Key parameters for Early Mars climate research

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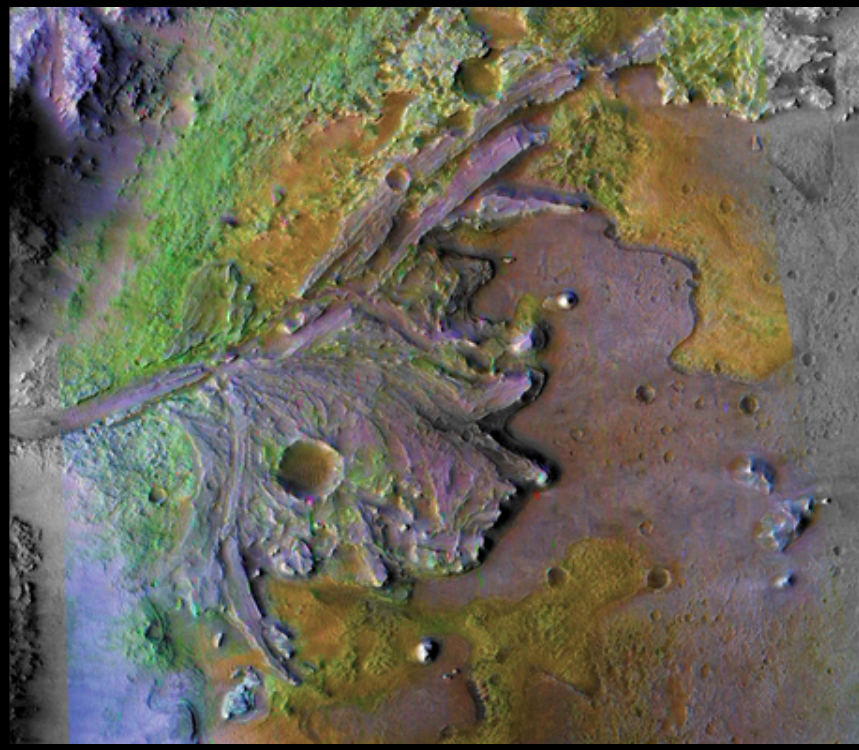
Today: set out geological constraints for early Mars parameters that can be used to evaluate models for early Mars climate.



Ehlmann et al. Nature Geosci. 2008

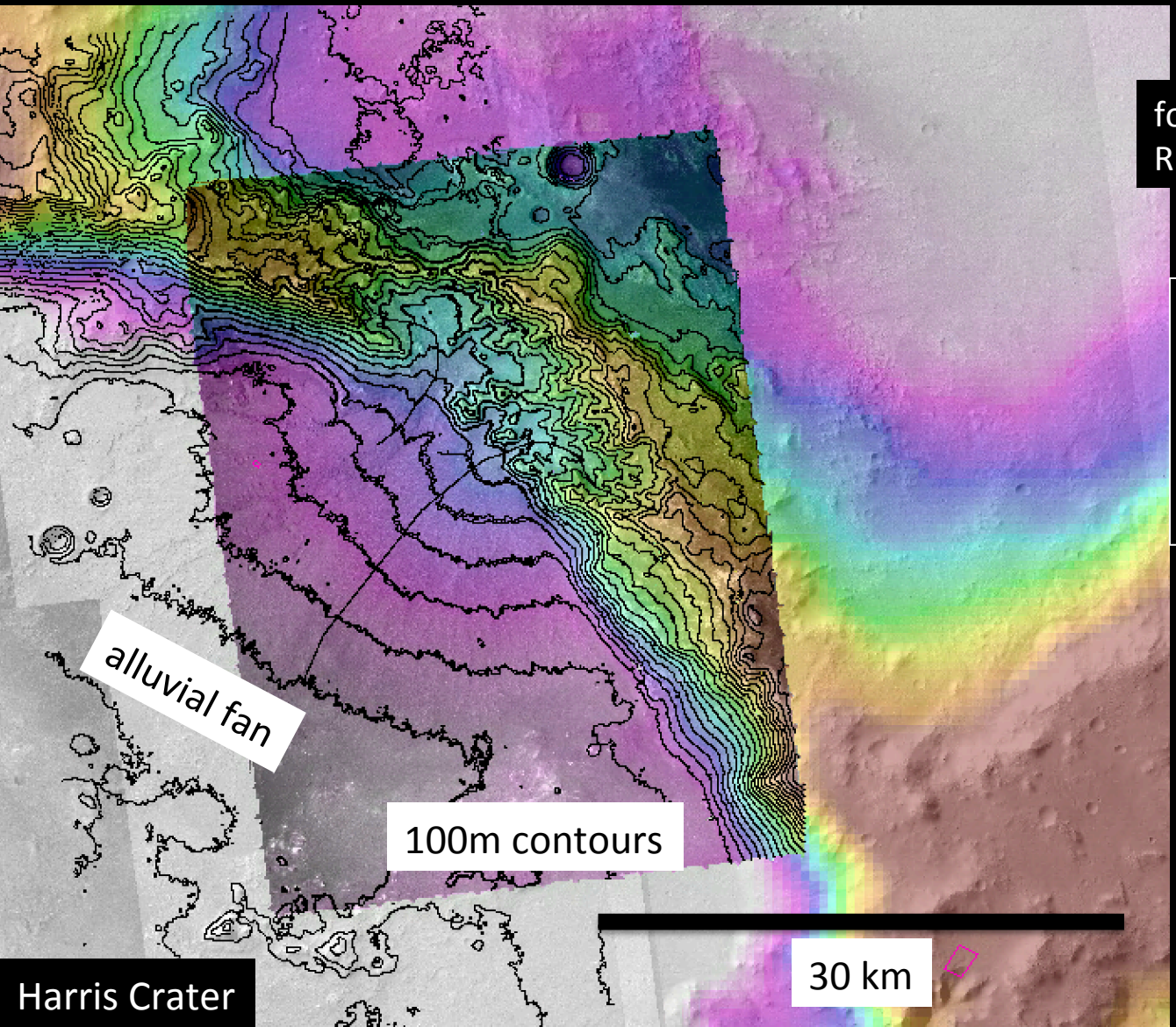
With thanks to: **Jonathan Sneed*, Sam Holo*, David Mayer*, Megan Mansfield*, Liam Steele*, Mohit Melwani Daswani*,** Leila Gabasova, Antoine Lucas, Joel Davis, Michael Mischna, Peter Gao, Yuk Yung, Colin Goldblatt, HJ Seybold, Caleb Fassett, Tim Michaels, Bethany Ehlmann, Kevin Lewis, Oded Aharonson, Mike Lamb, Michael Wolff, Itay Halevy, Melinda Kahre, Stuart Robbins, Alan Howard, Jean-Pierre Williams, Becky Williams, Brian Hynek, Ross Irwin

**** = group members and former group members***

My confidence level for this geologic constraint:

VERY HIGH

Precipitation-sourced water: > 1 km column



for 77% sediment by volume
R.M.E. Williams et al. 2011 Icarus

more about Harris-era erosion:
- Poster #2083, Sneed et al.
"Water on Mars" poster session Tuesday pm
-Waterway 1, 1:30pm-

