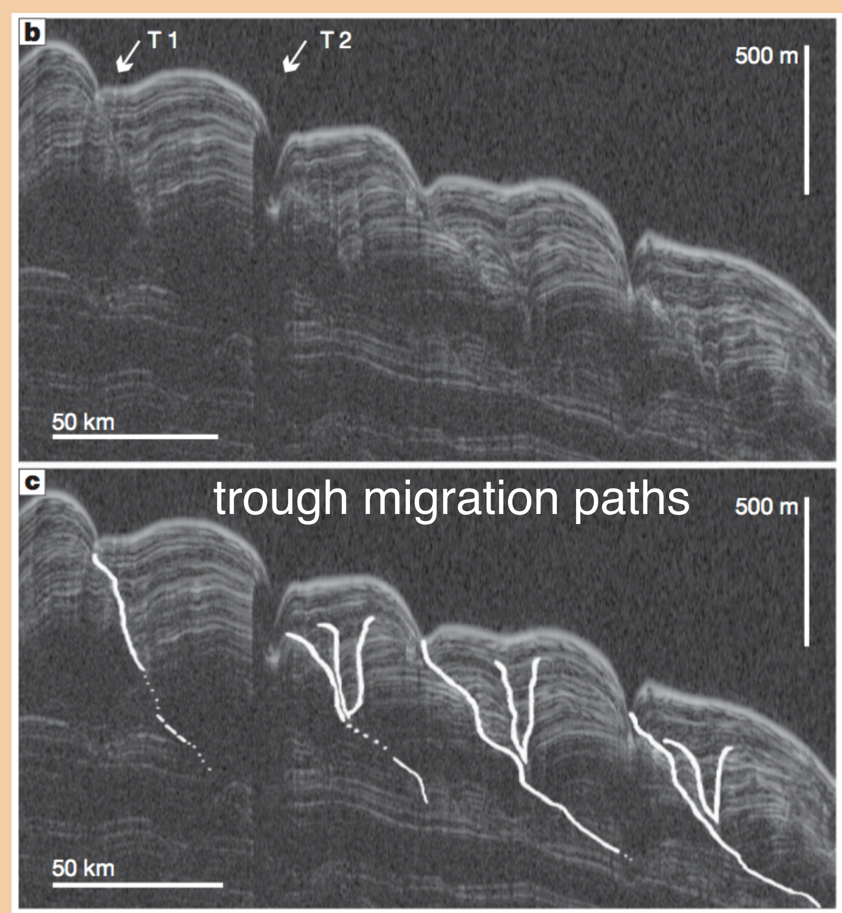
- – Strong basal returns imply relatively pure ice (<~5% lithics)
- – NPLD packet structure likely related to climate; age ~ 4.2 Ma
- – Older basal unit rarely layered, missing below >1/3 of NPLD
- **– Flat basal boundary has ~ 0 flexure ⇒ very low heat flow**

Phillips et al. (Science 2008); Putzig et al. (Icarus 2009)

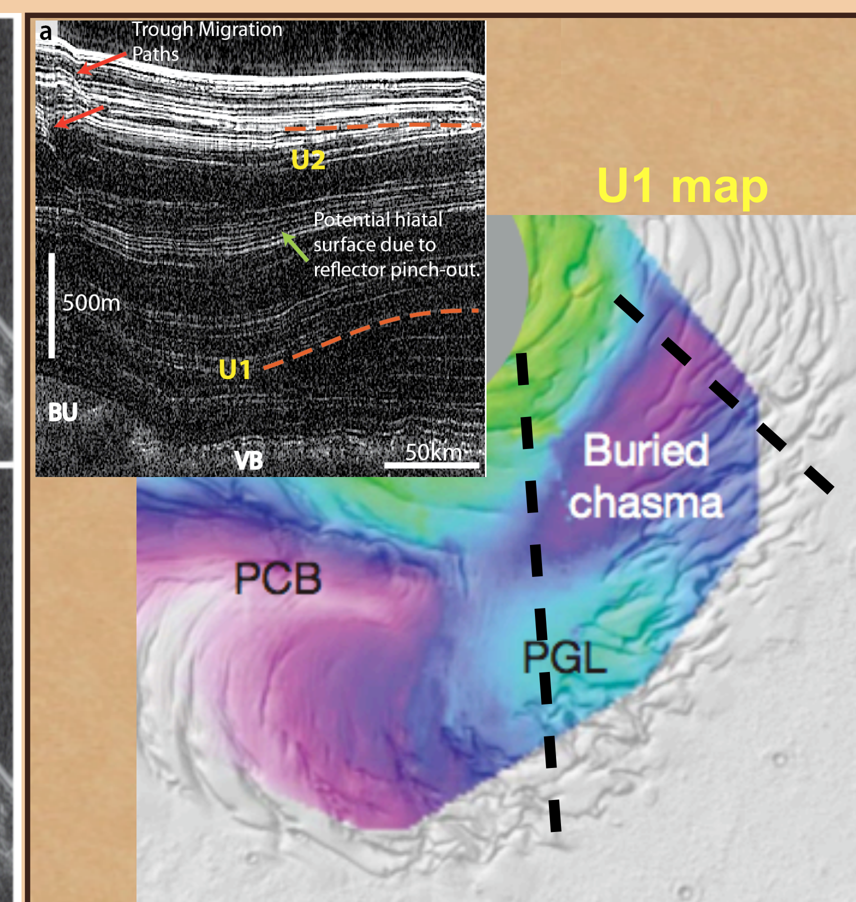
A growing grid of 2-D radar data is yielding important new science:

- Revised BU boundary led to a change of view on Chasma Boreale from an erosional to a constructional feature.
- Spiral troughs are shown to be wind-driven icy bedforms that are actively migrating poleward.
- Mapping internal unconformities revealed a buried chasma with no surface expression.





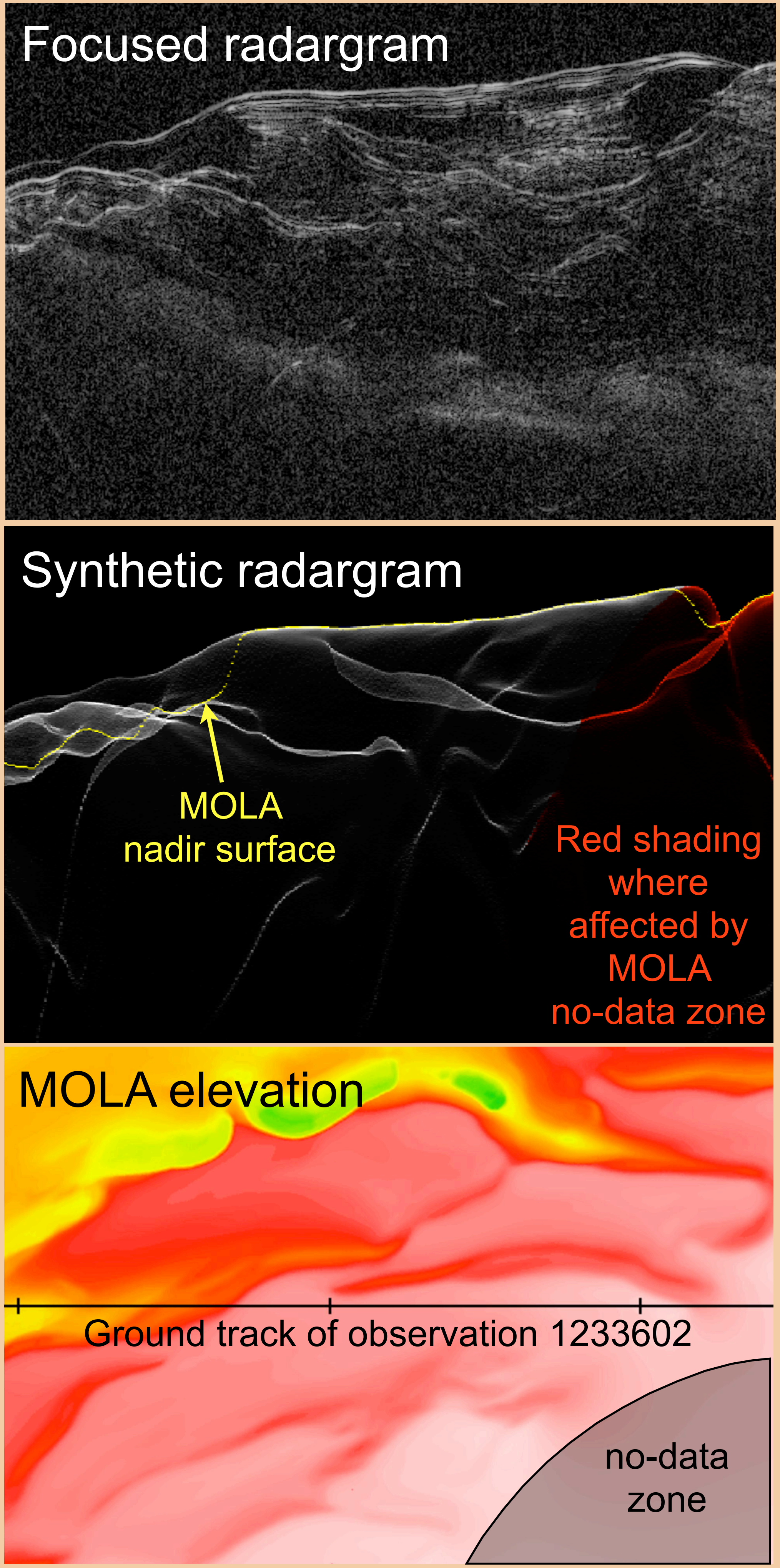
Smith and Holt (Nature 2010)



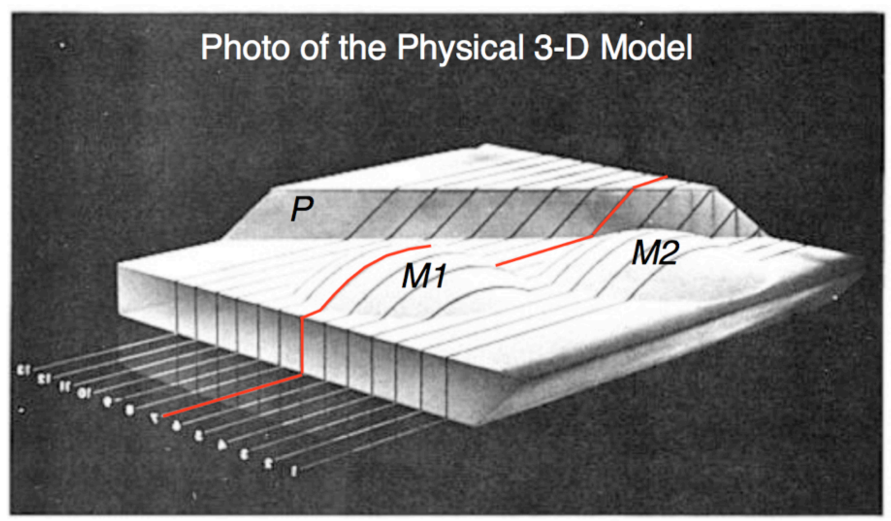
Holt et al. (Nature 2010)

