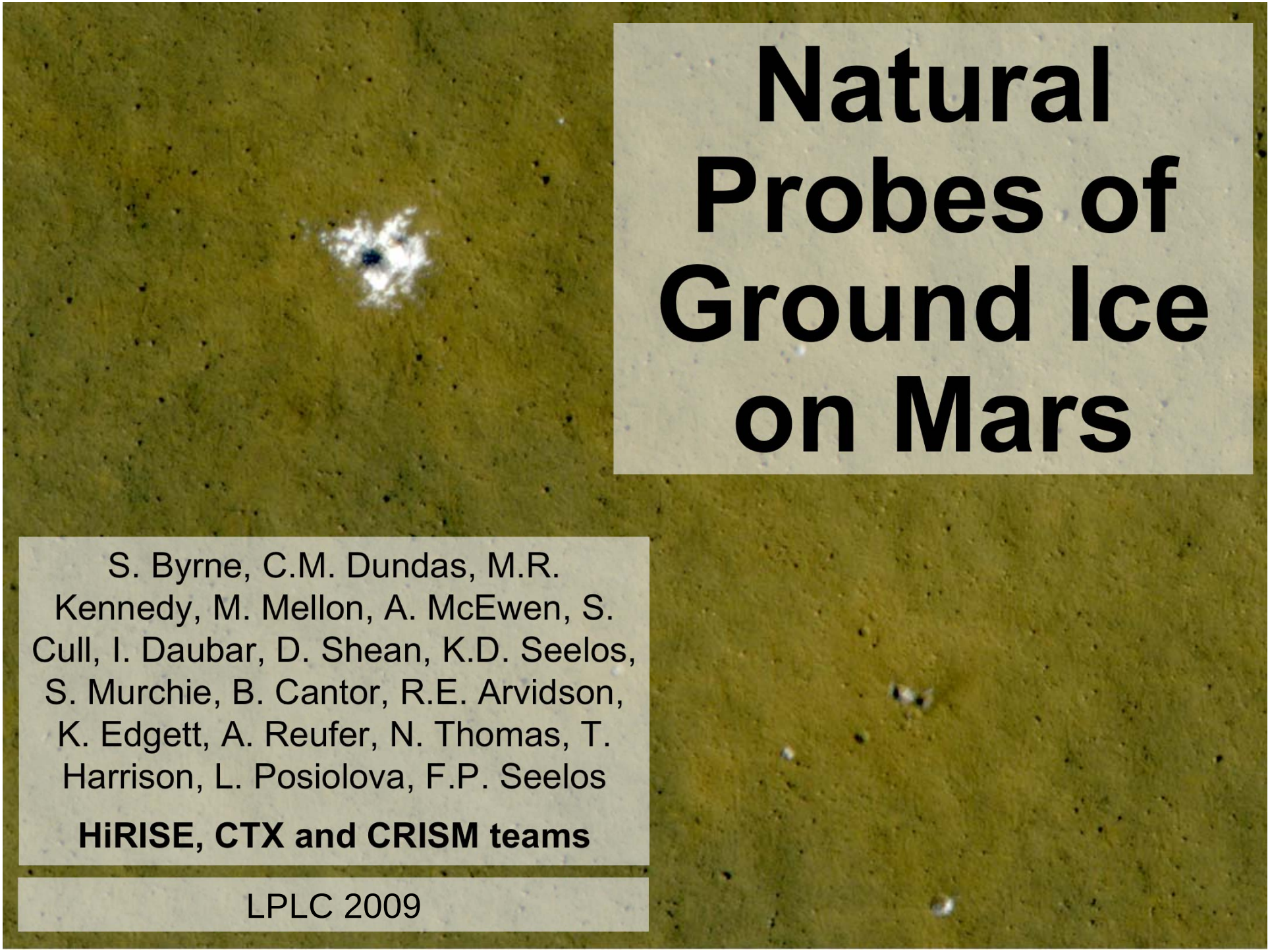


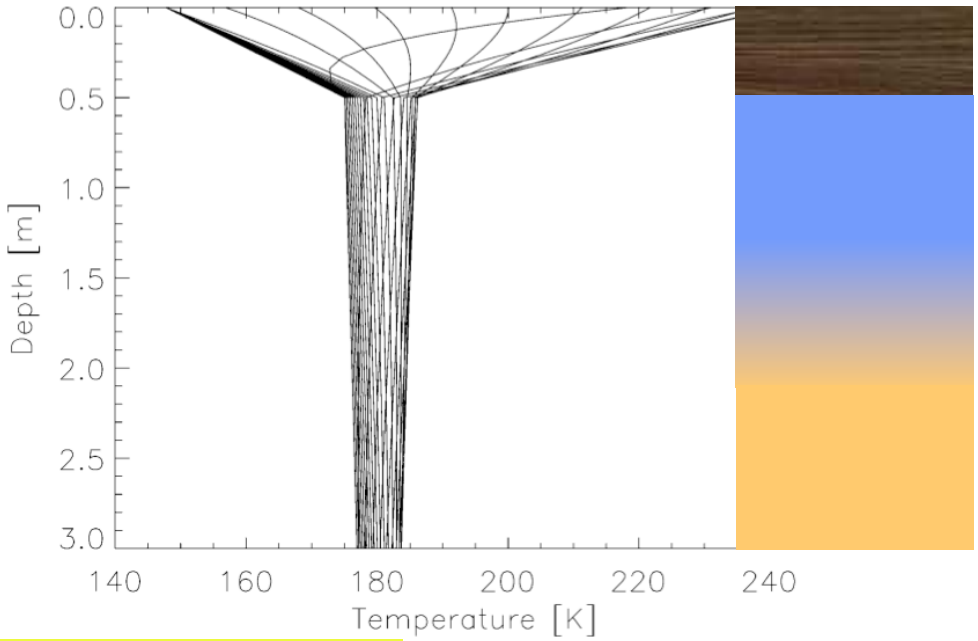
Natural Probes of Ground Ice on Mars

S. Byrne, C.M. Dundas, M.R. Kennedy, M. Mellon, A. McEwen, S. Cull, I. Daubar, D. Shean, K.D. Seelos, S. Murchie, B. Cantor, R.E. Arvidson, K. Edgett, A. Reufer, N. Thomas, T. Harrison, L. Posiolova, F.P. Seelos

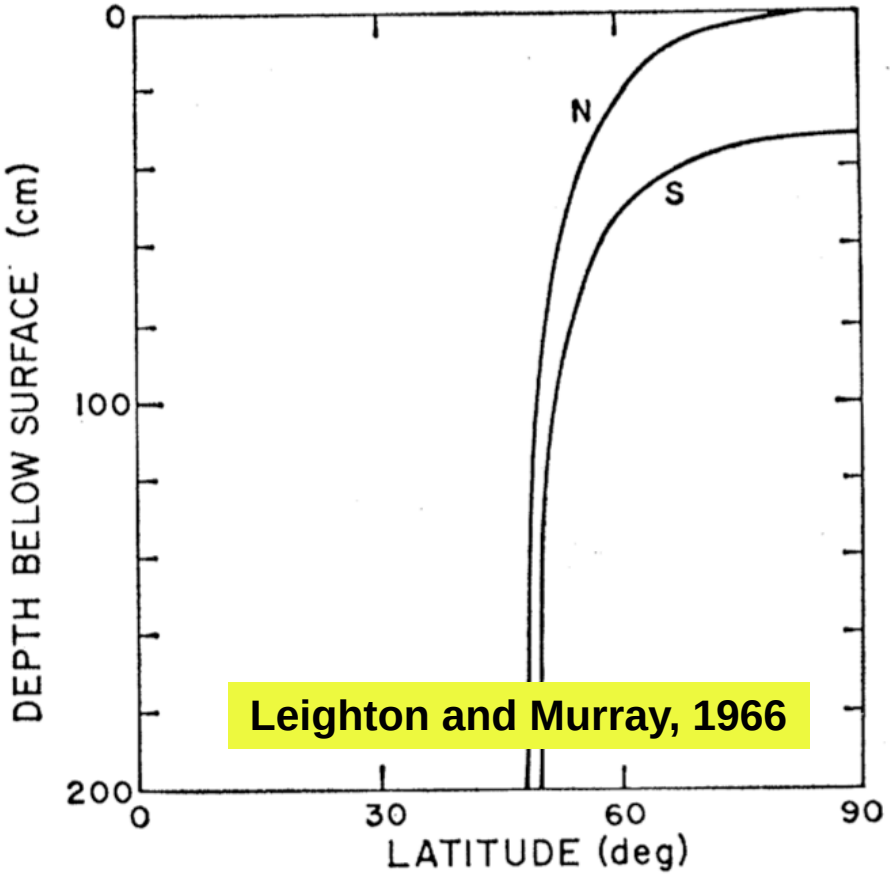
HiRISE, CTX and CRISM teams

LPLC 2009

- **Ground ice on Mars theorized to exist for some time**
  - **Regolith provides the thermal insulation**
  - **Sharp latitude cutoff**
  - **Stable ice distribution changes with climate**
  - **Diffusive contact with the atmosphere**