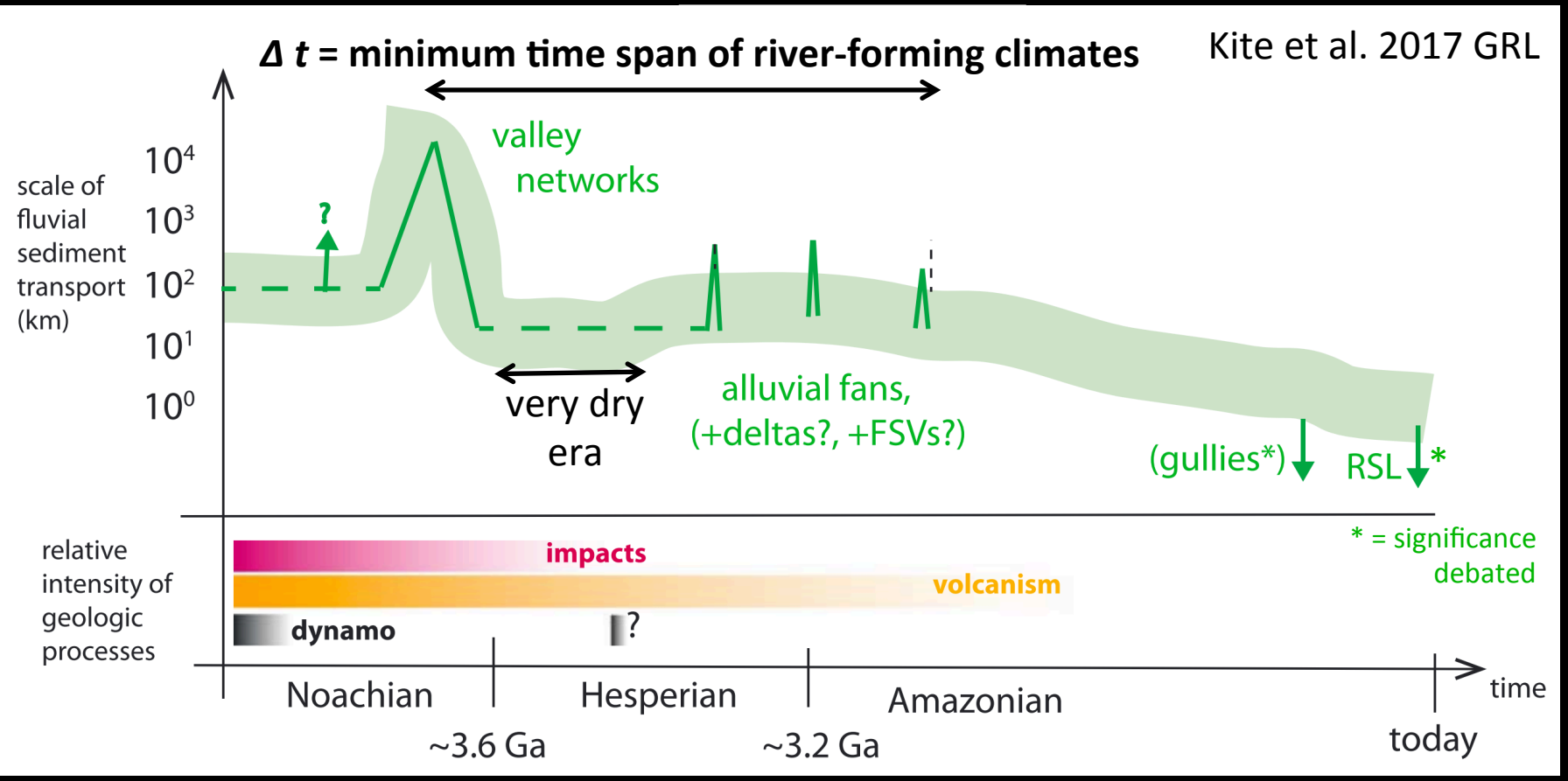
Also: e.g. Palucis et al. 2014 JGR, Irwin et al. 2015 Geomorphology, Morgan et al. 2014 Icarus, Carter et al. 2015 Icarus, Howard et al. 2005 JGR, Grotzinger et al. 2014 Science Dietrich et al. in Tsutsumi & Laronne 'Gravel Bed Rivers' 2017

CTX DTM:
Mayer & Kite LPSC 2016

There is no single Early Mars climate problem!

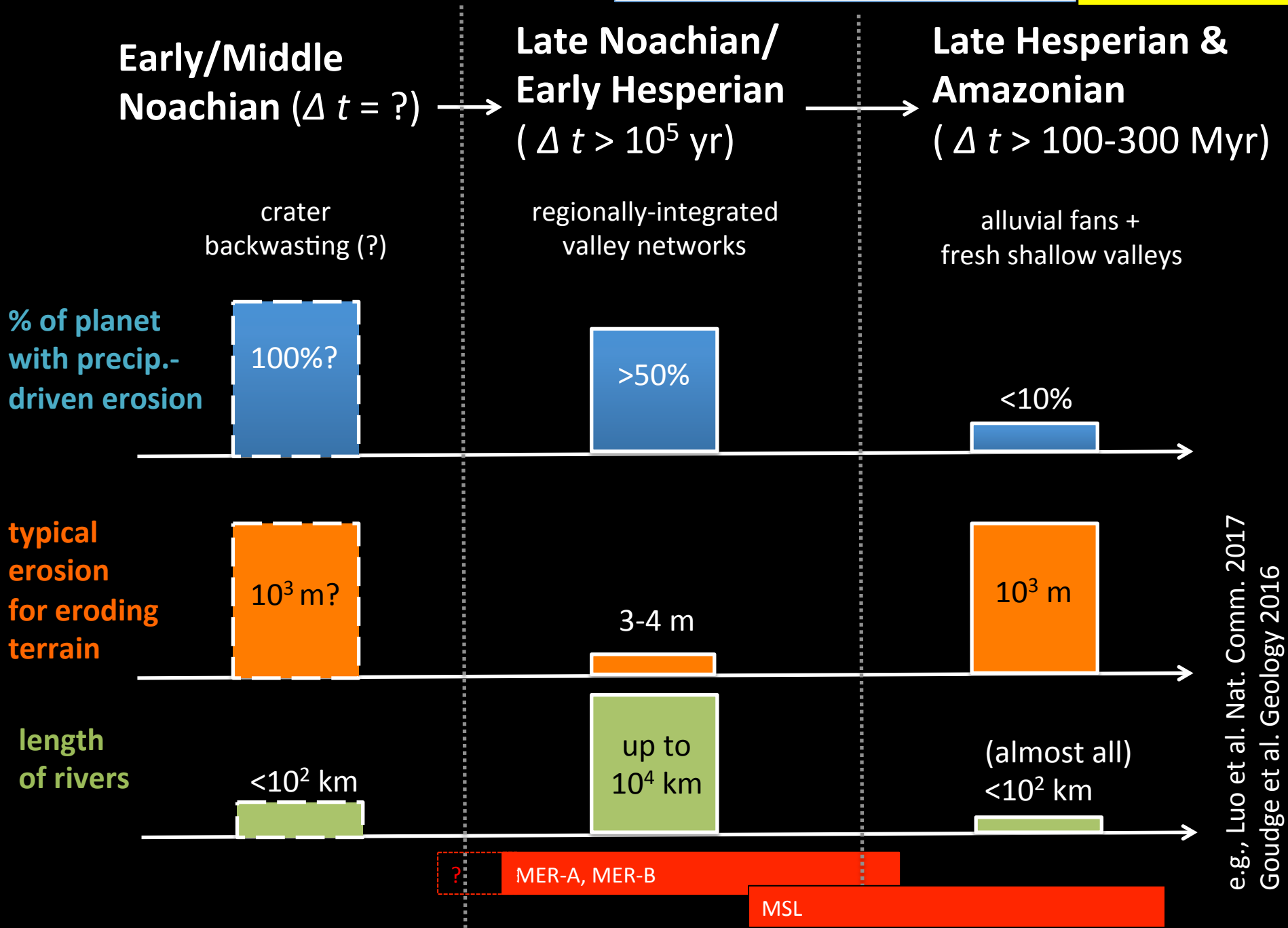
Confidence level
HIGH

time spanned by river-forming climates ≫100 Myr,
with multiple river-forming climates:

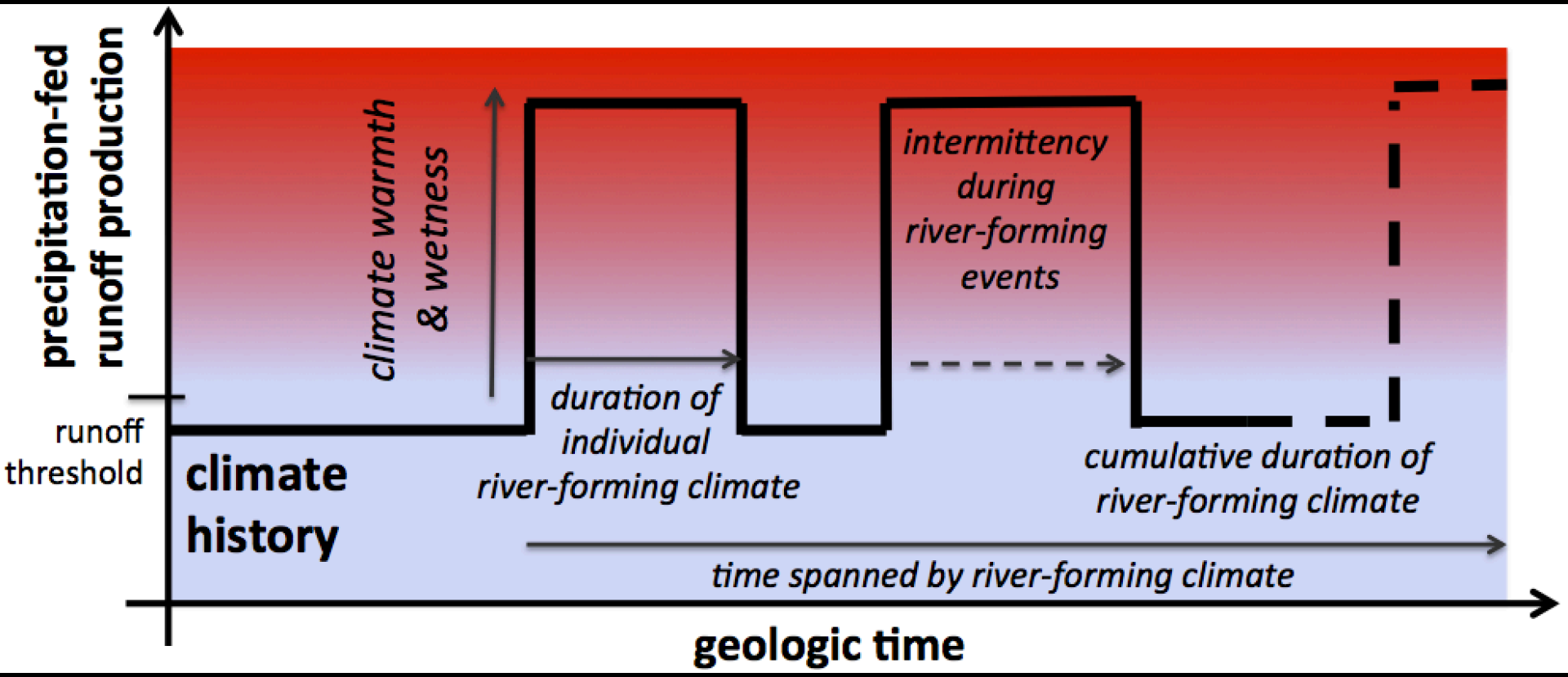


Pre-valley-network fluvial erosion (?): e.g. Forsberg-Taylor et al. 2004 JGR, Irwin et al. 2013 JGR (& this session)
Valley networks: e.g. Fassett & Head Icarus 2008 v.195
Very dry era: e.g. Palucis et al. JGR 2016, Zabrusky et al. 2012 Icarus, Kite et al. 2015 Icarus
Alluvial-fan era: e.g. Grant & Wilson 2011 GRL; S. Wilson et al. 2016 JGR, Kite et al. 2017 GRL

Confidence level in these trends: **MEDIUM**



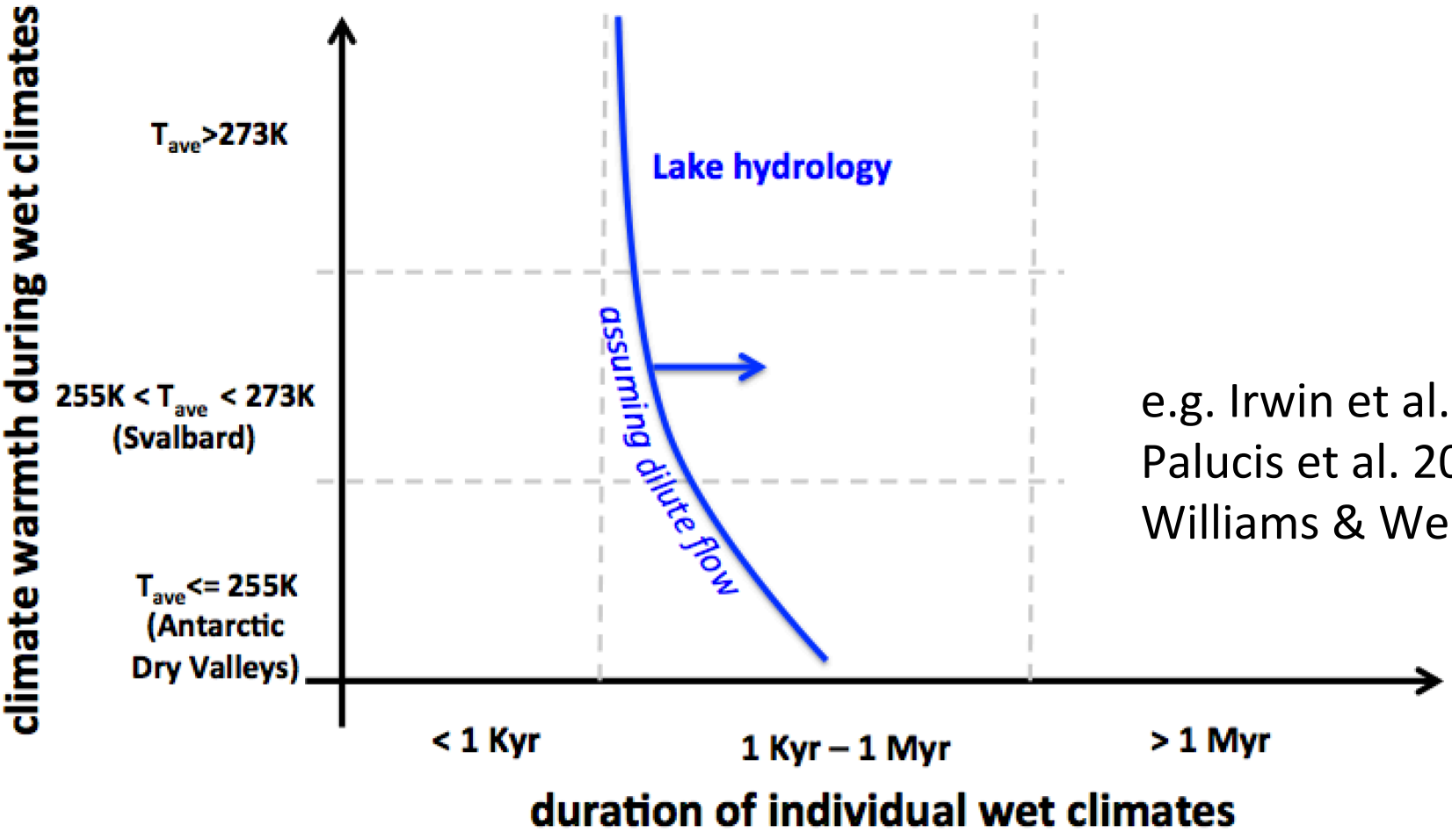
Anatomy of a river-forming climate



Early Mars geomorphology is not a palimpsest of catastrophic events

Confidence level
HIGH

Duration of longest river-forming climate: >3 kyr



e.g. Irwin et al. 2015,
Palucis et al. 2016,
Williams & Weitz 2014

Early Mars geomorphology is not a palimpsest of catastrophic events

Confidence level
HIGH

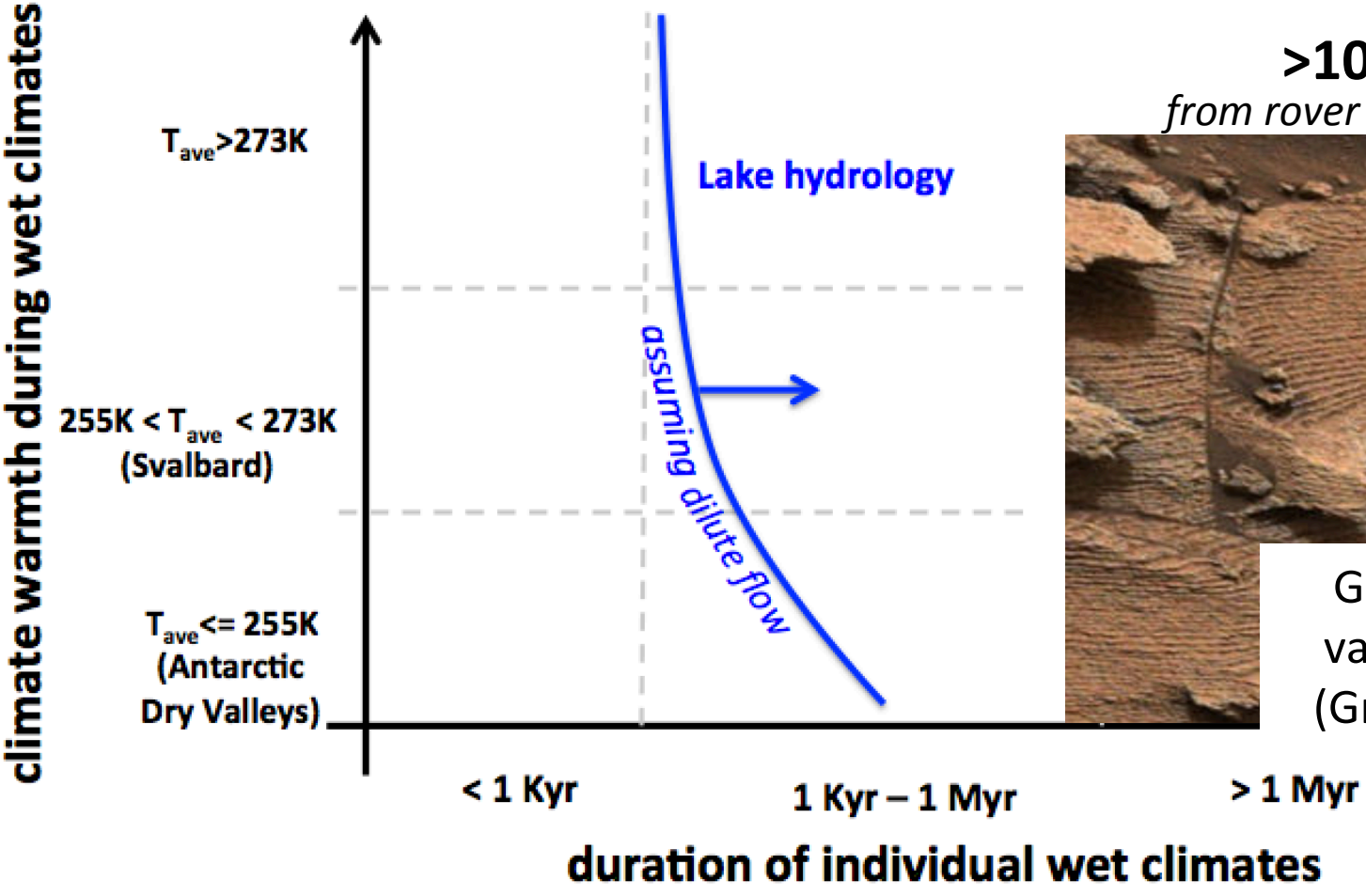
Duration of longest river-forming climate: >3 kyr