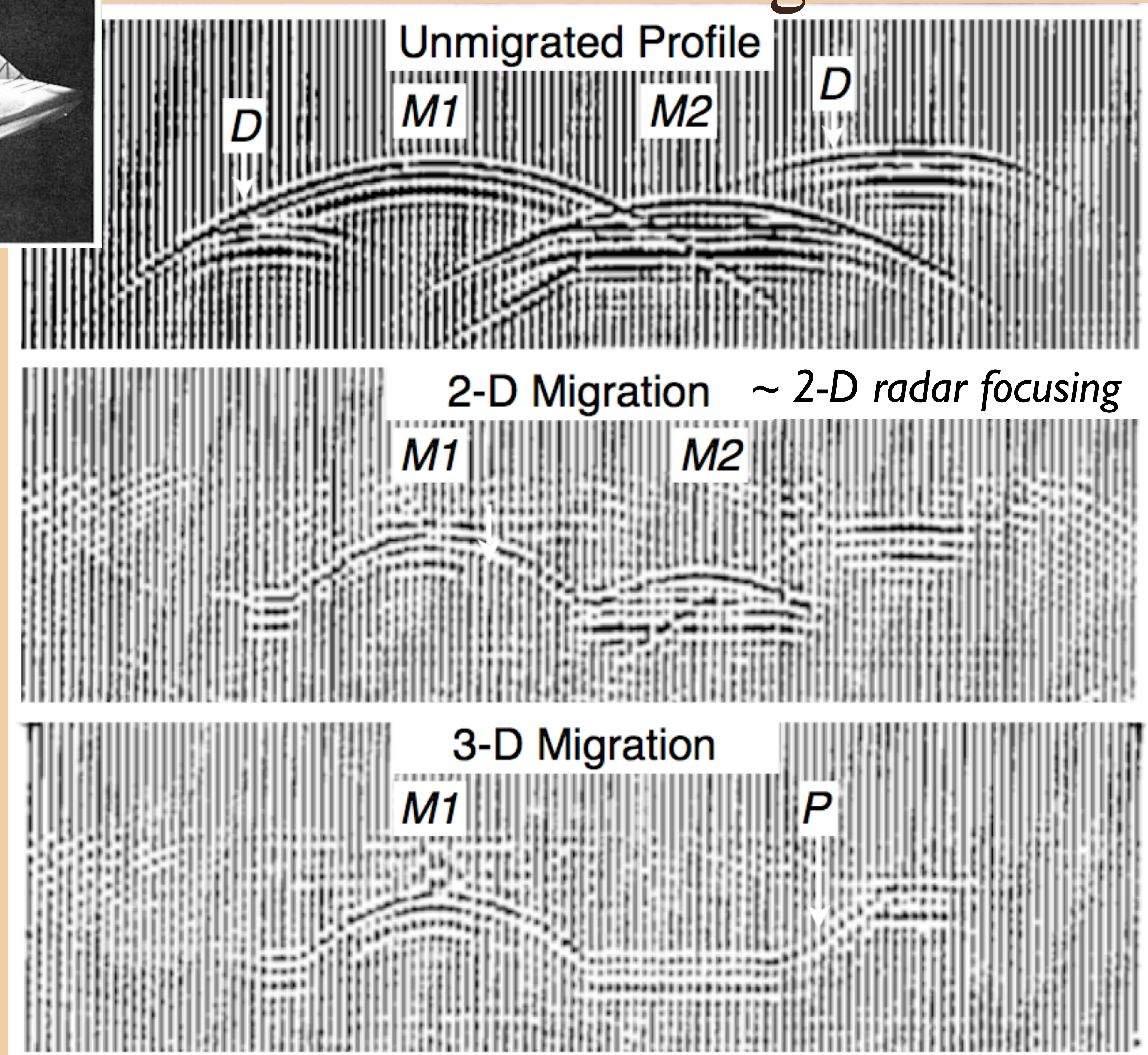
Limitations of conventional 2-D radar analysis

- **Clutter**: off-nadir returns that interfere with or can be mistaken for nadir-surface or subsurface returns.
- No returns are seen from features at nadir that slope away from the radar.
- Topographic models can be used to simulate surface returns and clutter. Corresponding features in data may then be dismissed as “noise”.
- However, subsurface clutter and off-nadir surface features not sampled in topographic data will not appear in synthetics.



Solution: 3-D migration





3-D migration will **collapse diffractions (D)** and **reposition out-of-plane returns (M2)** to their source locations.

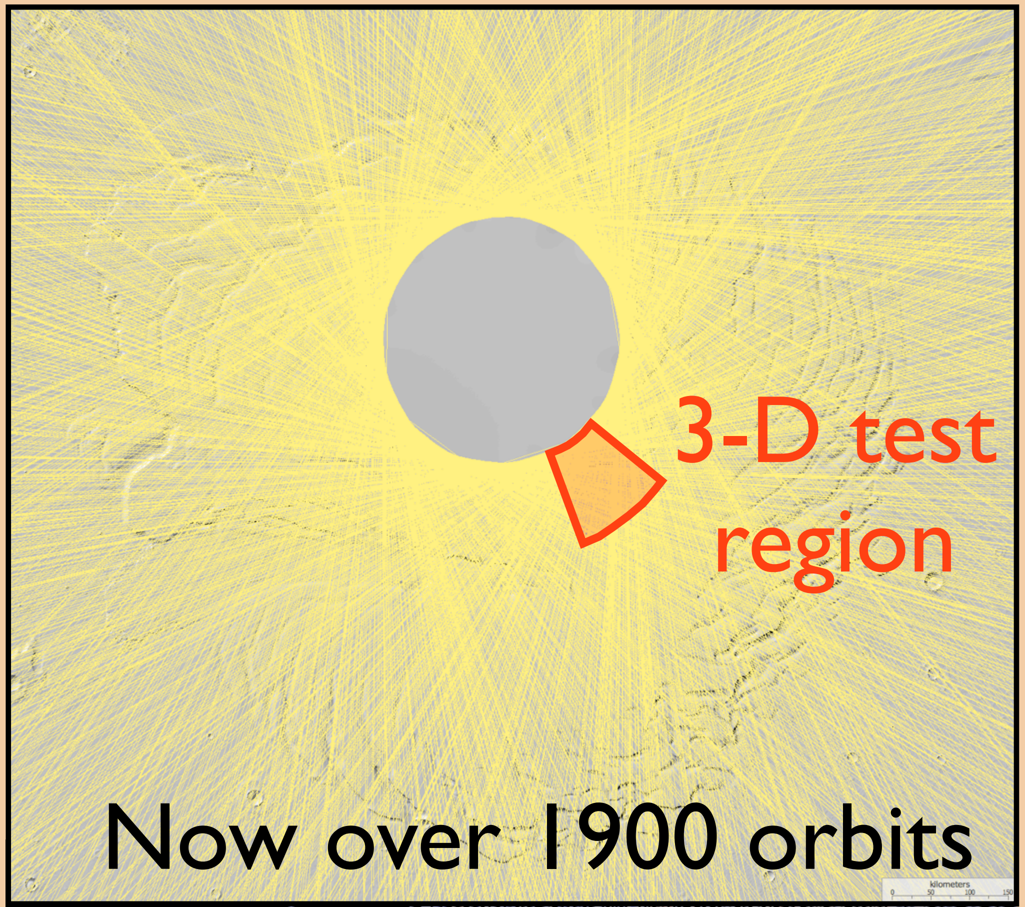
Energy from adjacent profiles will be restored, thereby **imaging features oriented obliquely to the profile (P)**.

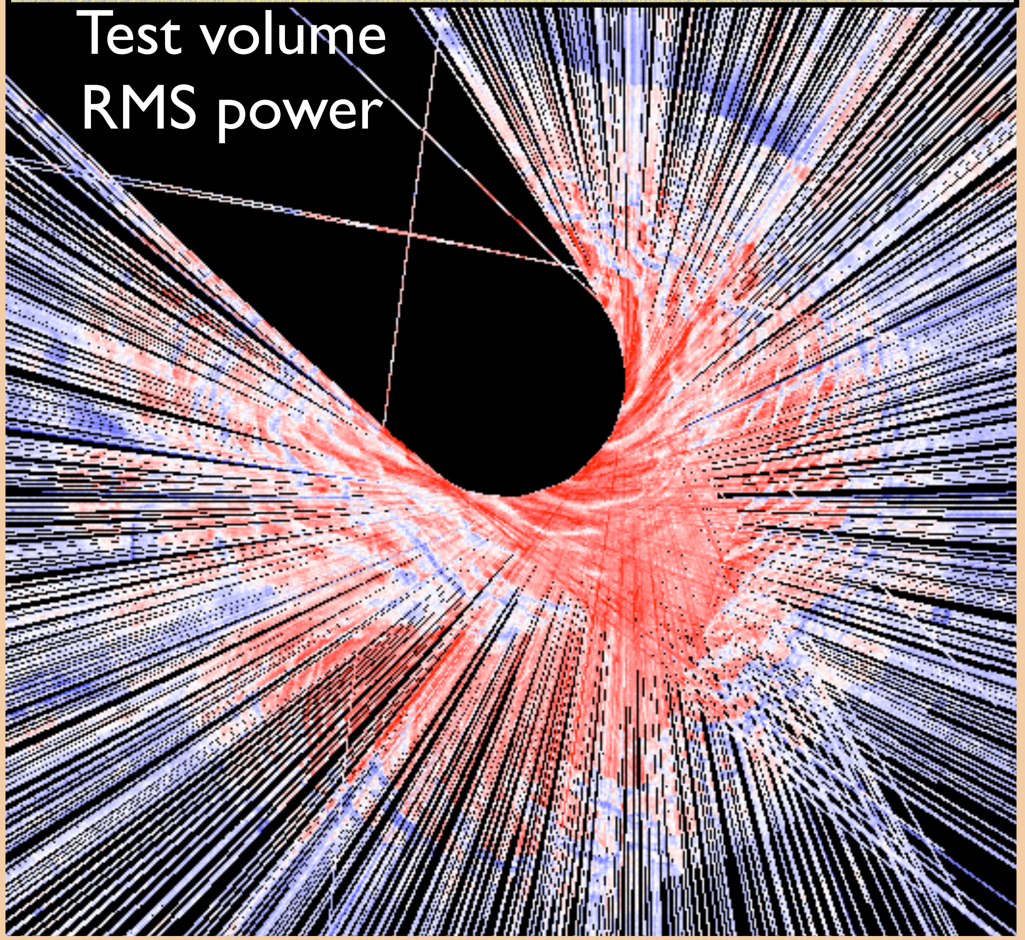
Utrasonic laboratory study by French (1974)

The SHARAD 3-D volume

- We **reference** the 2-D radargrams **to a common datum*** and bin them into a rectilinear grid.
- Our 3-D grid covers 1500×1500 km with **9 million bins** of 500×500 m.
- For **binning and migration tests**, we selected 540 radargrams crossing the Planum Boreum saddle region.

* *Non-trivial step due to variable ionospheric delays*

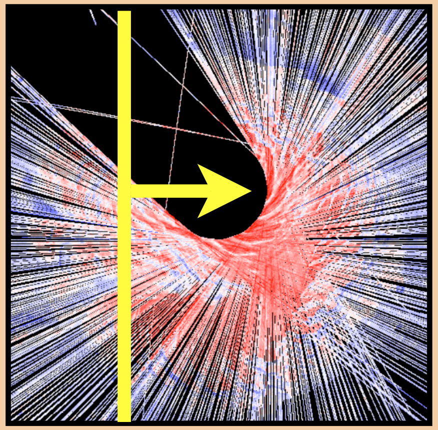




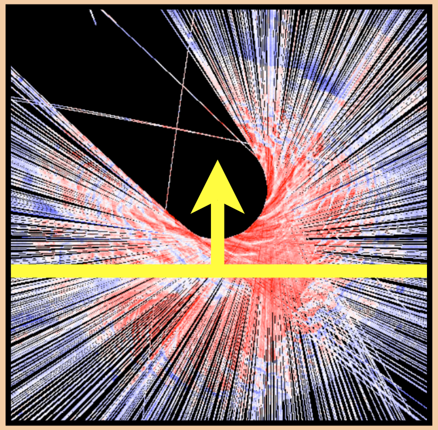
Movie of the test volume:

(prior to 3-D migration)

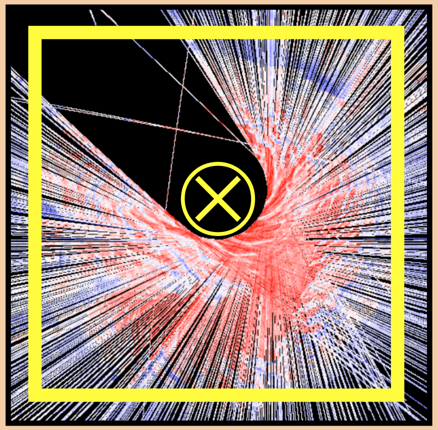
- First sequence shows **inline** profiles scanning from left to right across the 3-D grid.