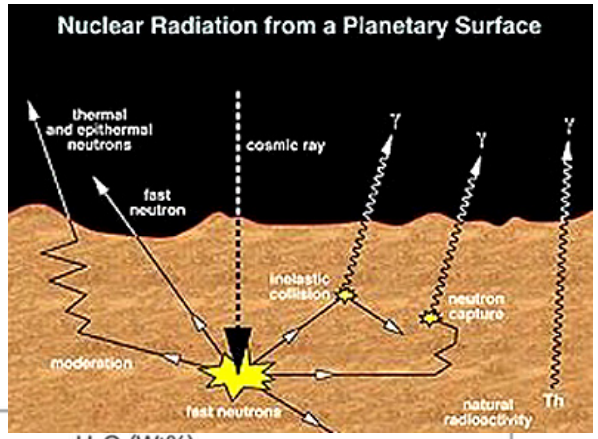


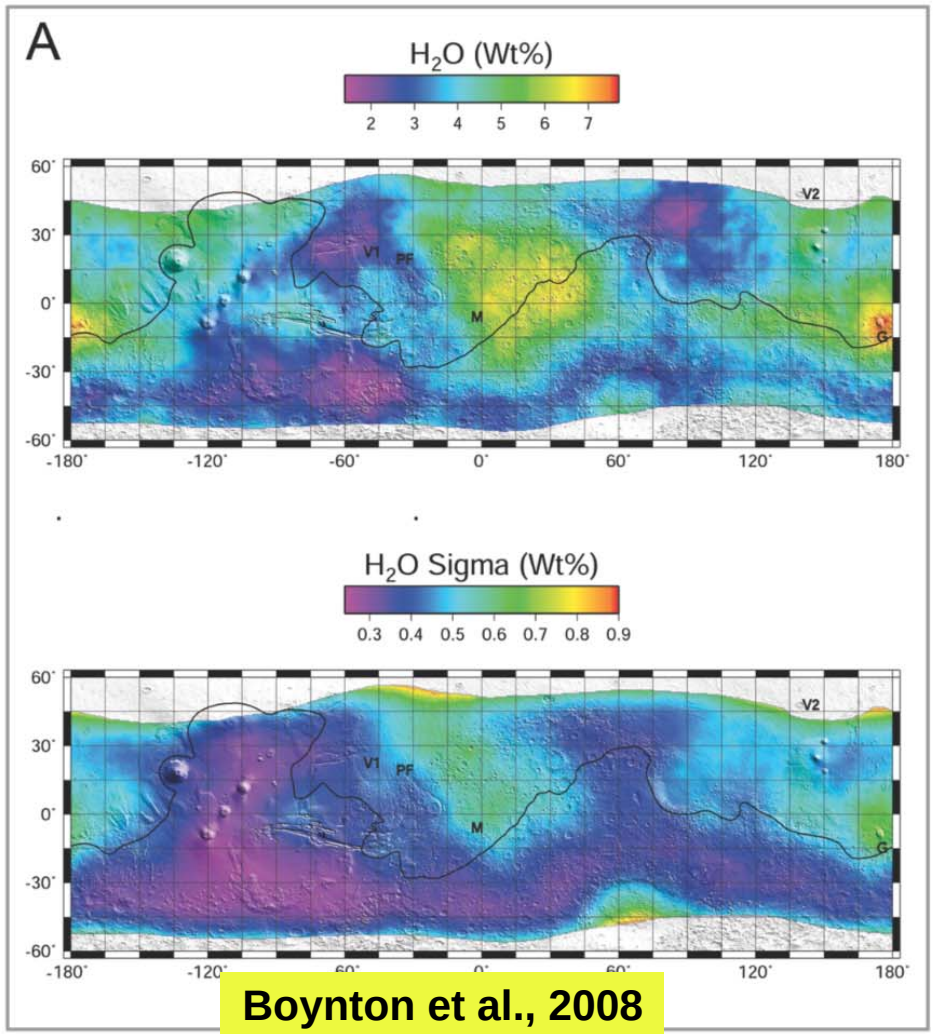
Mellon et al., 2004

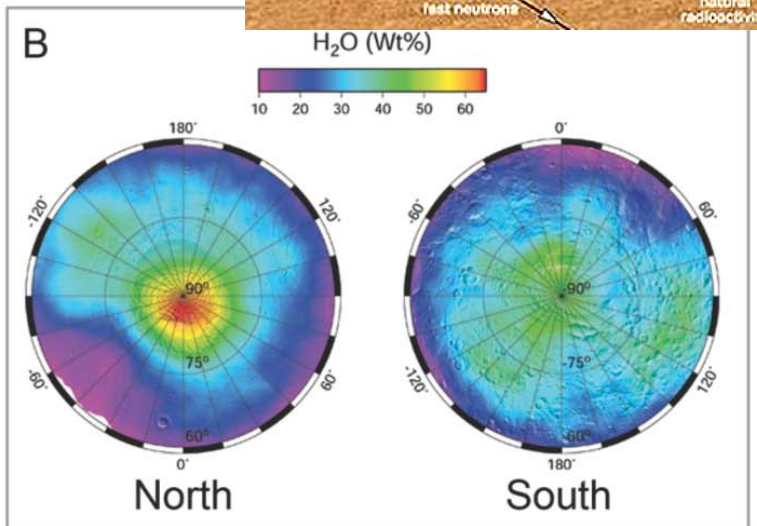


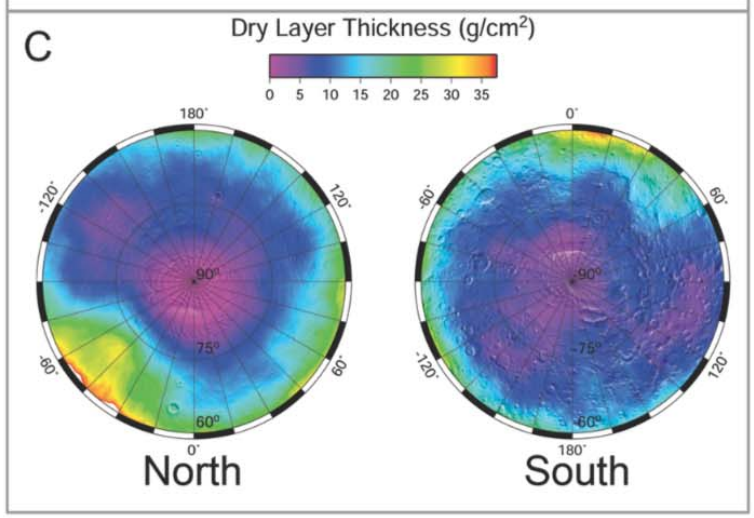
Leighton and Murray, 1966

- **Detected by GRS instruments on Mars Odyssey**



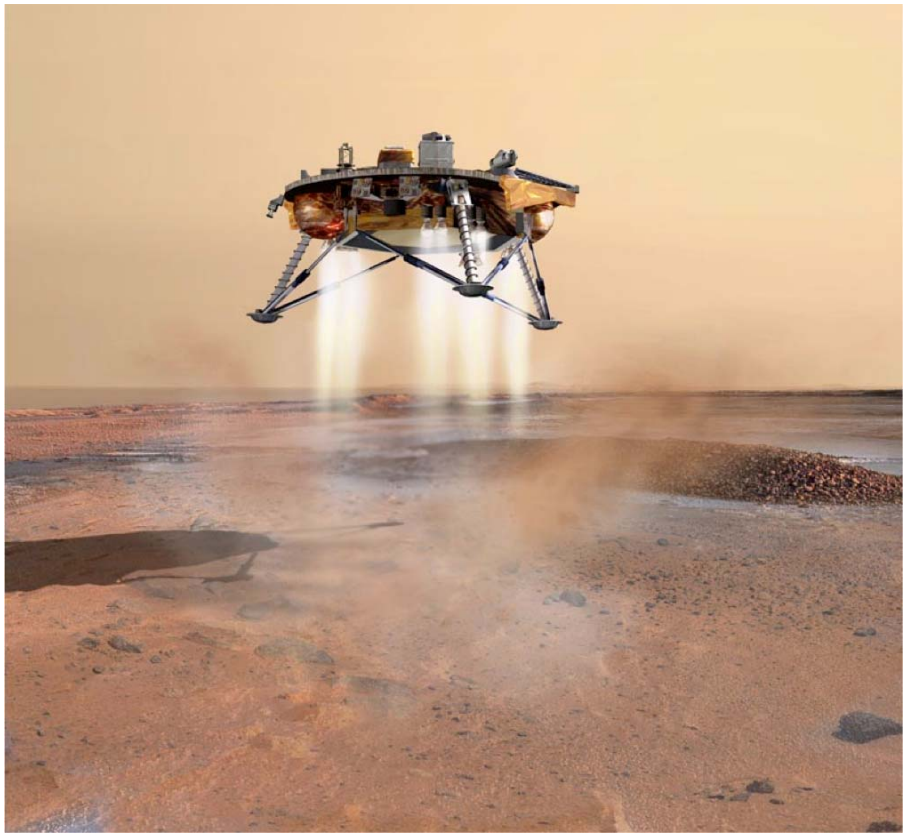






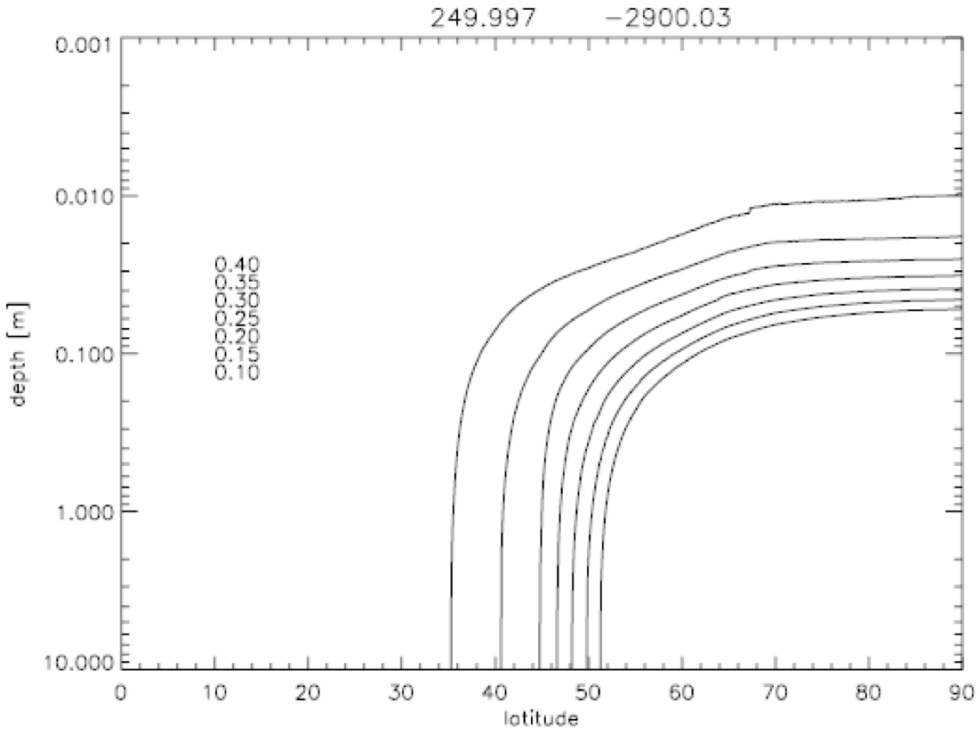
Boynton et al., 2008

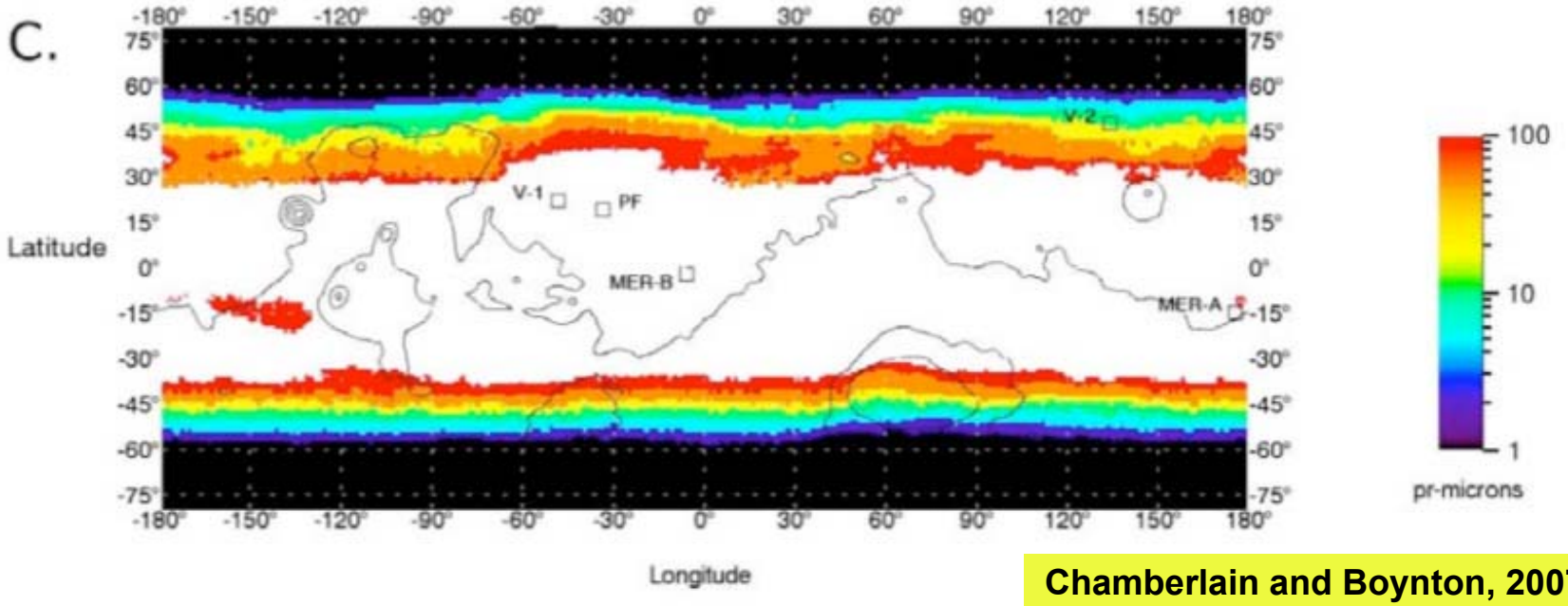
- **Phoenix investigated ice at high latitudes**
  - **Ice table was found at the expected (from stability models) depth**
  - **I'll talk about ice a few 1000km away**



Associated Press / NASA

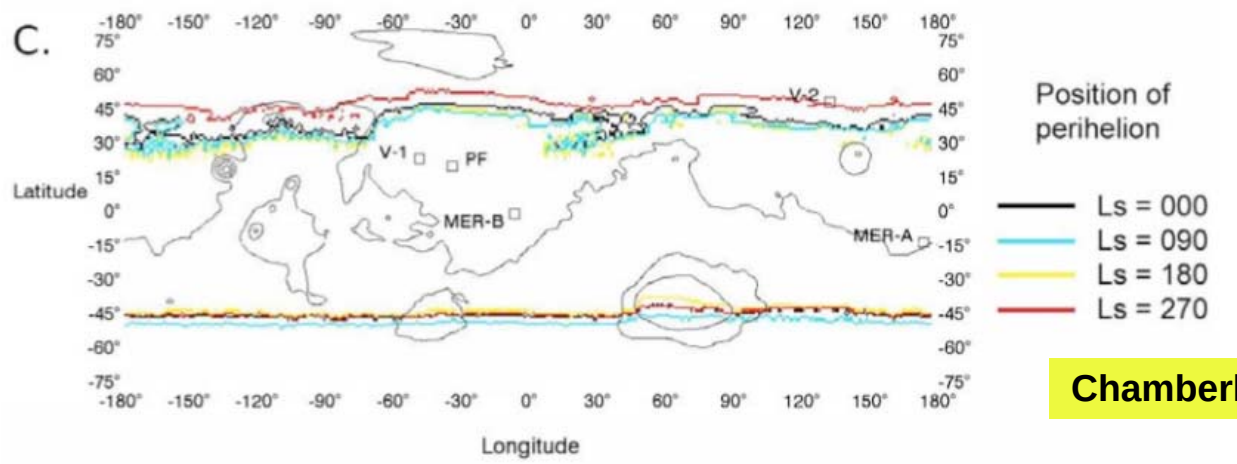
- **Many models – same behavior**
  - **Shallow high-latitude ice**
  - **Ice-free equatorial region**
  - **Very sharp boundary**
- **Boundary position very sensitive**
  - **Thermophysical properties**
    - **Independently determined**
  - **Global average water vapor**
    - **Today's value is 10-14 pr μm**





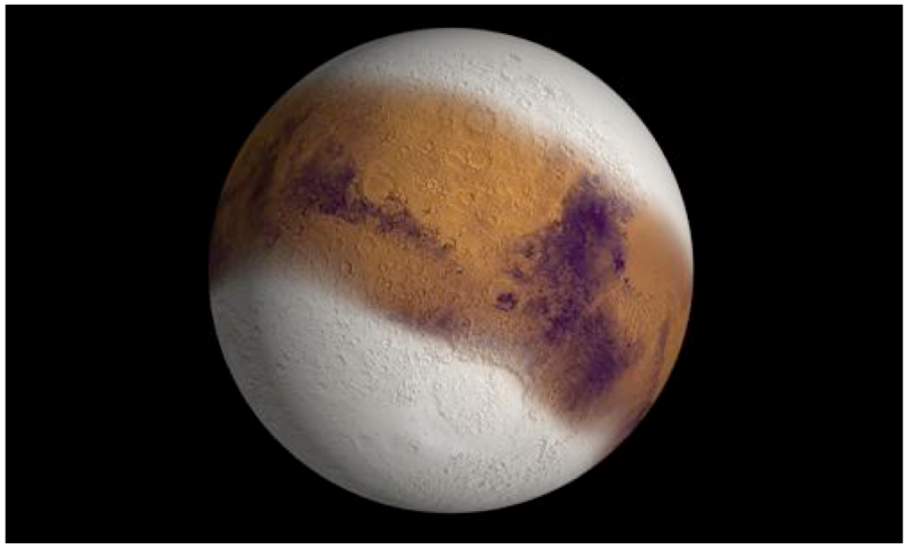
Chamberlain and Boynton, 2007

- **Boundary changes with climate**
  - **Orbital variations e.g. argument of perihelion**

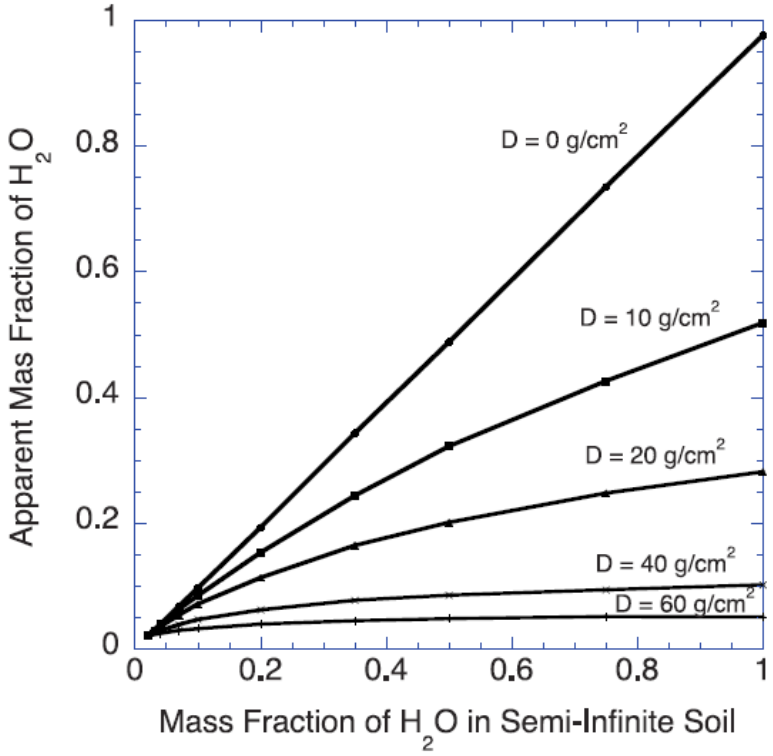


Chamberlain and Boynton, 2007

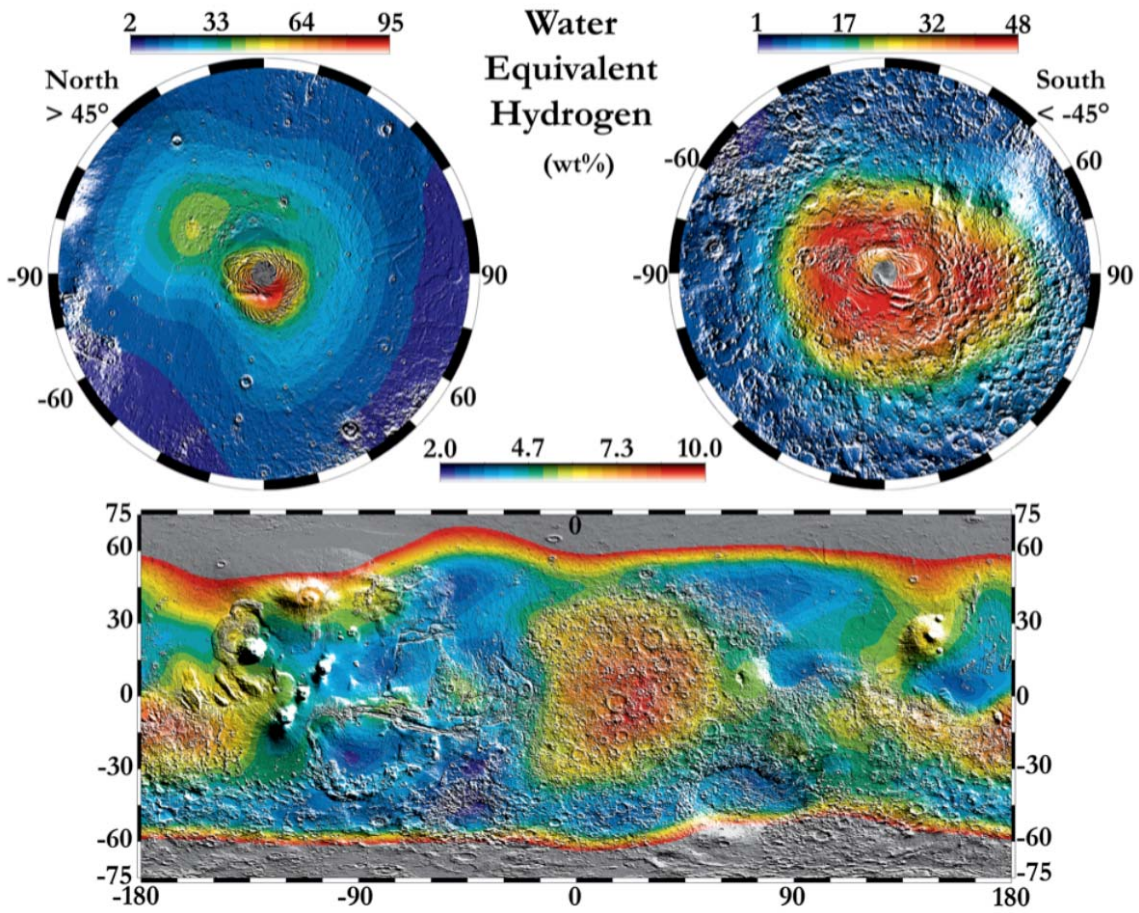
  - **Longer-term variations linked to martian ‘ice ages’**

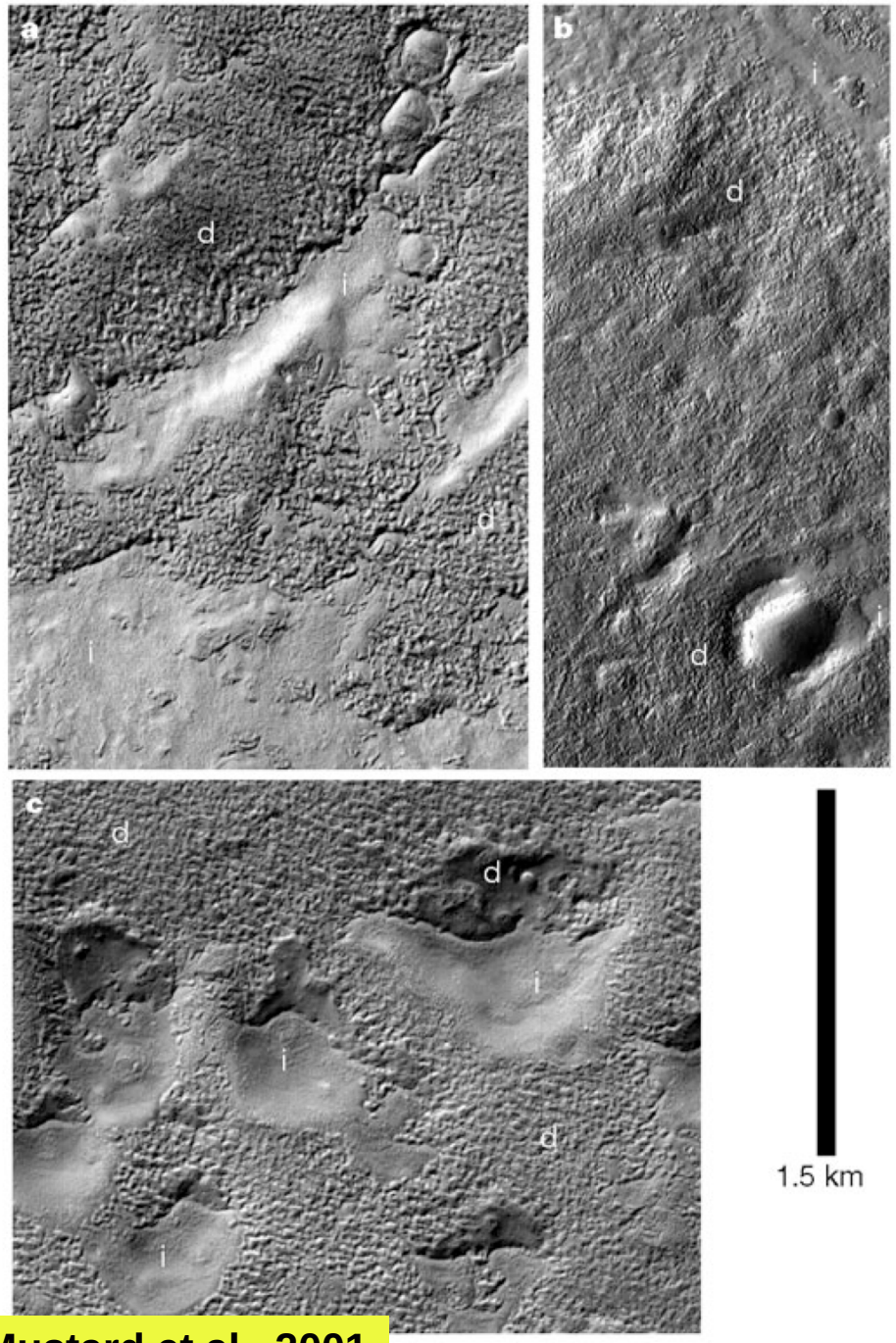


- **How GRS sees this mid-latitude boundary**
  - **Instrument footprint ~10° of latitude**
  - **Small surface slopes and heterogeneities become very significant**
  - **Ice is hard for GRS to see >0.5m down**