from orbiter data

$>10^5$ yr

from rover data

MEDIUM



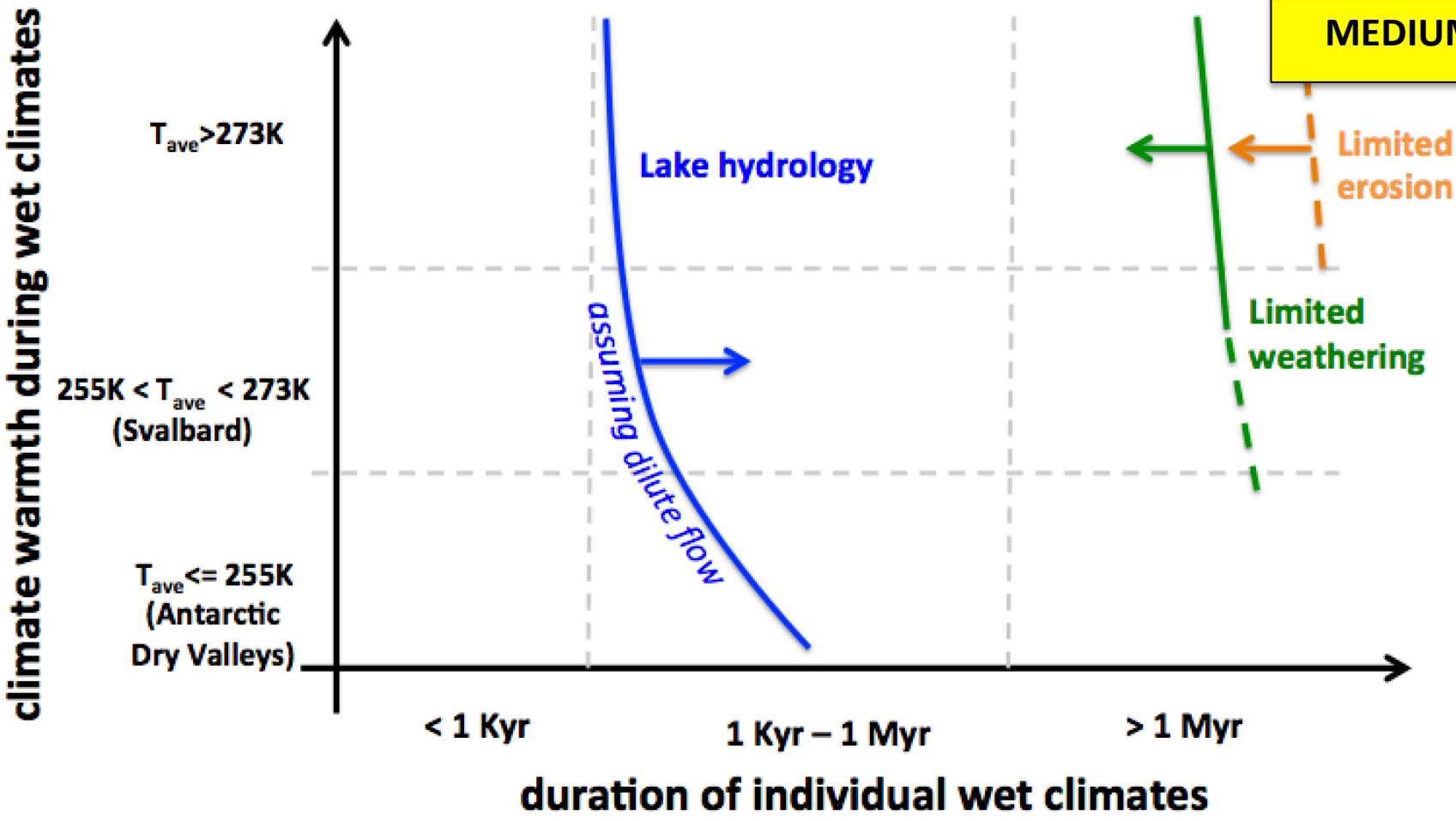
Gale laminae – annual varves in lake deposit? (Grotzinger et al. 2015)

e.g. Irwin et al. 2015, Palucis et al. 2016, Williams & Weitz 2014, Hoke et al. EPSL 2011; G.H. Peters et al. 2017 GRL q.v. Rosenberg & Head 2015 P&SS (loose-sediment transport)

Duration of surface liquid water at an "average" place on Mars: <10 Myr

Confidence level:

MEDIUM/HIGH



lake hydrology: e.g. Irwin et al. 2015, Palucis et al. 2016, Williams & Weitz 2014

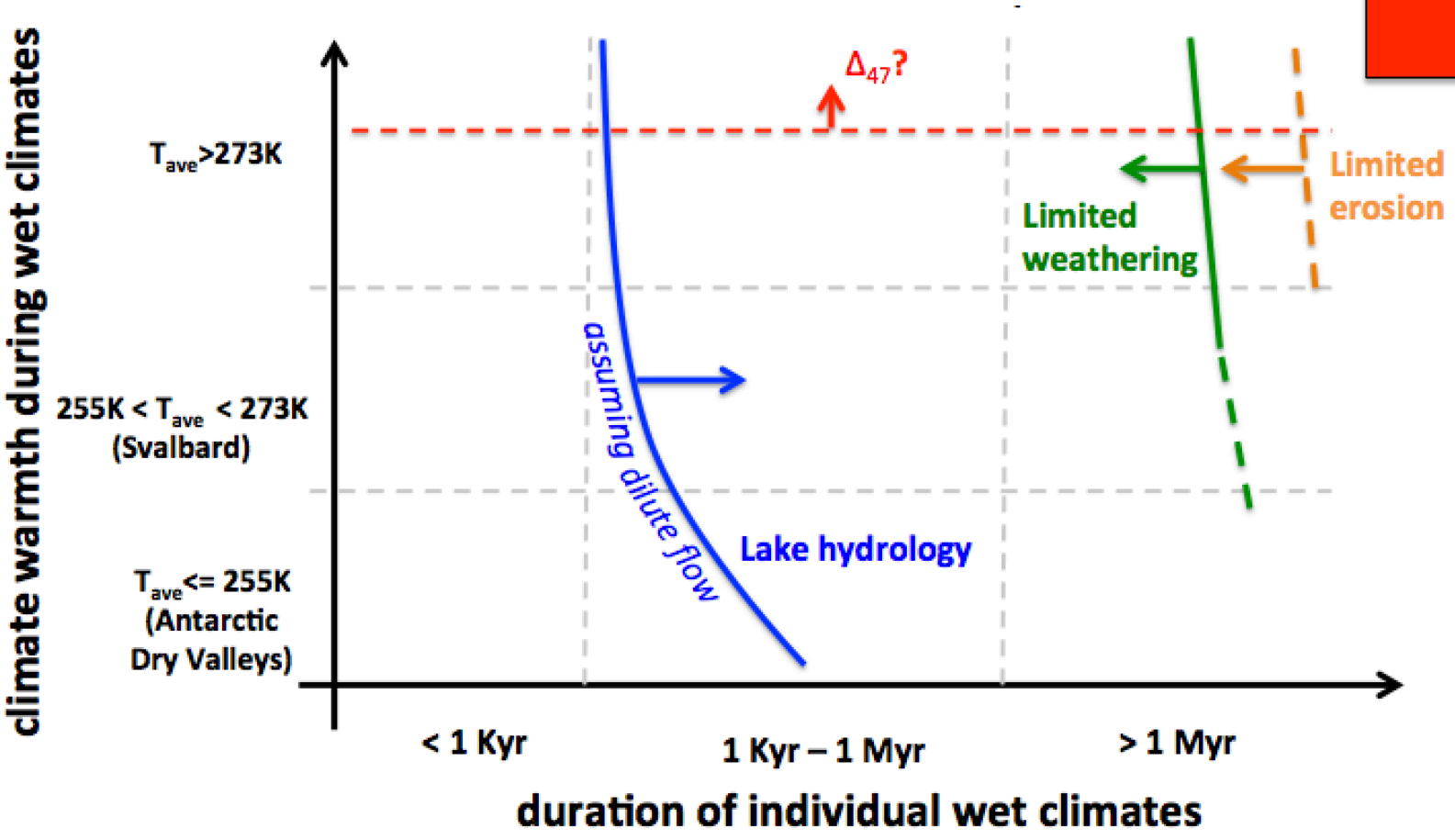
limited weathering: e.g. Stopar et al. 2006, Olsen & Rimsdidt 2007, McLennan et al. 2014, Ehlmann et al. Nature 2011, Siebach+ 2017

limited erosion: e.g. Aharonson et al. 2002, Som et al. 2009, Luo et al. 2017, Goudge et et al. 2016; see Howard et al. 2016 for an alternative explanation.