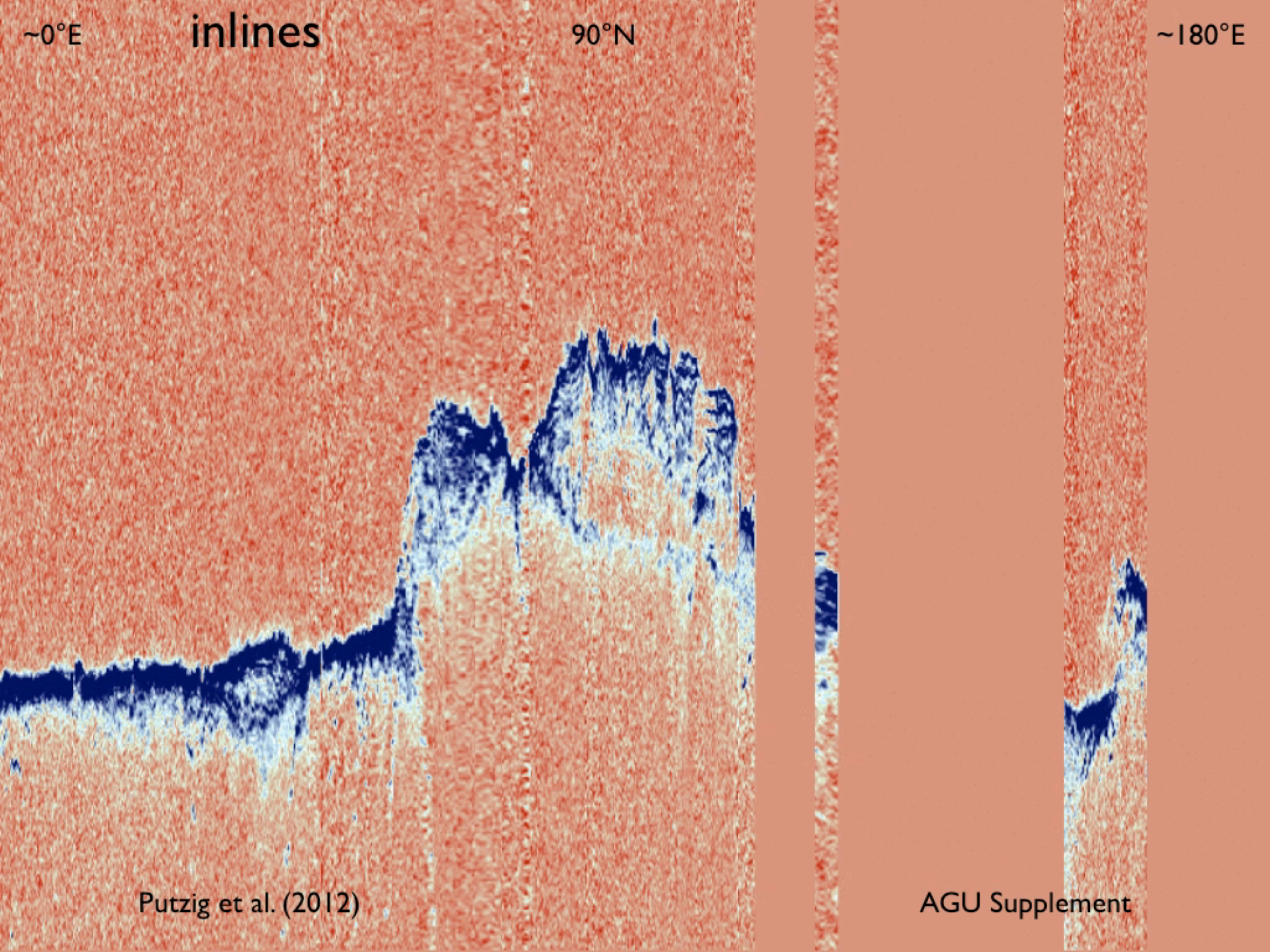
- Second sequence shows **crossline** profiles scanning from bottom to top over the 3-D grid.



- Third sequence shows **timeslice** views scanning in delay time (into the subsurface).

