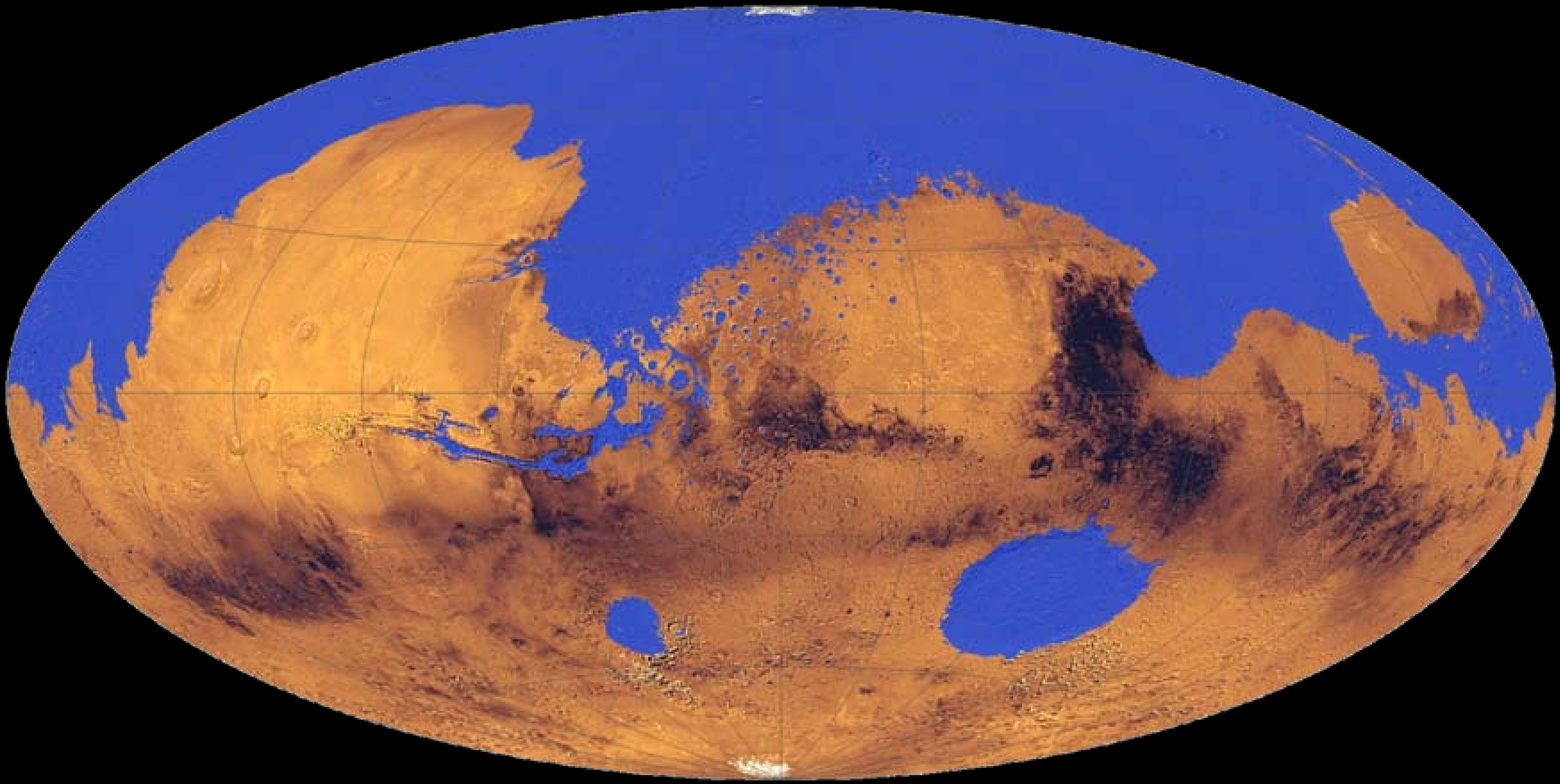
The History of Water on Mars: Synthesis of New Results from Valley Networks and Deltas



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Thanks to Collaborators:

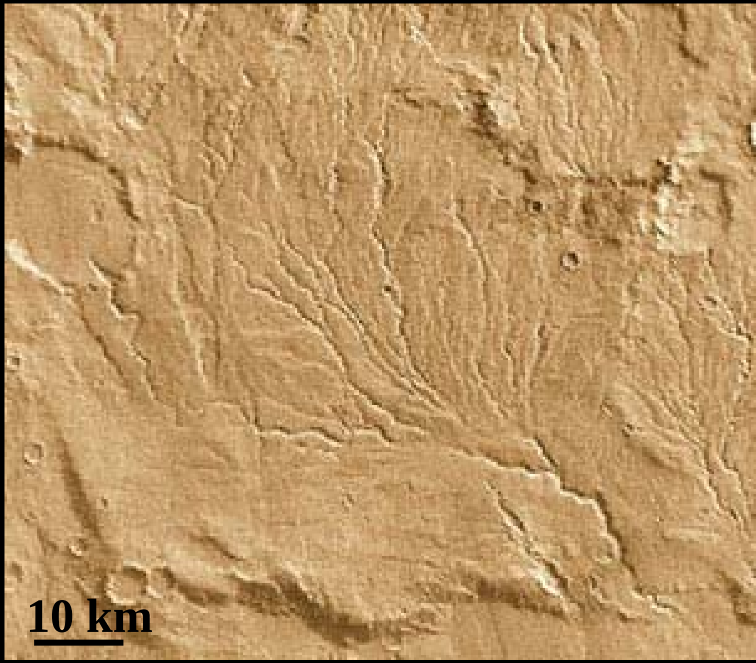
Monica Hoke, LASP
(valley network mapping, age-dating)

Gaetano Di Achille, LASP
(deltas, ocean)

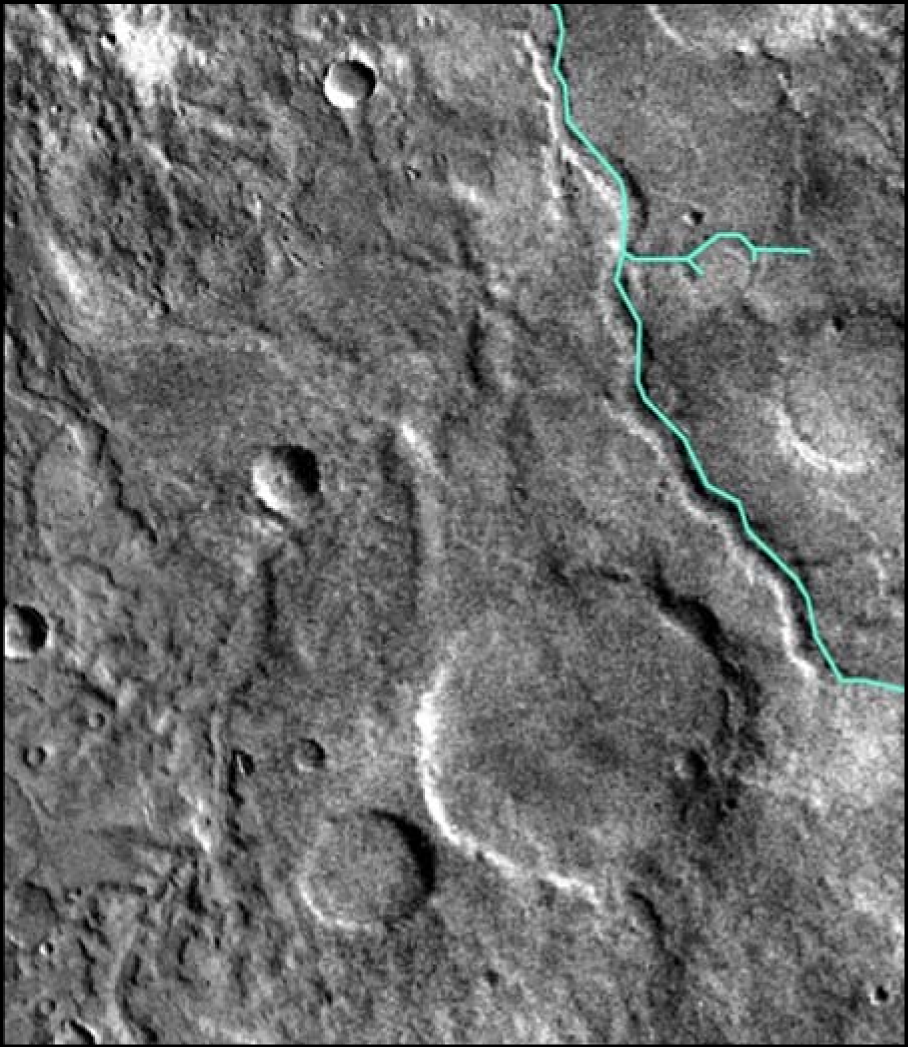
Martian Valley Networks

- The networks occur over much of the southern highlands and are generally thought to be ancient features (90% are >3.7 Ga).
  - a few dissect younger volcanoes

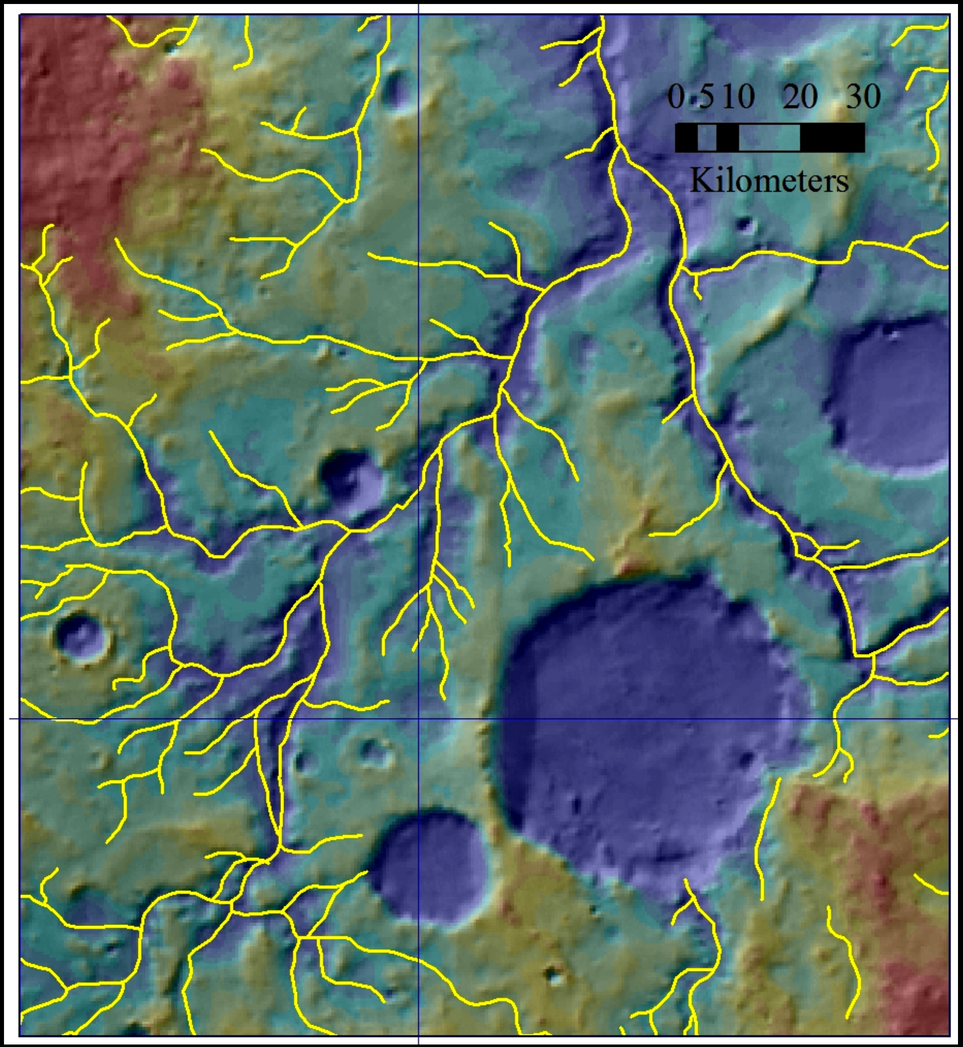
- They remain the best evidence for widespread liquid water at the Martian surface
  - groundwater vs. surface runoff