Paleo-temperature is poorly constrained

paleo-T Confidence:

LOW



Previous temperature arguments are equivocal:

ALH 84001 Δ_{47} → T (18 ± 4)°C [Halevy et al. 2011]; (Antarctic) Lake Vanda bottom T = 23 °C

Al-clays can form under cold, low pH conditions [Zolotov & Mironenko 2016] or cold, extremely prolonged, wet conditions [but see Bishop et al. Nature Astronomy 2018]

No evidence that the Gale lake was ice-covered - but do we know what to look for?

Peak runoff production, *R*

(mm/hr averaged over catchment area)

Confidence level
HIGH

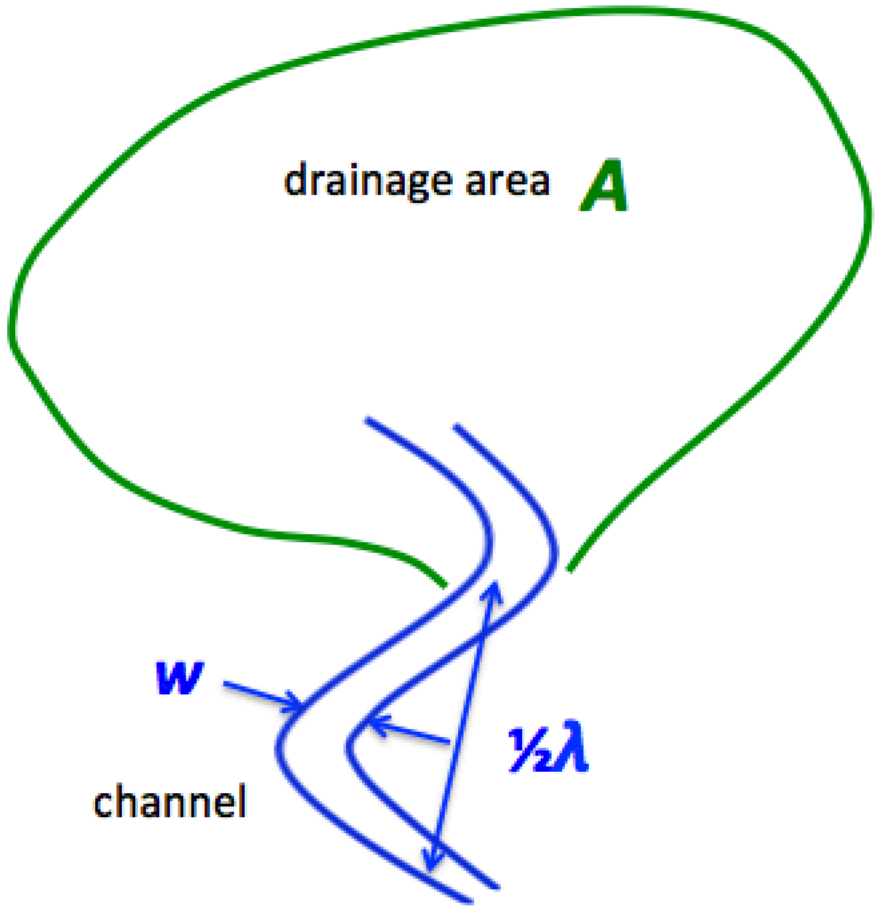
>0.1 mm/hr

e.g. Dietrich et al. in Tsutsumi & Laronne Gravel Bed Rivers 2017 Palucis et al. 2014 JGR, Irwin et al. Geology 2005, Jacobsen & Burr GRL 2018

$R = Q / A$

$Q = f(w)$

$Q = f(\lambda)$



>(Earth)? **LOW/MEDIUM**

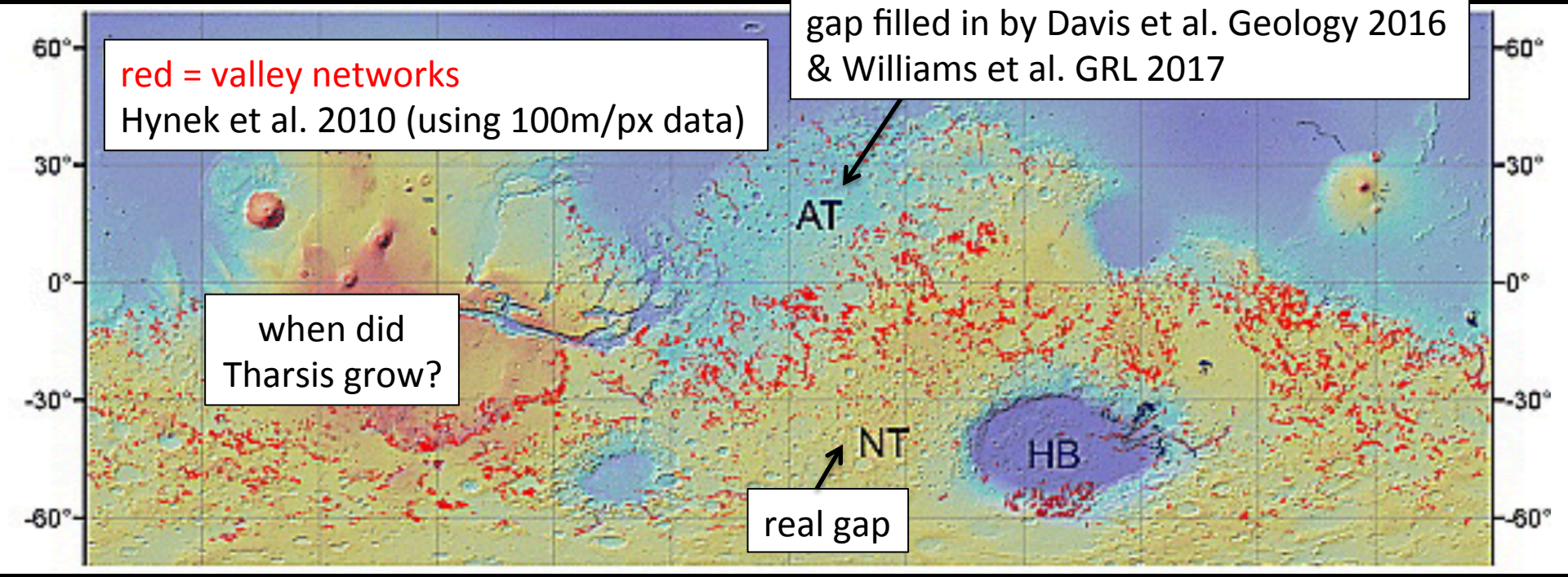
Poster #2738, Kite et al.
"Water on Mars" poster session Tuesday pm

Interpreting climate change from river deposits: e.g. Foreman et al. Nature 2012, Amundson et al. GSA-B 2012, Chen et al. eartharxiv 2018. But see Jerolmack & Paola 2010 for caution in Earth context.