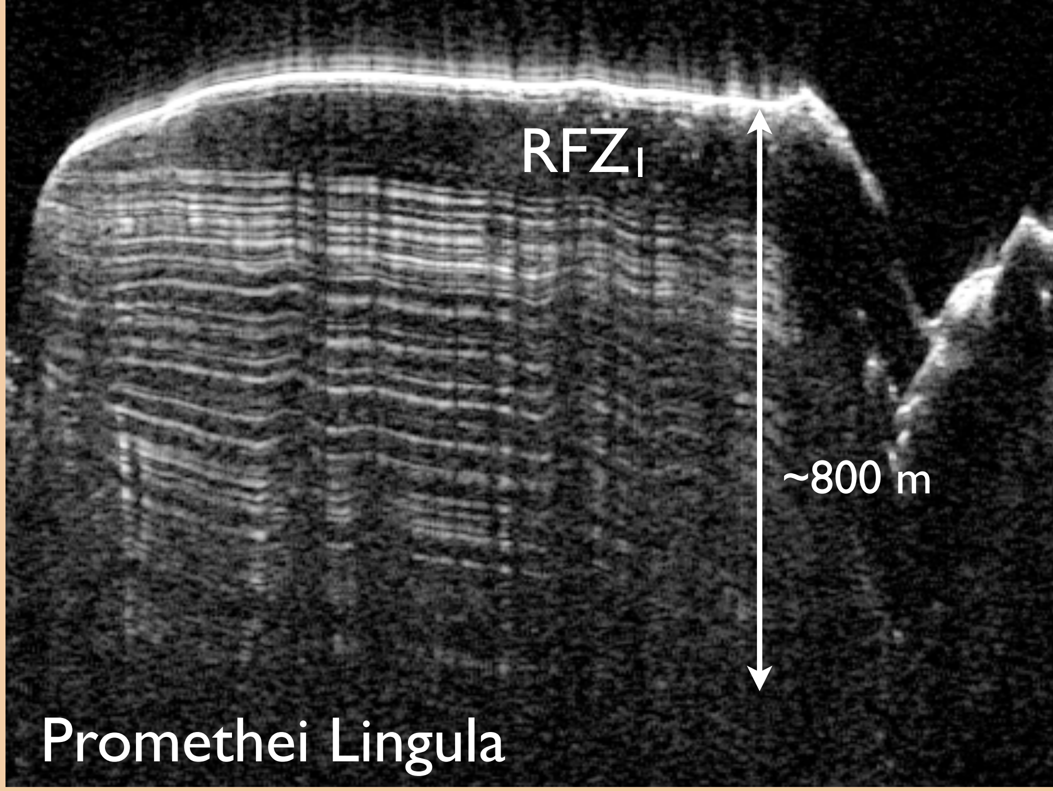


Than Putzig, SwRI

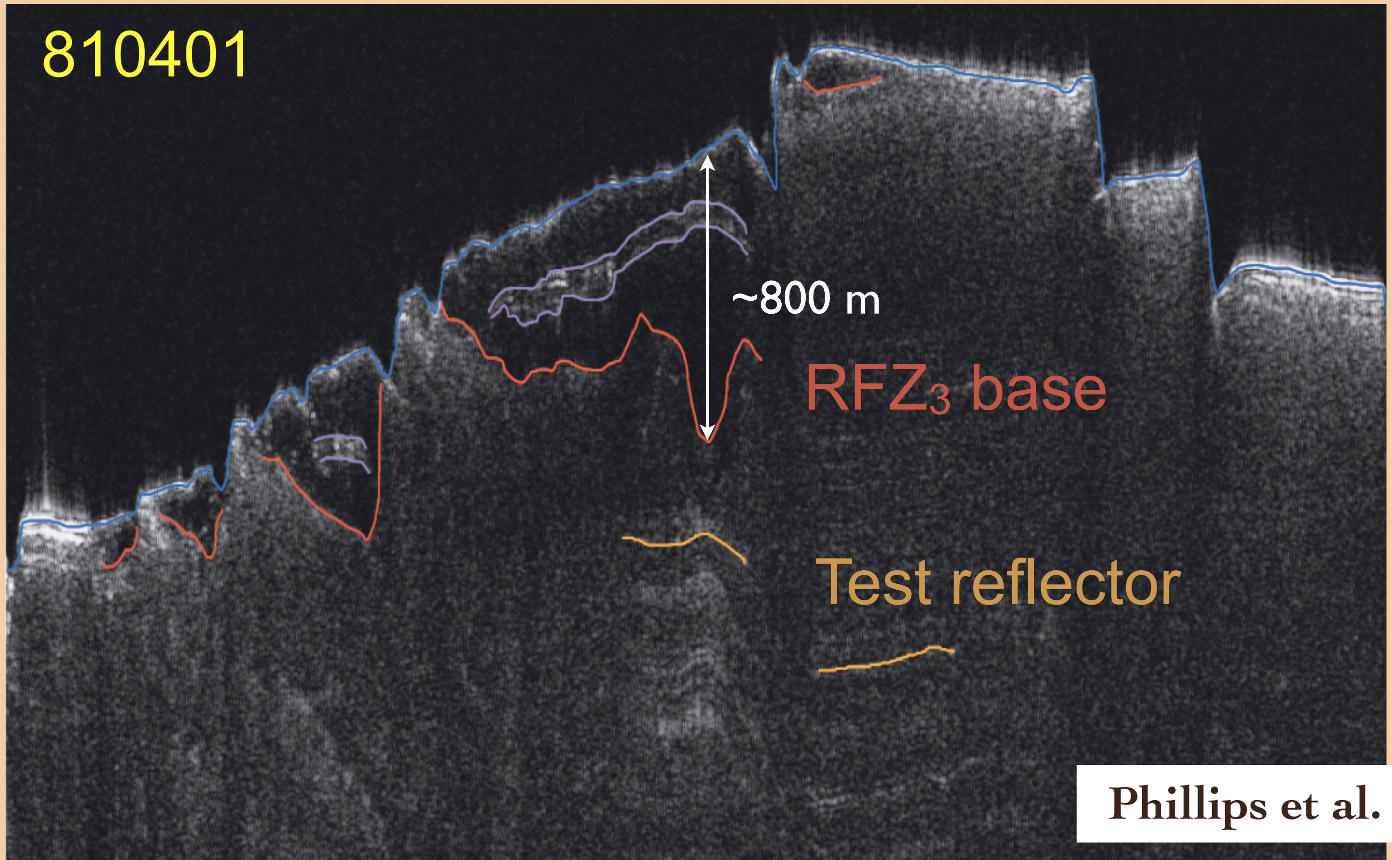

~0°E
inlines
90°N
~180°E
Putzig et al. (2012)
AGU Supplement

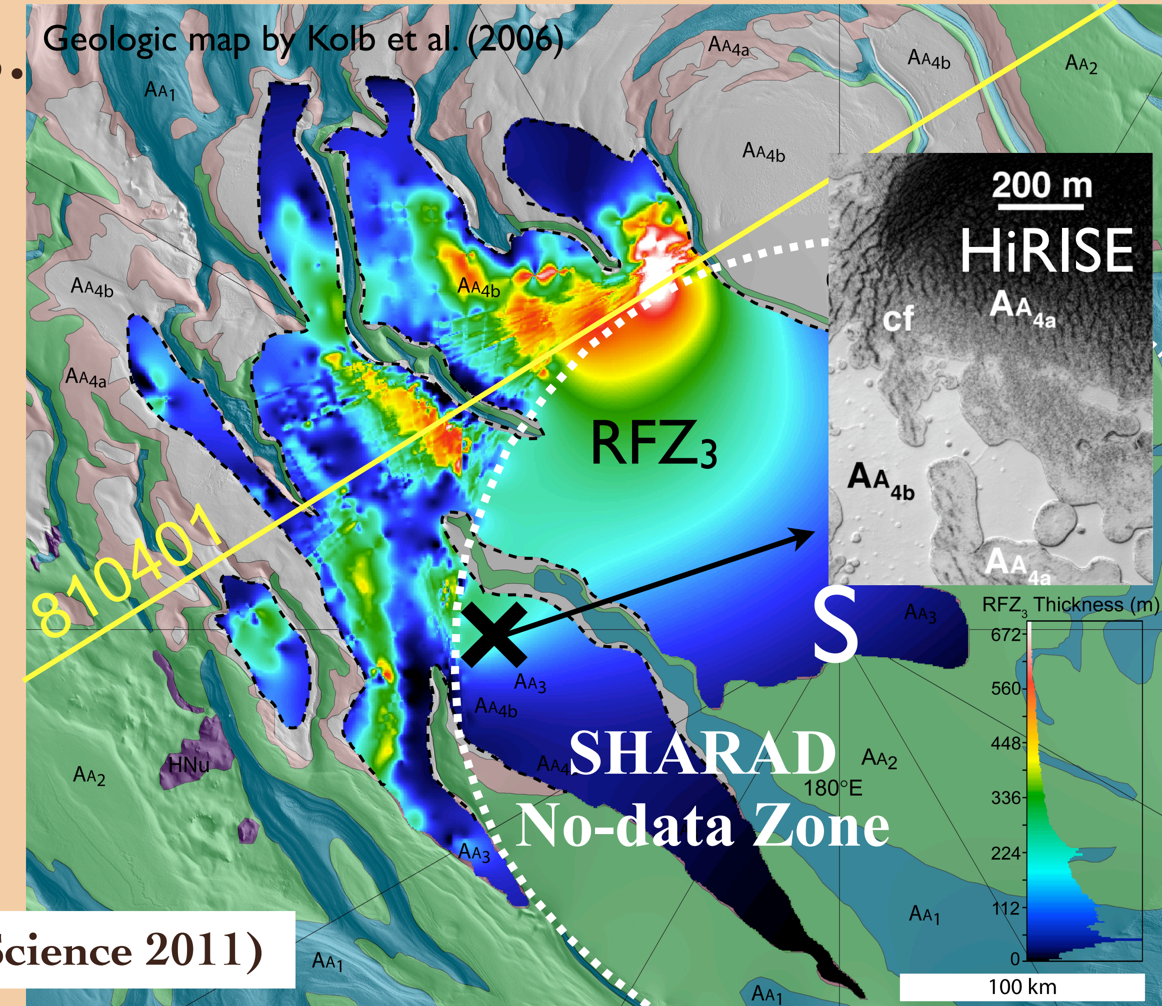
What about the south?

- Layering is discontinuous and often truncated just below the surface
  ⇒ **likely much older than NPLD.**
- Odd reflection-free zones (RFZs) occur near surface. Near the pole, **RFZ_3 has dielectric properties consistent with CO_2 ice** and maps to a unit with CO_2 sublimation features.



4–5 mbar of CO_2!

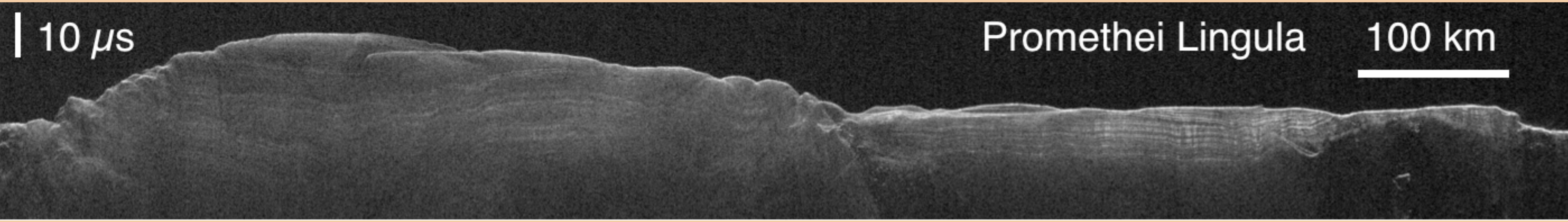




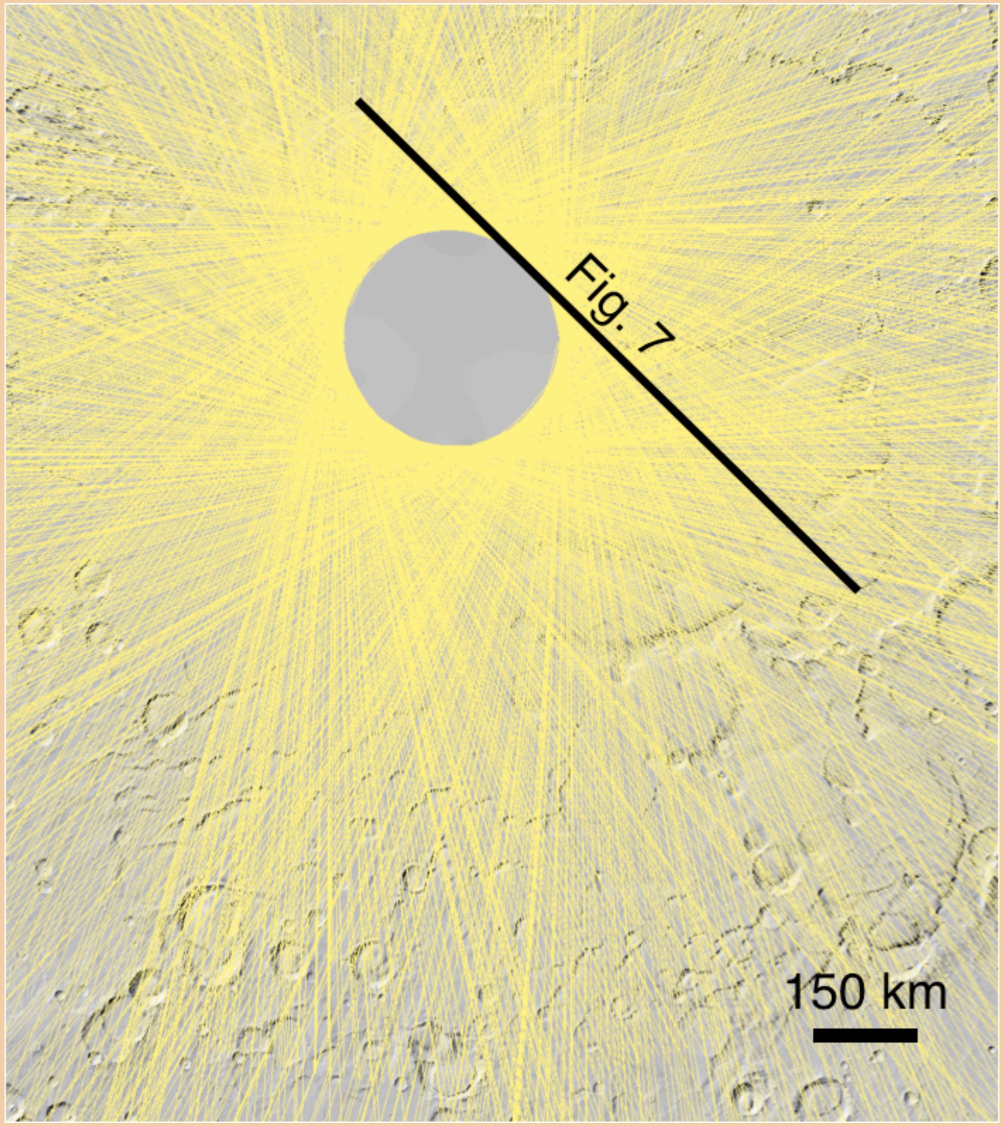
Phillips et al. (Science 2011)

3-D for the Planum Australe?

Please fund our MDAP



- SNR improvements and geometric corrections of 3-D migration may be critical for:
    - mapping water-ice layers
    - assessing RFZs 1, 2, & 4



Conclusions

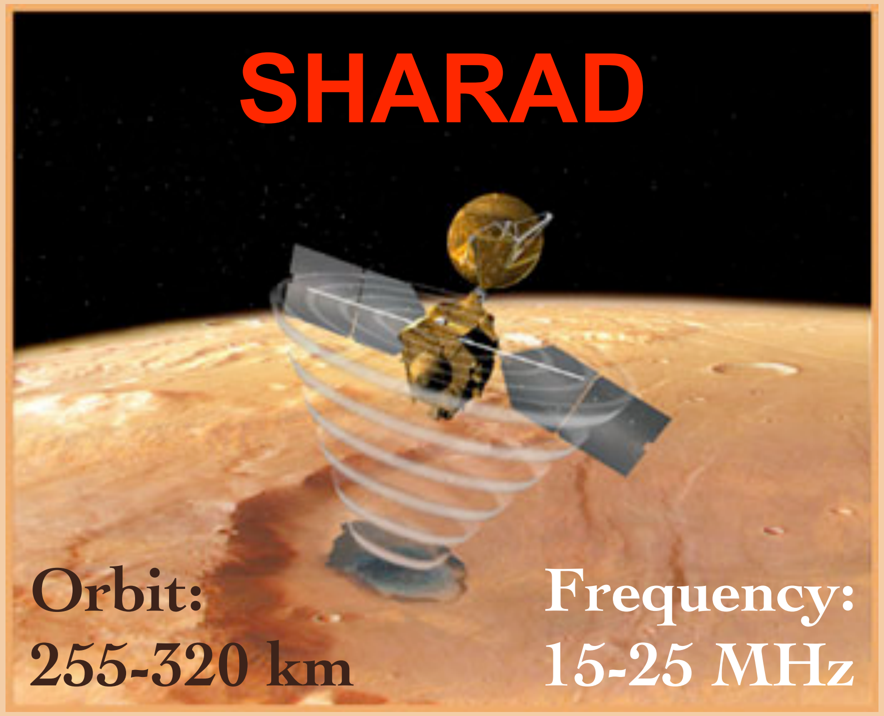
- Analysis of 2-D SHARAD radar data has yielded a wealth of discoveries in the Martian polar ices.
- 3-D binning and migration processing promise to add a new level of clarity to this rich volume of data.
- Further improvements will shed new light on the nature and timing of the polar deposits at both poles.

Thanks to…

- SeisWare for software access.
- NASA, ASI (Italian Space Agency), the MRO Project, and the SHARAD Instrument Team.
- NASA's Mars Data Analysis Program for funding this work.