Feldman et al., 2008

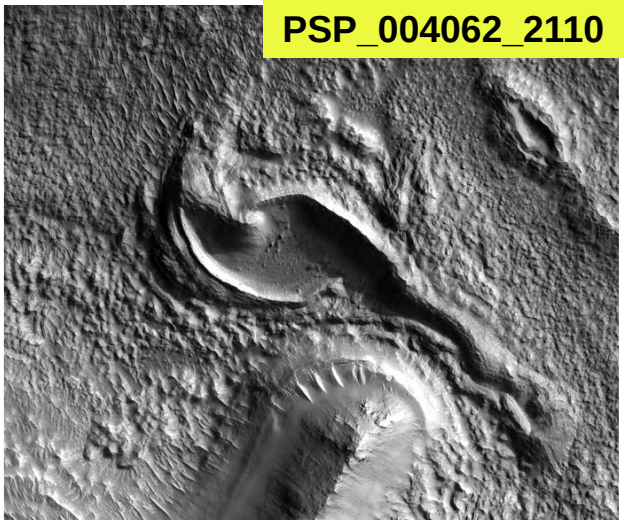


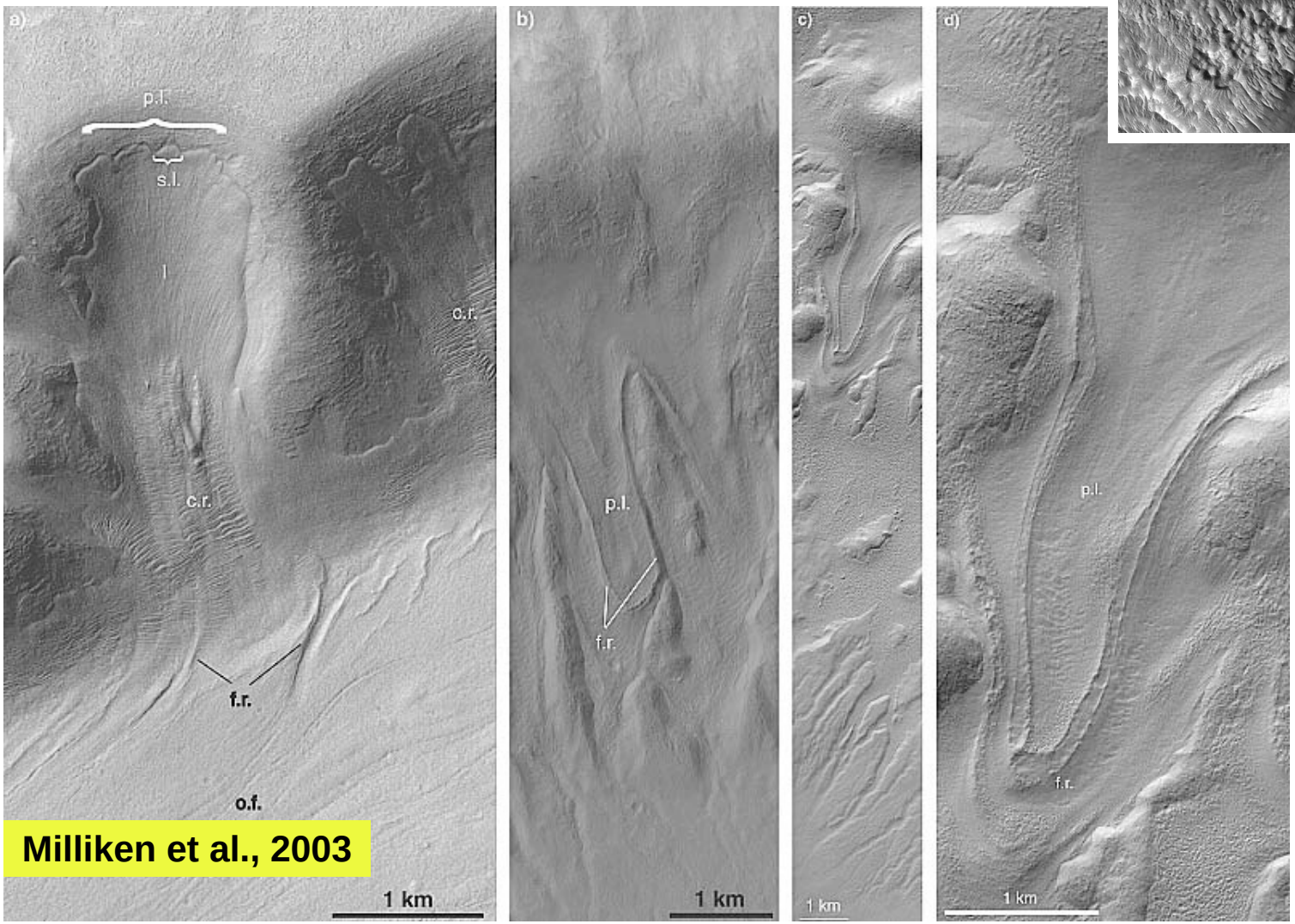


Mustard et al., 2001

- A dissected mantle deposit in the mid-latitudes
  - Ice-rich material
  - Currently being transported to the poles

- **Viscous flow features**

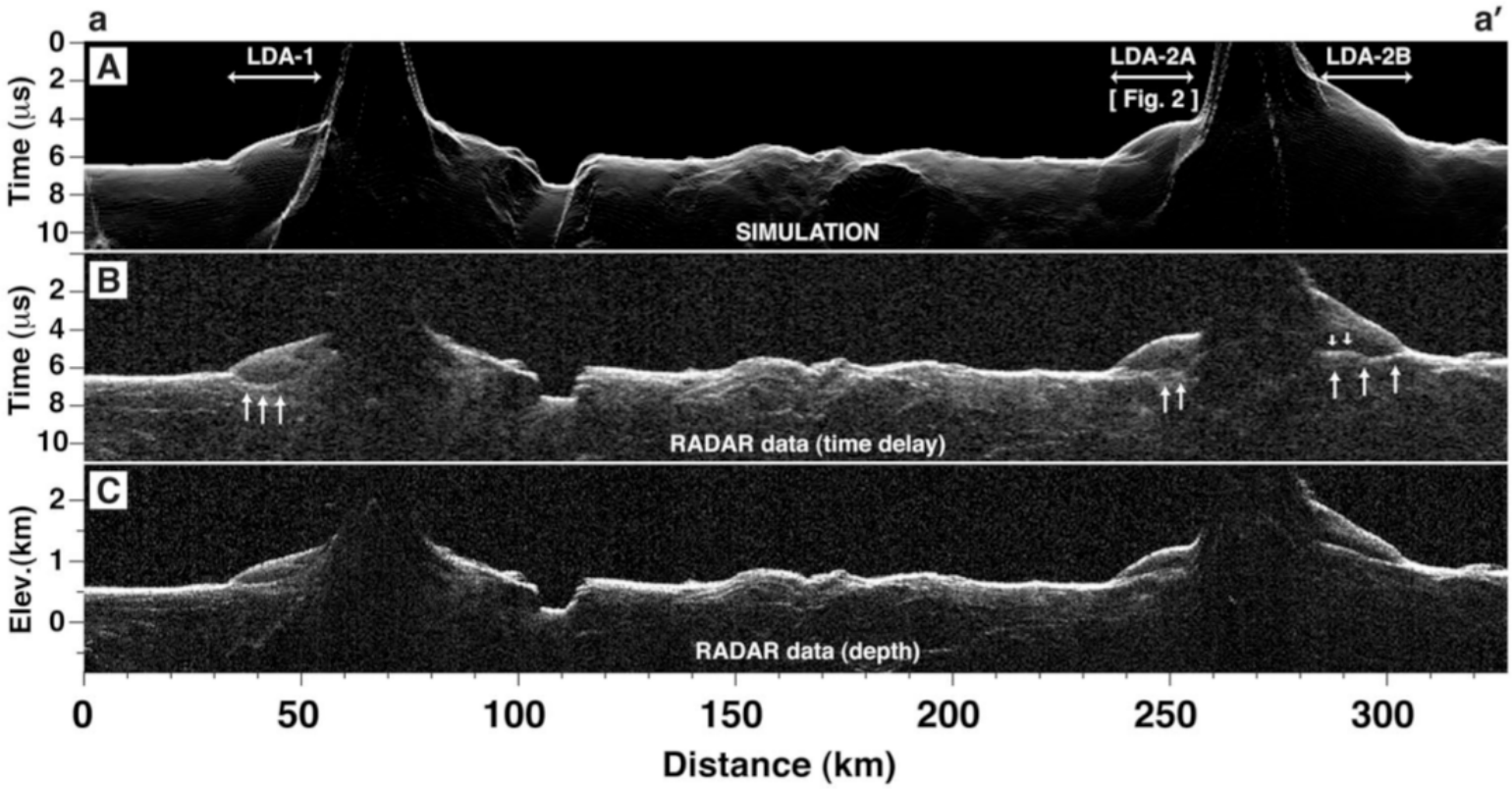


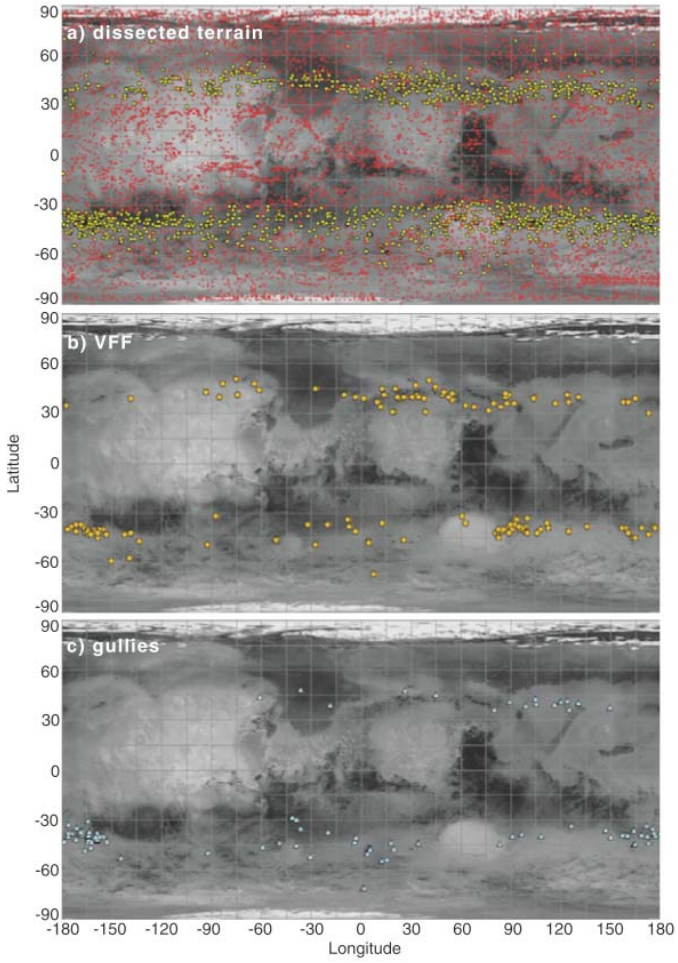


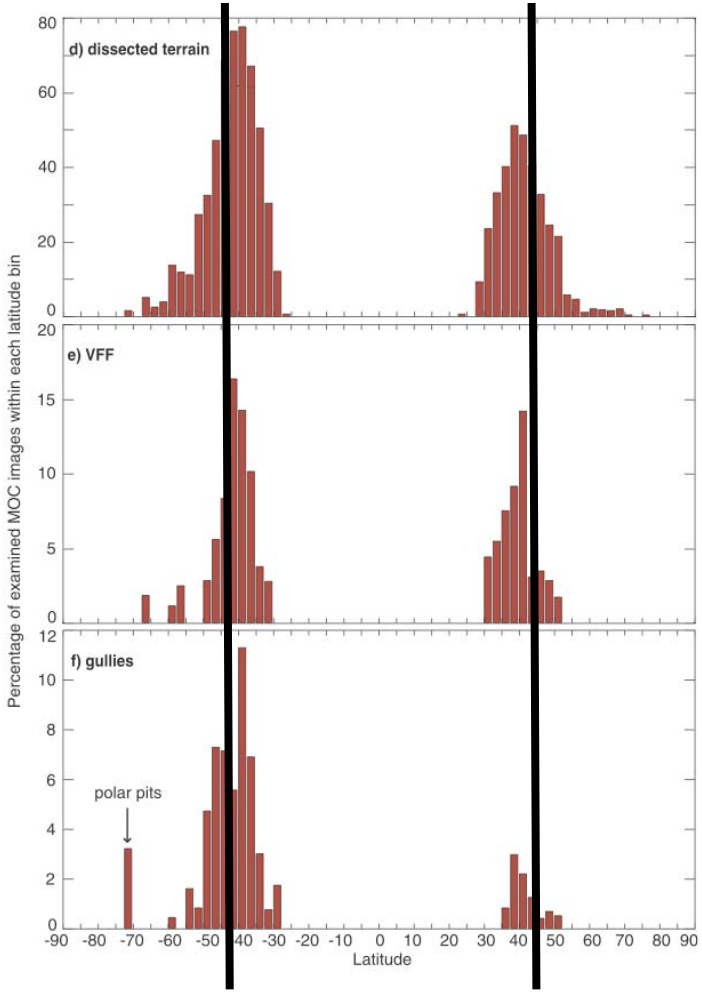
Milliken et al., 2003

- **Mid-latitude gullies**
  - **Carved by liquid water**
  - **Very recent activity**
  - **Possibly formed from snowmelt**