Misleading: ambiguous distribution of valley networks

Confidence level

LOW



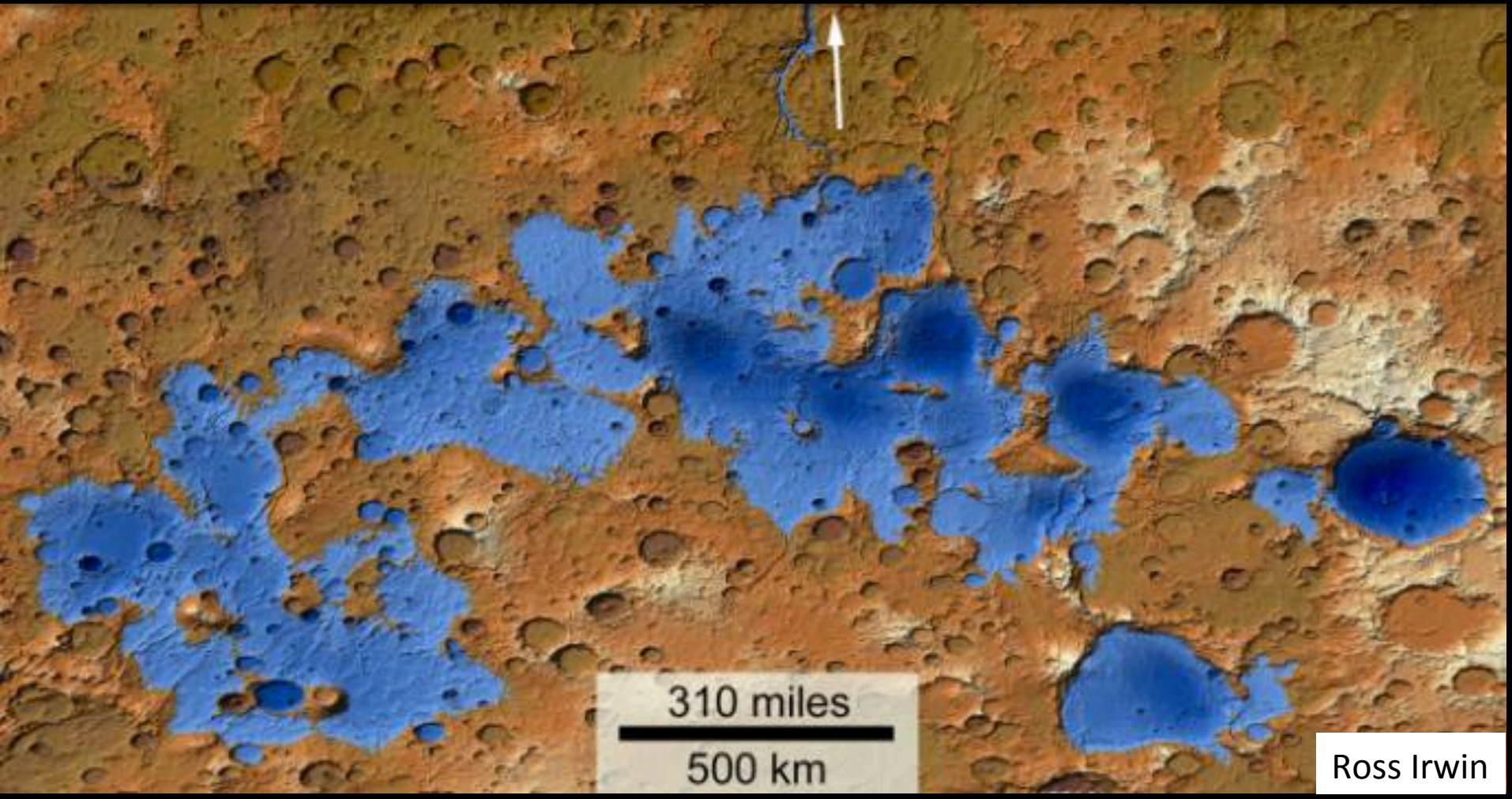
e.g. Wordsworth et al. JGR 2015, Bouley et al. Nature 2016

But: (1) latitudinal trends in VN depth are intriguing (*Becky Williams et al. JGR-E 2001*)
(2) patchy distribution of alluvial fans is real (Erin Kraal et al. Icarus 2008; Sharon Wilson et al. LPSC 2012,Alex Morgan presentation this conference).

Maximum ocean size >(1.1 x 10^6) km^2

J. Head, V. Baker, R. Citron, P. Fawdon talks - this session

Confidence level
HIGH

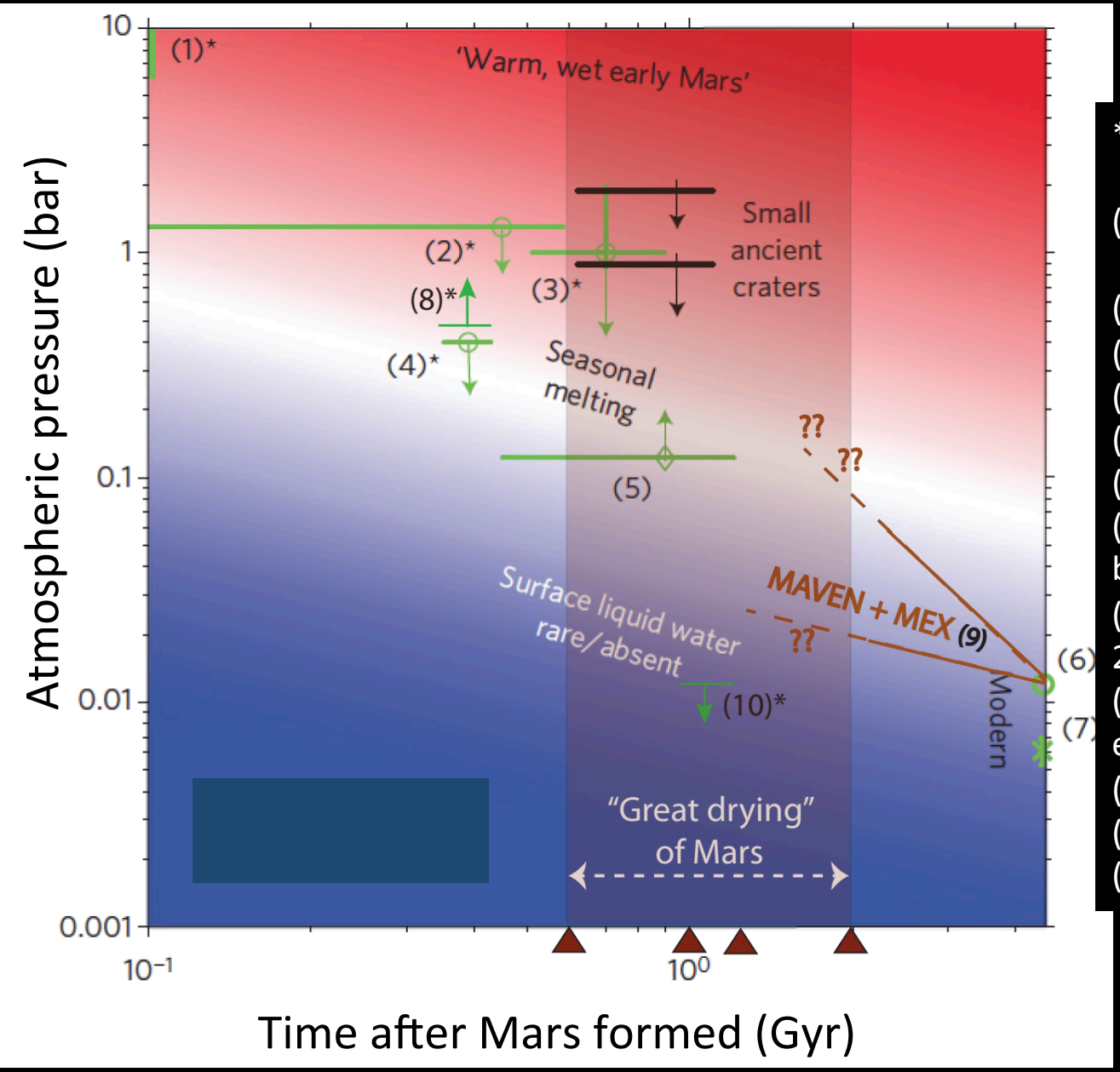


e.g. Irwin et al. Science 2002, Irwin et al. JGR-E 2004, Michalski et al. Nature Geosci. 2017, Pajola et al. 2016, Adeli et al. 2015, …