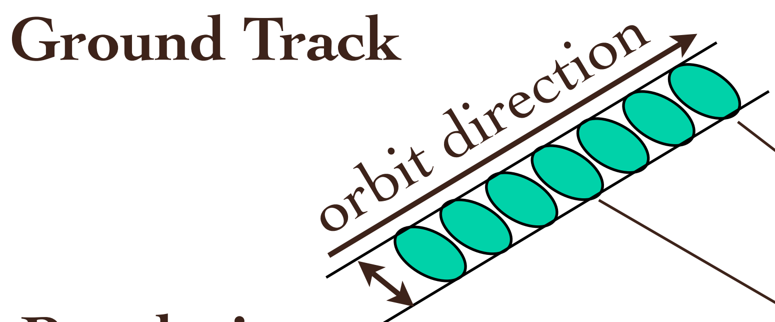
extra slides

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.



<u>**Resolution**</u>

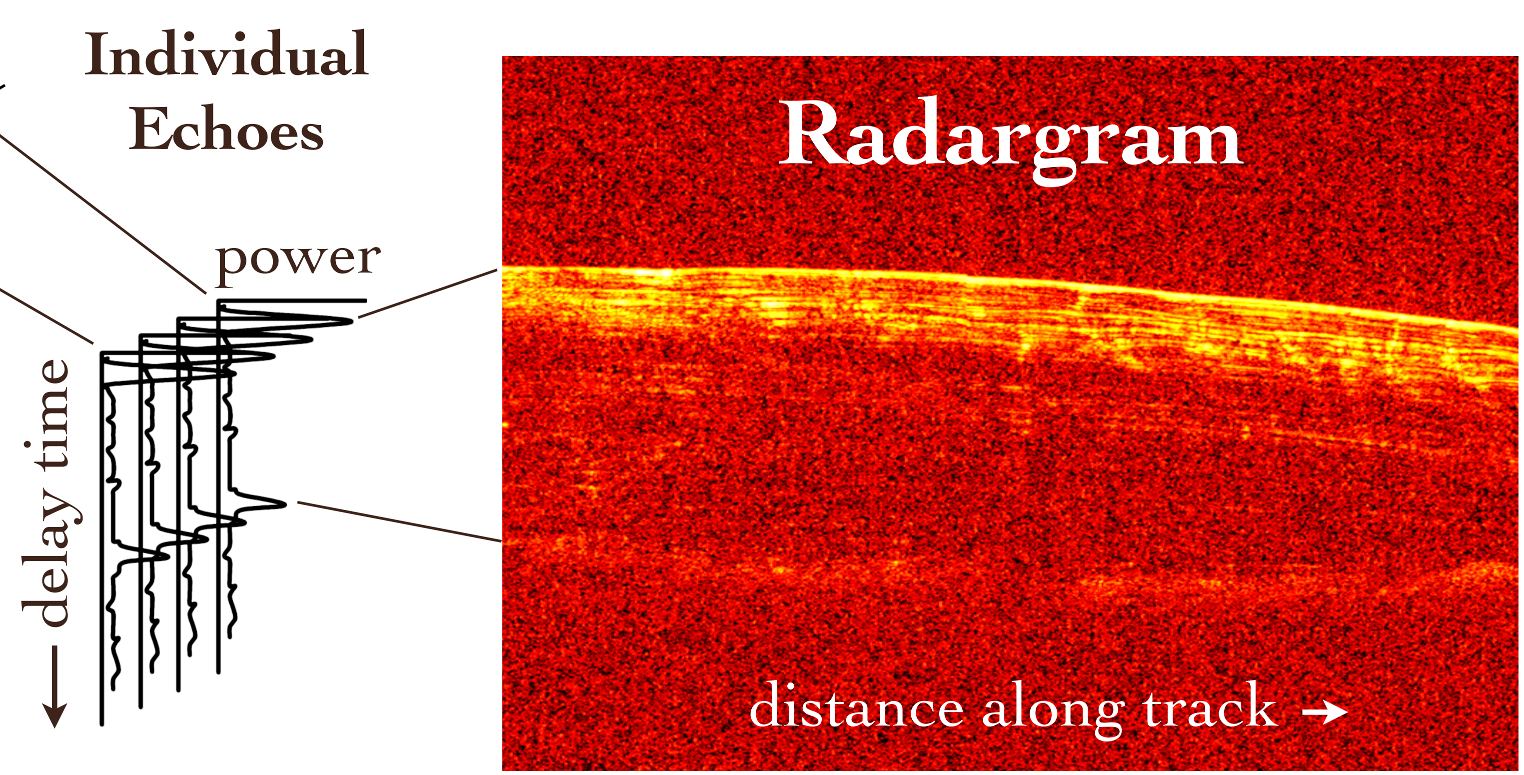
Cross-track: 3-6 km

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

The North Polar Region of Mars

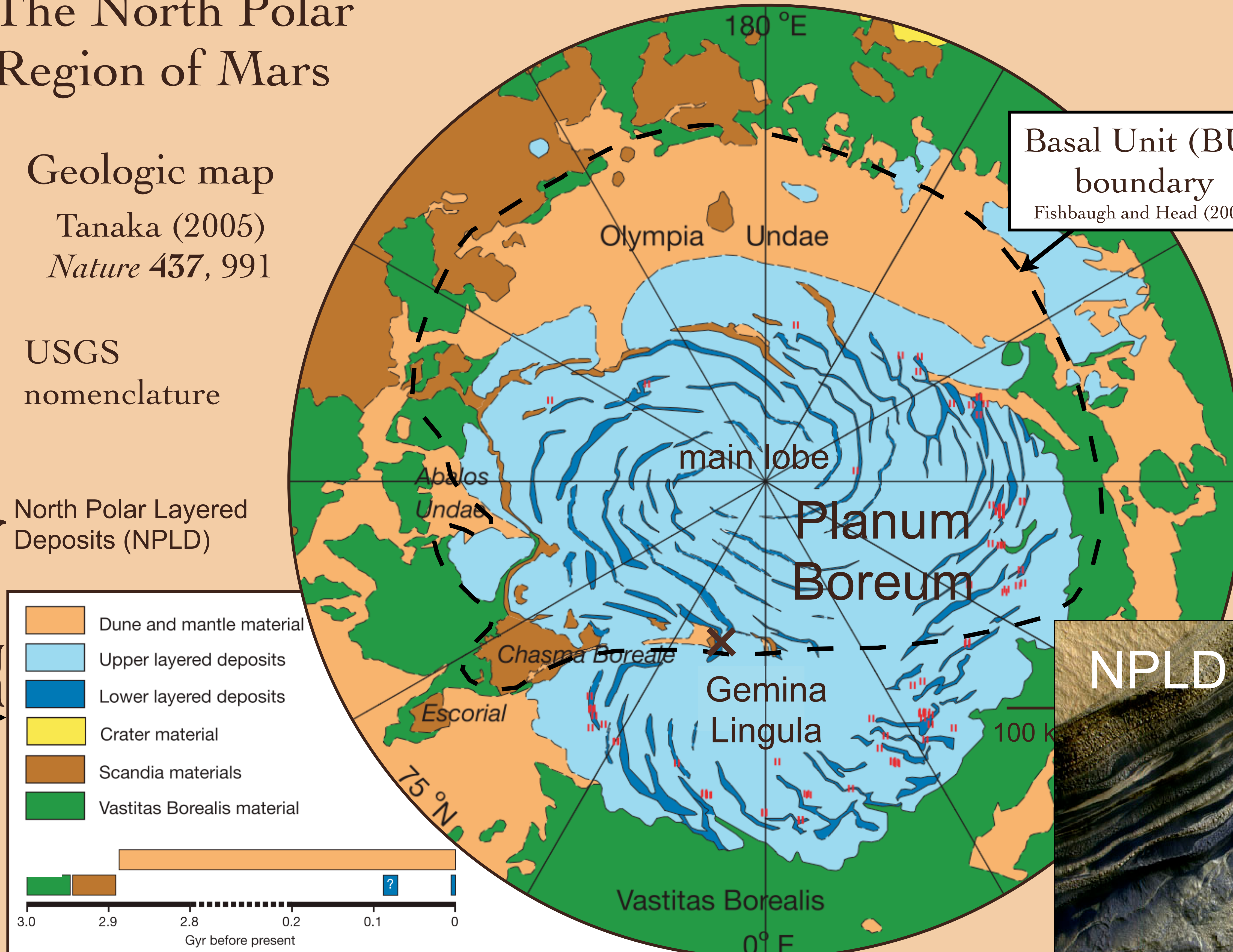
Geologic map

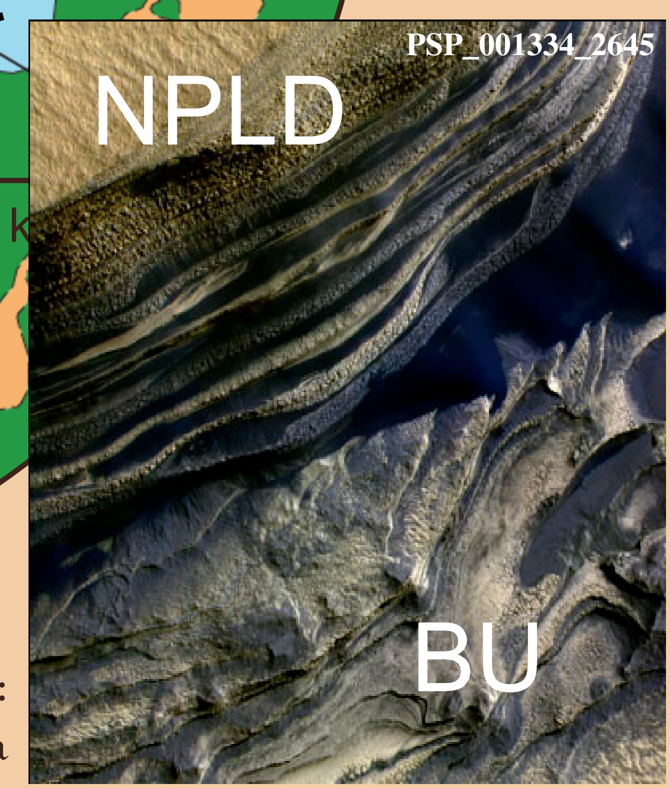
Tanaka (2005)
Nature **437**, 991

USGS nomenclature

North Polar Layered Deposits (NPLD)

