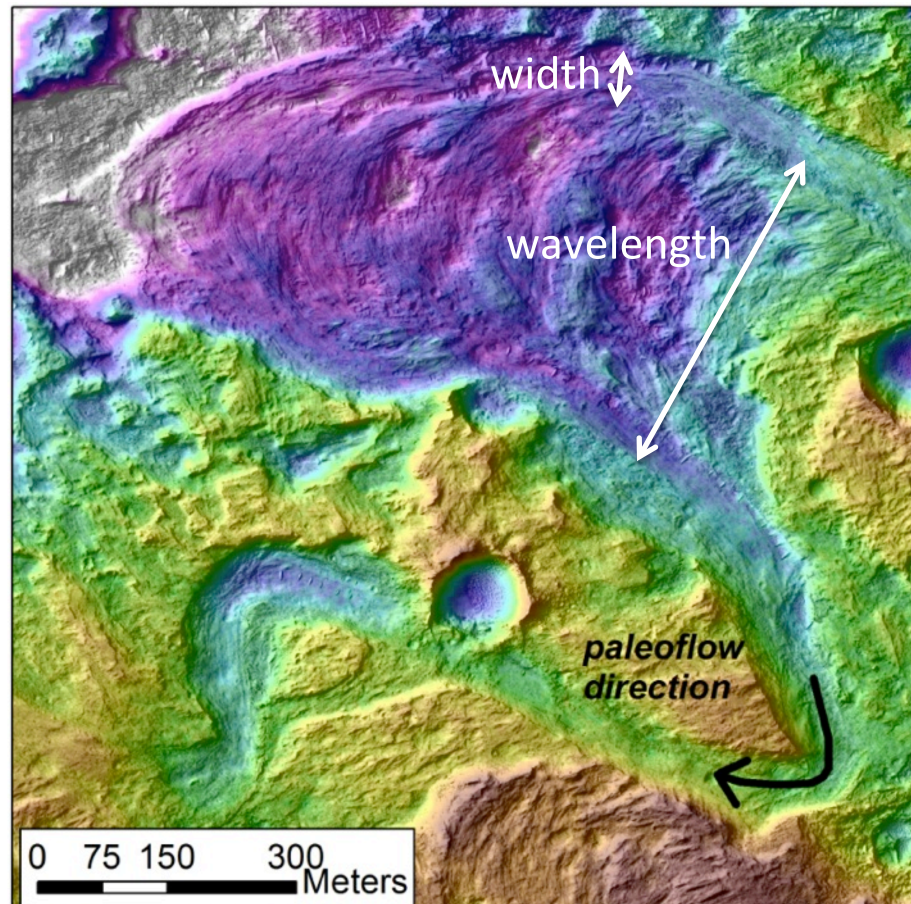
Resolving the great drying of Mars: sequence stratigraphy of Aeolis Dorsa

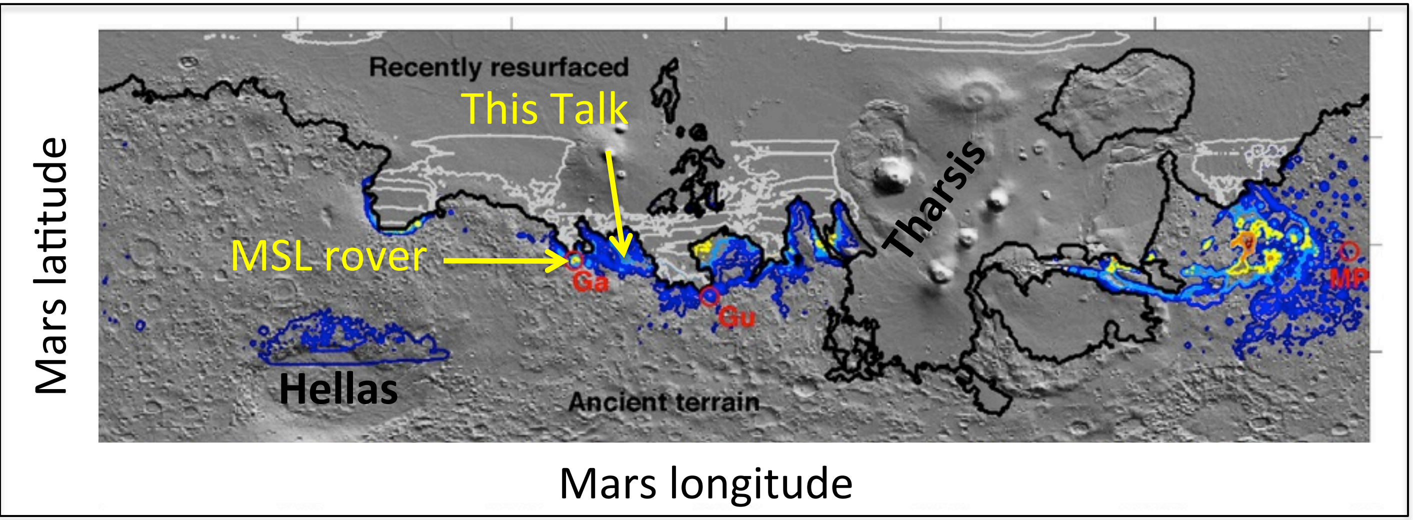
Edwin Kite (Caltech), Antoine Lucas (Caltech, Paris VII),
Oded Aharonson (Caltech, Weizmann) & John Armstrong (Weber State)