Paleo-atmospheric pressure 0.01-2 bars

Confidence level

MEDIUM

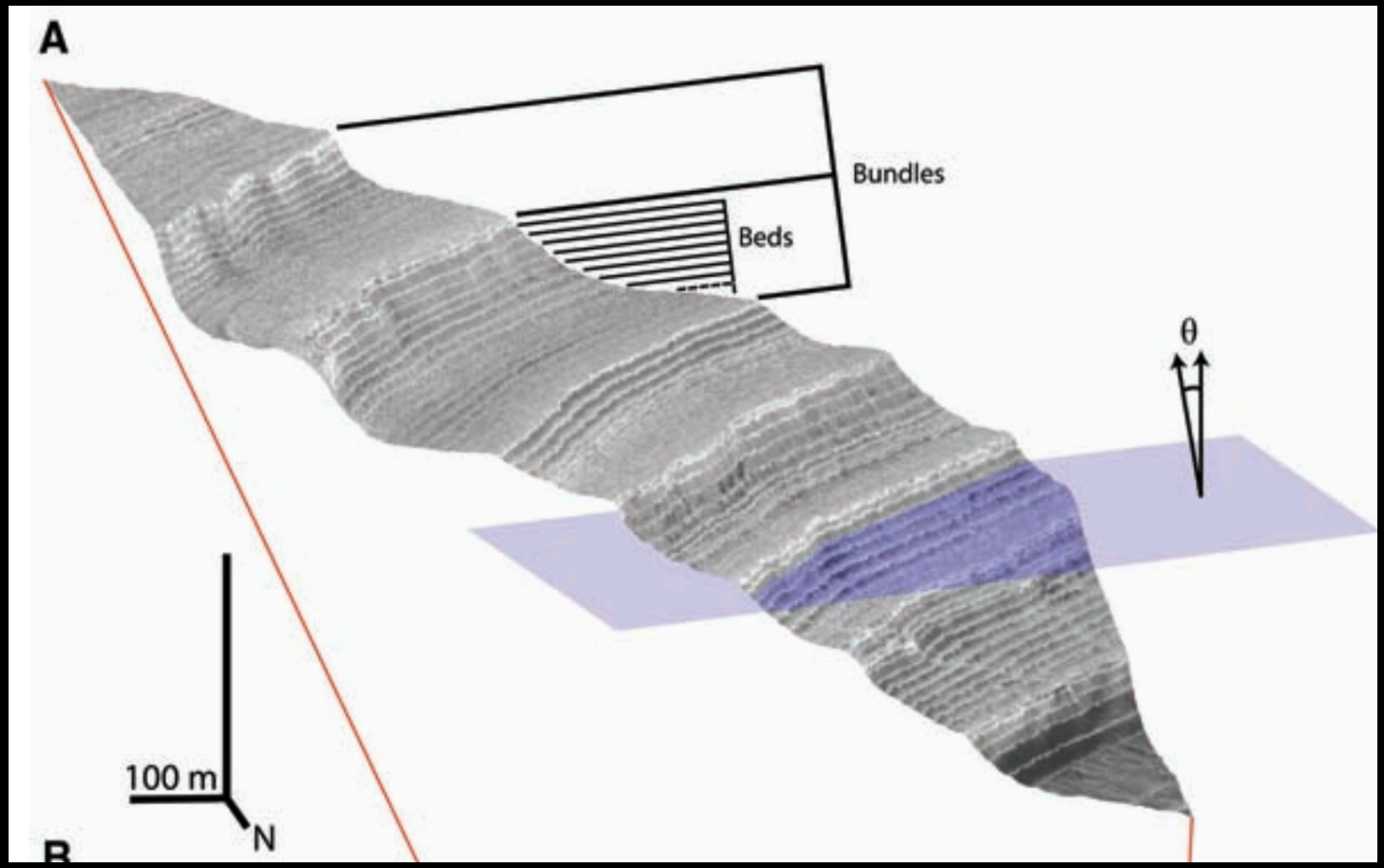


* = indirect.
Black symbols = Kite et al. 2014.
(1*) cosmochemical estimate;
(2*) prehnite stability;
(3*) carbonate Mg/Ca/Fe (van Berk et al. 2012);
(4*) $^{40}Ar/^{36}Ar$ (Cassata et al. 2012)
(5) bomb sag (Manga et al. 2012)
(6) modern atmosphere;
(7) modern atmosphere + buried CO_2 ice;
(8) $^{40}Ar/^{36}Ar$ (Kurokawa et al. 2018)
(9) modern escape-to-space extrapolated into past (Lillis et al. 2017).
(10*) bedform wavelengths (Lapotre et al. 2016).

updated from Kite et al. Nature Geoscience 2014

Years of sediment deposition recorded by sedimentary rocks: >10^8 yr

Confidence level
HIGH



K. Edgett talk, this session

Lewis et al. Science 2008

e.g. McLennan et al. 2005 EPSL, Niles et al. 2017 Nature Comunications, Lewis et al. 2008 Science Lewis & Aharonson 2014 JGR, Kite et al. 2015 Icarus, Becerra et al. GRL 2017, MSL RMI presentations this conference

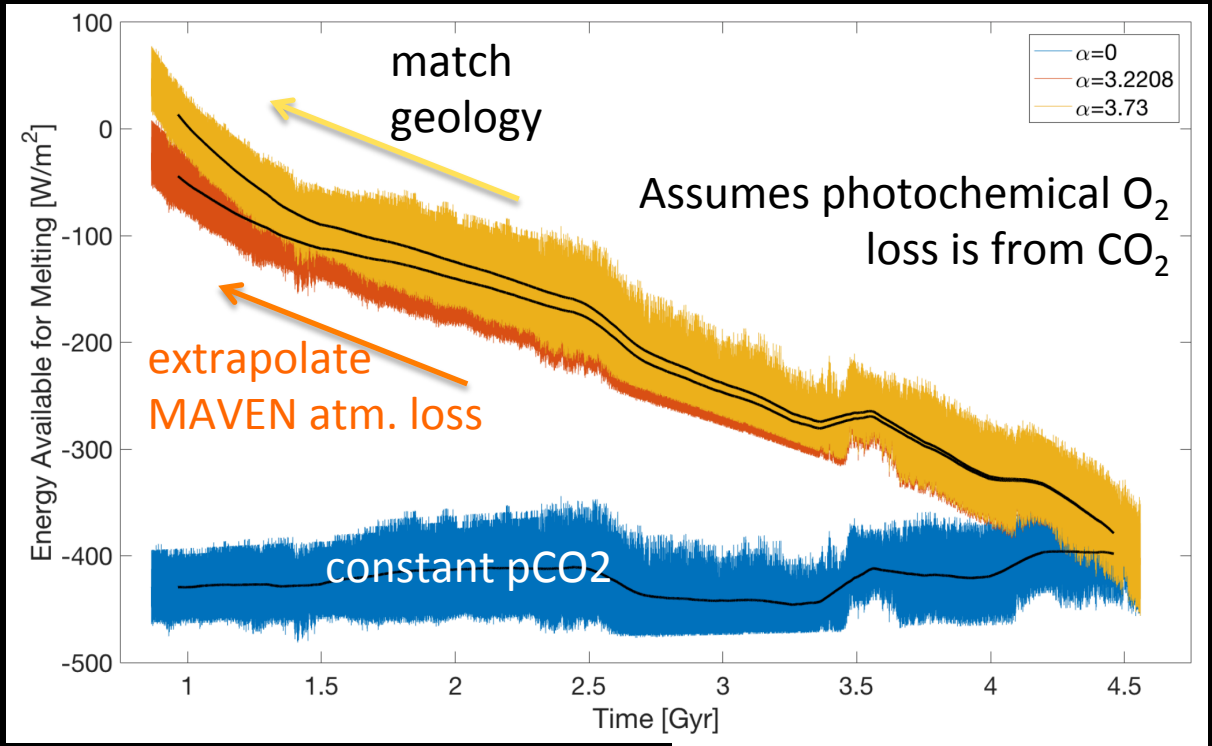
What drove climate and climate change?

Confidence level

Speculation only

- Consistent with a snow/ice melt climate?

  e.g. J. Cassannelli talk, this session; "'The great climate paradox of Early Mars', Hynek 2016 see also Bishop et al. Nat. Astron. 2018



Mansfield et al. JGR 2018

O_2 loss rate from Lillis et al. JGR-A 2017

- Obliquity versus time?

  e.g. Mischna et al. 2013, Kite et al. Icarus 2013a

- Atmospheric pressure versus time?

  e.g. Tian et al. GRL 2009, Jakosky et al. Science 2017, Megan Mansfield et al. JGR 2018

Key constraints on Early Mars climate parameters

	My confidence level for this geologic constraint:
Precipitation-sourced water: > 1 km column	VERY HIGH
Time spanned by river-forming climates $\gg$ 100 Myr	HIGH
Number of river-forming climates > 2	HIGH
Duration of longest river-forming climate > 3 Kyr	HIGH
Duration of surface liquid water for "average" Mars < 10 Myr	MEDIUM/HIGH
Maximum ocean size > (1.1×10^6) km^2	HIGH
Years of sediment deposition in rock record > 10^8 yr	HIGH
Paleo-atmospheric pressure 0.01-2 bars	MEDIUM
Paleo-temperature is poorly constrained	LOW

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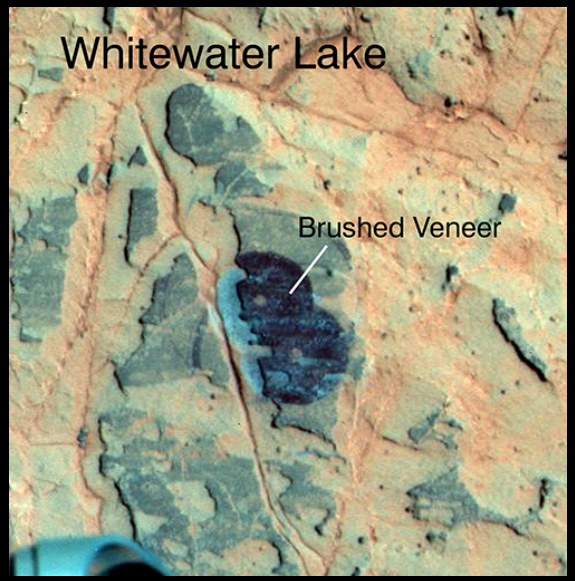
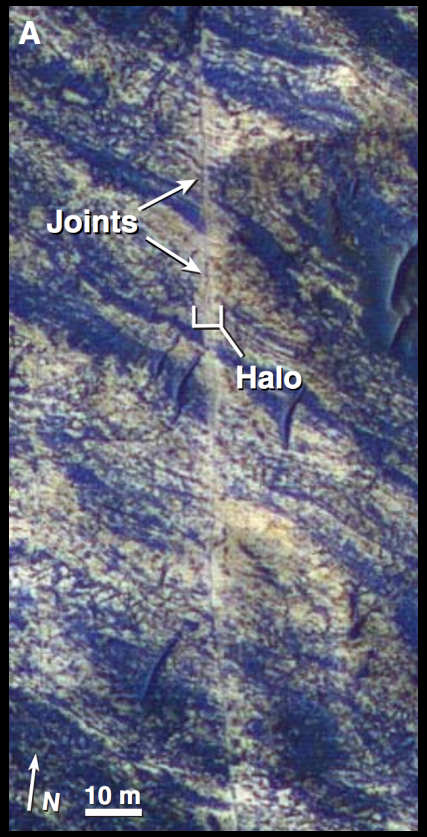
Bonus slides