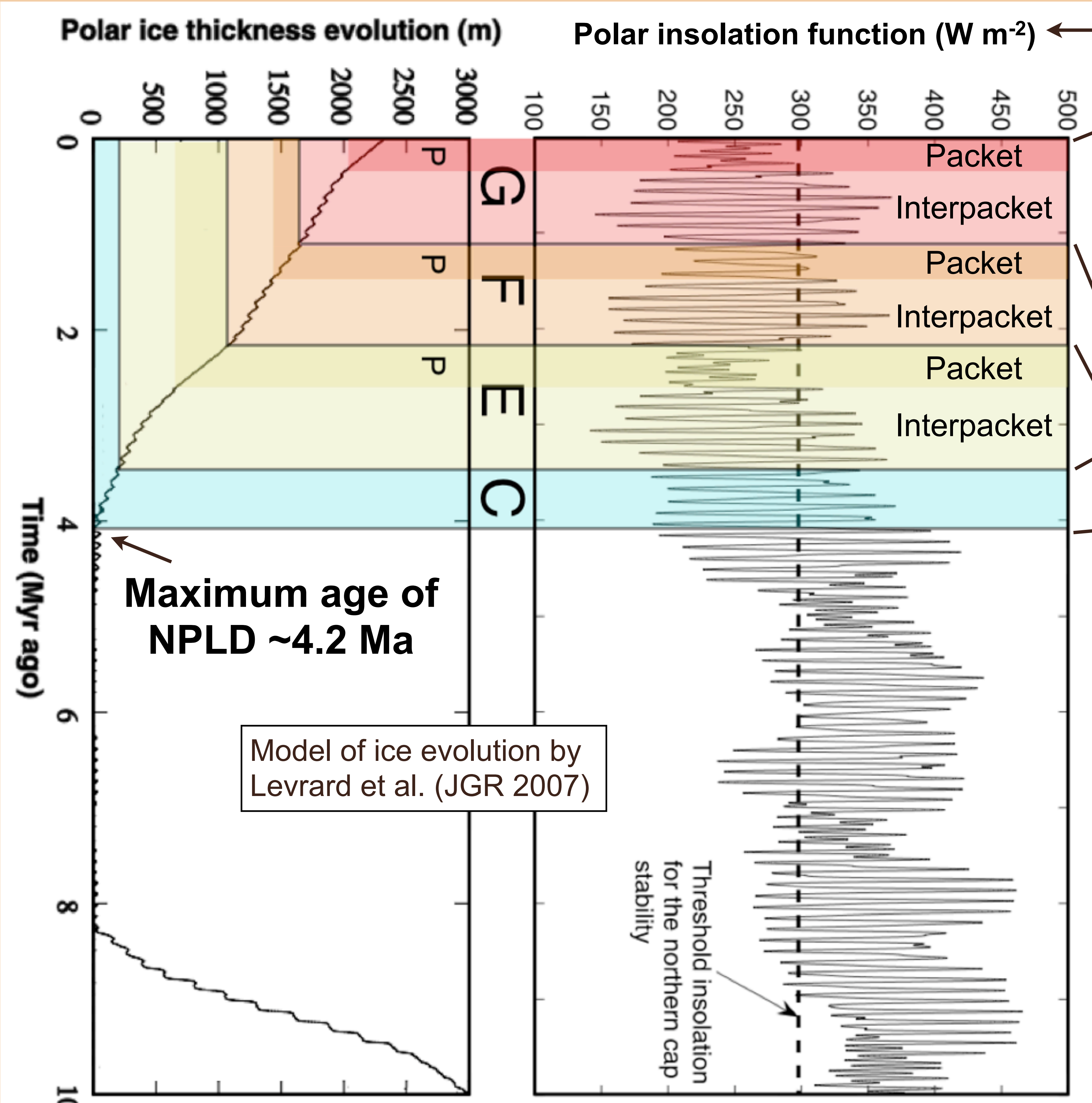
BU



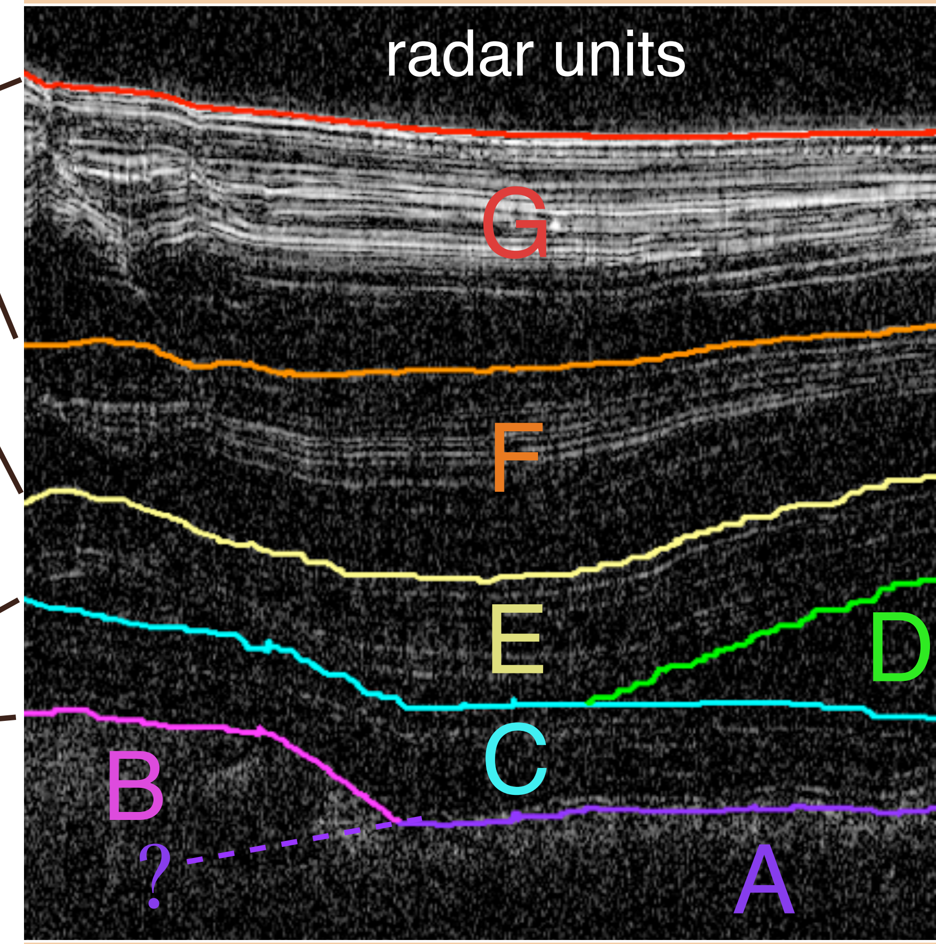


HiRISE image credit:
NASA/JPL/University of Arizona

Correlation of radar units to climate cycles



Martian orbit is well-constrained from -20 Ma to +10 Ma (Laskar et al., 2004)

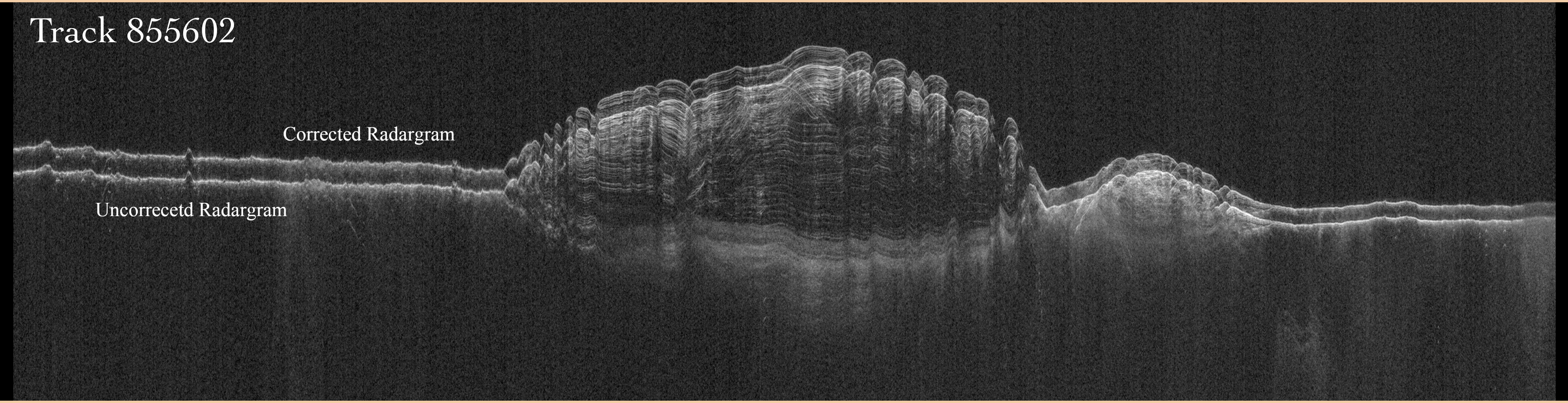


Strongly layered packets may correspond to periods with **low amplitude in the variation of insolation** — the present era, ~1.3 Ma, and ~2.4 Ma.

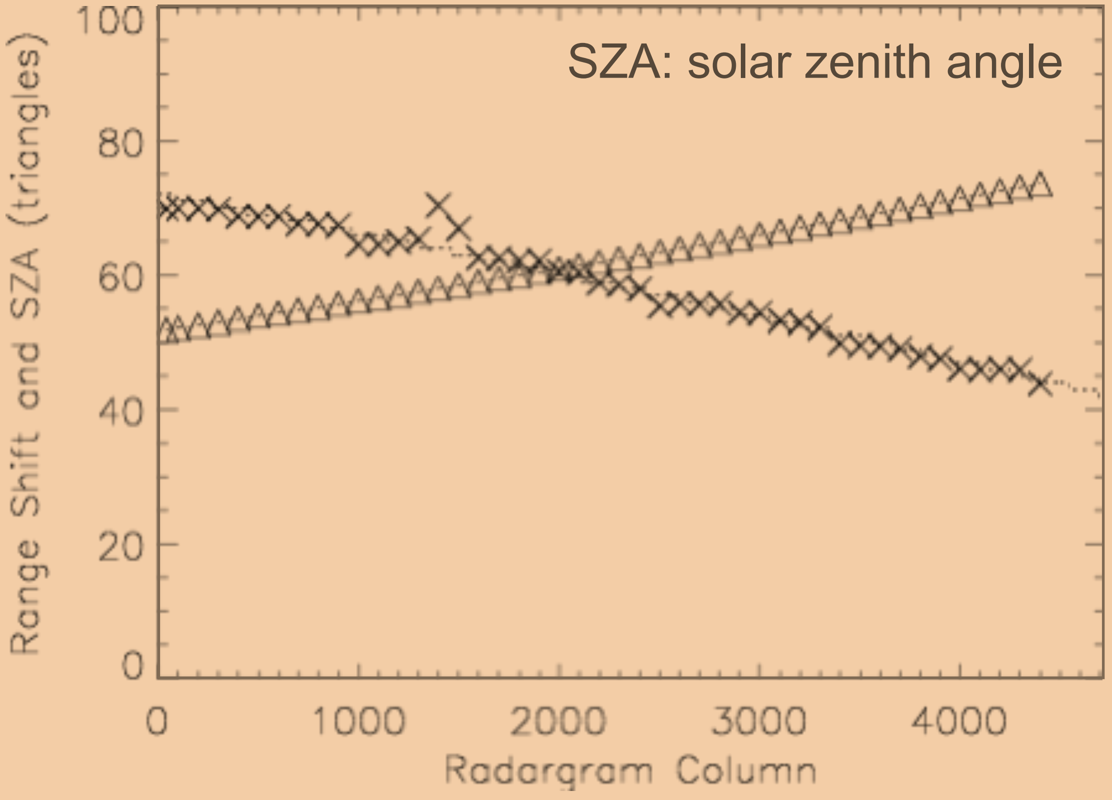
Putzig et al. (Icarus 2009)

Challenge to 3-D Processing

- Comparison of crossing 2-D radargrams at their intersections revealed variable shifts in range (delay time), most pronounced in data acquired on the daylit side of the planet:



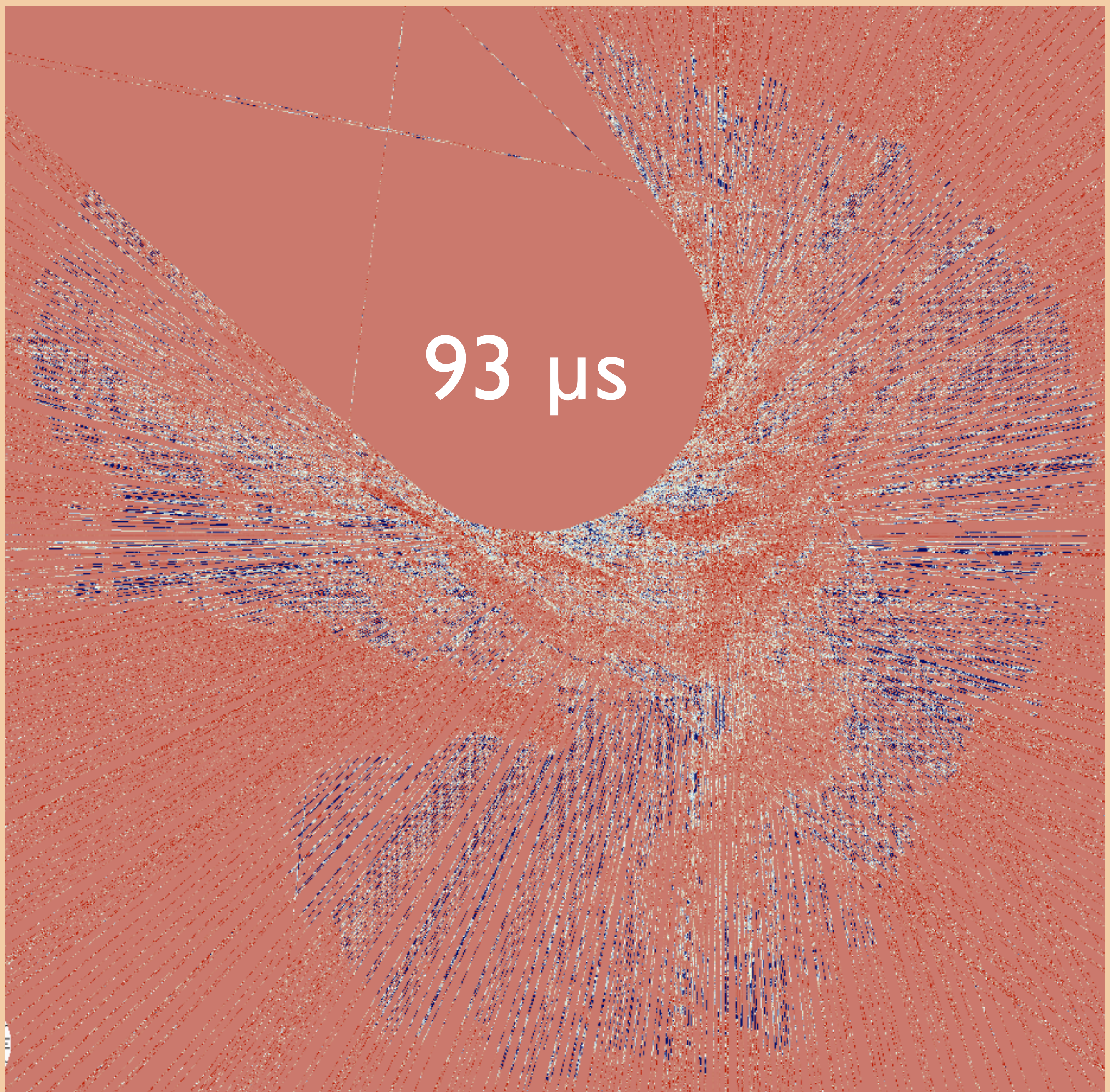
- The delay is attributable to the Martian ionosphere, and can be approximated by a linear fit to the phase distortion derived in the pre-processing (× symbols at right).
- Correction greatly reduces mismatches in vertical positioning and is critical for proper 3-D migration.



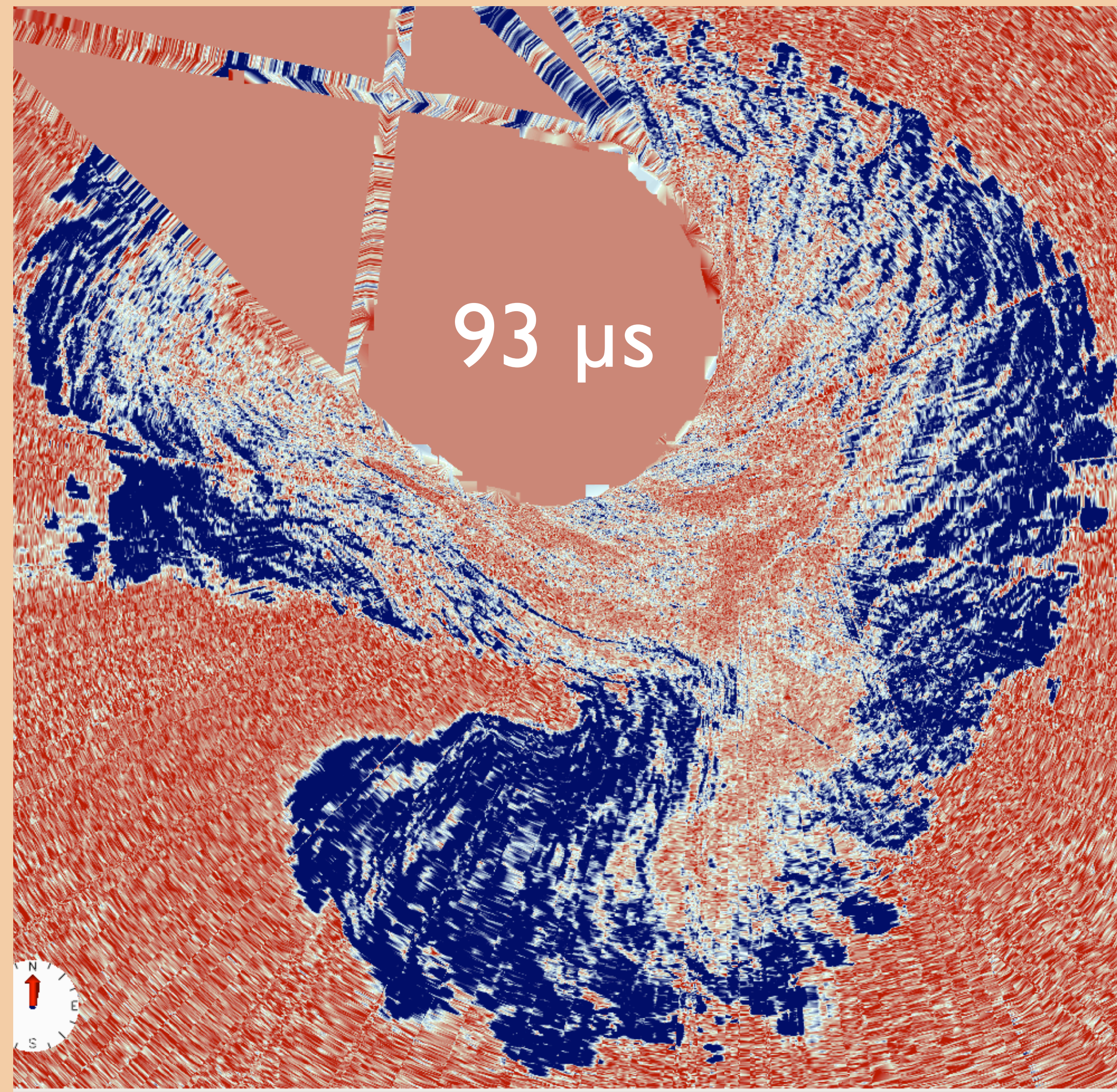
3-D Binning Process

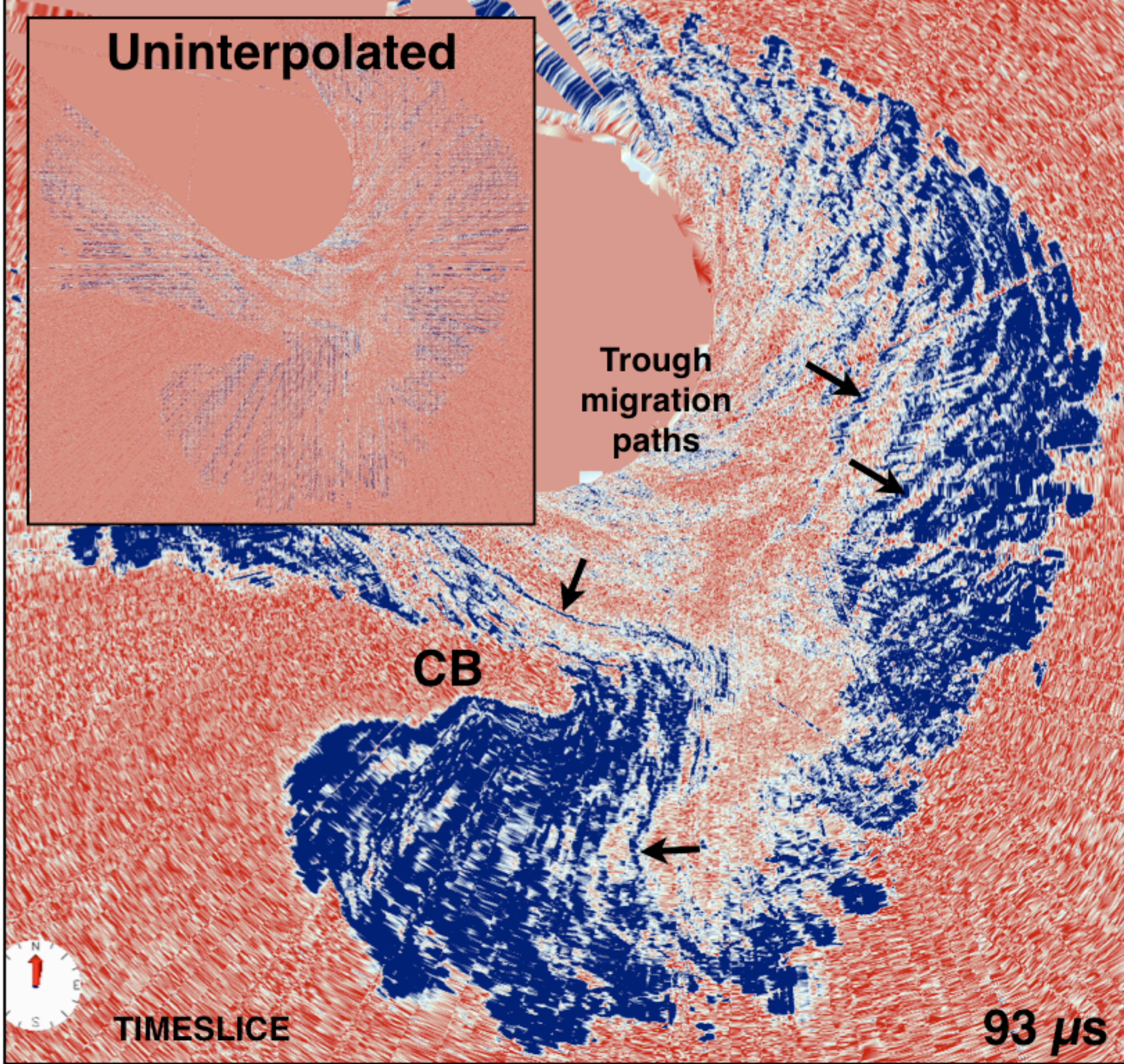
Spatial Delauney triangulation, bilinear interpolation, and amplitude regularization in 9×10^6 bins of 500 m × 500 m.