Comparison of Viking and MGS data

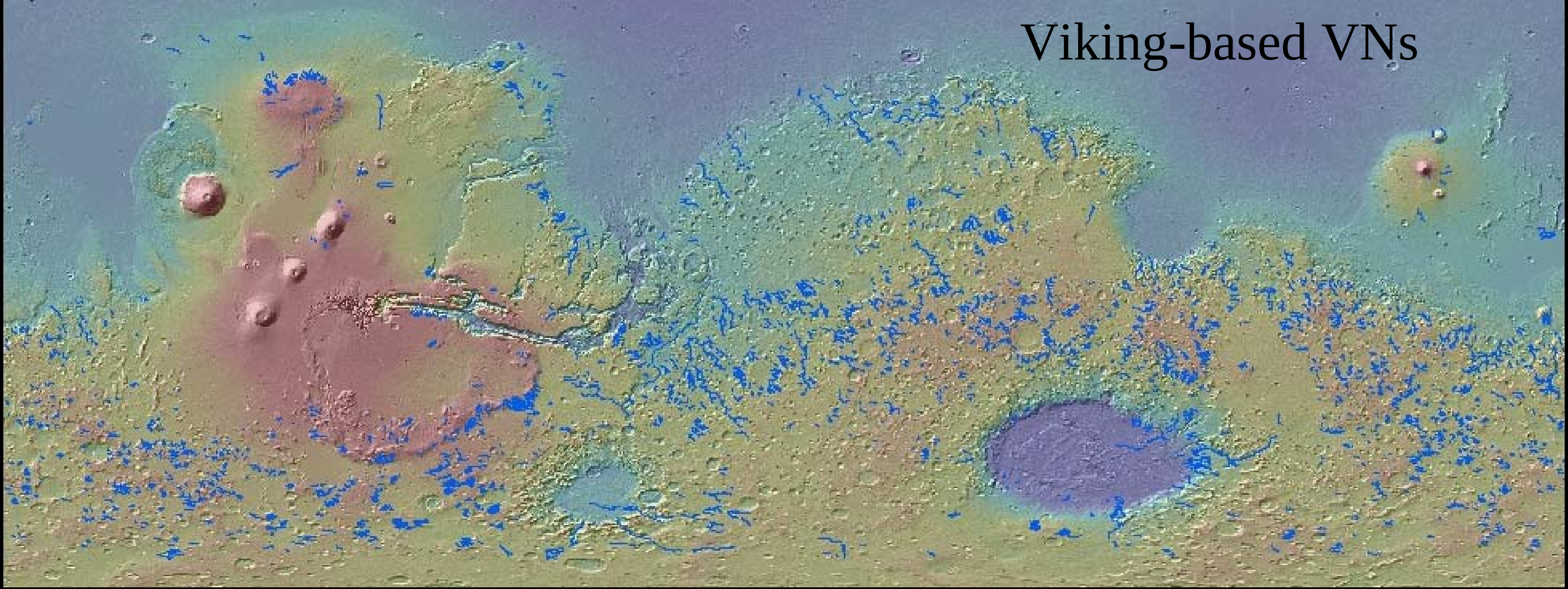


Viking MDIM and Carr VN

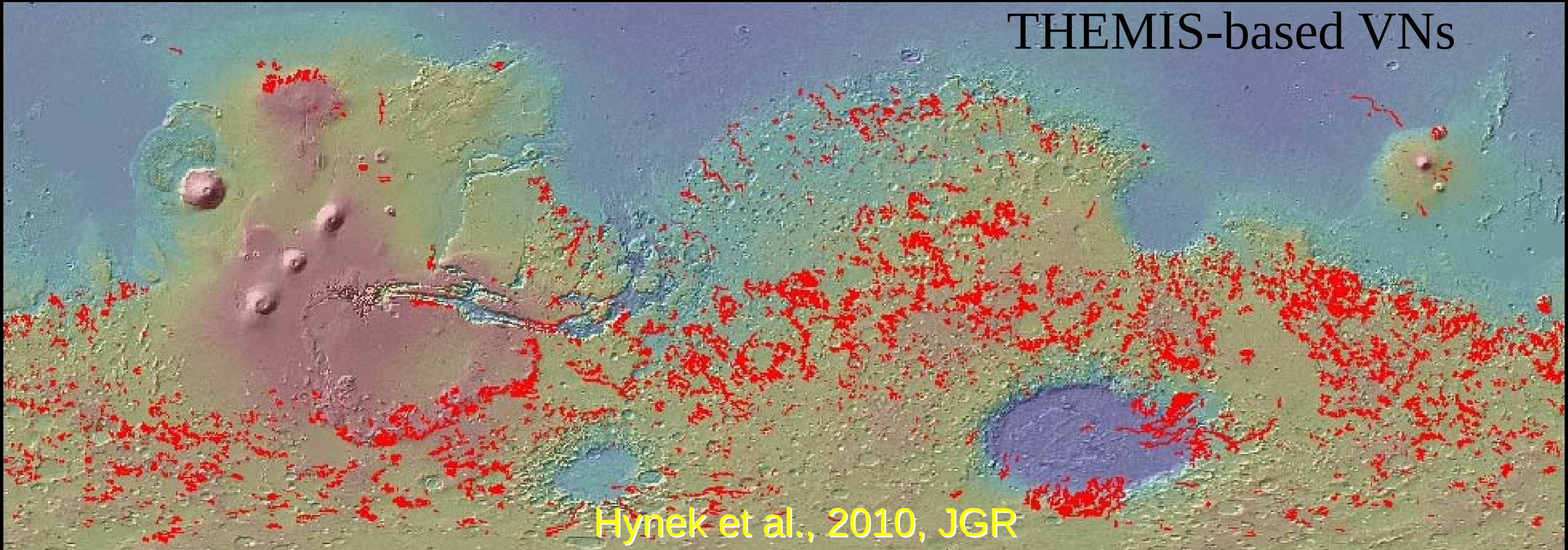


MGS data and newly recognized VN

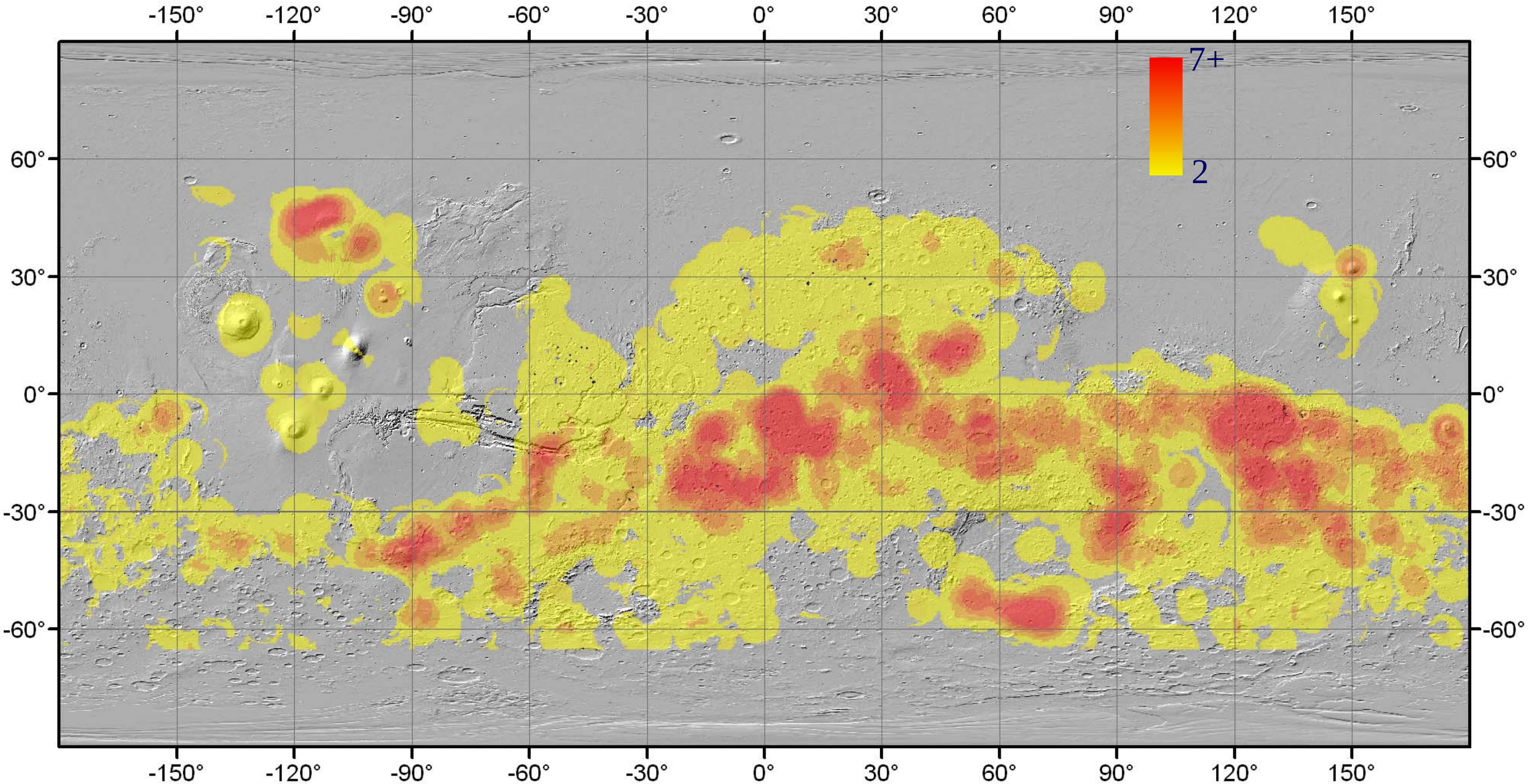
Hynek and Phillips, 2003, *Geology*



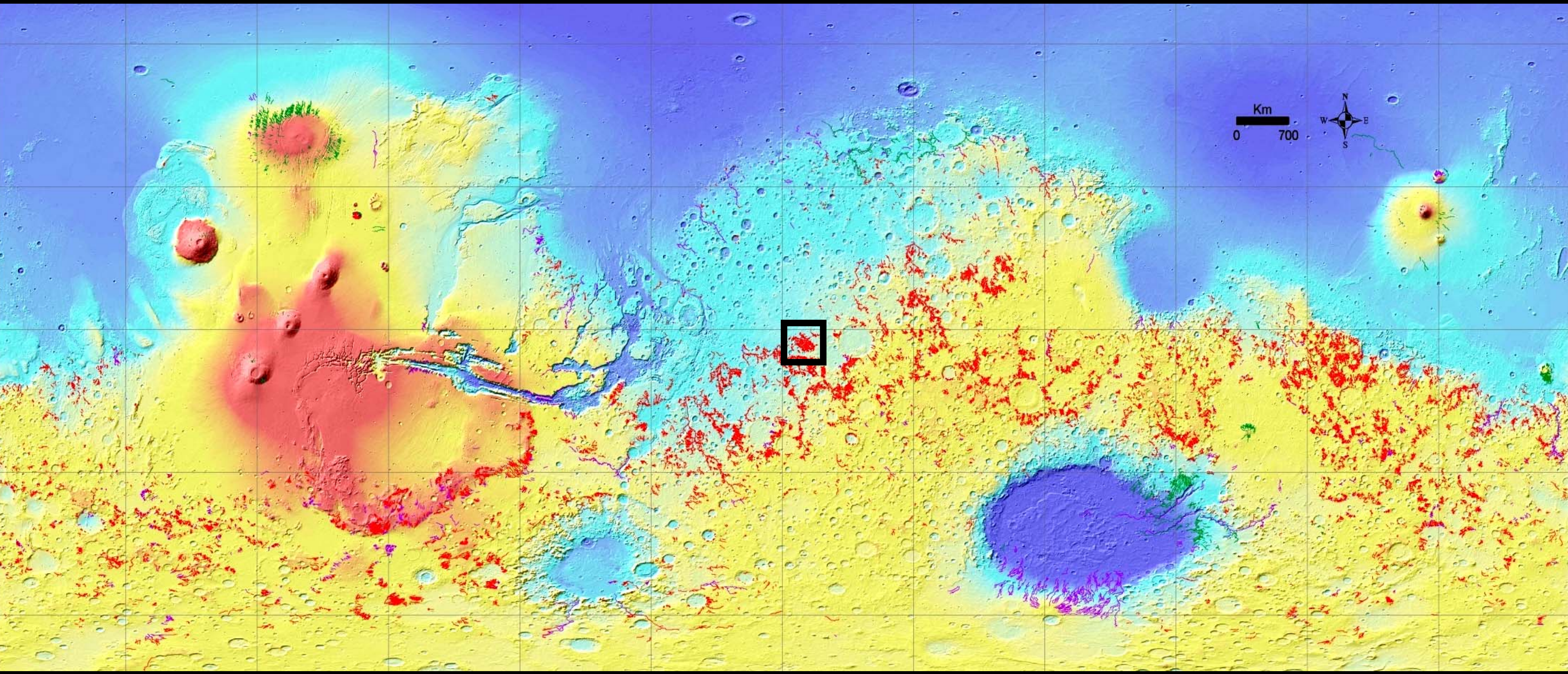
Approach: Manual Remapping of all valleys on Mars