- **Lobate ‘debris’ aprons**
  - **Now known to be almost pure ice**





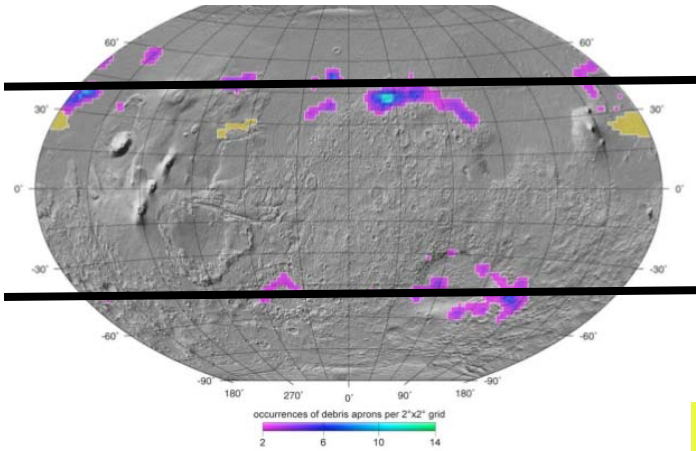


Dissected mantle distribution

Viscous flow features distribution

Gully distribution

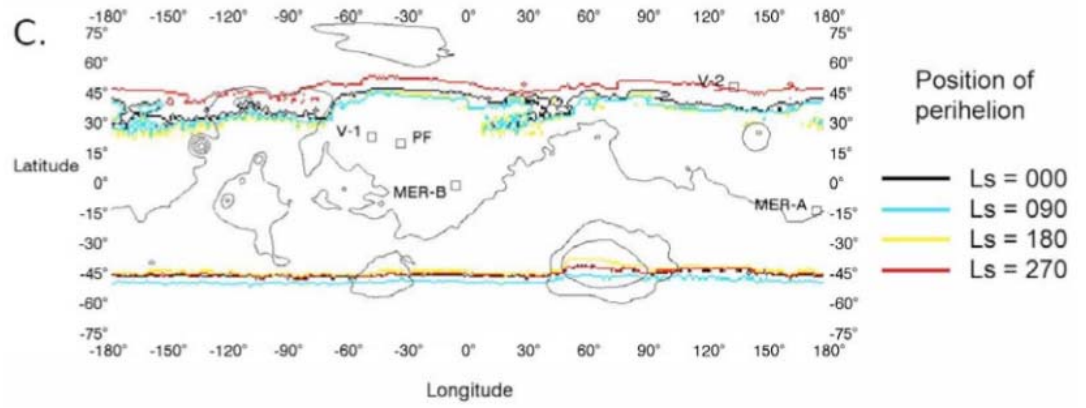
Milliken et al., 2003



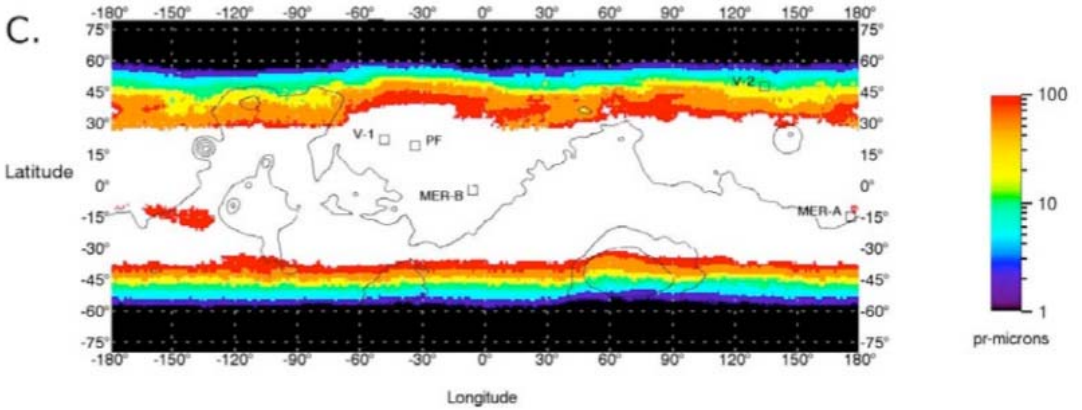
Lobate ‘debris’ apron distribution

Hauber et al., 2008

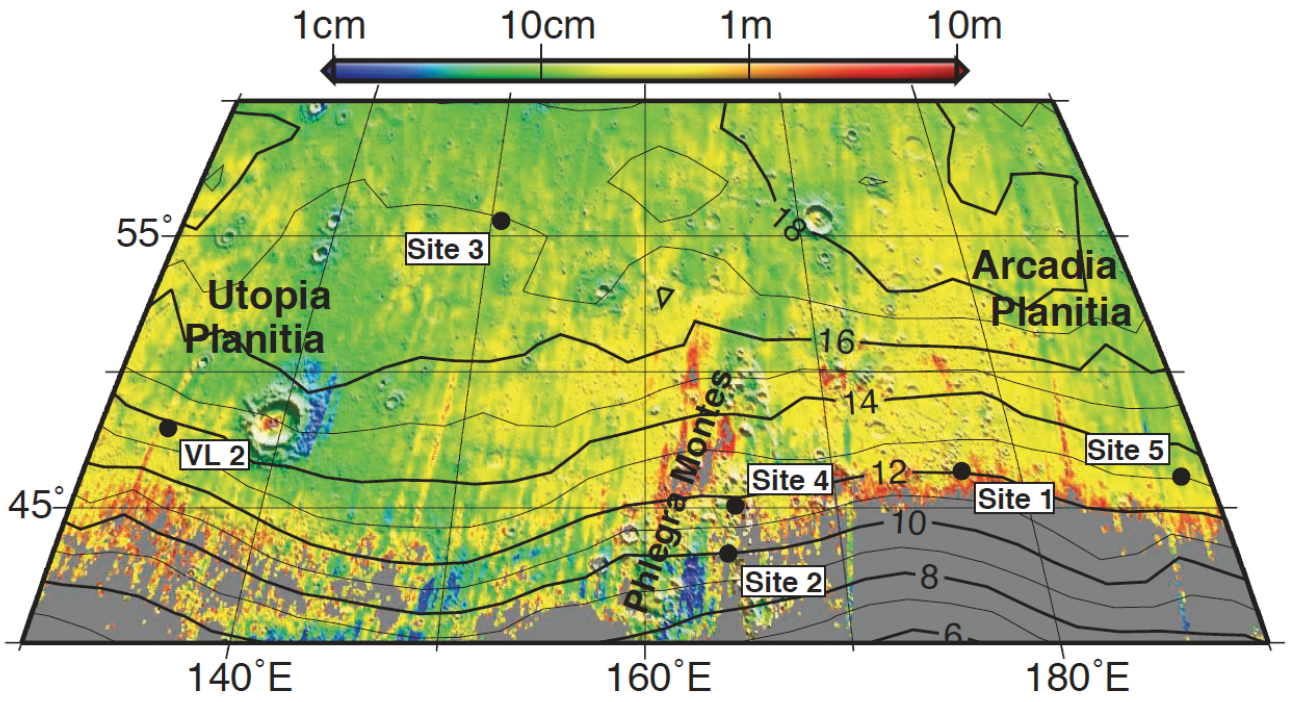
- **Martian mid-latitudes**
  - **Changing ice stability**
  - **Very sensitive to climatic conditions**
  - **Periglacial and glacial landforms**
- **Certainly a place that could tell us a lot about recent geology and climate**

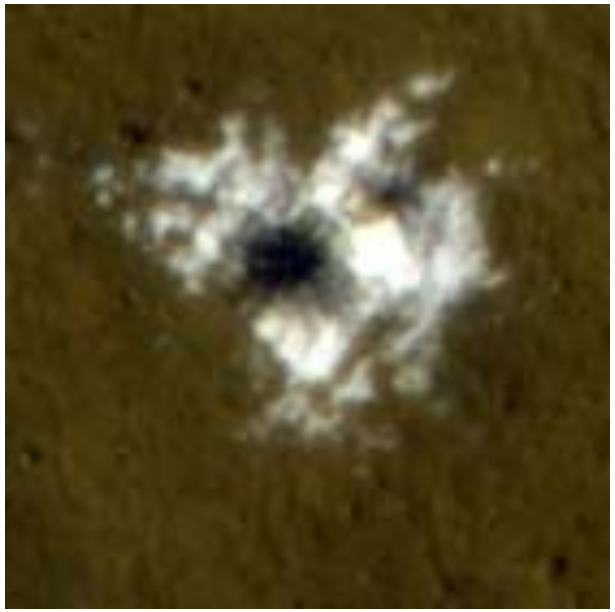


Chamberlain and Boynton, 2007

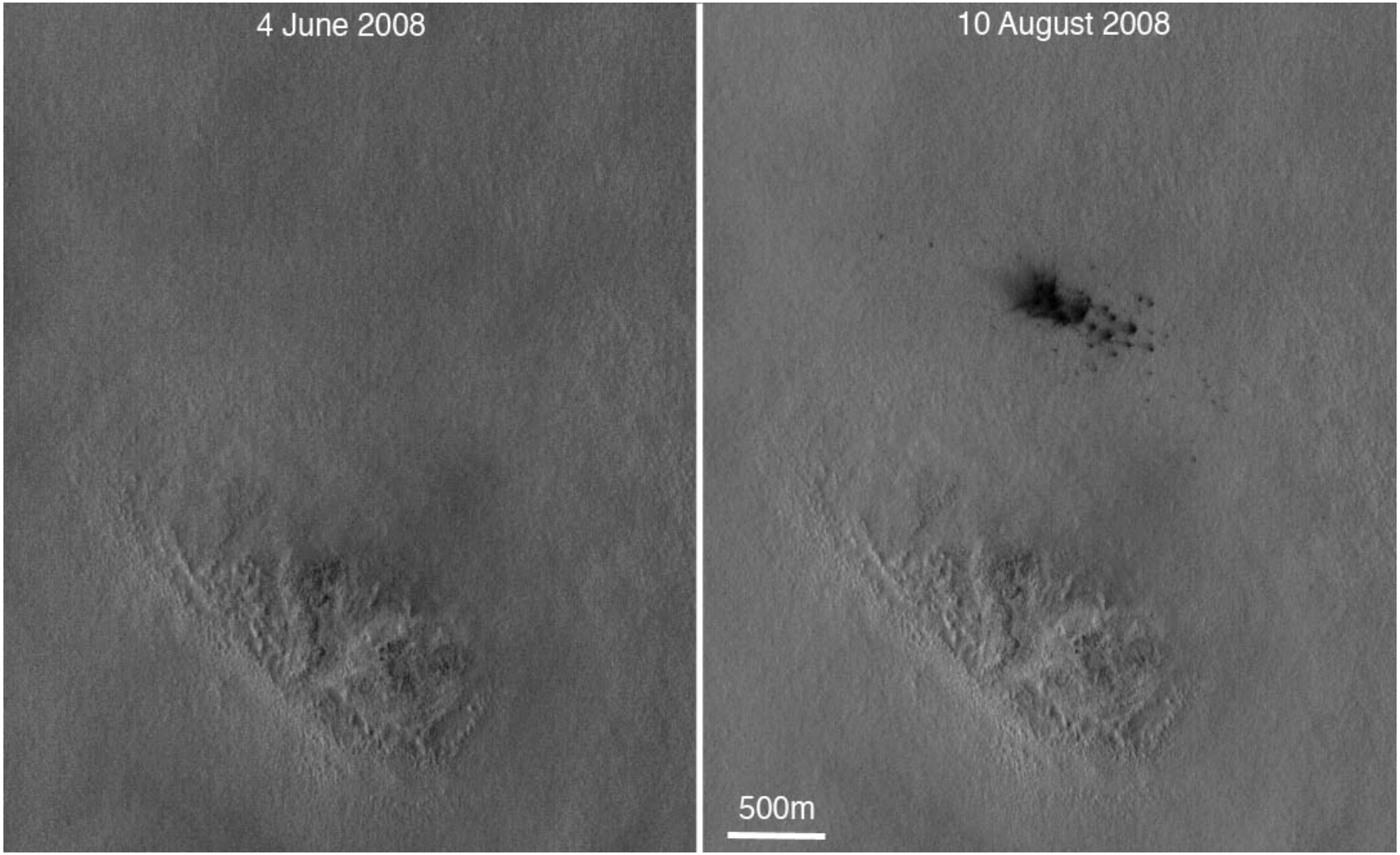


- **Natural probes of ground ice on Mars**
  - **Information on a critical region we can't get any other way**
  - **Five (probably six) sites**
  - **Concentrated on this boundary**

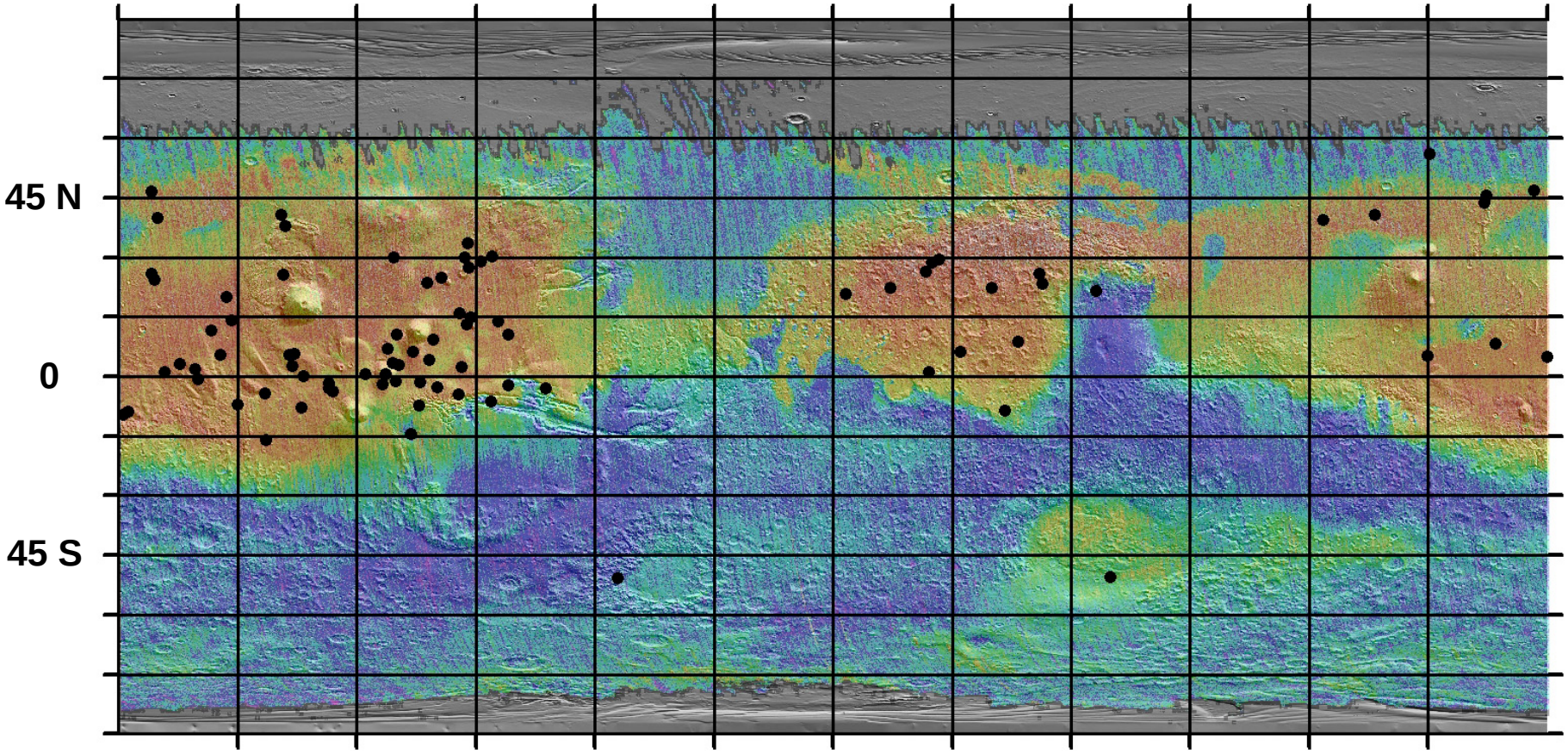




- **New craters detected in before/after image pairs**
  - **Continues on from MOC studies (Malin et al., 2006)**
  - **Dark spots from surficial dust removal**

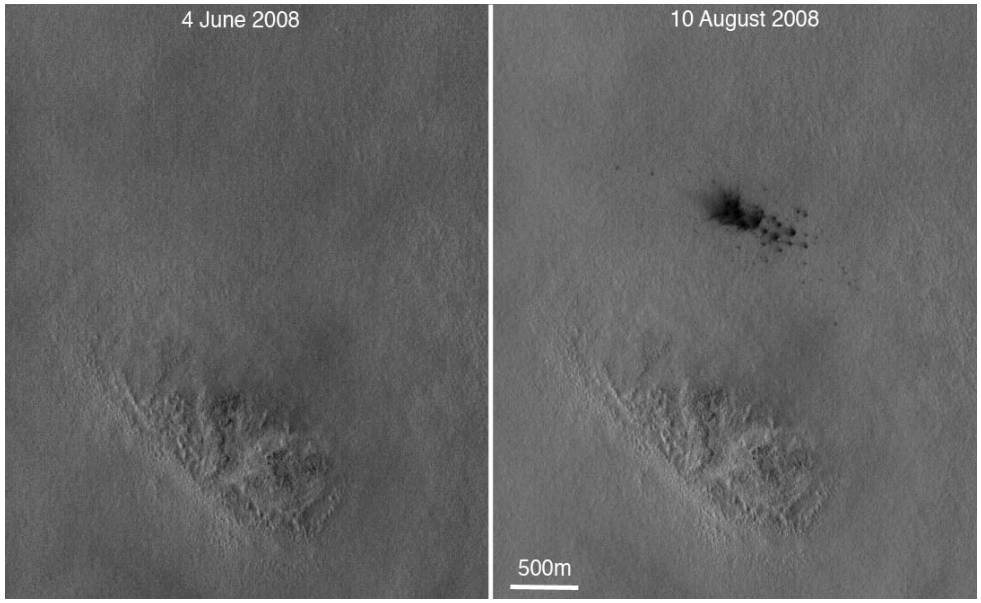


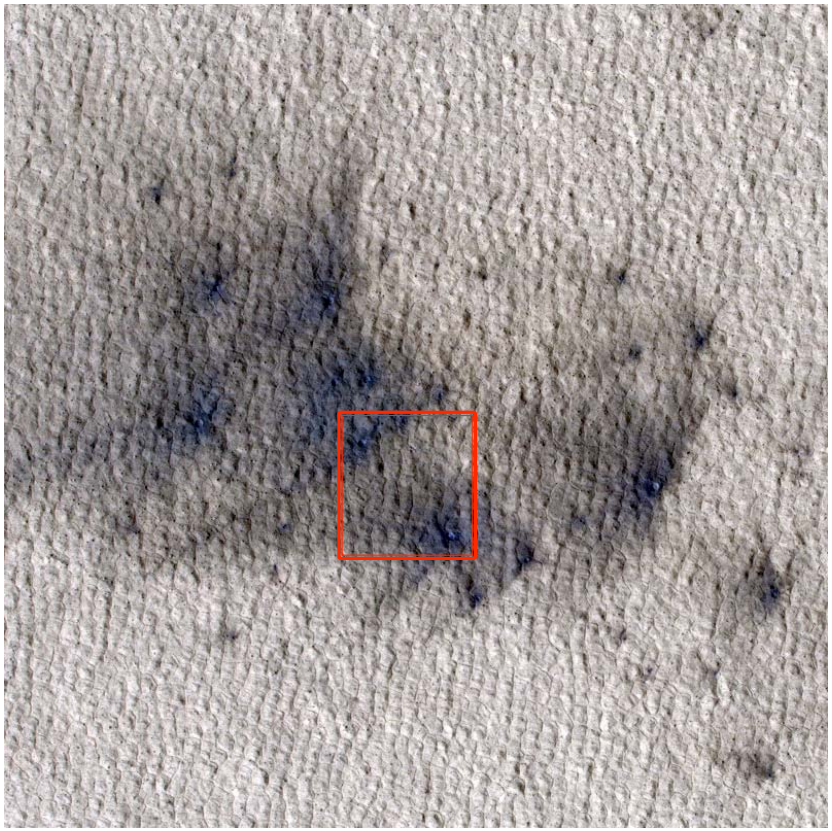
- **85 confirmed with HiRISE followup**
  - **More on the way**
- **Huge bias in crater discovery locations**
  - **Dusty areas – lend themselves to ice preservation**
  - **Good weather**