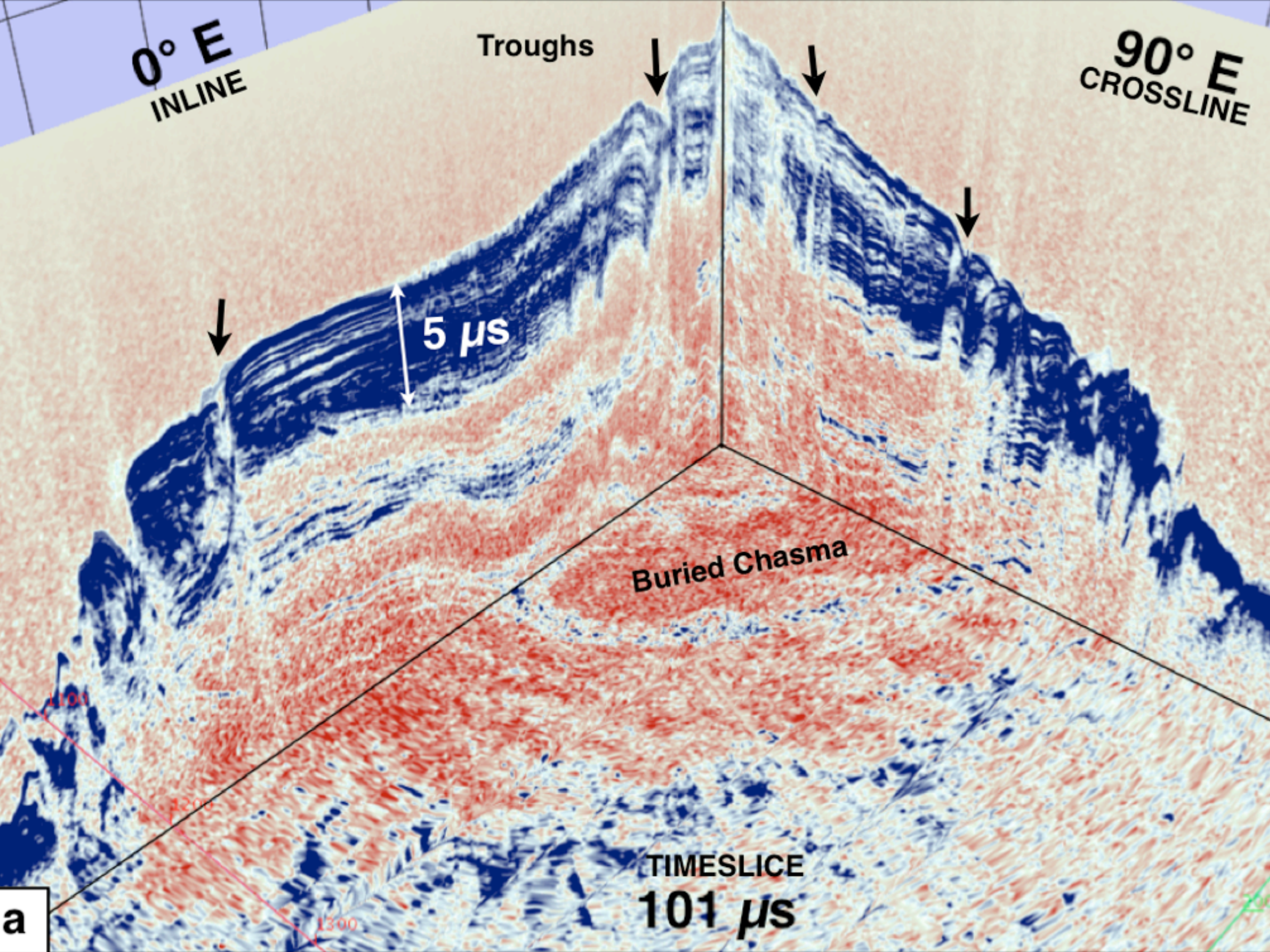
Timeslice prior to interpolation and regularization

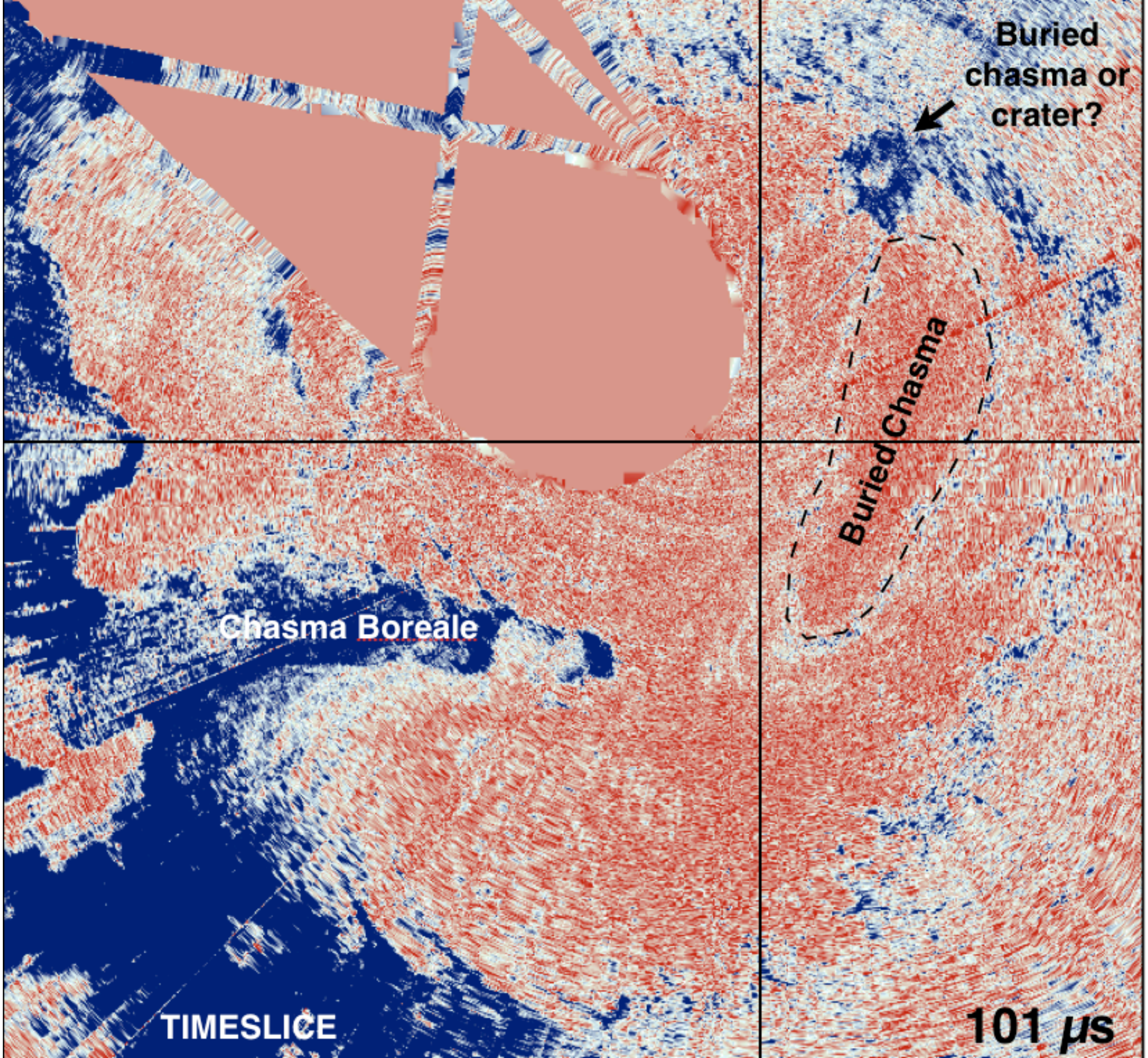


Timeslice after interpolation and regularization

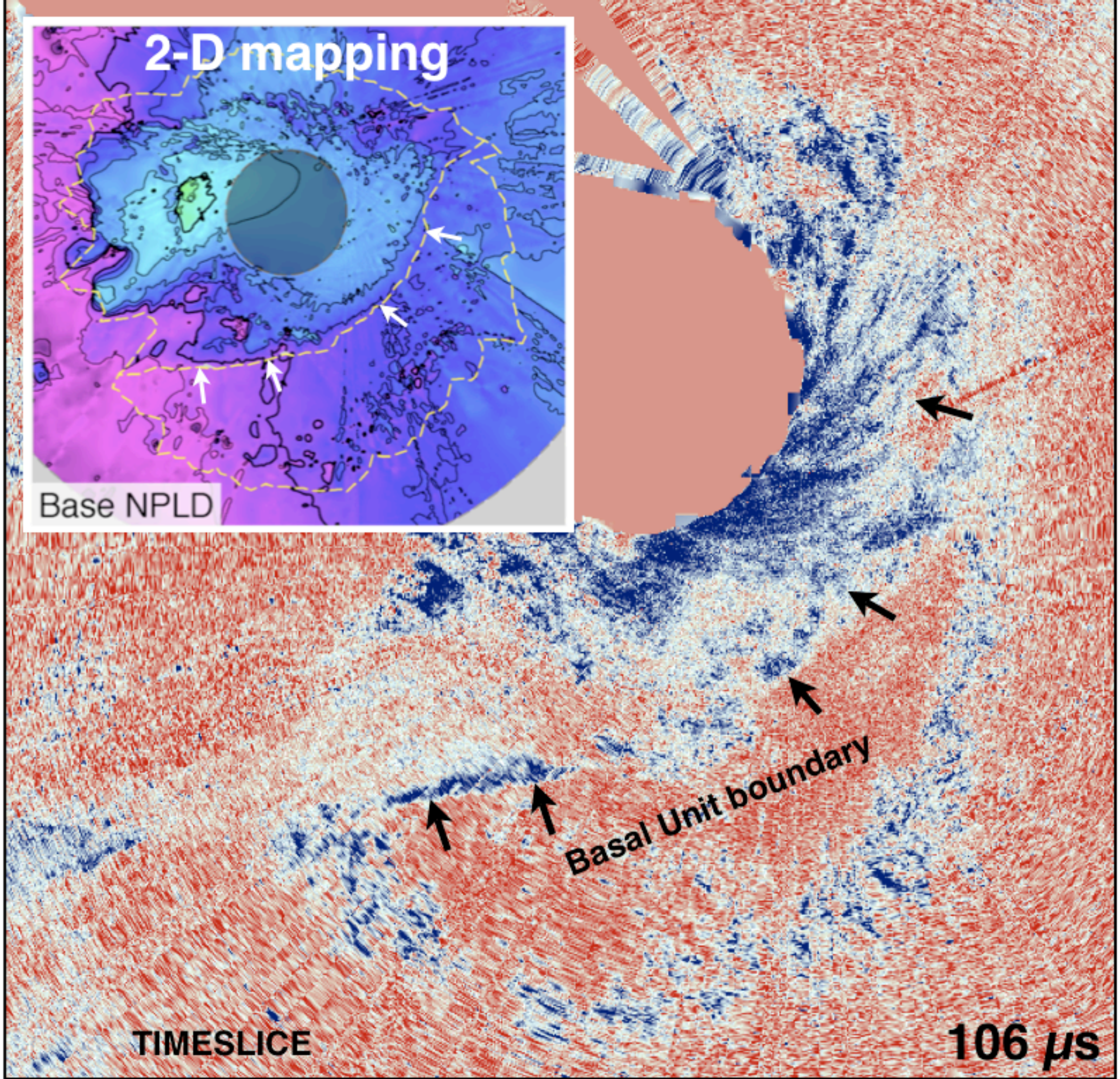



Uninterpolated
Trough migration paths
CB
TIMESLICE
93 μs


0° E
INLINE
Troughs
90° E
CROSSLINE
5 μs
Buried Chasma
TIMESLICE
101 μs
a



Buried chasma or crater?
Buried Chasma
Chasma Boreale
TIMESLICE
101 μs



2-D mapping
Base NPLD
Basal Unit boundary
TIMESLICE
106 μs