Drainage density maps: Hynek - Carr

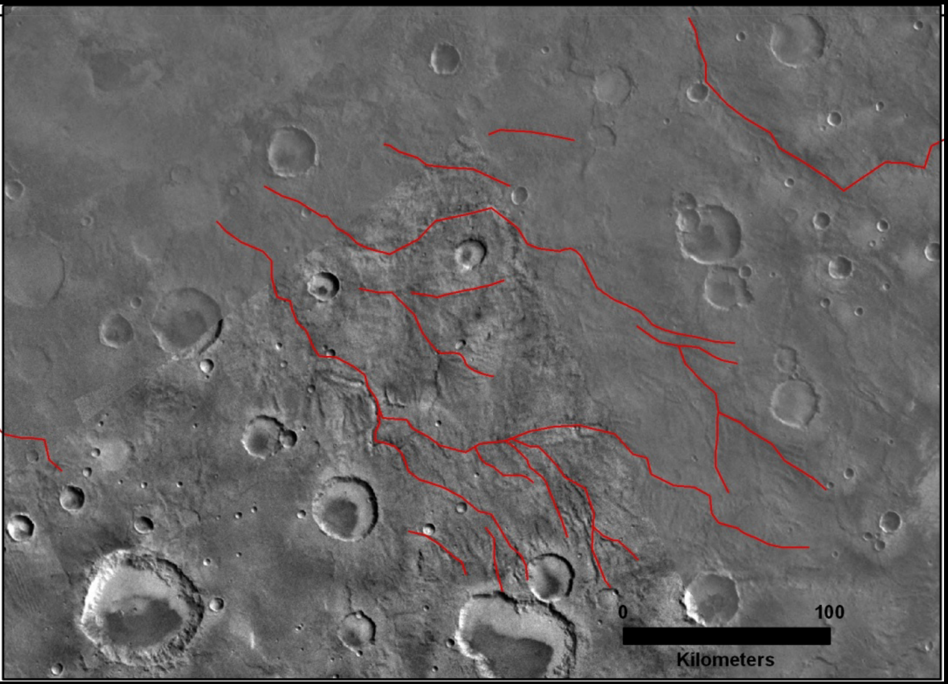


Increased density in nearly all locations;
generally by a factor of 2 to 10



South Meridiani Planum

Carr, 1995

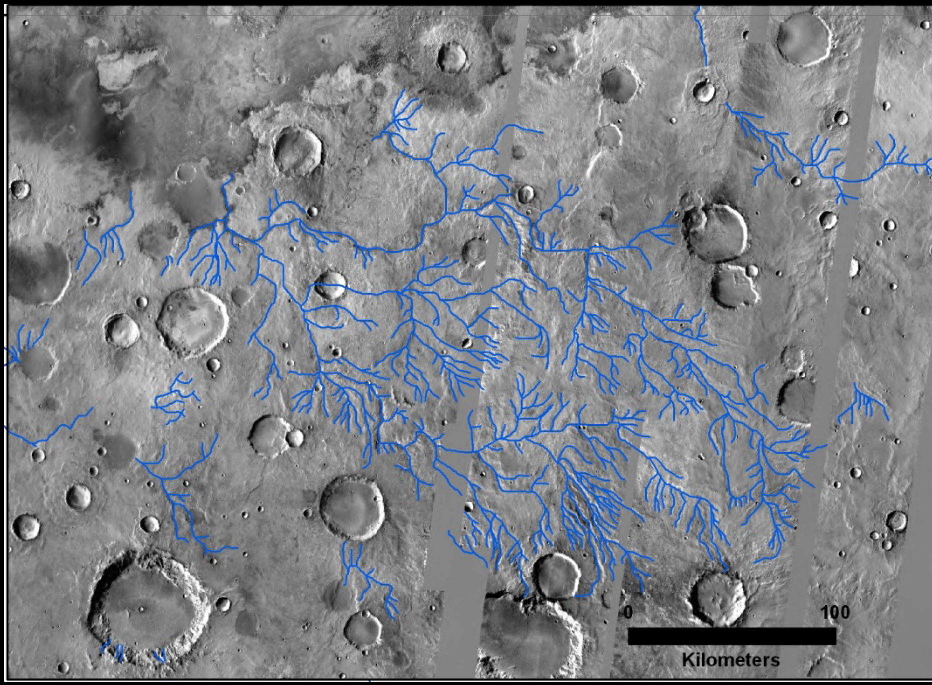


16 valley segments

1,492 km in total length

drainage density of 0.034 km^{-1}

this study

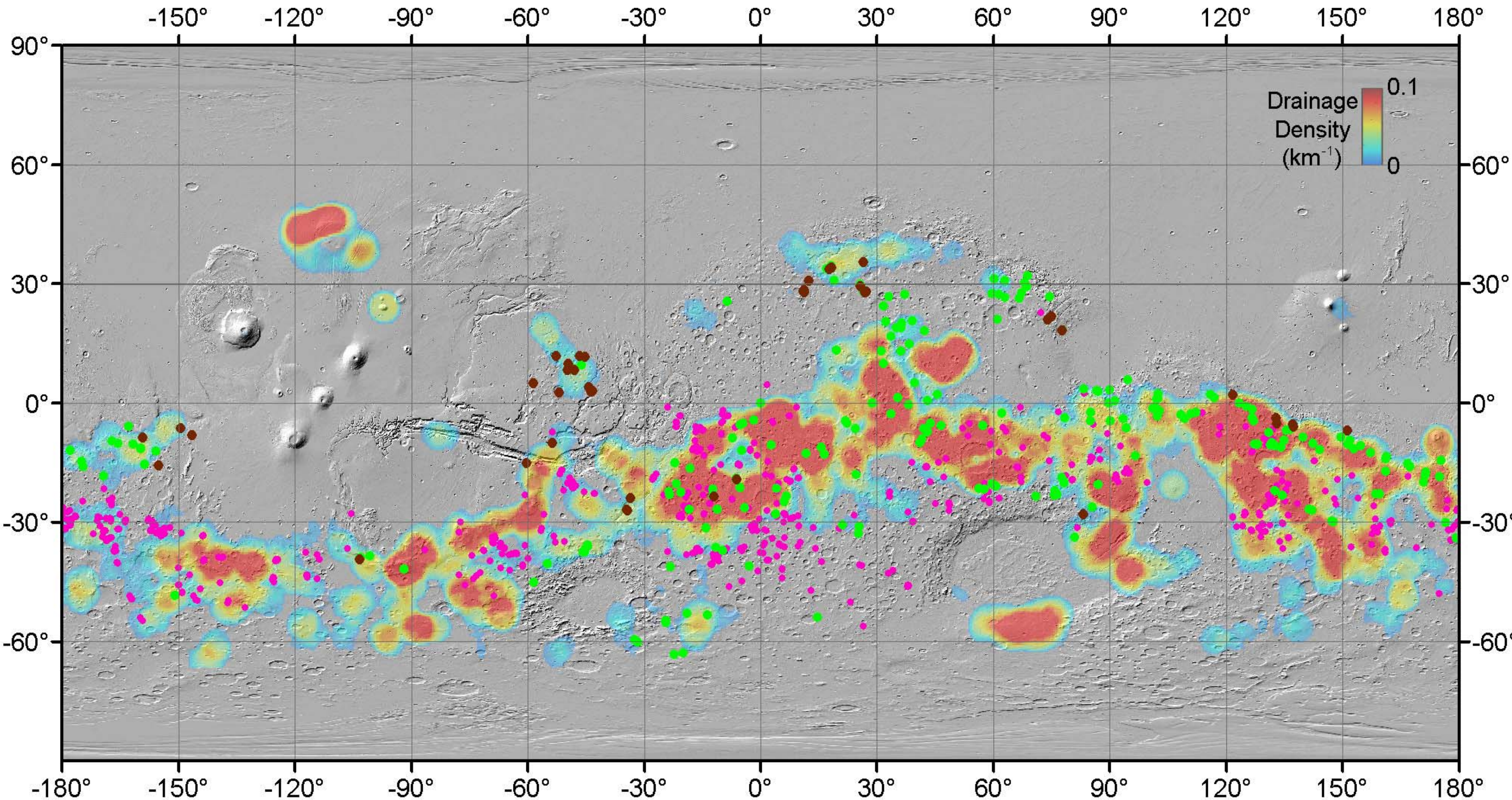


462 valley segments

6,031 km in total length

drainage density of 0.14 km^{-1}

Connection to Other Datasets



● paleolake basins

Fassett and Head, 2008

● deltas

Di Achille and Hynek, 2010

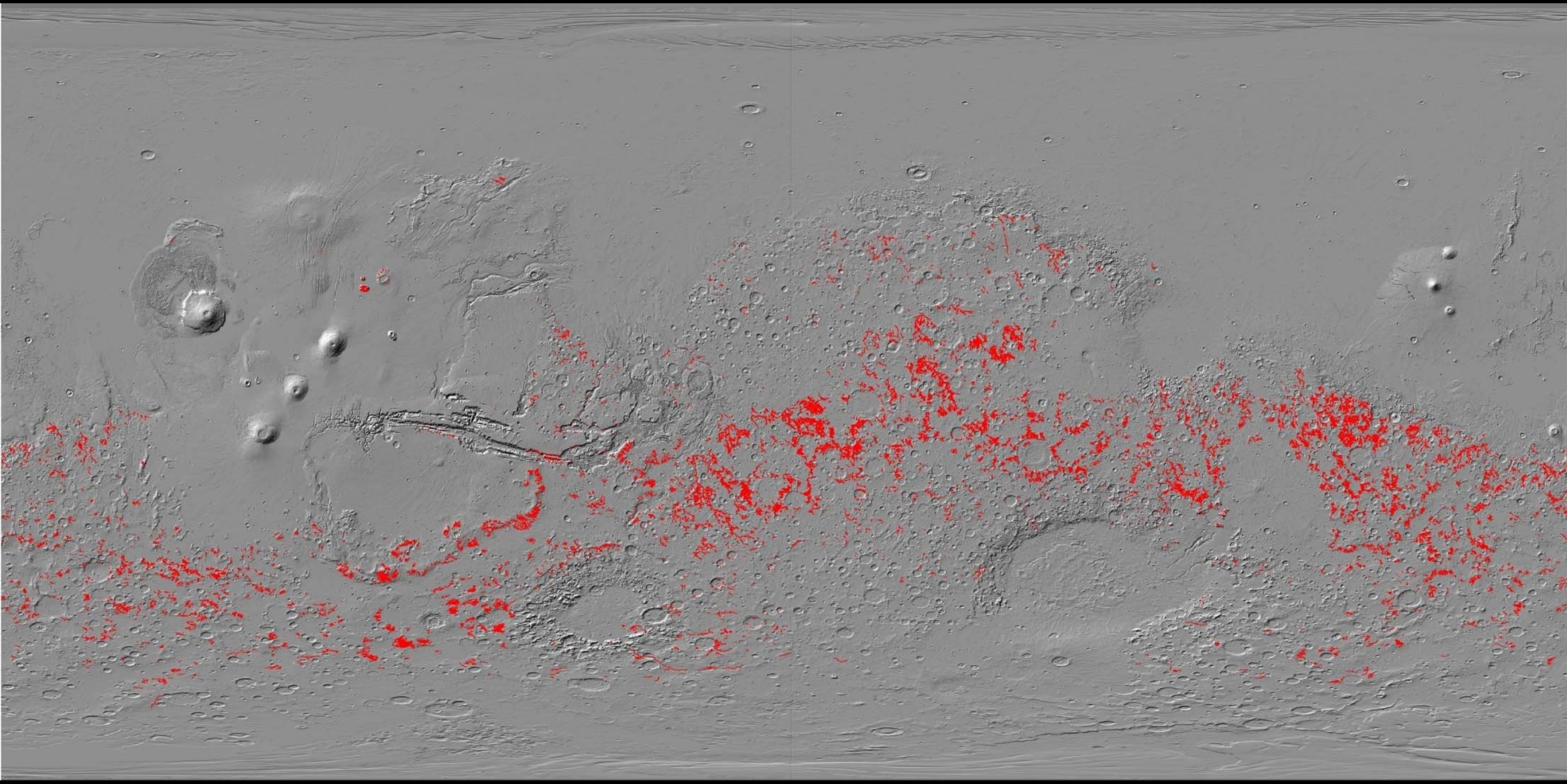
● chloride deposits

Osterloo et al., 2010

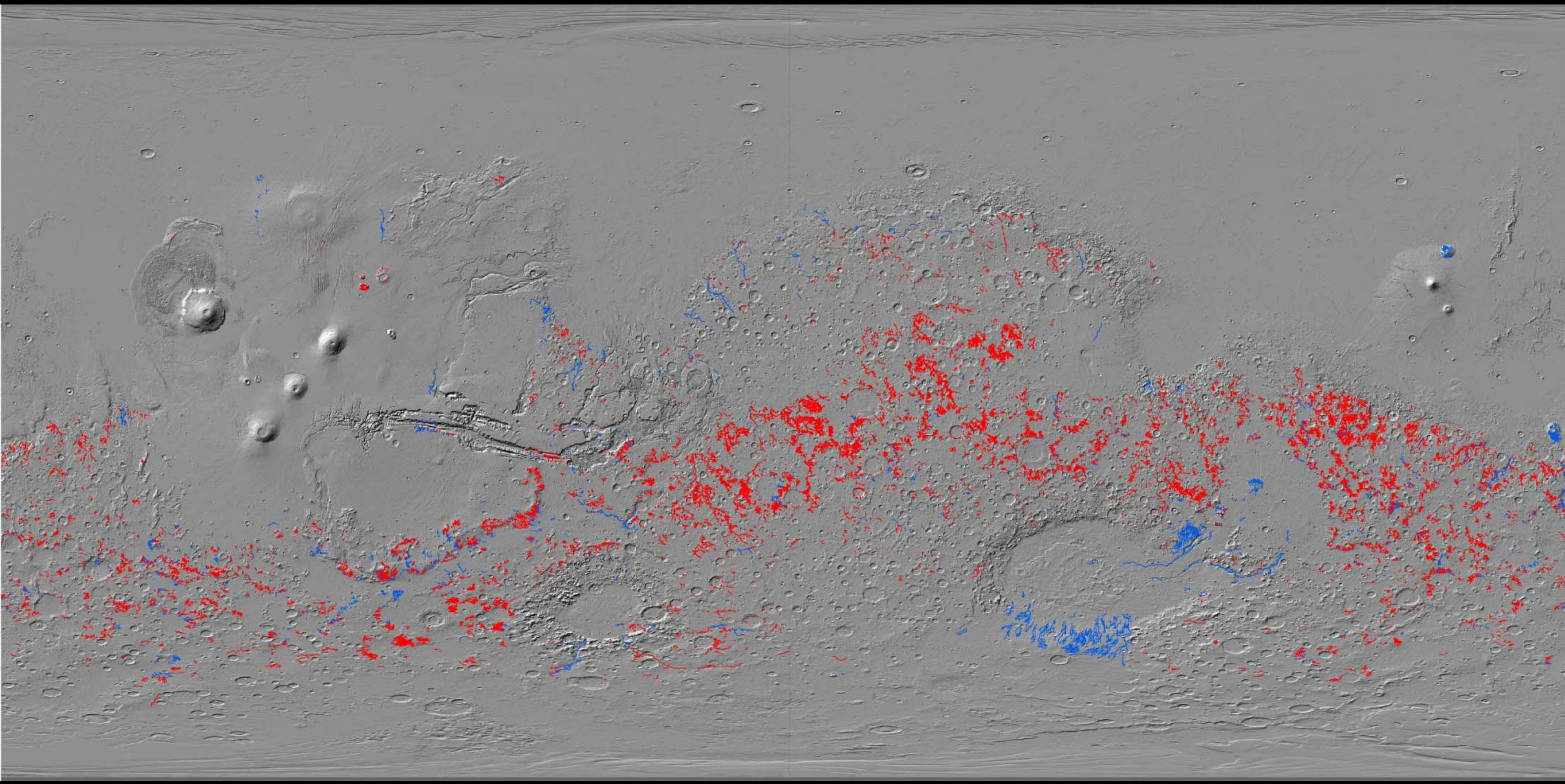
	Carr, 1995	This study
# valley segments	11,336	81,227
total length (km)	398,935	797,083
highest stream order	4	7
highest network drainage density (length/area)	0.009 km^{-1}	0.16 km^{-1}
age breakdown	N H A 90%, 5%, 5%	N H A 90%, 6%, 4%
Noachian units' avg. drainage density	0.0041 km^{-1}	0.015 km^{-1}

Valley Network Age Distribution

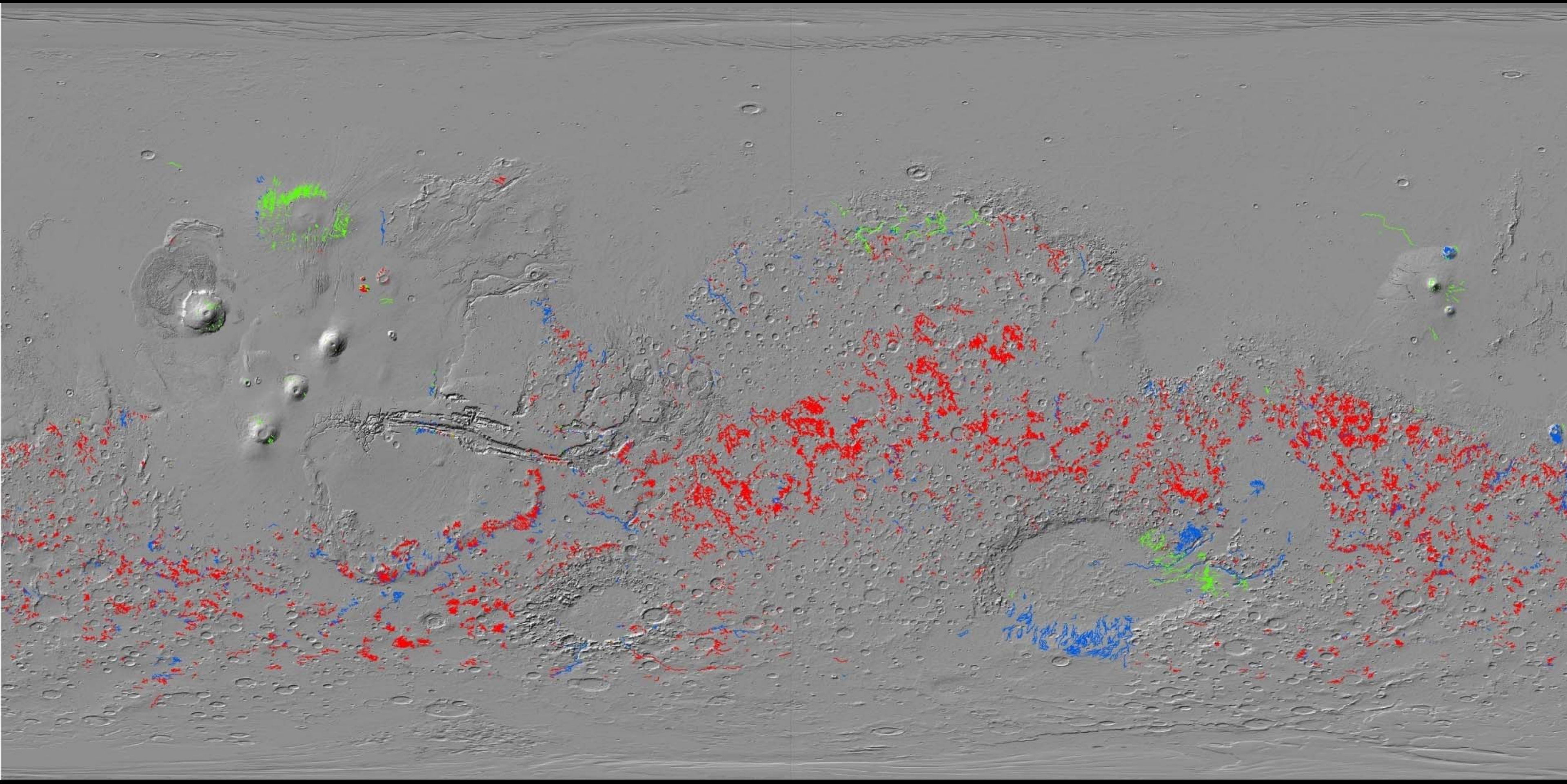
Noachian (>3.7 Ga)