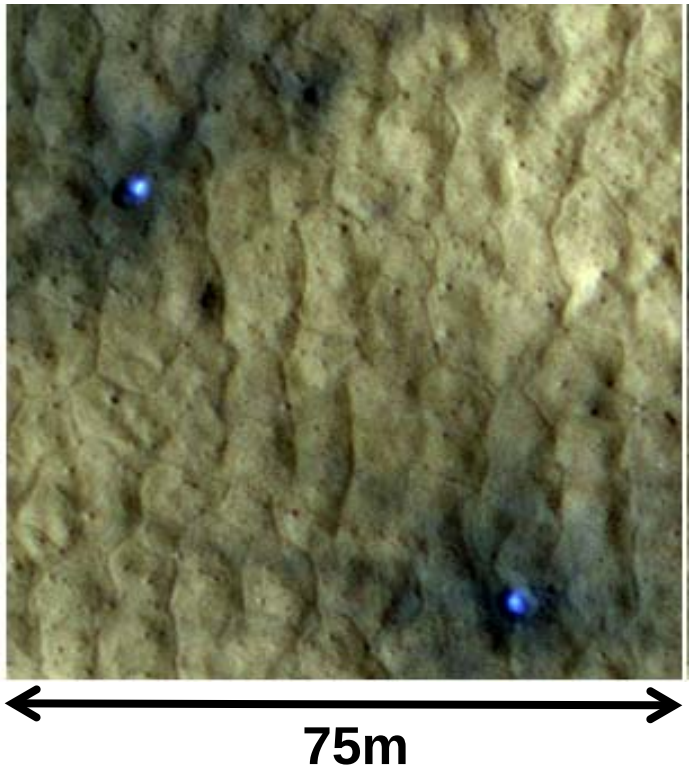


Craters from the CTX team with TES dust index (Ruff & Christensen, 2002)

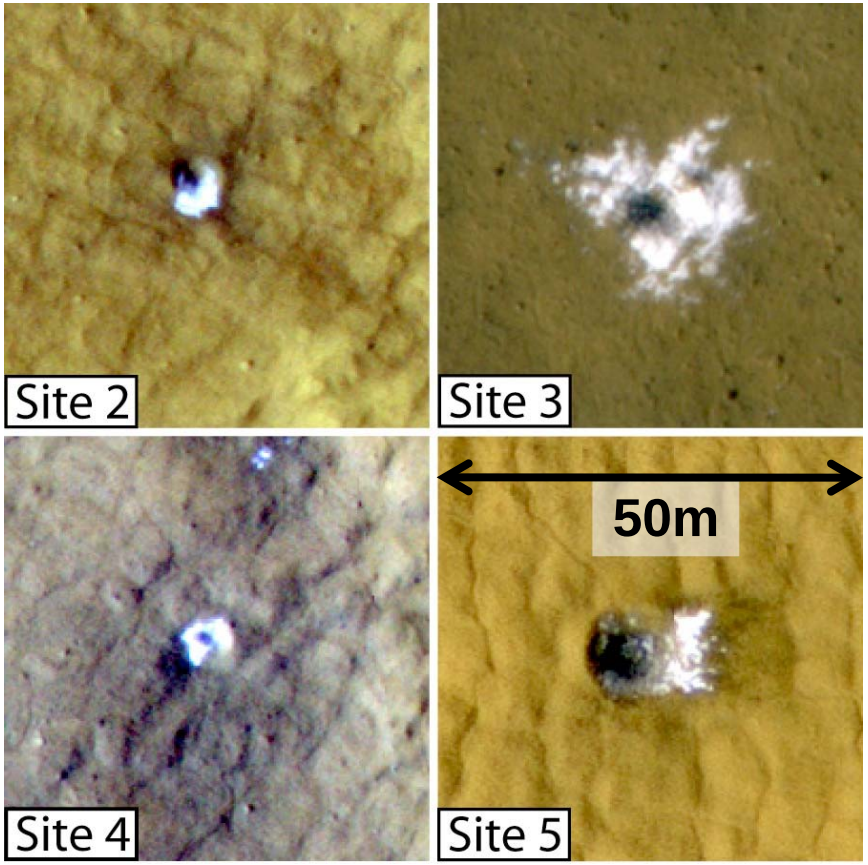
- **A fortuitous discovery…**
  - **CTX discovers newly formed crater**
    - **46.3 N**
  - **HiRISE followup showed something unusual**
    - **Color and Brightness suggest ice**

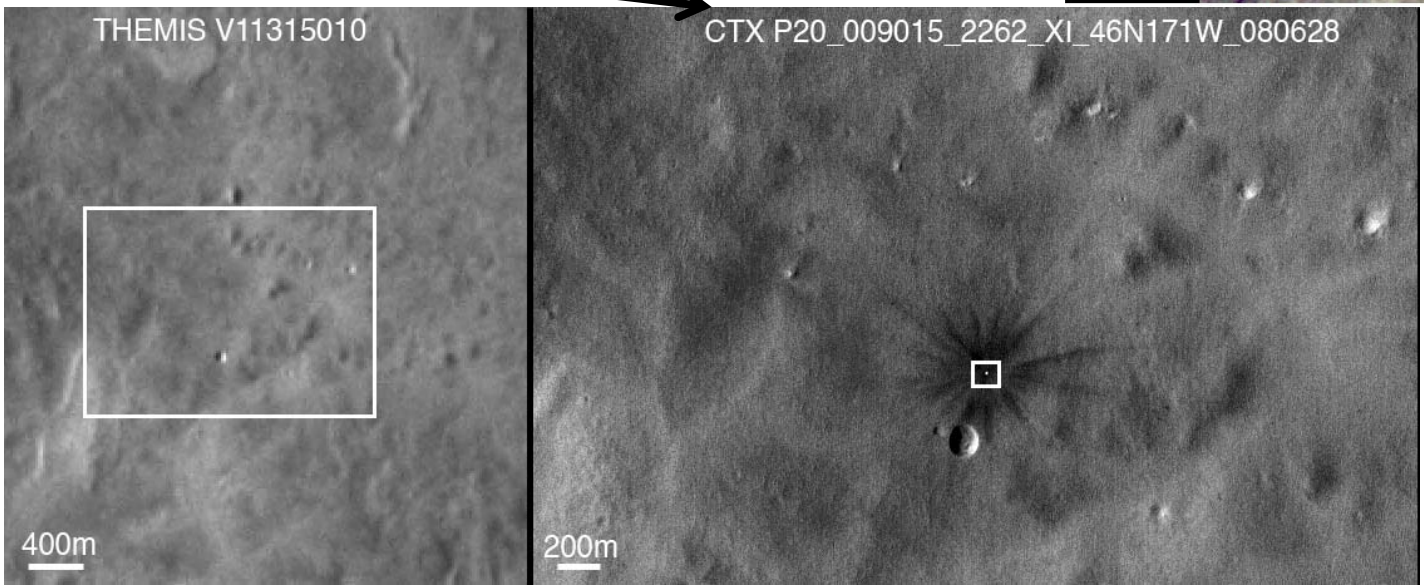


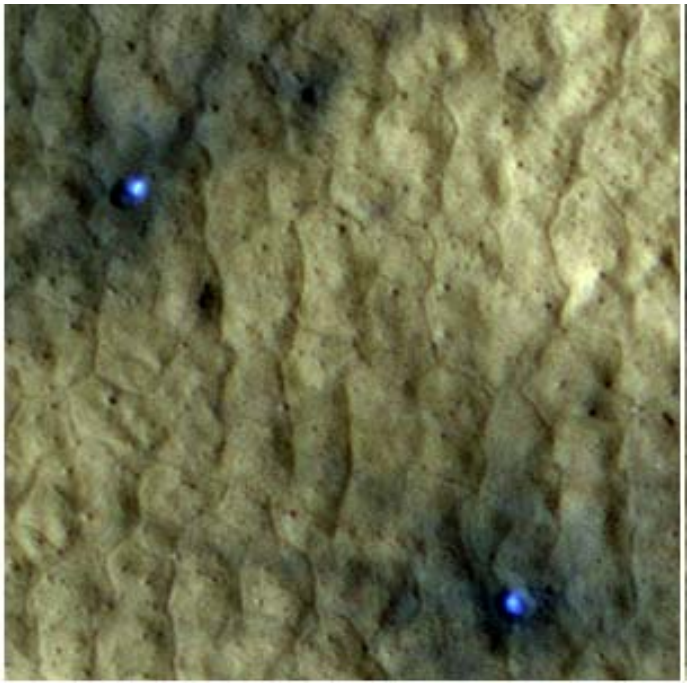


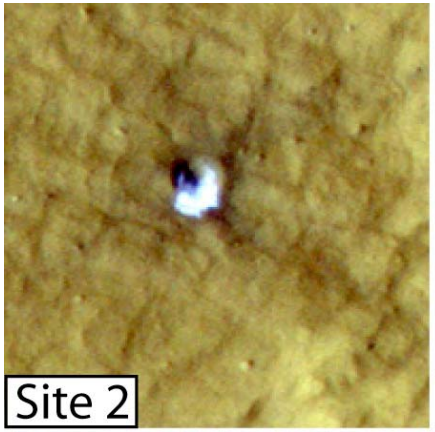


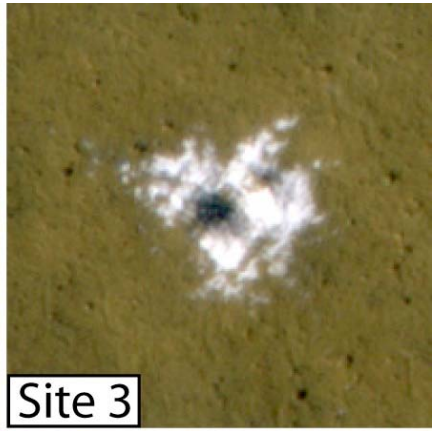
- **More discoveries follow…**
  - **CTX continuously discovers more high-lat. Impacts**
  - **HiRISE followups show more craters with associated ice**
  - **5 sites in total**
  - **All new impacts poleward of 43N have associated ice**
    - **More on that later**
  - **All a few meters across**
    - **Site 5 (largest) is ~12m across**

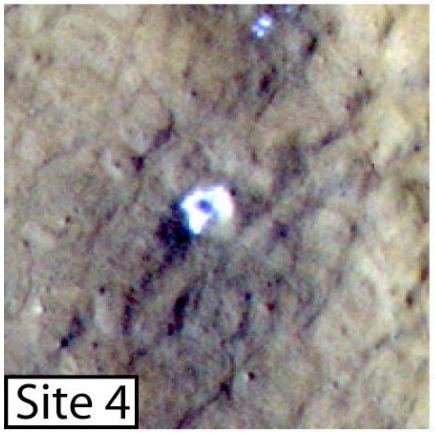


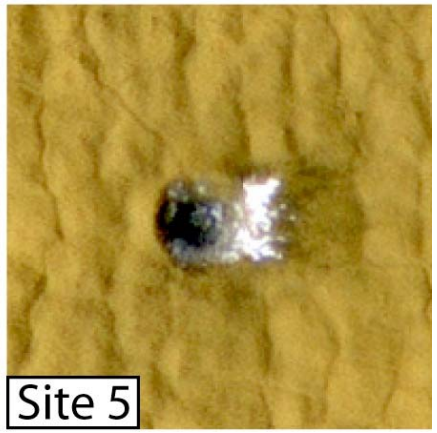








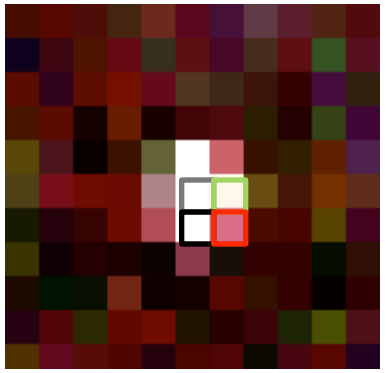


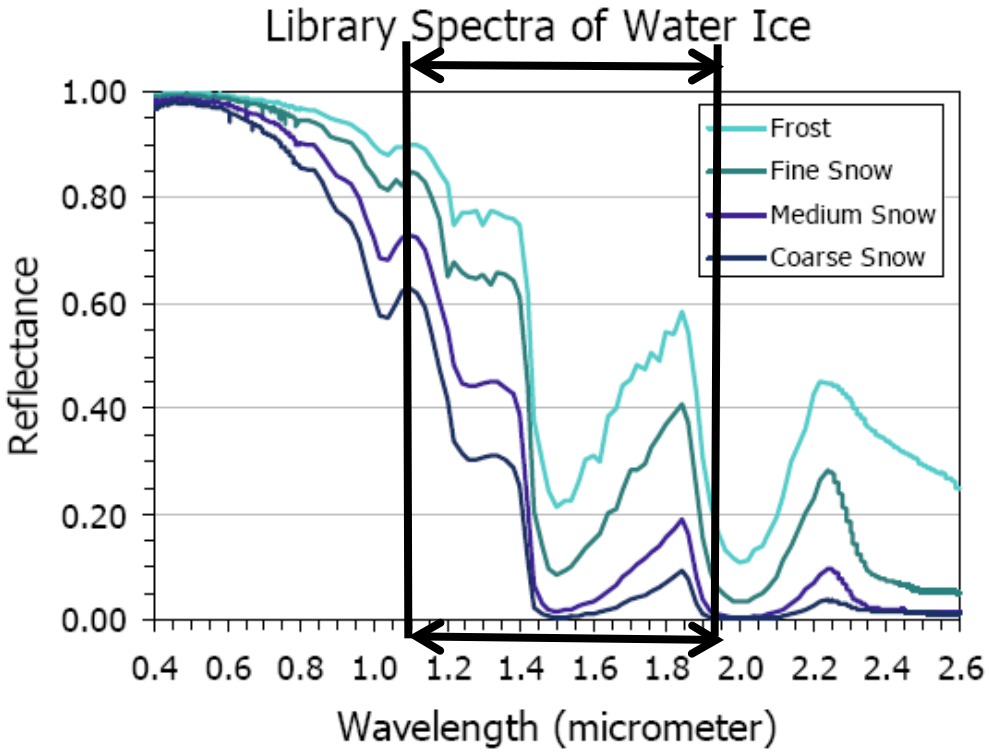


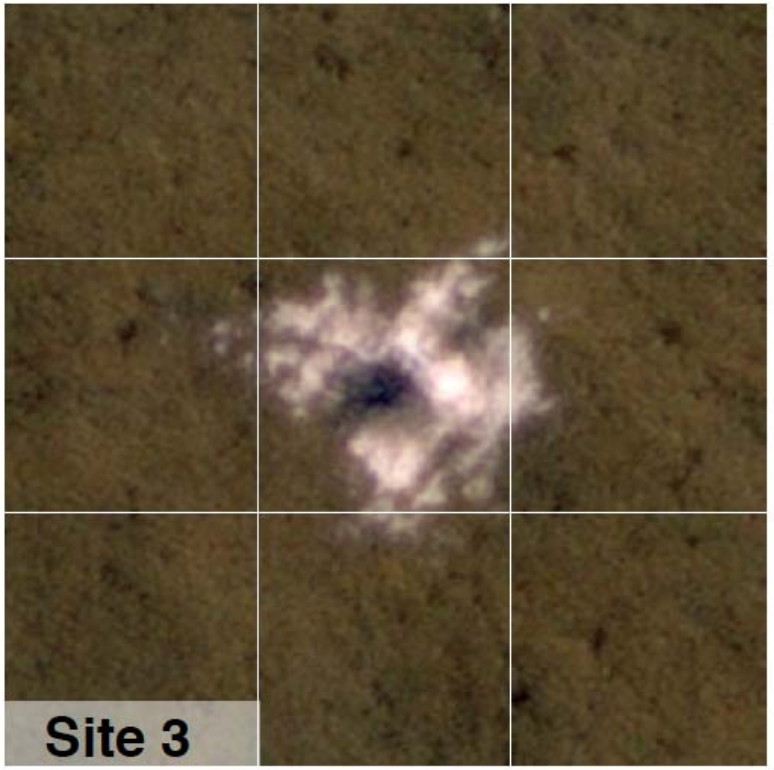
18m

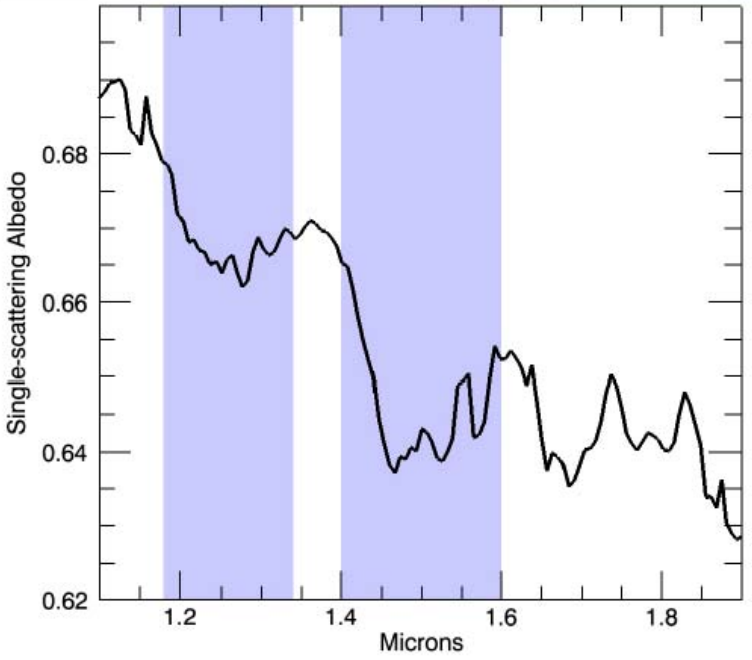
- **CRISM data**
  - **CRISM pixels big by comparison**
  - **Bright stuff at most sites <10% of a CRISM pixel**
    - **No water ice detected…**
  - **Except site 3…**