Water flowed through rocks in the subsurface …



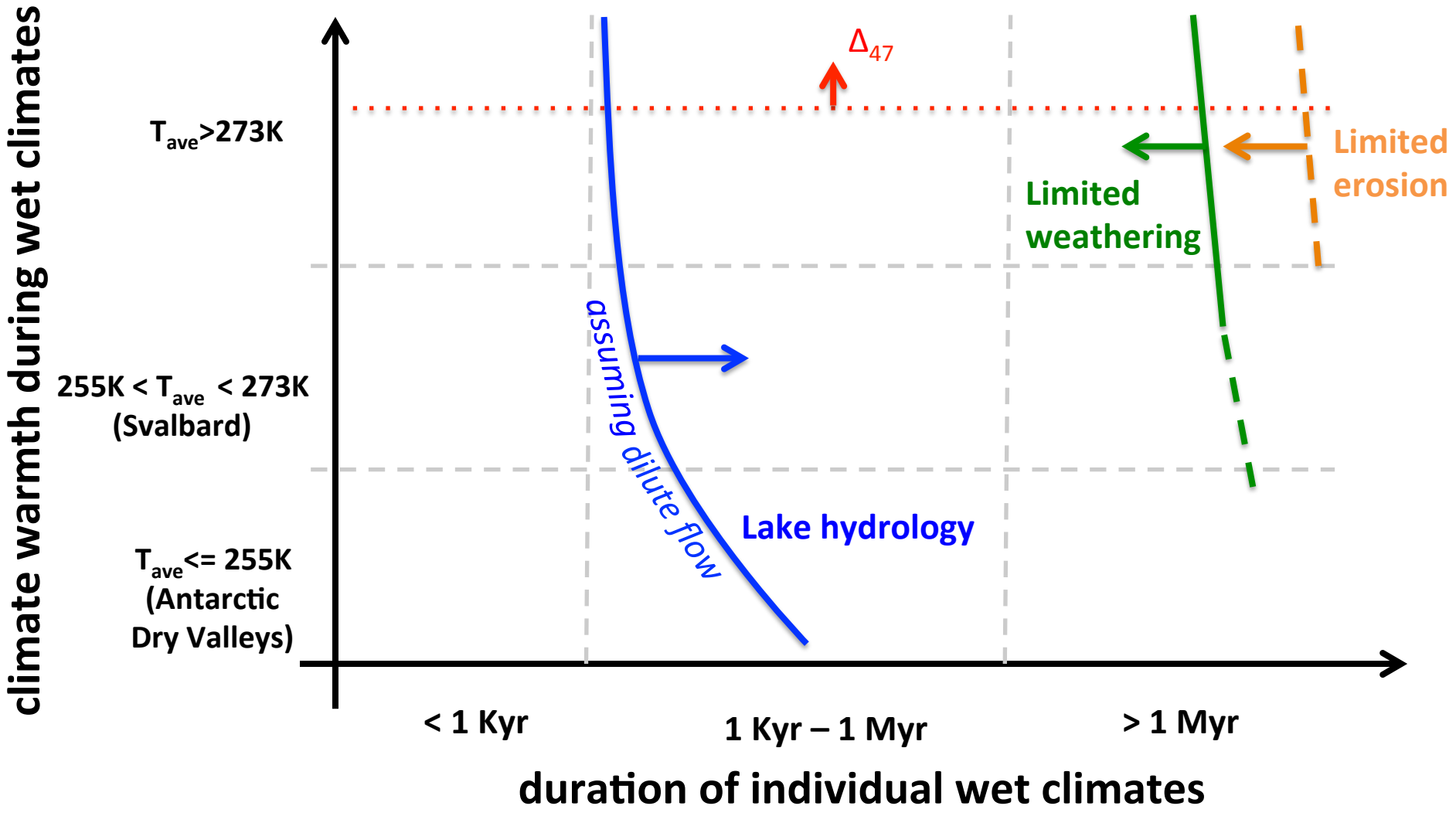


Okubo & McEwen, Science, 2007

… but analyses proving a relationship between groundwater flow and climate are lacking

(but see Andrews-Hanna et al. 2010).

Existing constraints permit either warm, or cold, wet climates



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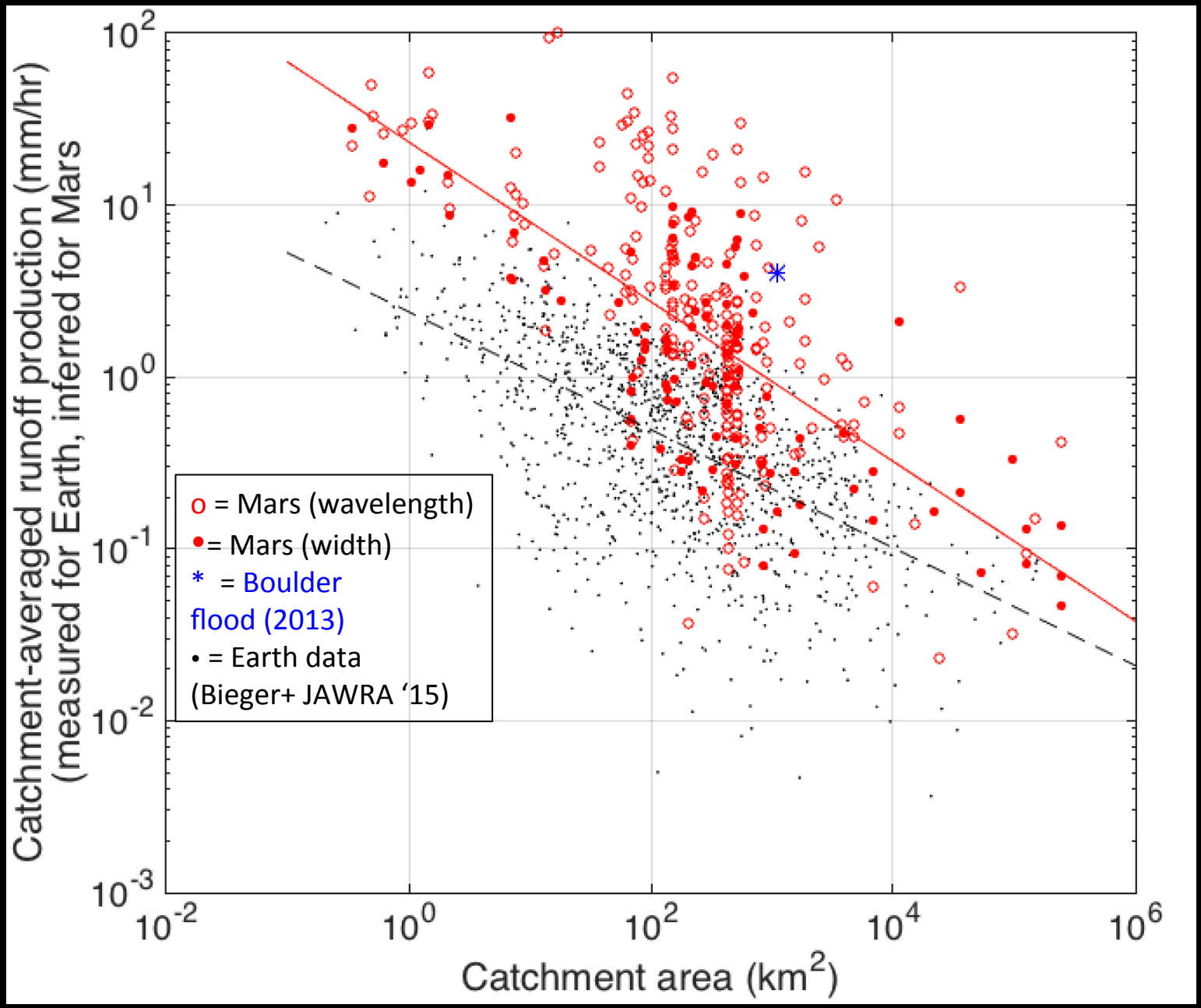
No evidence that the Gale lake was ice-covered - but do we know what to look for?

What have I left out from this simplified story?

- Scientific wildcards:
- Dorsa Argentea Formation
- <u>Very</u> early Mars
- Meteorites


Catchment-averaged runoff production (mm/hr)
(measured for Earth, inferred for Mars
Catchment area (km2)
o = Mars (wavelength)
• = Mars (width)
* = Boulder flood (2013)
• = Earth data (Bieger+ JAWRA '15)