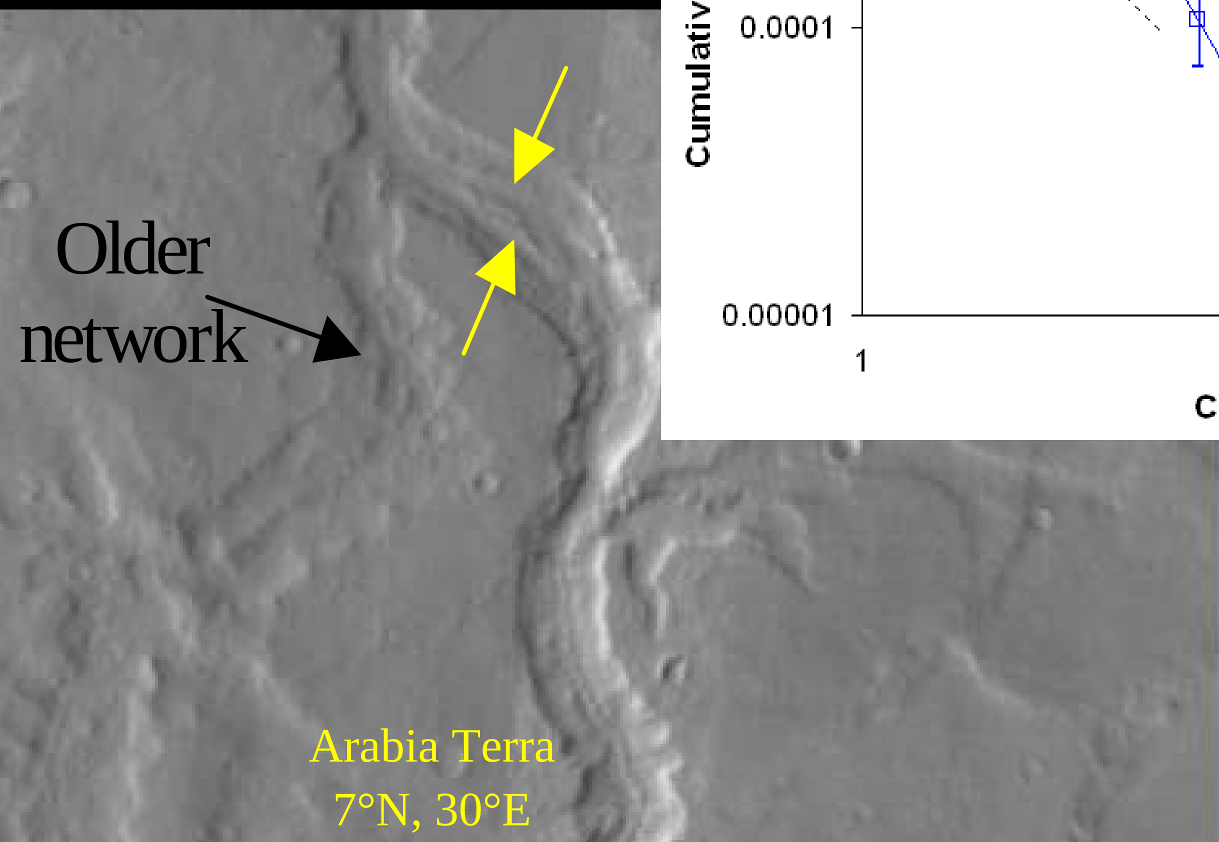
Noachian + Hesperian (3.0-3.7 Ga)

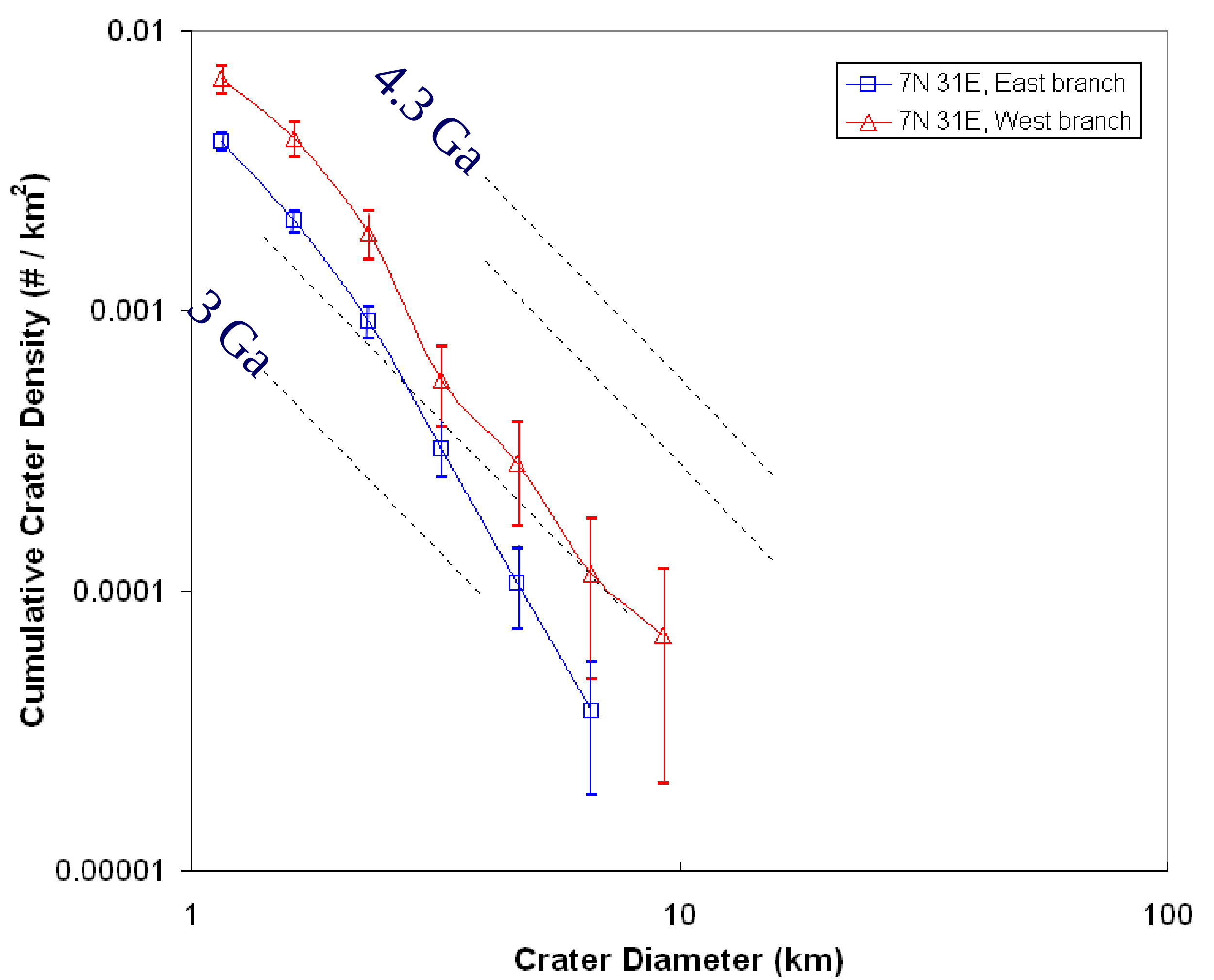


Noachian + Hesperian + Amazonian (<3 Ga)



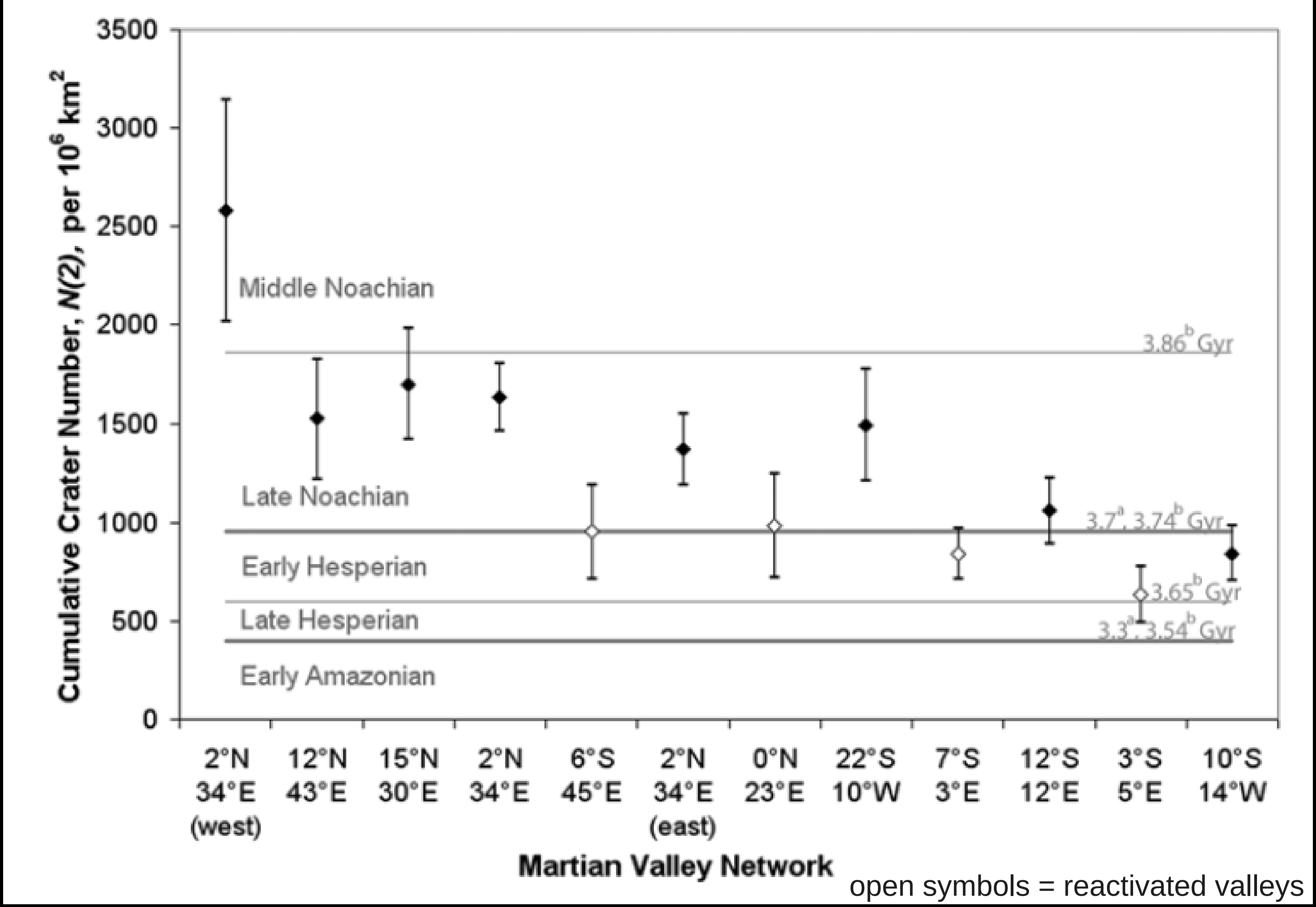
Valley network ages reveal differences!





Roughly 120 m.y. passed between fluvial episodes

Hoke and Hynek, 2009, JGR



Most larger valleys formed between 3.80-3.65 Ga ago

(after large impacts had formed)

Valley Network Formation Timescales*

1) Determine flow velocity from measurements of valley dimensions, slope, and other factors

Flow Velocity

Darcy-Weisbach depth- and width-averaged flow velocity

$$u = \sqrt{\frac{8ghS}{f}}$$

Friction function [10]

$$\sqrt{\frac{8}{f}} = 2.2\left(\frac{h}{D_{50}}\right)^{-0.055} S^{-0.275}$$

Settling velocity [13]

$$w_s = \frac{\nu}{D_{50}}\left(\sqrt{10.36^2 + 1.049 D^{*3}} - 10.36\right) \qquad D^* = D_{50}\left(\frac{Rg}{\nu^2}\right)^{1/3}$$

2) Plug into physically-based sediment transport models

Sediment Transport Models

Bagnold [7]

$$q_b = (\omega - \omega_0)^{3/2}\left(\frac{D_{50}^{1/4}}{h}\right)\left(\frac{1}{\rho^{1/2} g^{1/4}}\right)$$

$$\omega_0 = 5.75\left[0.055(\rho_s - \rho)\right]^{3/2}\left(\frac{g}{\rho}\right)^{1/2} D_{50}^{3/2} \log\left(\frac{12h}{D_{50}}\right)$$

Ribberink [8]

$$\phi_b = 11(\theta' - \theta_{cr})^{1.65} \qquad \theta = \frac{\tau}{(\rho_s - \rho_w) g D_{50}}$$

van Rijn [9]

$$q_b = 0.015 \rho_s u h \left(\frac{D_{50}}{h}\right)^{1.2} M_e^{1.5}$$

$$M_e = \frac{(u_e - u_{cr})}{\sqrt{(s-1) g D_{50}}}$$

$$u_e = u + \gamma U_w$$

$$u_{cr} = \beta u_{cr,c} + (1-\beta) u_{cr,w} \qquad \beta = u/(u + U_w)$$

$$u_{cr,c} = 8.5 * 0.62 * D_{50}^{0.6} \log(12h/3D_{90})$$

3) Calculate sediment discharge and use actual sediment volumes to infer formation time and precipitation rates.