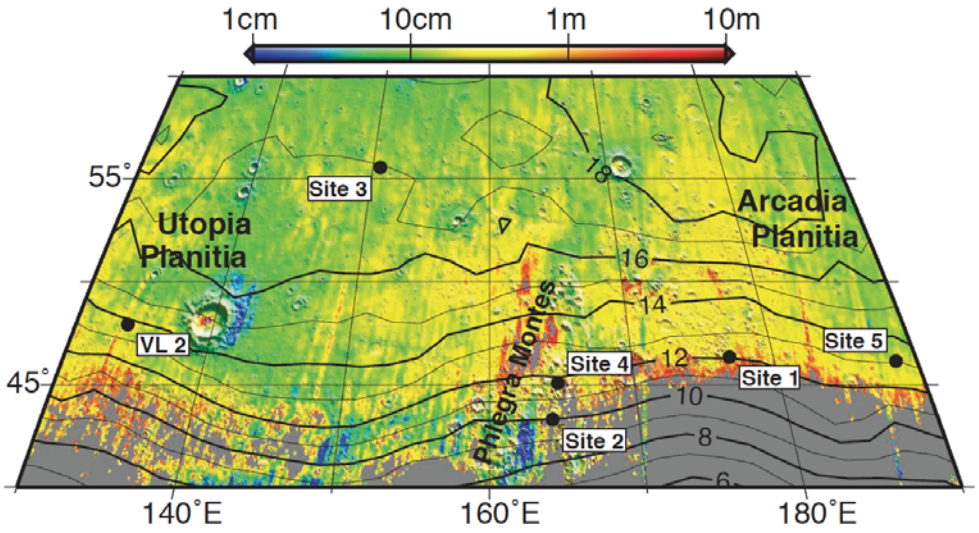
- **CRISM**
  - **Detected water ice**
  - **Spread over a few pixels**

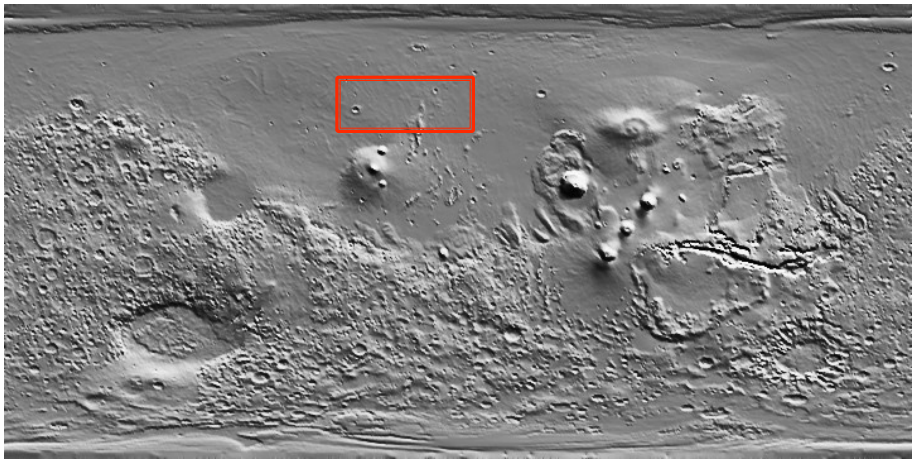






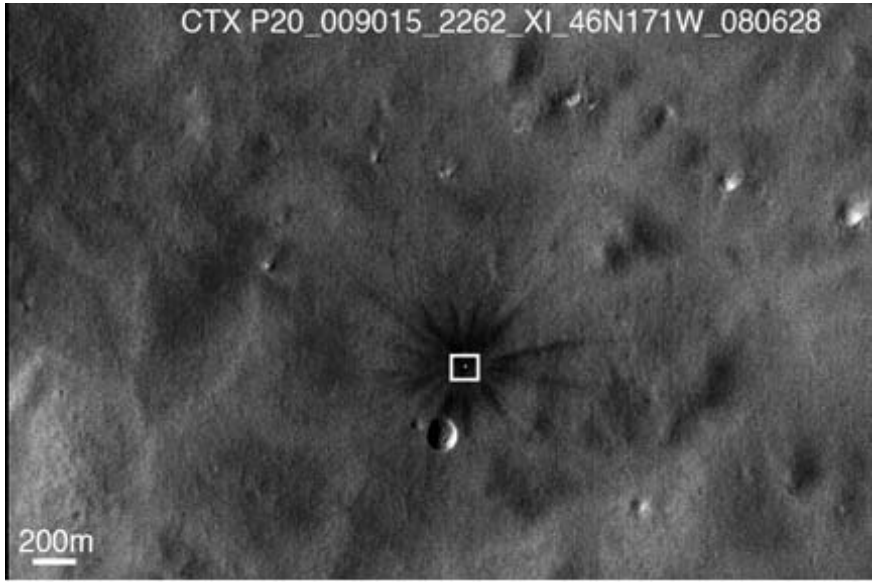


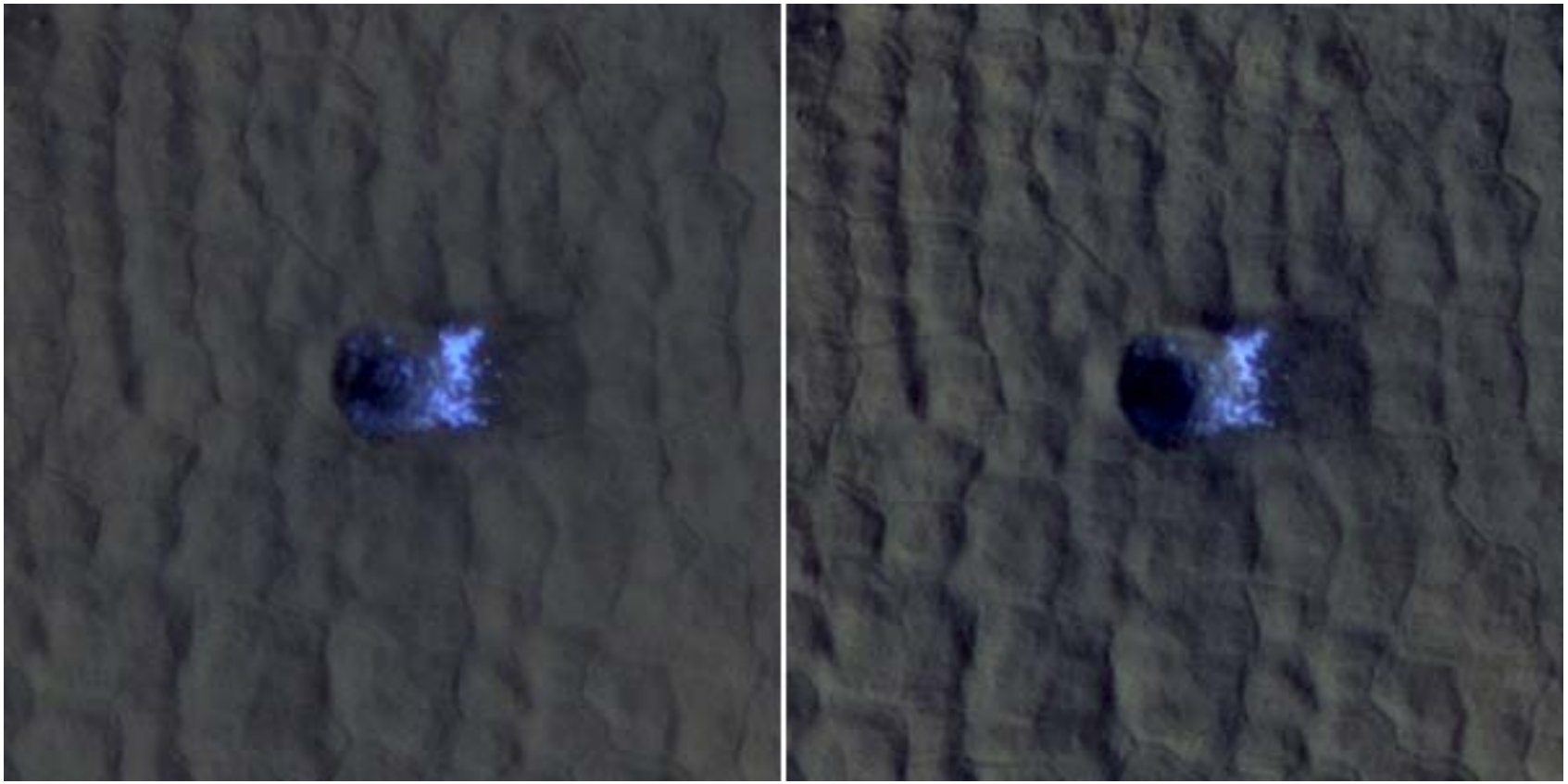




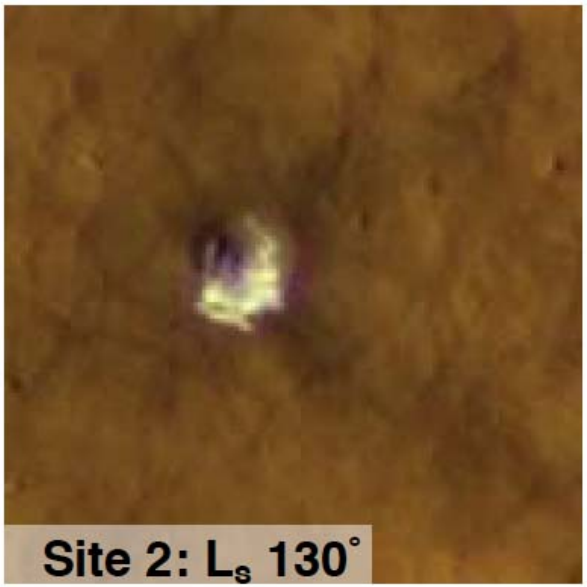
	Lon.	Lat.	Latest Before	Soonest After	HiRISE	Ls/M29
					PSP_009978_2265	125.9
					PSP_010189_2265	133.8
			6/4/2008	8/10/2008	PSP_010334_2265	139.3
1	176.89°	46.34°	L_s 81/M29	L_s 111/M29	PSP_010400_2265	141.9
			P20_008699_2247	P22_009556_2263	PSP_010901_2265	162.0
					ESP_011323_2265	180.0
					ESP_011468_2265	186.5
					PSP_010084_2235	129.8
			12/22/2006	7/5/2008	PSP_010440_2235	143.5
2	164.21°	43.30°	L_s 154/M28	L_s 94/M29	PSP_010651_2235	151.8
			V22273012	P21_009095_2225	ESP_011574_2235	191.2
					ESP_011719_2235	197.9
			1/26/2008	9/18/2008	PSP_010625_2360	150.8
3	150.60°	55.57°	L_s 23/M29	L_s 129/M29	ESP_011337_2360	180.7
			V27128013	P23_010058_2375	ESP_011548_2360	190.1
			1/22/2008	9/15/2008	PSP_010585_2255	149.2
4	164.70°	45.06°	L_s 21/M29	L_s 127/M29	ESP_011442_2255	185.3
			V27090026	P23_010018_2247	ESP_012220_2255	221.6
			7/3/2004	6/28/2008	PSP_010861_2265	160.4
					ESP_011283_2265	178.3
5	188.50°	46.16°	L_s 55/M27	L_s 92/M29	ESP_011494_2265	187.6
			V11315010	P20_009015_2262	ESP_011850_2265	204.0

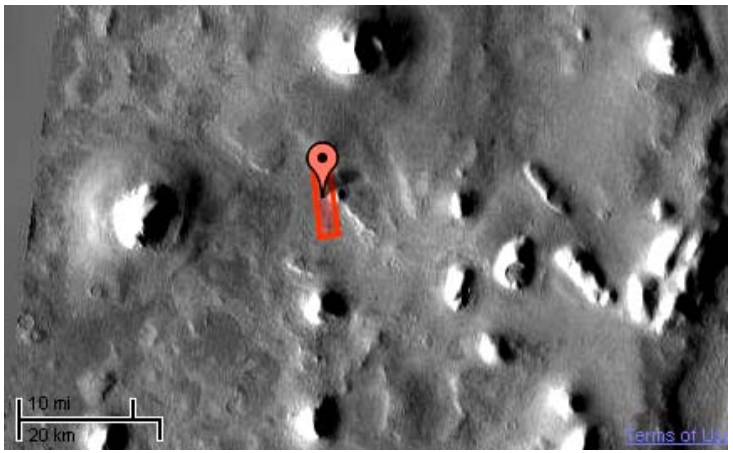
- **Change at site 5**
  - **Polygons similar to site 1**
  - **Ls 160 to 188**
  - **Extensive (1 km) dark rays**

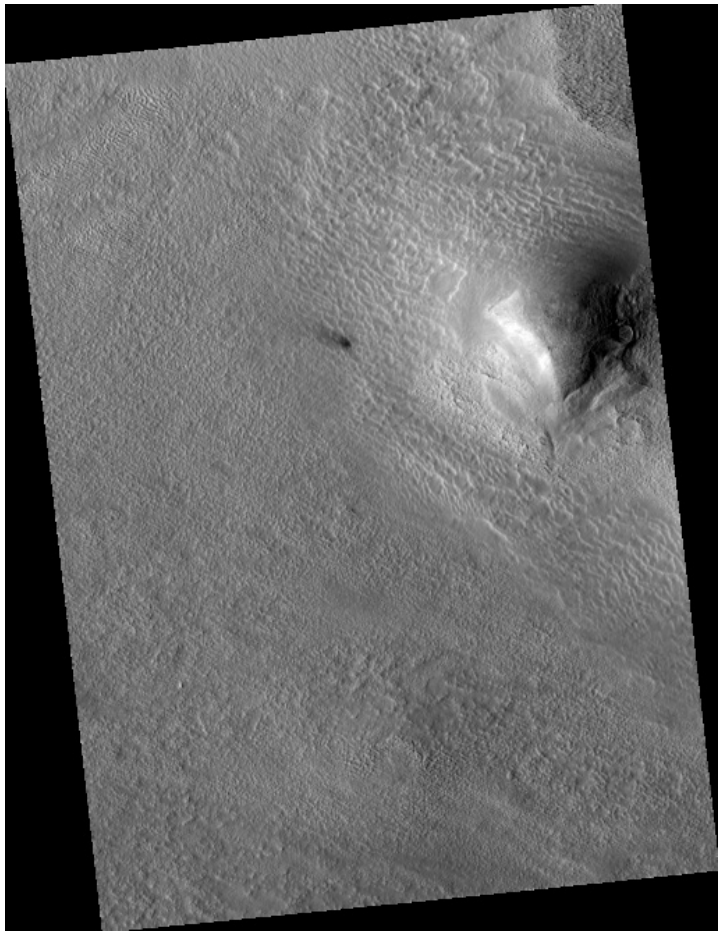




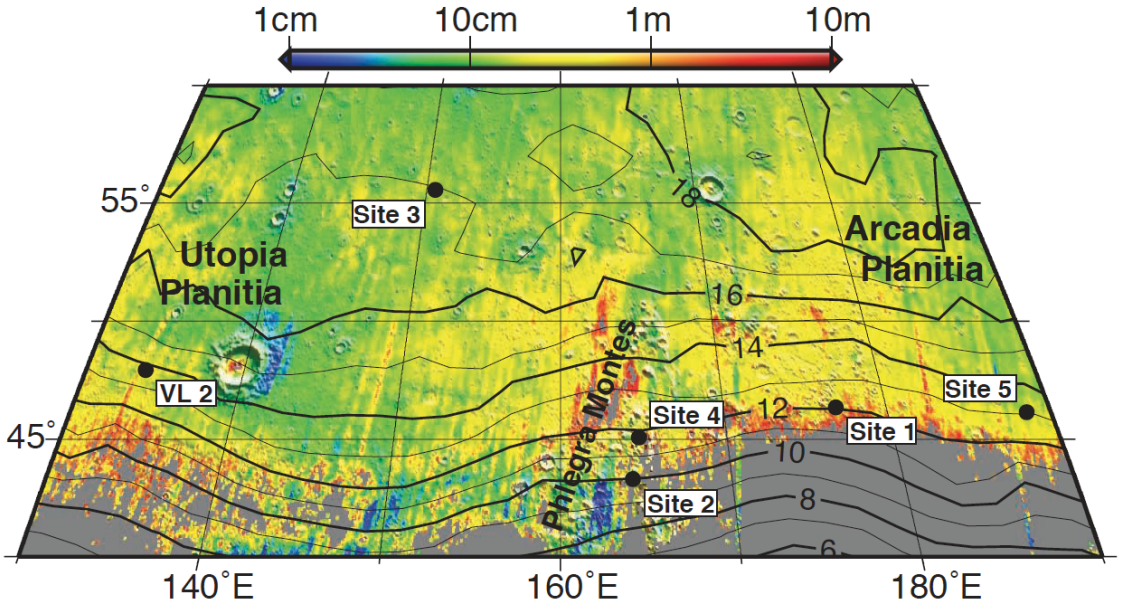
- **Sites 2 and 4**
  - **On massif aprons in Phlegra Montes**
  - **Ls 130 to 191 (2) and Ls 149 to 185 (4)**
  - **Massive glacial ice – probably not**