Precipitation Rate

$$P = \frac{Q}{A} = \frac{whu}{A}$$

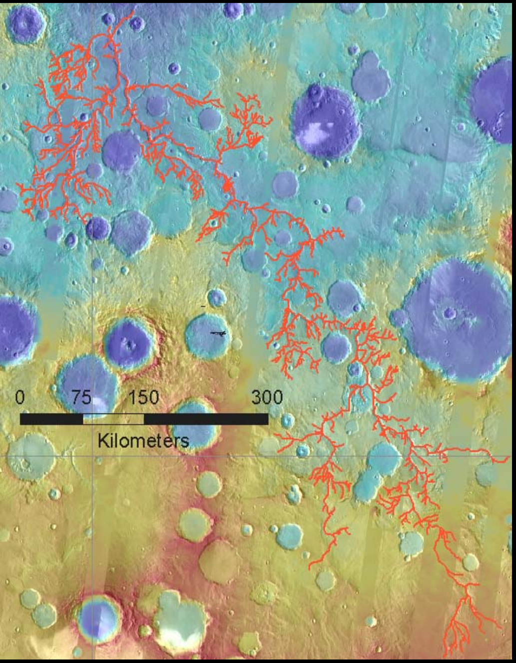
Sediment Discharge

$$Q_s = (q_b + q_s) w$$

Formation Timescale [10]

$$T_s = \frac{V_s}{(1-\lambda) Q_s}$$

* Following pioneering work by Maarten Kleinhans



Naktong Valles

Network Volume = 8.0×10^{12} m^3

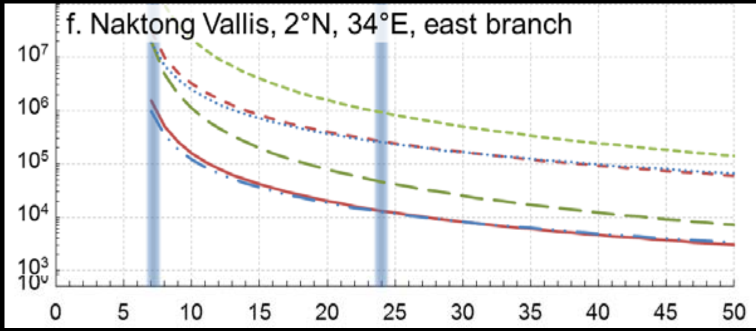
Channel slope = 0.0015 m/m

Channel width = 1400 m

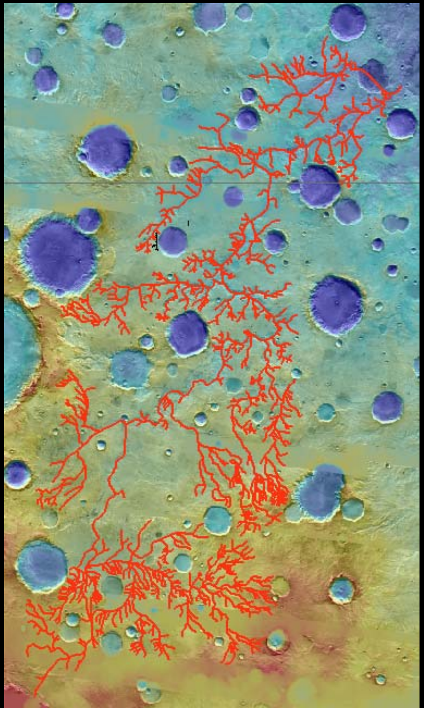
Crater Age = 3.70 Ga

Flow depth	11 m	35 m
Flow velocity	2.5 m/s	4.2 m/s
Sediment flux (Qs)	4×10^2 m^3/s	6×10^3 m^3/s
Precipitation rate	0.0062 mm/hr	3.4 mm/hr

Formation Times



Likely took 10^5-10^7 years to form



7°S, 3°E

Network Volume = 7.0×10^{11} m^3

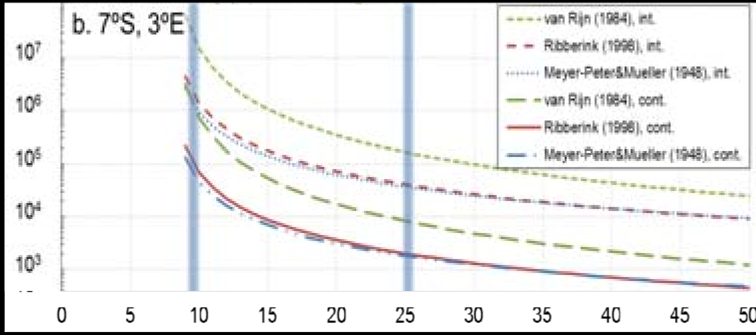
Channel slope = 0.0041 m/m

Channel width = 1460 m

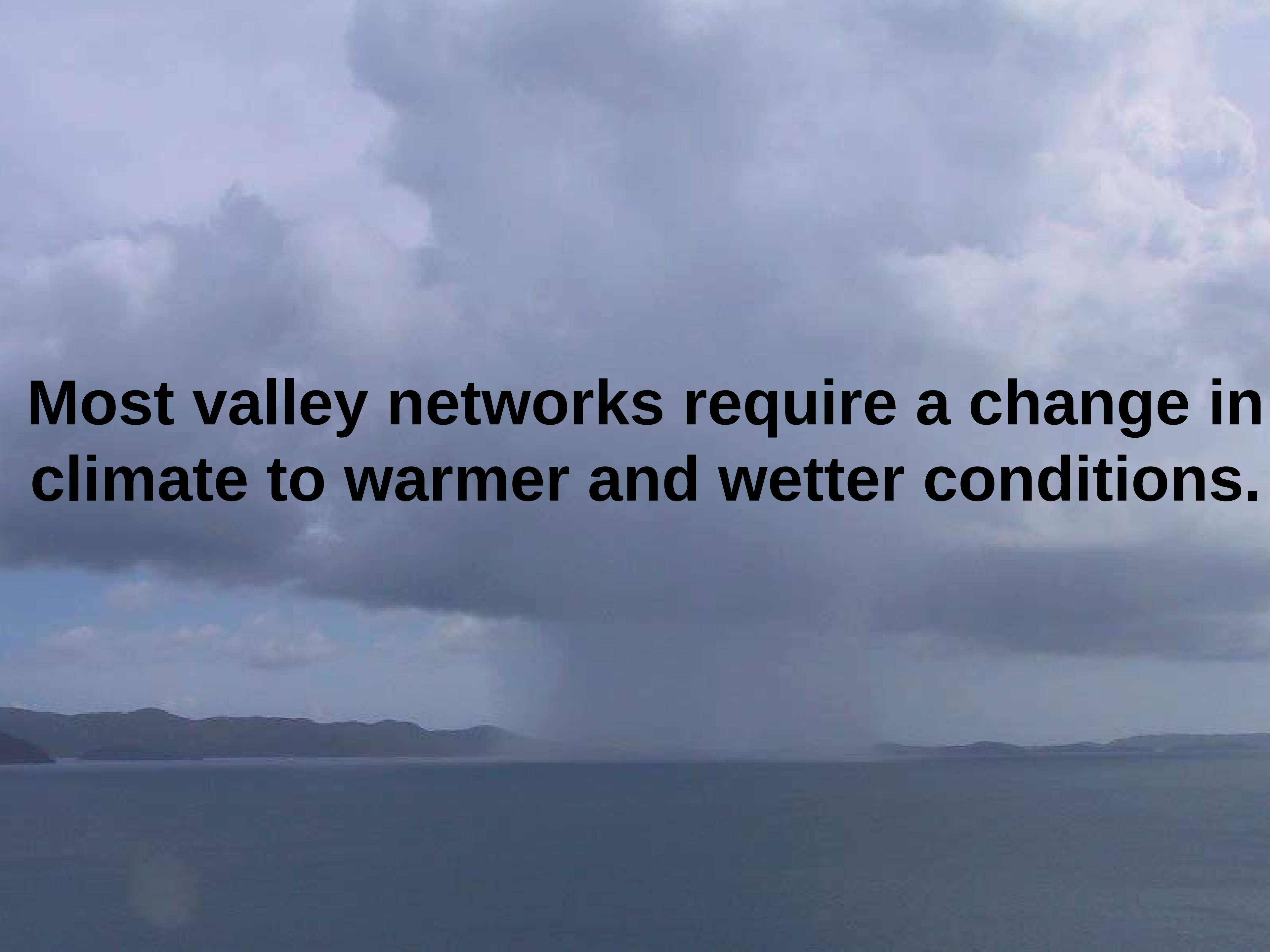
Crater Age = 3.65 Ga

Flow depth	10 m	25 m
Flow velocity	3.0 m/s	4.5 m/s
Sediment flux (Qs)	5×10^3 m^3/s	2×10^4 m^3/s
Precipitation rate	1.1 mm/hr	4.0 mm/hr

Formation Times

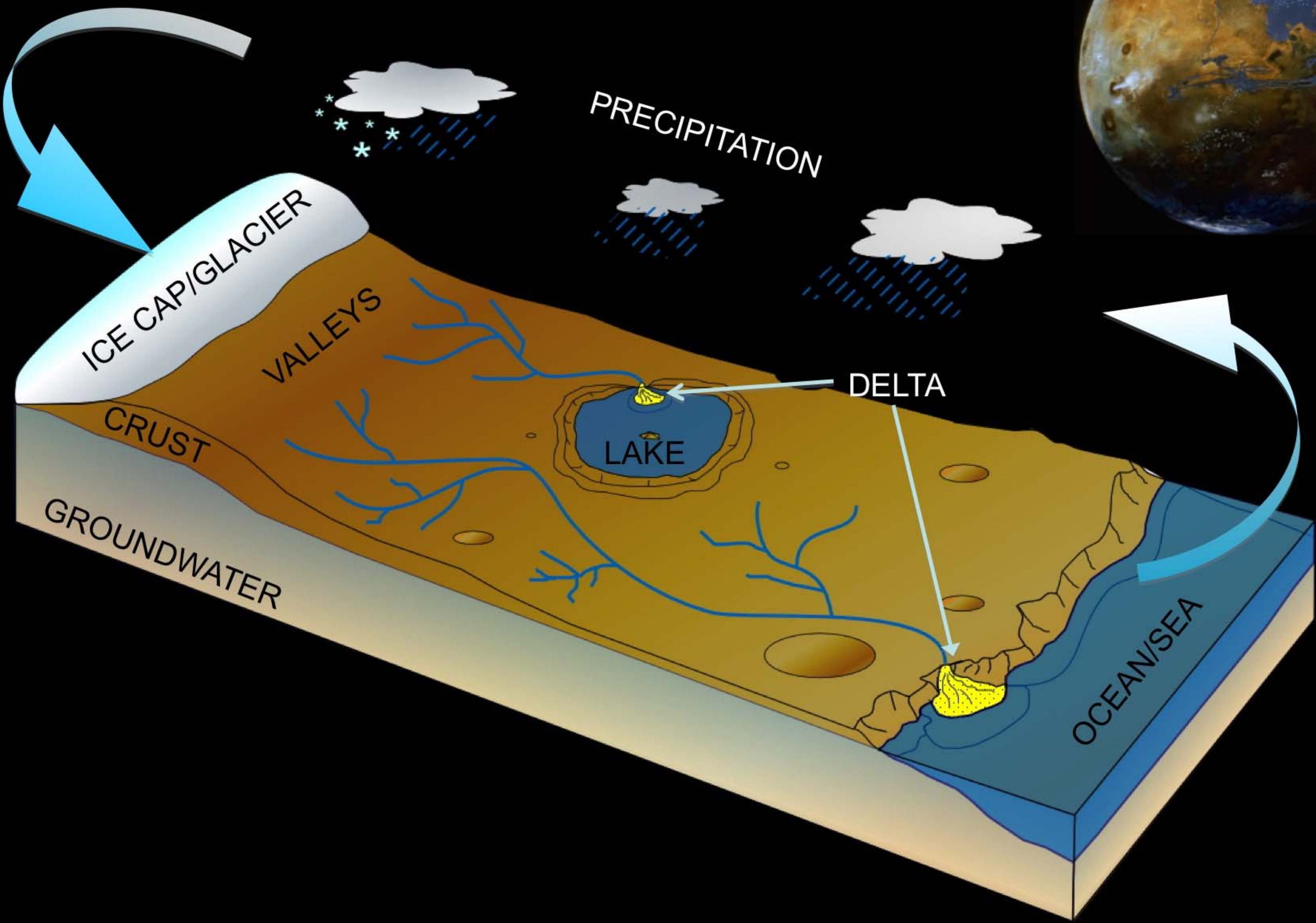


Likely took 10^4-10^6 years to form



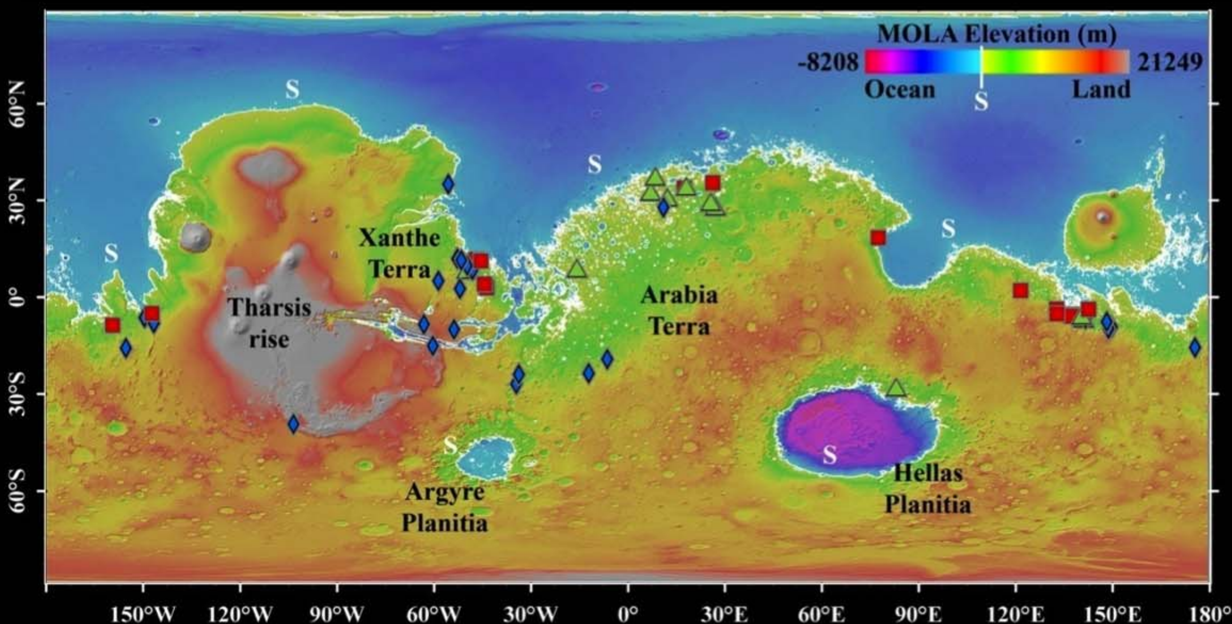
Most valley networks require a change in climate to warmer and wetter conditions.

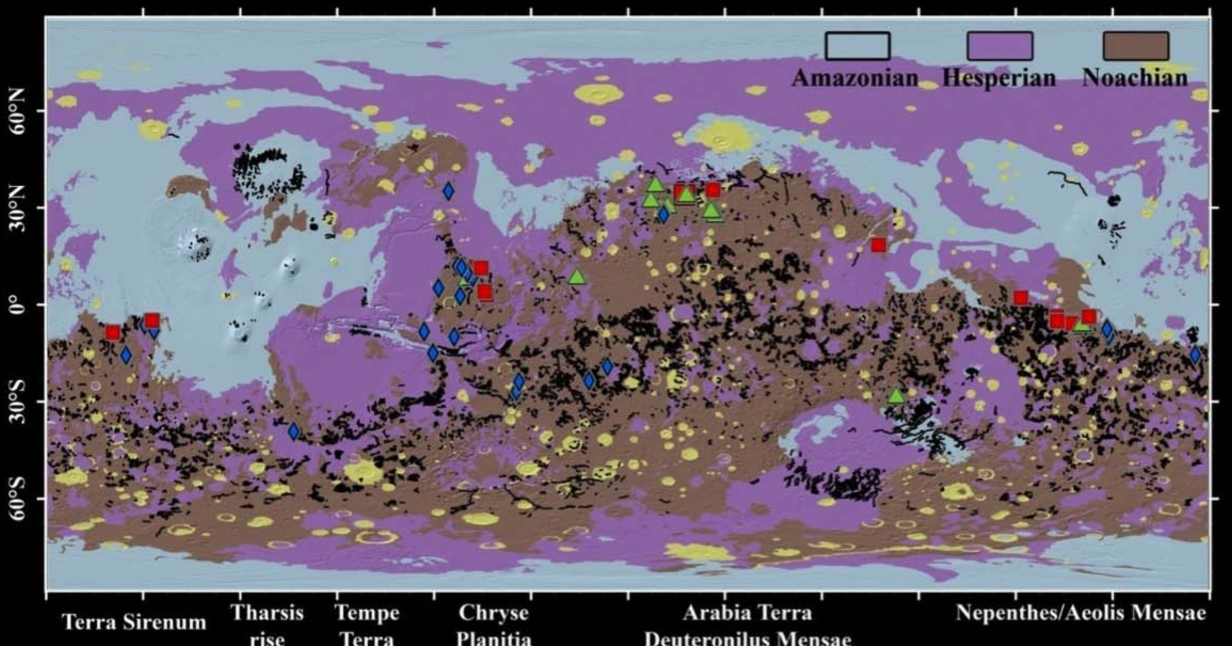
Did early Mars have a global hydrosphere?