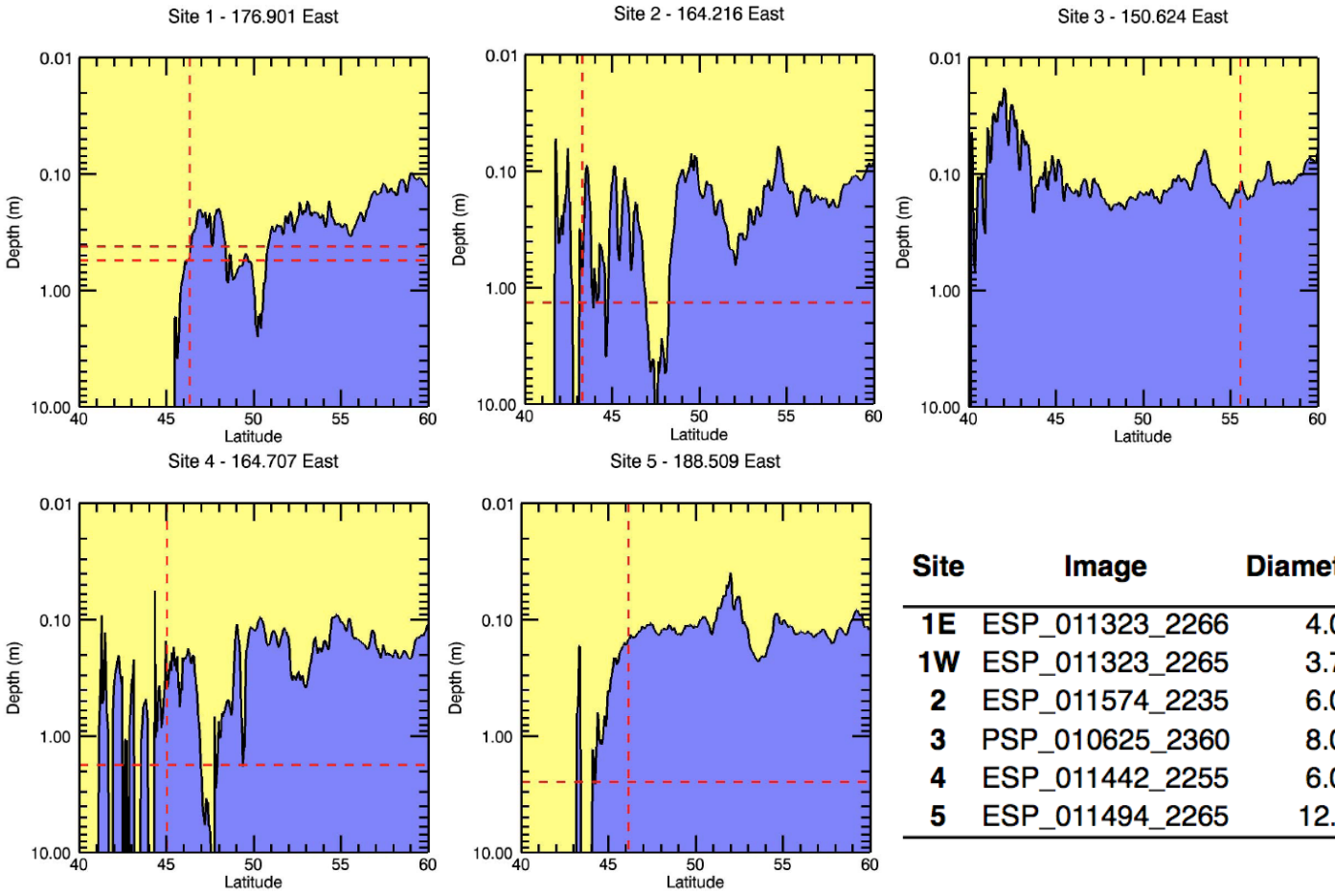




- **Site 3**
  - **55 N**
  - **Minor changes Ls 151-190**
  - **Crater floor dark**
    - **Bright ice has a finite thickness**

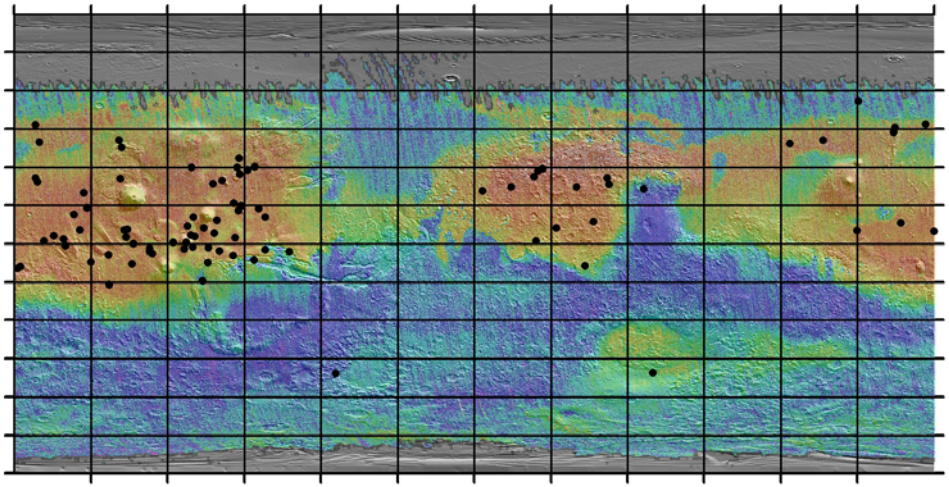


- **Site 1 excavated to ice**
- **Sites 2-5 excavate through the ice**
- **Model depths consistent with 20 pr microns**
  - **Today's values closer to 10 pr microns**
  - **Still retreating from last ground ice maximum 10Kyr ago**



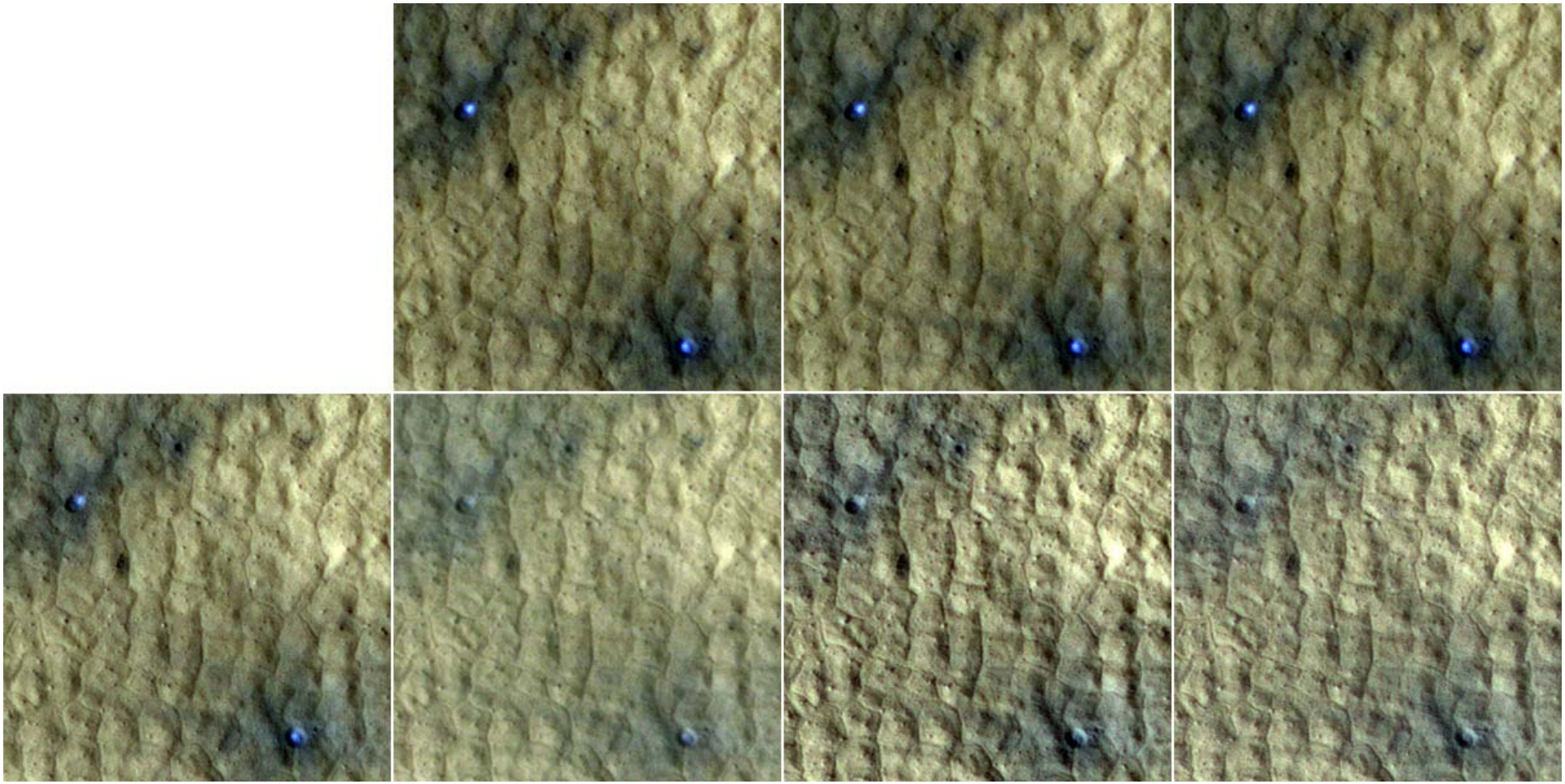
Site	Image	Diameter (m)	Depth (m)	Ice Table Predict (m)
1E	ESP_011323_2266	4.00	0.55	0.40m (0.21-1.47)
1W	ESP_011323_2265	3.75	0.42	0.40m (0.21-1.47)
2	ESP_011574_2235	6.00	1.33	0.14m (0.02-0.62)
3	PSP_010625_2360	8.00	?	0.16m (0.13-0.19)
4	ESP_011442_2255	6.00	1.76	0.25m (0.04-4.65)
5	ESP_011494_2265	12.00	2.46	0.18m (0.13-0.30)

- **Where we don't see ice**
  - **Equatorward of 41N**
  - **…but we these craters might be old**

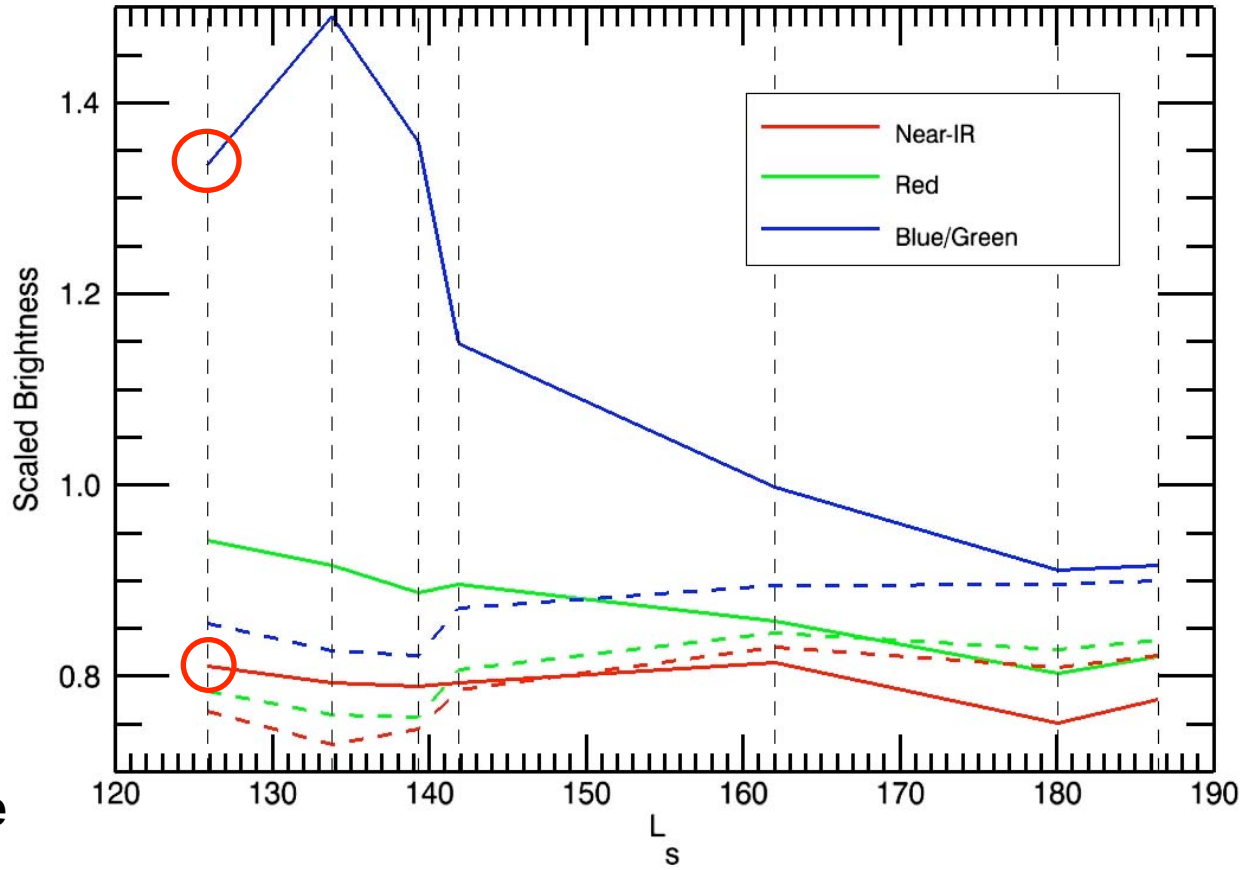


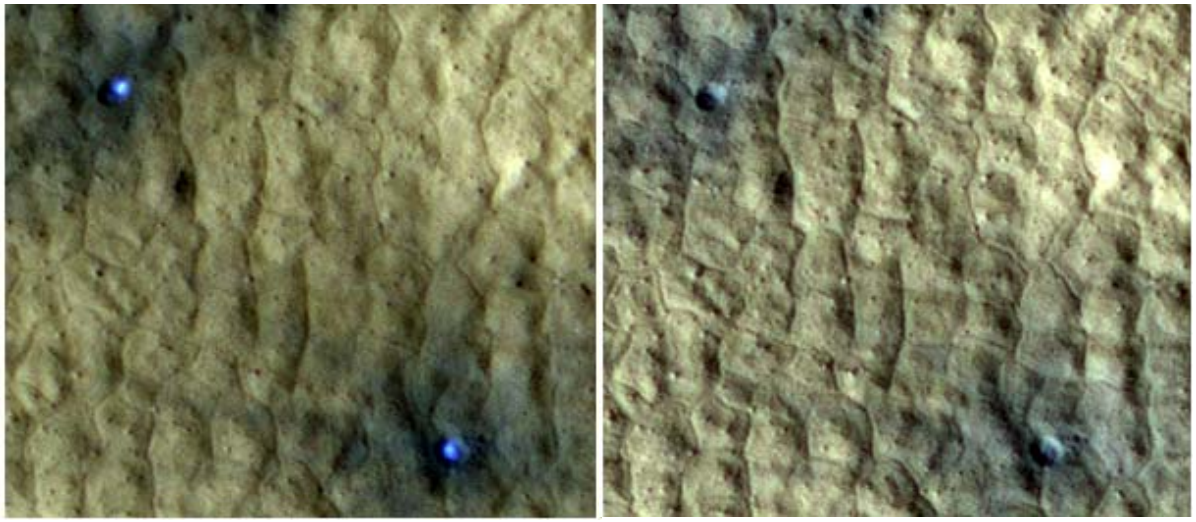
	Lon.	Lat.	Latest Before	Soonest After	HiRISE	L_s/M29
6	305.99°	-50.60°	1/31/2006 L_s 5/M27 V18325004	12/31/2007 L_s 11/M29 P14_006704_1279	PSP_007561_1290	41.8
7	70.10°	-50.16°	11/26/2005 L_s 330/M27 I17522007	1/3/2008 L_s 12/M29 P15_006739_1314	PSP_007596_1295	43.1
8	268.117°	33.15°	11/14/2004 L_s 115/M27 V12947007	7/9/2008 L_s 96/M29 P21_009144_2133	PSP_010634_2135	151.1
9	222.27°	37.46°	12/20/2006 L_s 153/M27 V22246010	3/21/2008 L_s 48/M29 P17_007735_2186	PSP_008236_2180	65.1
10	123.72°	38.92°	6/15/1999 L_s 155/M24 M02-02002	12/25/2007 L_s 8/M29 V26742021	PSP_010547_2195	147.7
11	190.04°	39.55°	12/10/2007 L_s 1/M29 V26565016	10/23/2008 L_s 146/M29 P24_010505_2205	ESP_011428_2200	184.7
12	221.22°	40.31°	2/6/2005 L_s 156/M27 V13972003	6/29/2008 L_s 92/M29 P20_009027_2190	ESP_011295_2205	178.8
13	136.58°	40.35°	2/28/2005 L_s 168/M27 V14237009	3/3/2008 L_s 40/M29 P17_007514_2208	PSP_008015_2205	57.5