Globe courtesy : **M. Carroll**

A possible test for the martian hydrosphere: Rationale (1/2)





We use global distribution of currently known

- **martian deltas**

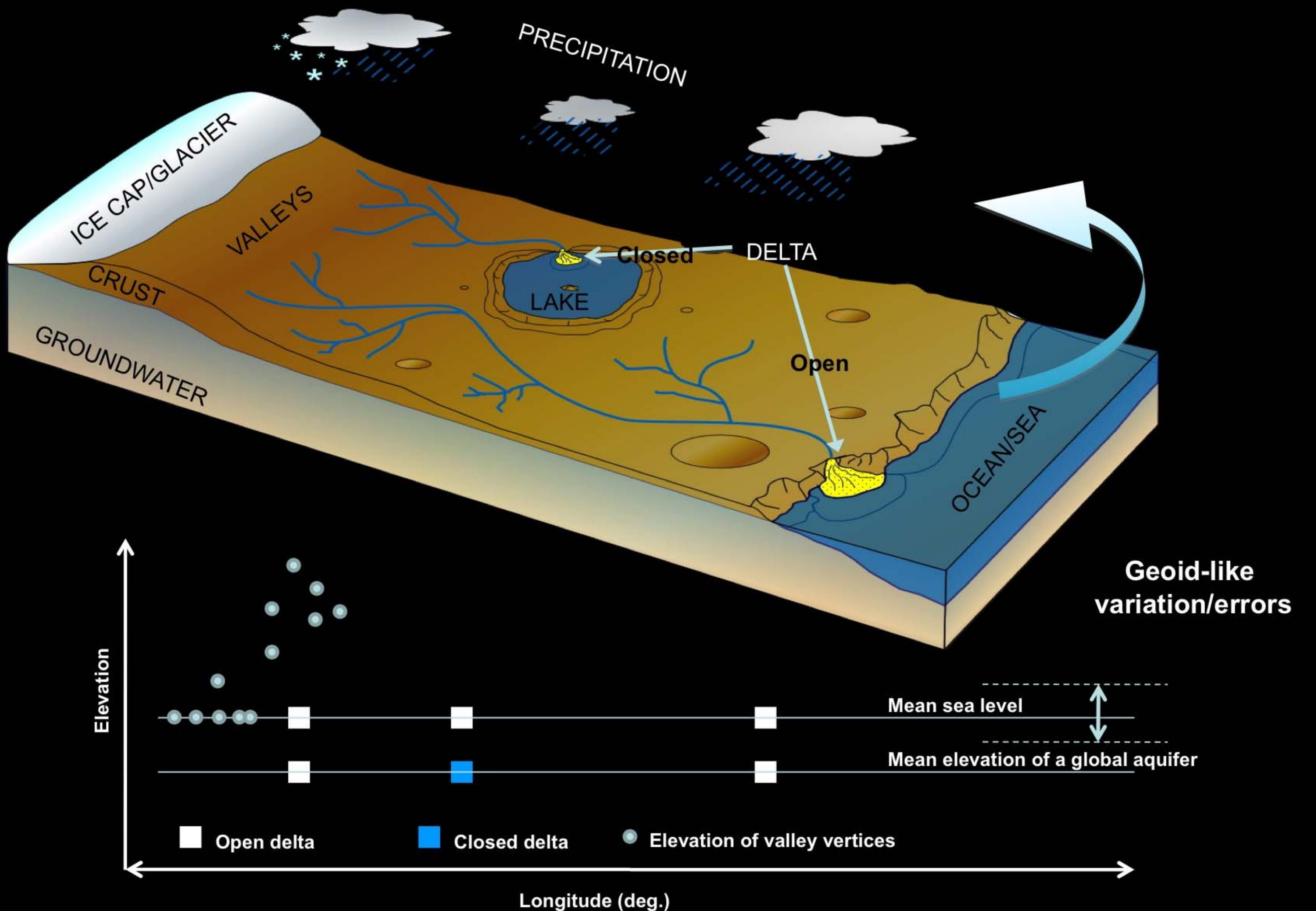
and

- **valley networks** (from Hynek et al., 2010)

in conjunction with

- **MOLA** data and all available **imagery**

A possible test for the martian hydrosphere: Rationale (2/2)



Data: Deltas

Database compiled from

- Literature

• Cabrol and Grin, 1999 (179 paleolakes)
• Ori et al, 2000
• Irwin et al. 2005 (**33 deltas**)

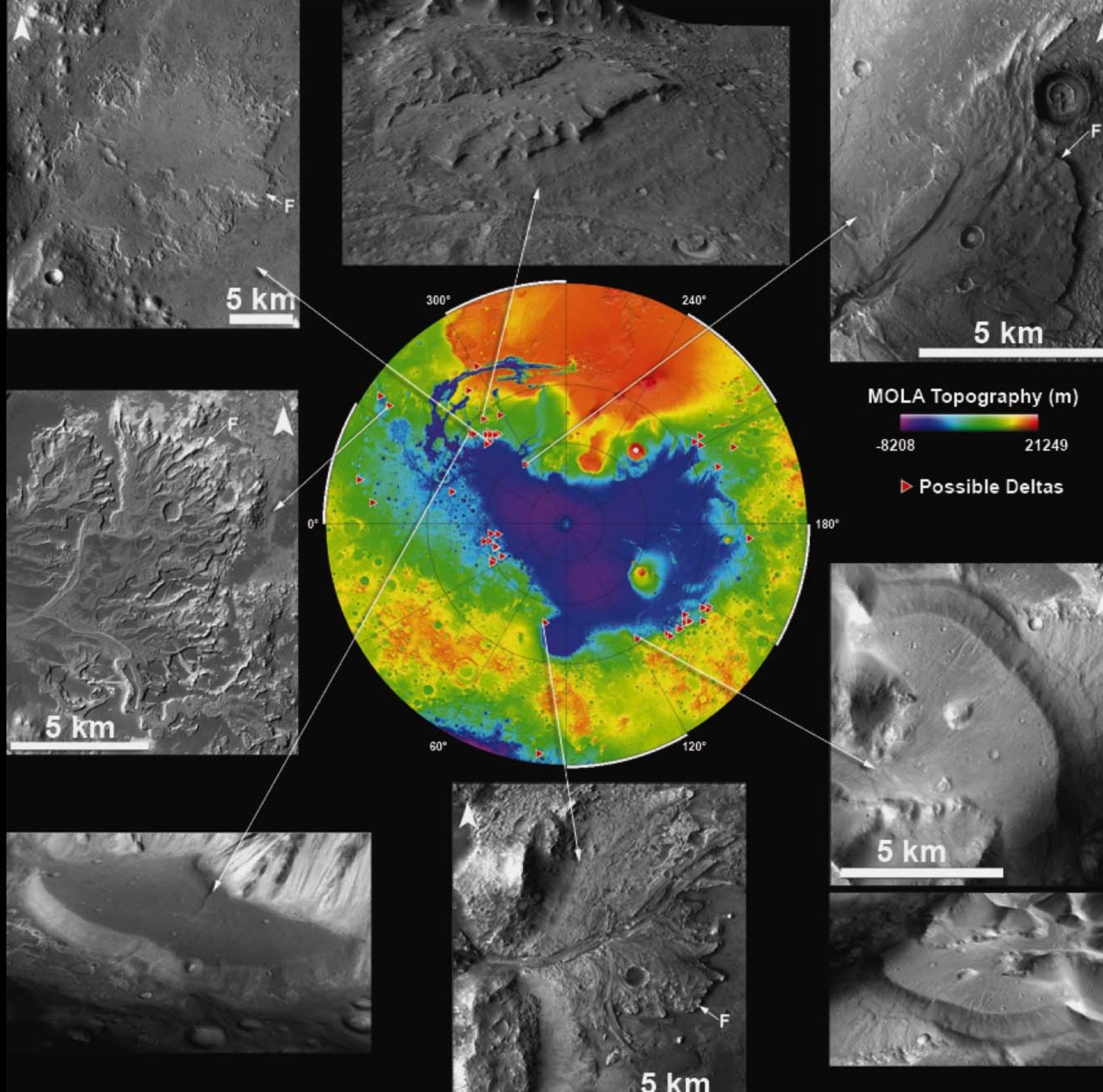
- Updates from HRSC:

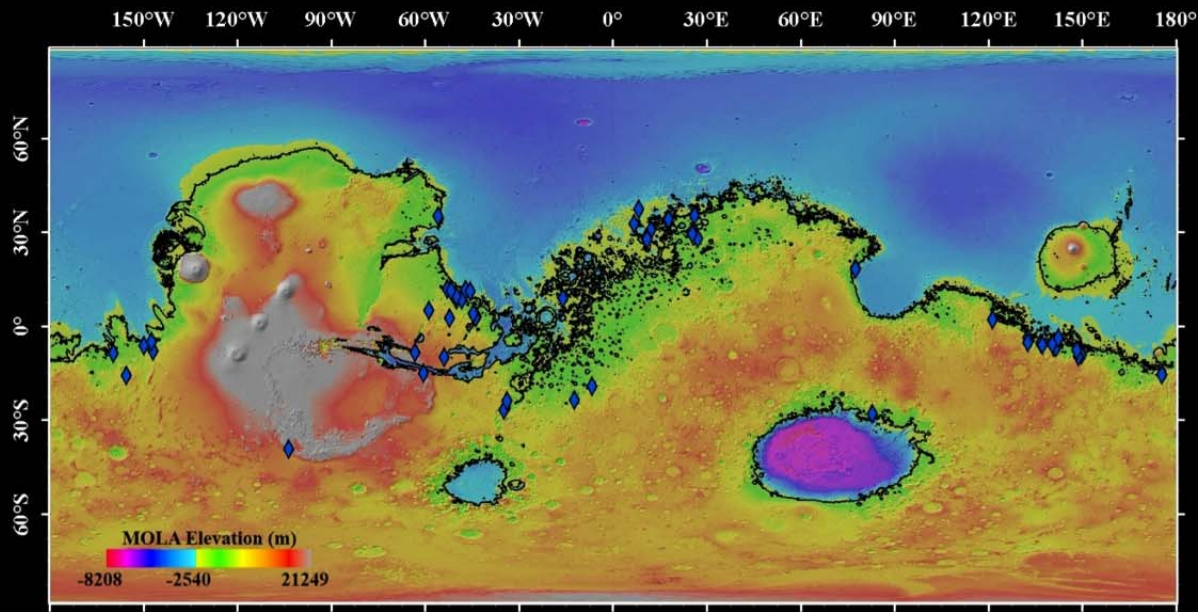
• Di Achille et al. 2006 and 2007
• Hauber et al., 2009

- Continuing survey

• a few previously unreported candidates

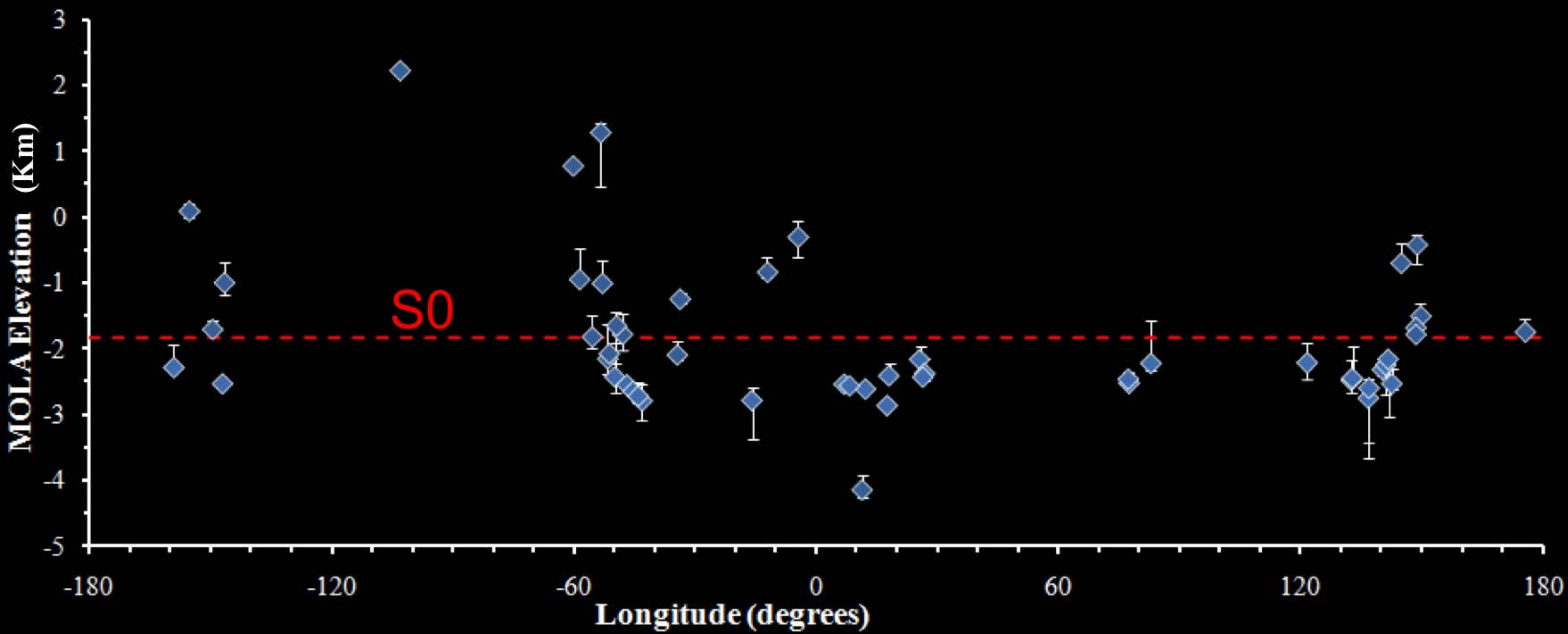
TOTAL of **52** possible deltas



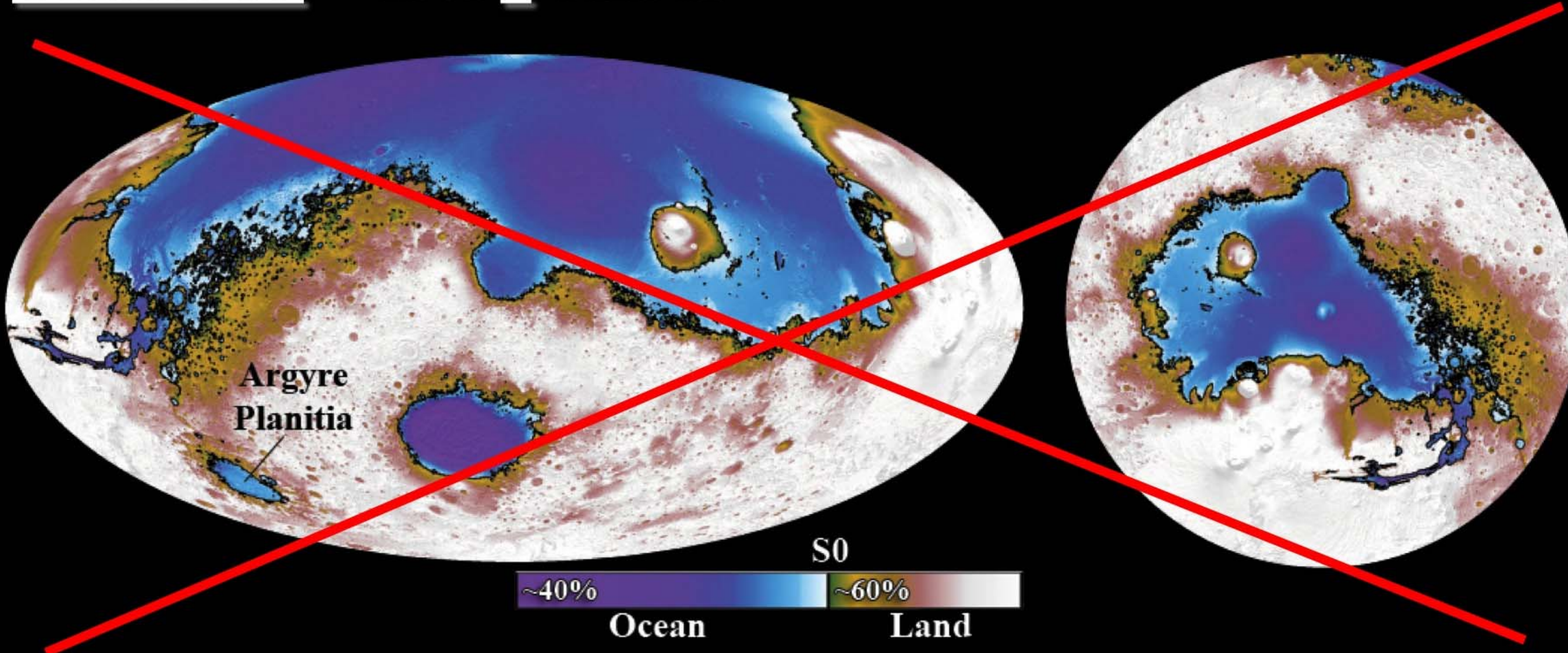


The highstand levels of **all** the **52** deltaic deposits show a mean value of about -1848 m with a standard deviation of 1126 m

S0 -1848 ± 1126 m



Contact S0 = -1848 ± 1126 m

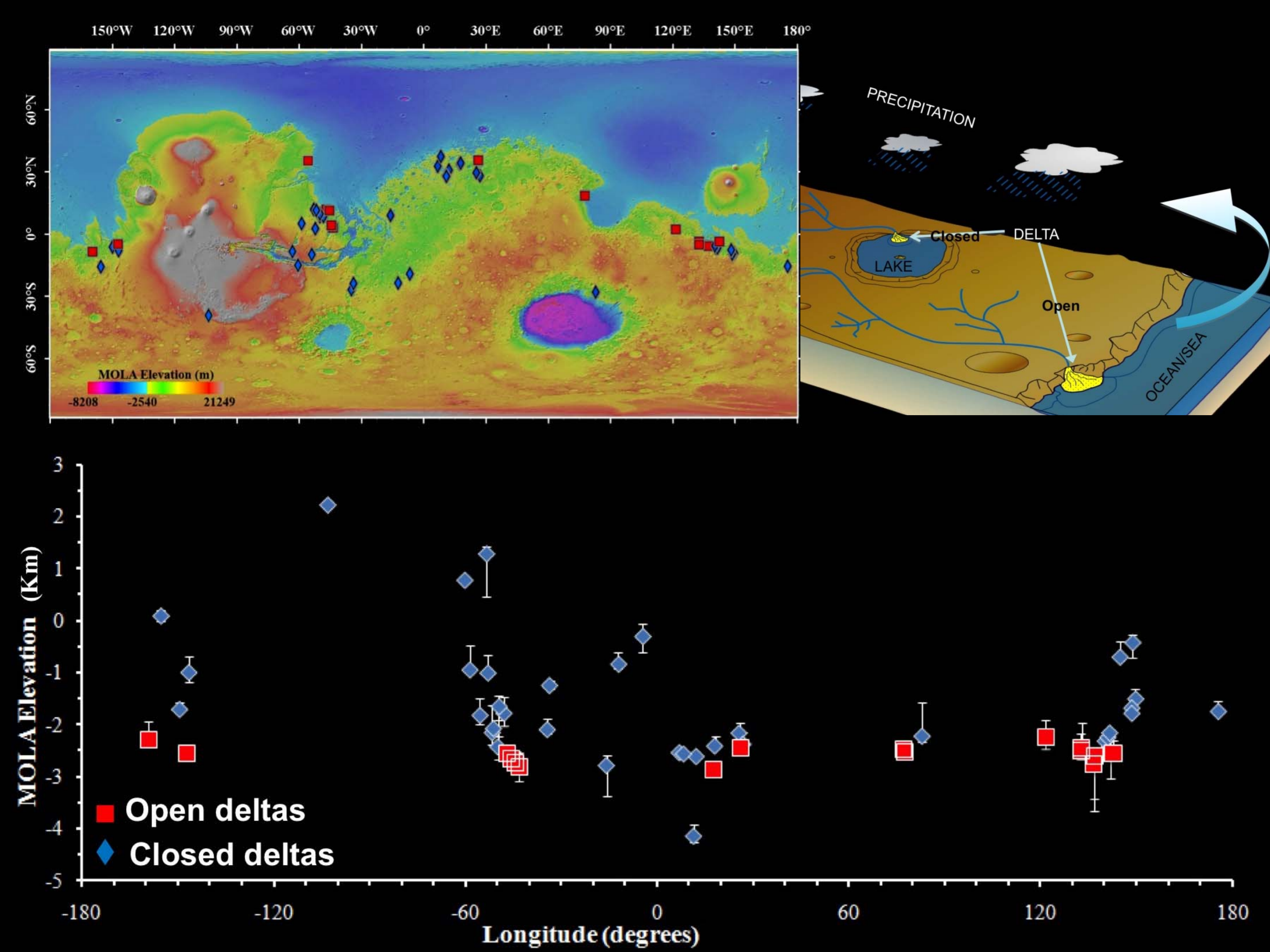


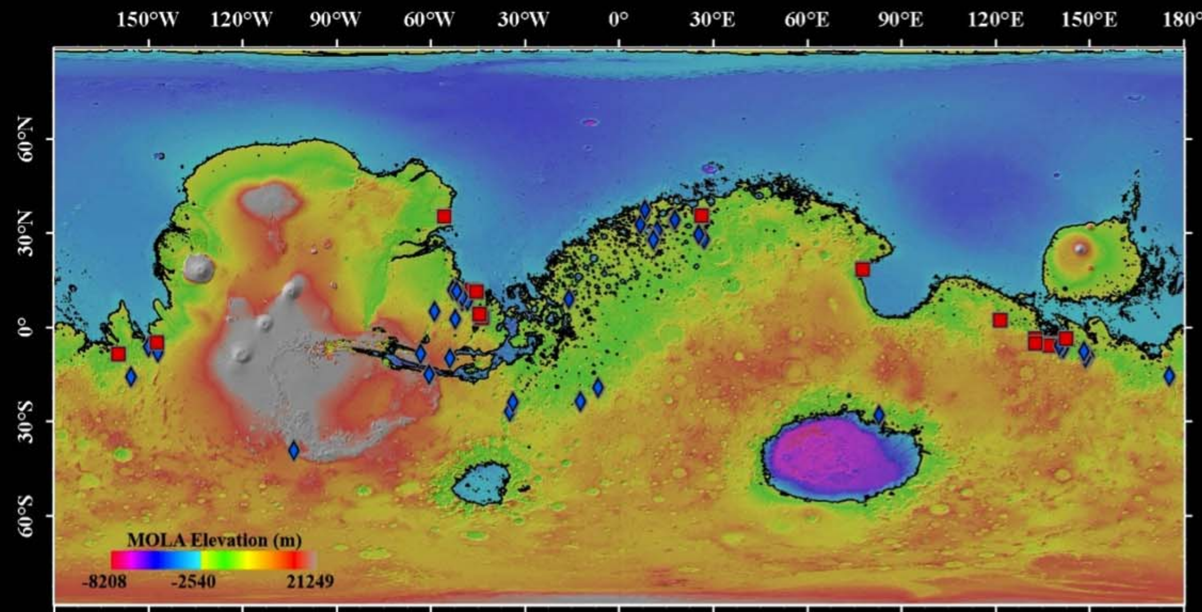
- effectively determines an enclosure

- encompasses Holden and Eberswalde craters, as well as Meridiani

- is consistent with the revised Meridiani shoreline (Fairen et al., 2003)

However its variation is too high for this kind of test

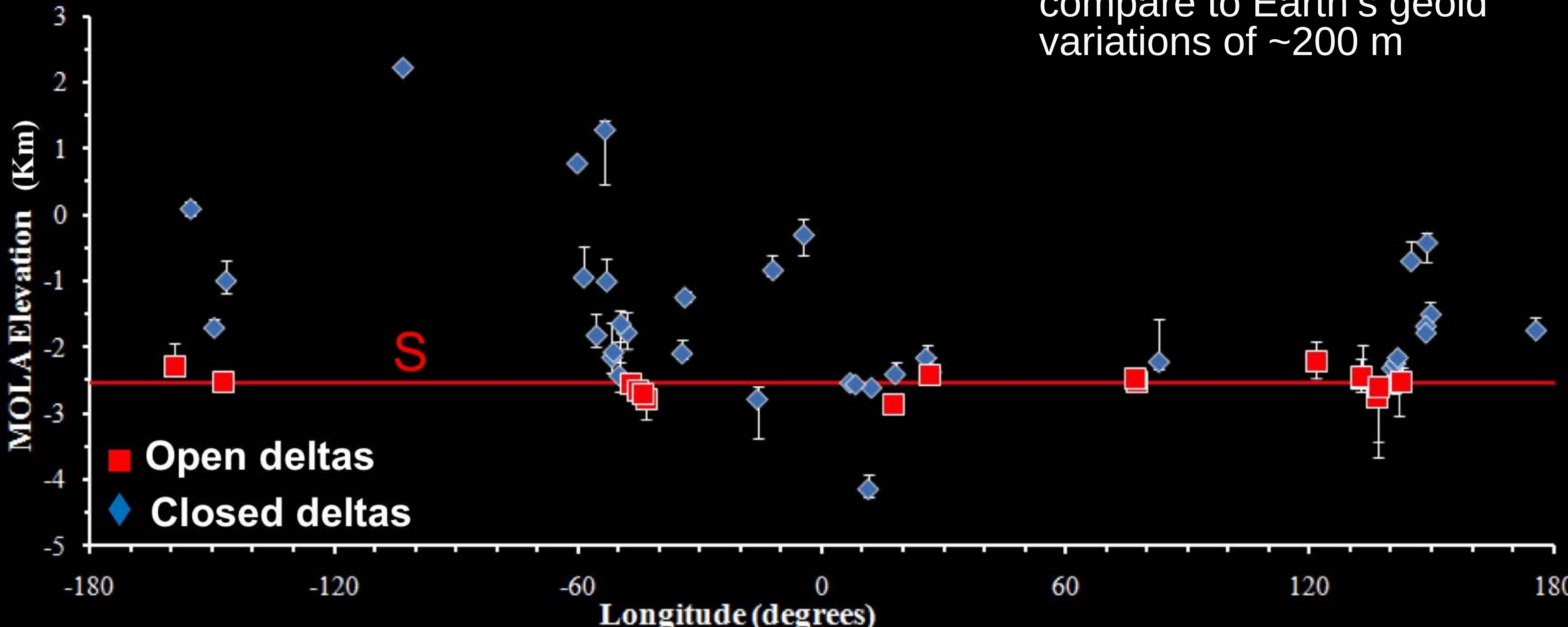

150°W 120°W 90°W 60°W 30°W 0° 30°E 60°E 90°E 120°E 150°E 180°
60°N
30°N
0°
30°S
60°S
MOLA Elevation (m)
-8208
-2540
21249
PRECIPITATION
Closed
DELTA
LAKE
Open
OCEAN/SEA
MOLA Elevation (Km)
3
2
1
0
-1
-2
-3
-4
-5
-180
-120
-60
0
60
120
180
Longitude (degrees)
Open deltas
Closed deltas



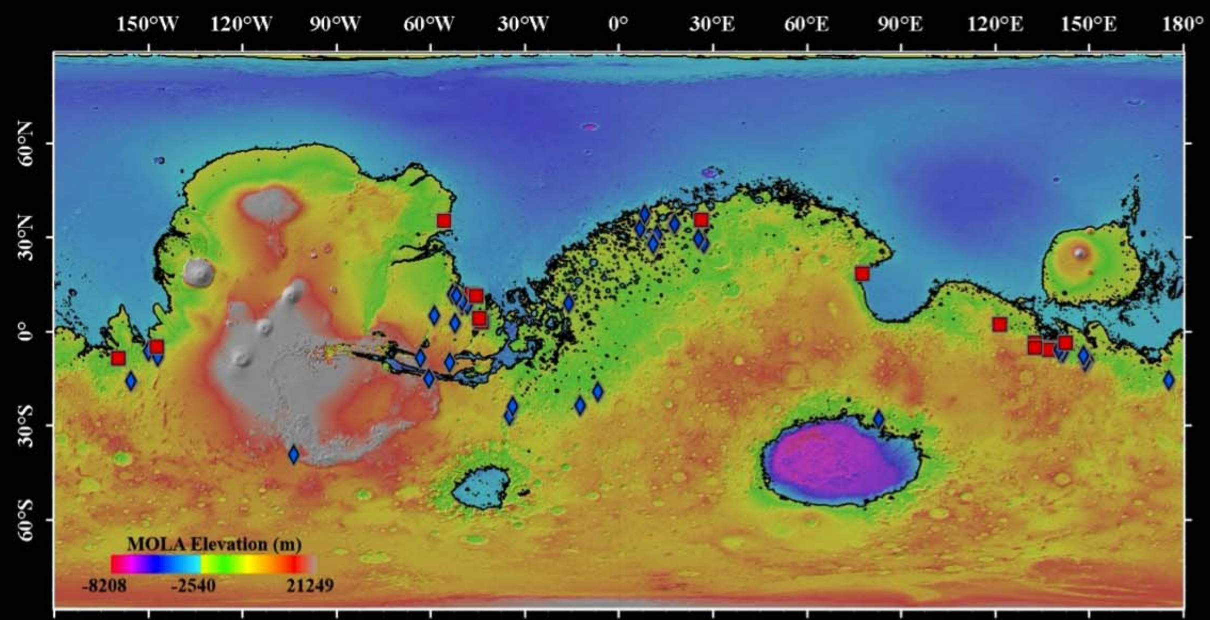
The highstand levels of the **17** open deposits (33% of total) show a mean value of about -2540 m with a standard deviation of 177 m