- **Site 1**
  - **Ice patches faded away over ~150 days**



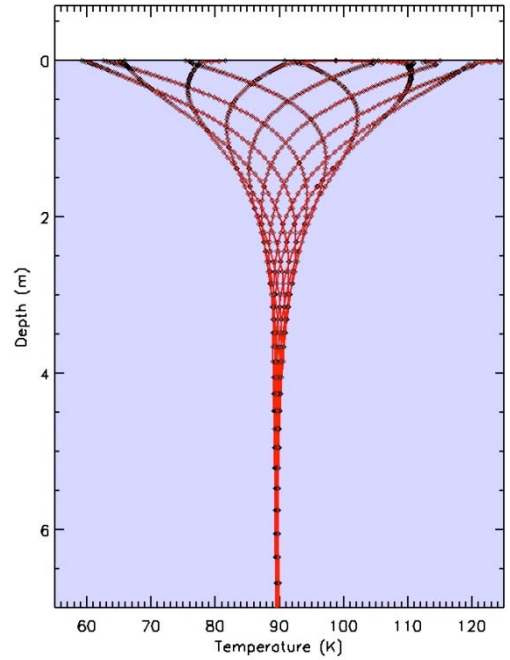
- **Ice changes**
  - **Steady reddening and darkening of ice**
  - **Sublimation lag**
  - **Atmospheric dust fallout**
  - **Grain growth**
- **Dark blast zone**
  - **Also fading**
  - **Brightening with time**
  - **Implies some dust fallout**

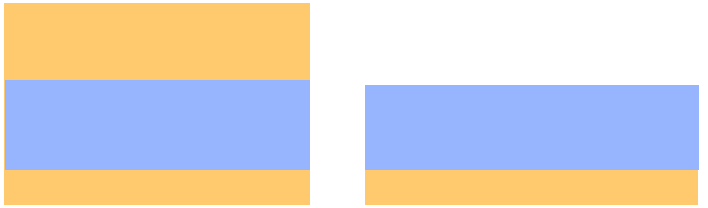


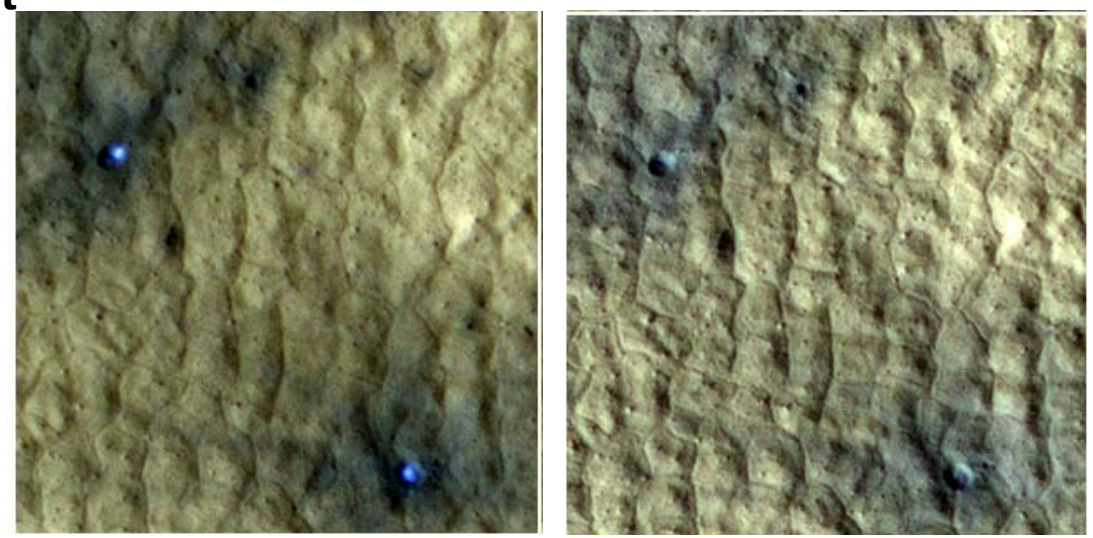


- **Thermal modeling to constrain sublimation**
  - **Model buried ice**
  - **Remove overburden**
  - **Track sublimation rate**

- **Many free parameters**
  - **Initial ice albedo (which we force to darken)**
  - **Albedo, thermal inertia of pre-impact terrain**
  - **Atmospheric temperature**
  - **Wind speed & drag coefficient**
  - **Ice table thickness**
  - **Depth to ice table**
  - **Timing of the impact**
  - **Heat injected during impact**





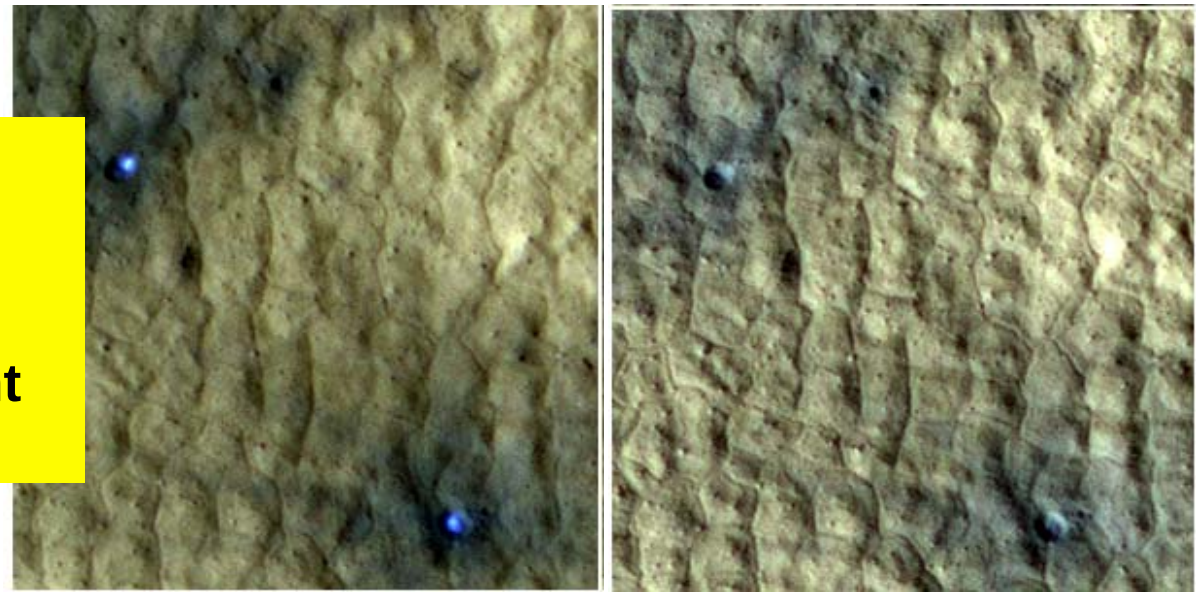


- **Most important parameters**
  - **Windspeed, nominally 2.5 ms^{-1} – Viking II data**
  - **Initial ice albedo, nominally 0.4**
- **Nominal sublimation gives ~1.7 mm by Ls 180**
  - **Range for reasonable inputs ~1 to several mm.**

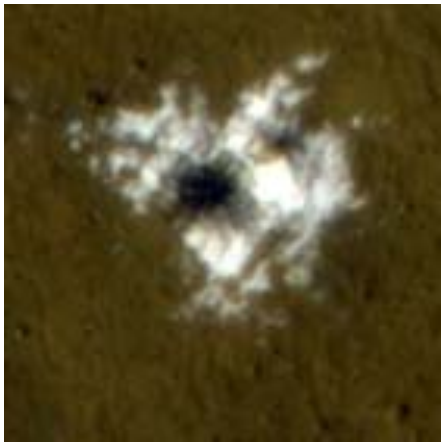
- **Optically thick lag in HiRISE BG (0.55 microns) of ~17 microns**
  - **17 microns of dust in 1.7mm of ice is very clean: 1% by volume**
- **An upper limit as some darkening is due to…**
  - **Atmospheric dust fallout**
  - **Grain growth**

Similar fading of ice for all sites.

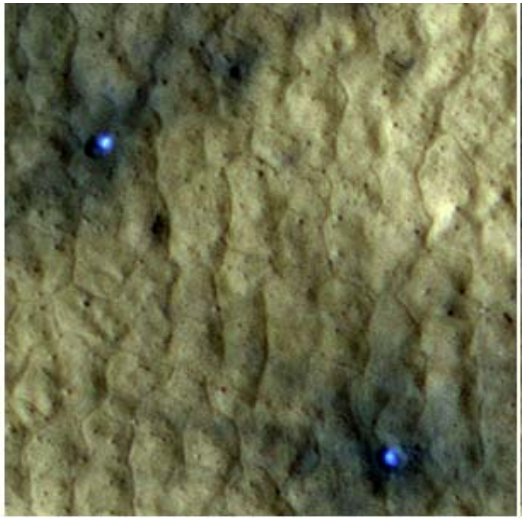
Site 3 (55N) substantially slower though (as one might expect)



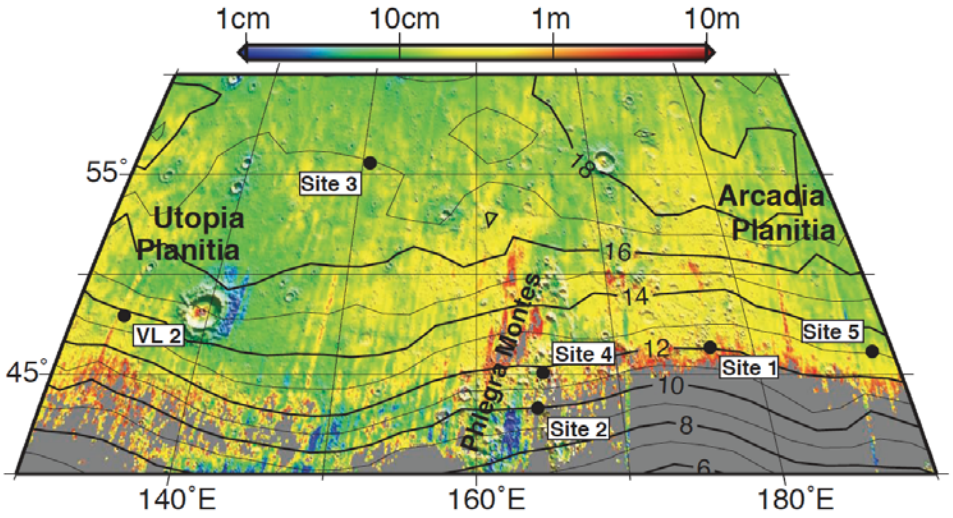
- Ground ice appears clean
  - Ice lenses from frost heave – liquid films?
  - Thermal contraction and vapor deposition

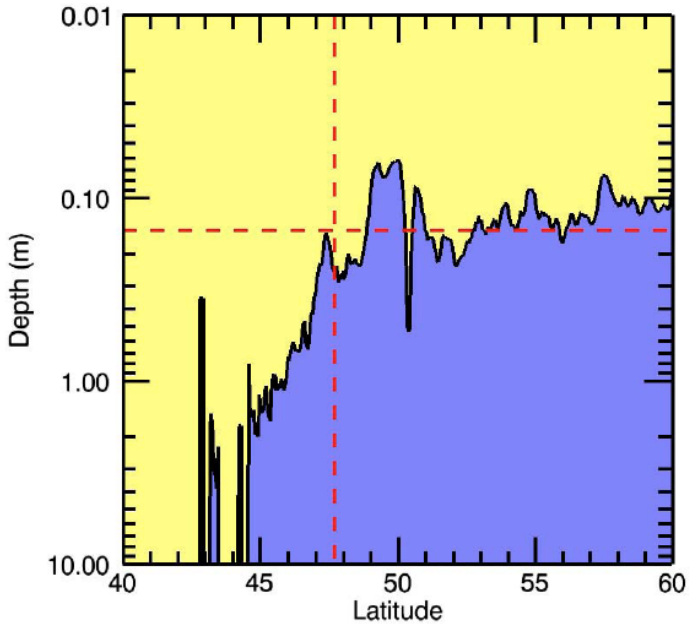


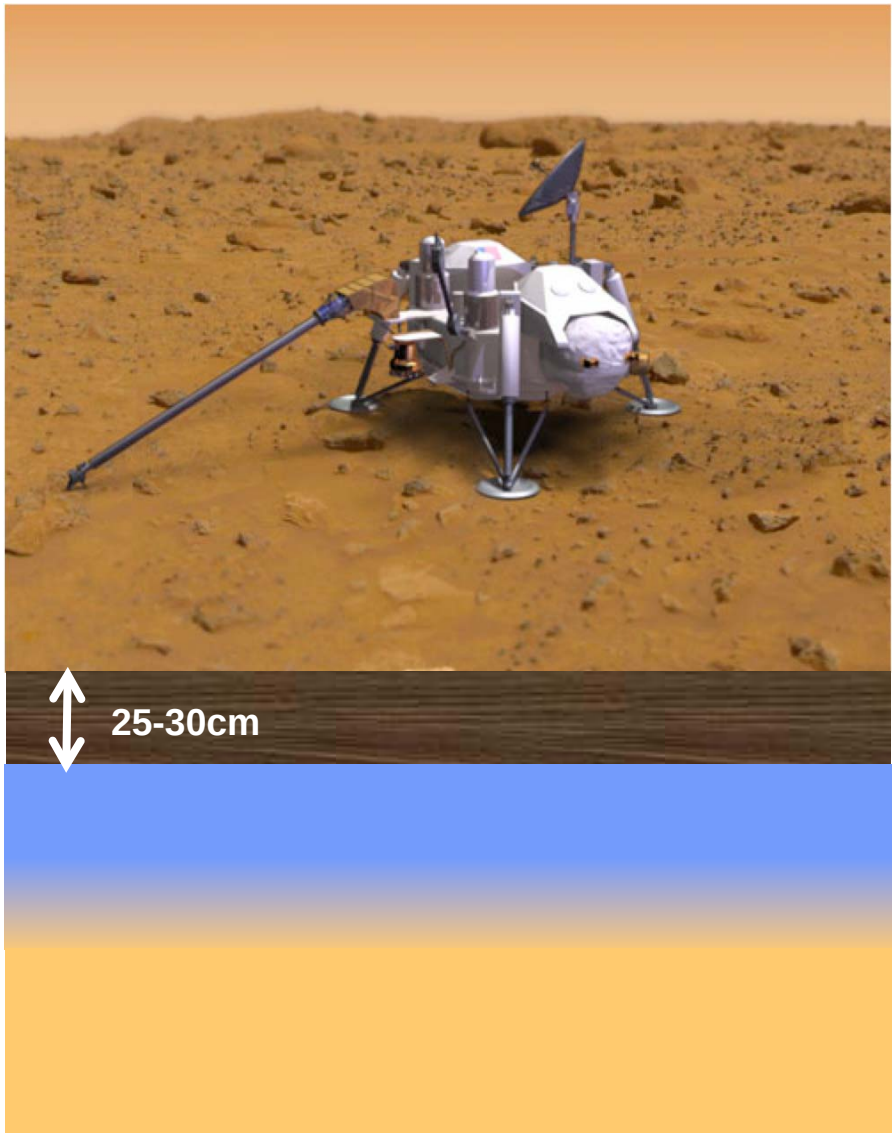
- Site 1 excavated to ice
- Sites 2-5 excavate through the ice
- Clean ice has finite thickness



- **Viking lander II – bummer…**
  - **Came close: 1976-1980**
  - **Dug to depths of ~15cm**







Conclusions

- Fresh craters have probed the extent and depth of ground ice on Mars
- Results are consistent with present models
  - With a wetter atmosphere than present
- Upper ice appears to be very clean
  - Clean ice appears restricted in thickness
- More of these constraints are inevitable – stay tuned for next northern summer