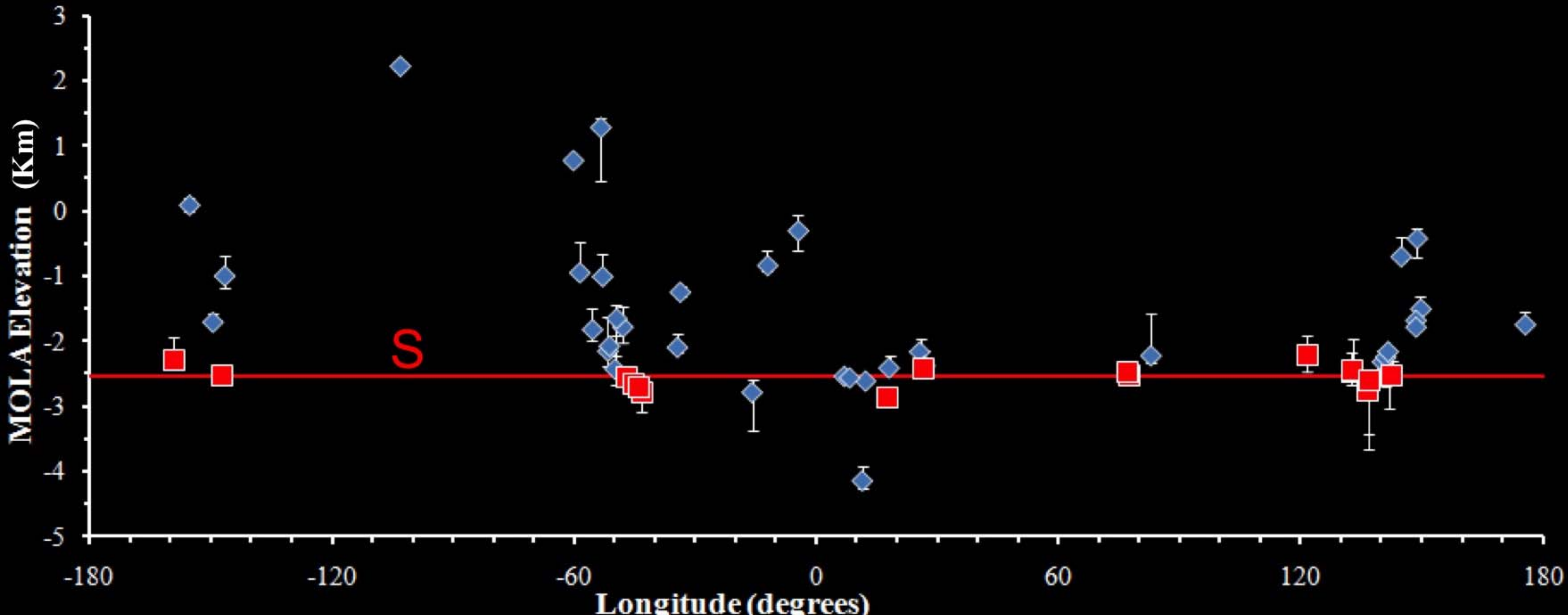
S -2540 ± 177 m

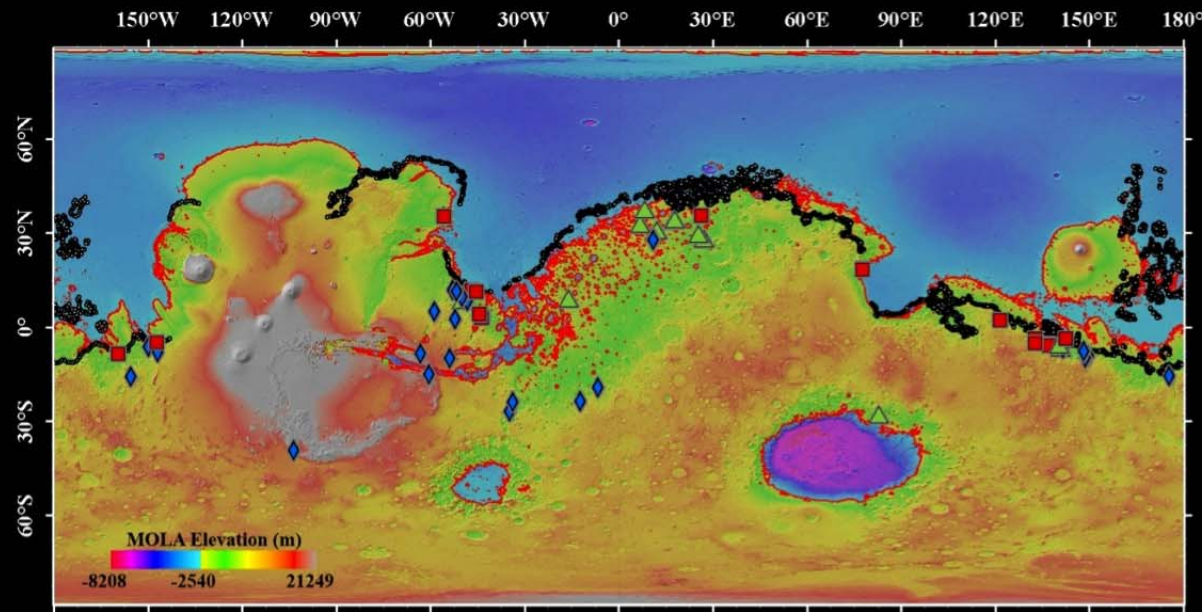
compare to Earth's geoid variations of ~200 m



Support for contact
S = -2540 + 177 m

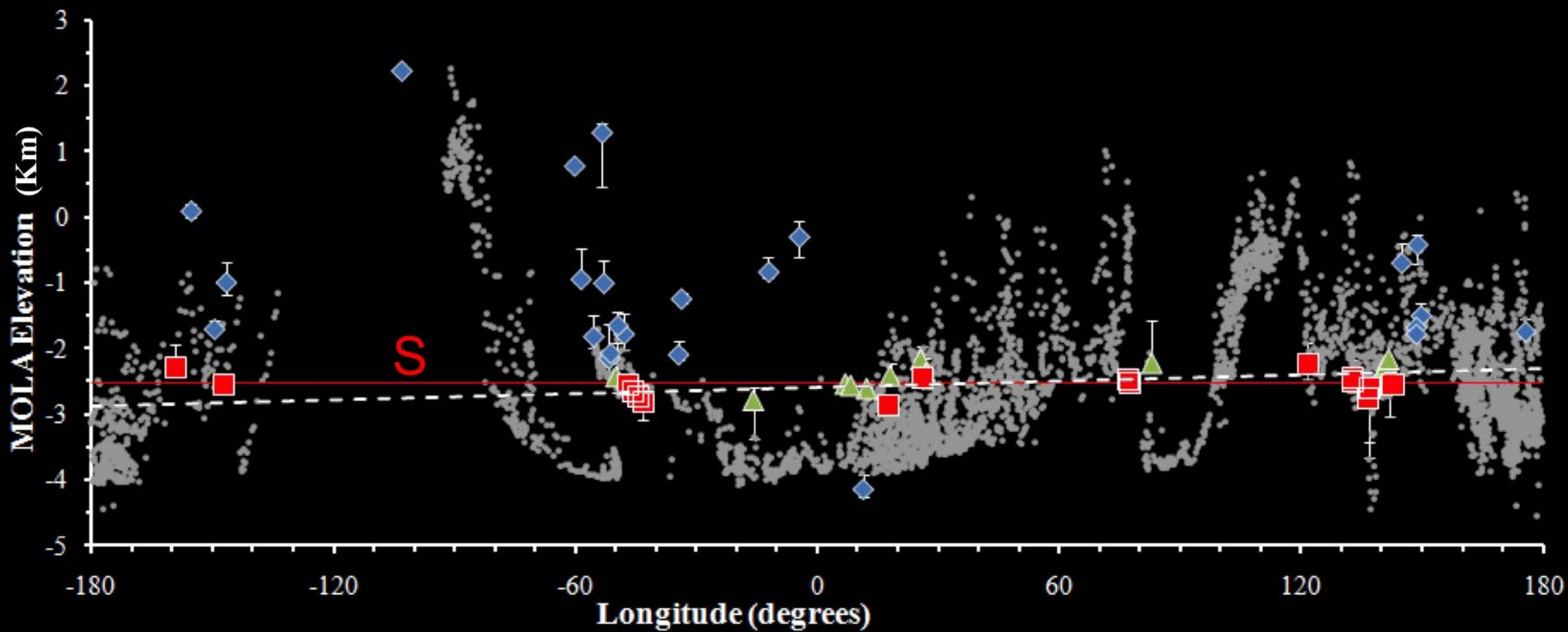


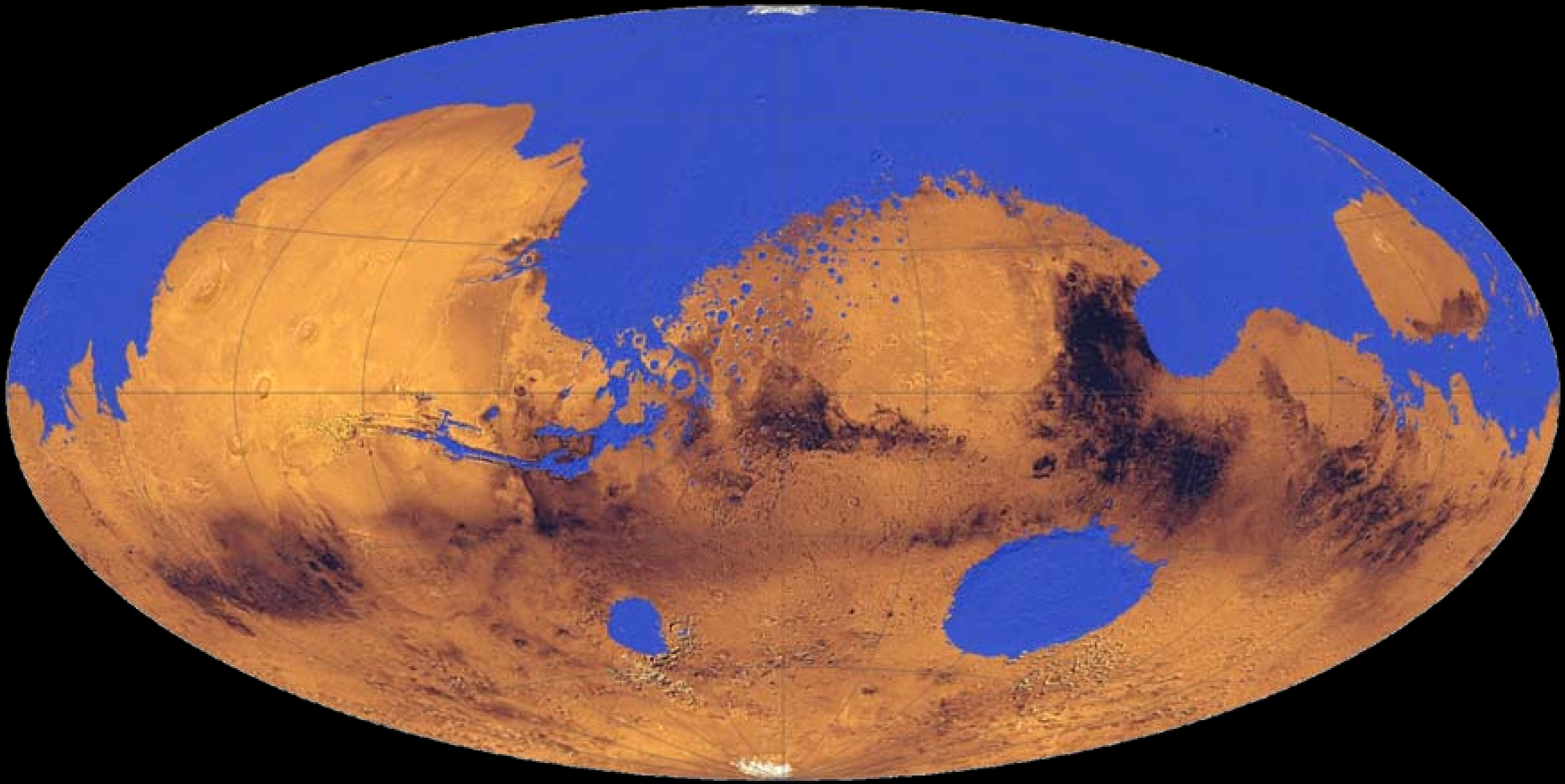




Support for contact
S = -2540 ± 177 m:

An additional **12** closed deltas (totaling ~55% of the global database) fall within the error bars of **S**





- This putative shoreline implies 36% of the surface of Mars was covered by an ocean in the Early Hesperian (the time of peak delta and valley activity).
  - ~10% of Earth’s ocean volume
- The standard deviation of these deltas is smaller than variations in Earth’s geoid.

Tying it all together

- The deltas and valleys show characteristics requiring a vigorous hydrologic cycle.
  - Significant precipitation and standing bodies of water were needed.
- The vast majority of these features formed around the same time, ~3.8-3.6 billion years ago.
  - Valley formation became more localized as time went on.
- Invoking an ocean is the easiest way to explain the location, elevation, and character of the valleys and deltas.

References and Databases

Valley Networks

Hoke, M. R. T., G. Tucker and B. M. Hynek, Formation Timescales of Large Martian Valley Networks, *Earth and Planetary Science Letters, (in review)*, 2011.

Hynek, B. M., M.R.T. Hoke, and M. Beach, Updated Global Map of Martian Valley Networks and Implications for Climate and Hydrologic Processes, *Journal of Geophysical Research*, *115,* doi:10.1029/2009JE003548, 2010.

Hoke, M. R. T. and B. M. Hynek Roaming Zones of Precipitation on Ancient Mars as Recorded in Valley Networks, *Journal of Geophysical Research*, 114, doi:10.1029/2008JE003247, 2009.

Hynek, B. M., and R. J. Phillips, New Data Reveal Mature, Integrated Drainage Systems on Mars Indicative of Past Precipitation, *Geology*, 31, 757-760, 2003.

Deltas

Di Achille, G. and B. M. Hynek, Ancient ocean on Mars supported by global distribution of deltas and valleys, *Nature Geoscience*, *3*, 459-463, doi:10.1038/ngeo891, 2010.

Di Achille, G. and B. M. Hynek, Chapter 10: Deltas and Valley Networks on Mars: Implications for a Global Hydrosphere, in Lakes on Mars, Cabrol and Grin, eds., ISBN 978-0-444-52854-4, 2010.

Valley network database completed, released to PIGWAD or available on request.