Rationale: River-deposit dimensions constrain hydrology and climate on Early Mars, but stratigraphy is essential to build a time series of constraints on climate change

Today, use geologic mapping to:
1) Order river deposits by relative time
2) Determine if drying-out of Mars was steady or unsteady



Making best use of geologic proxies for paleoclimate in Aeolis Dorsa requires stratigraphy



Map of Early Mars water-availability model output (Kite et al., 'Seasonal melting …' Icarus 2013a)

Aeolis Dorsa is a 10^5 km^2 low-latitude sedimentary-rock basin, ~10°E of MSL rover

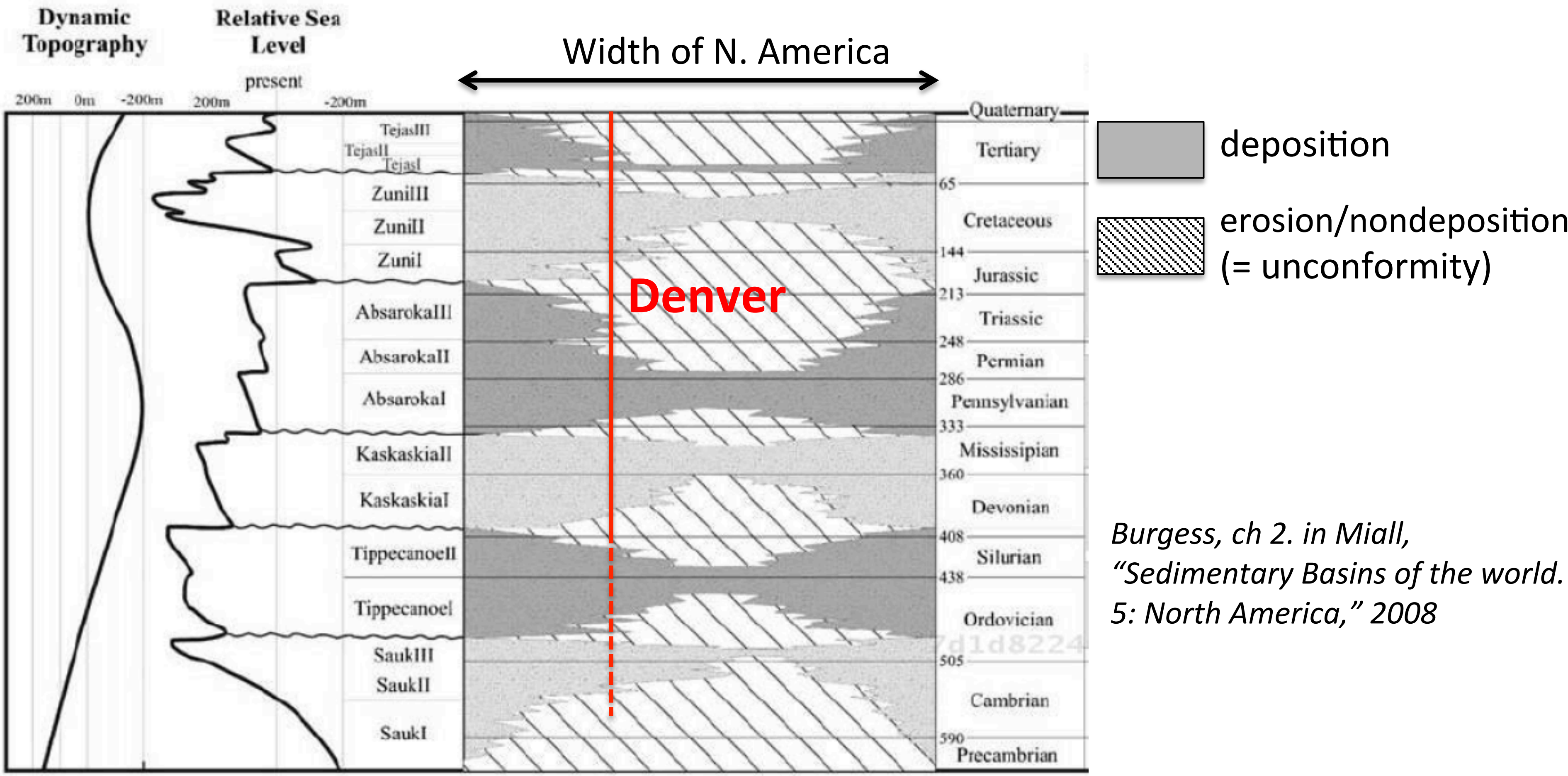
- more river deposits than the rest of Mars put together

<u>Parameters:</u>

- Discharge $10^1 – 10^3$ m^3/s	Burr et al., JGR 2010
- Age Hesperian (or older)	Zimbelman & Scheidt, Science 2012
- Deposition interval >(1-20) Ma	Kite et al., 'Pacing fluvial ..,' Icarus 2013
- Atmospheric pressure <760±70 mbar (stat. error)	Kite et al., 'Paleopressure …,' arXiv:1304.4043, 'accepted in principle,' Nature Geoscience

At Aeolis Dorsa we can constrain magnitude, duration, intermittency, and number of wet events, but we need to put river deposits in relative-time order to get a time series.

Key step in reading history of any sedimentary basin: identify unconformity-bounded sequences



Burgess, ch 2. in Miall, "Sedimentary Basins of the world. 5: North America," 2008

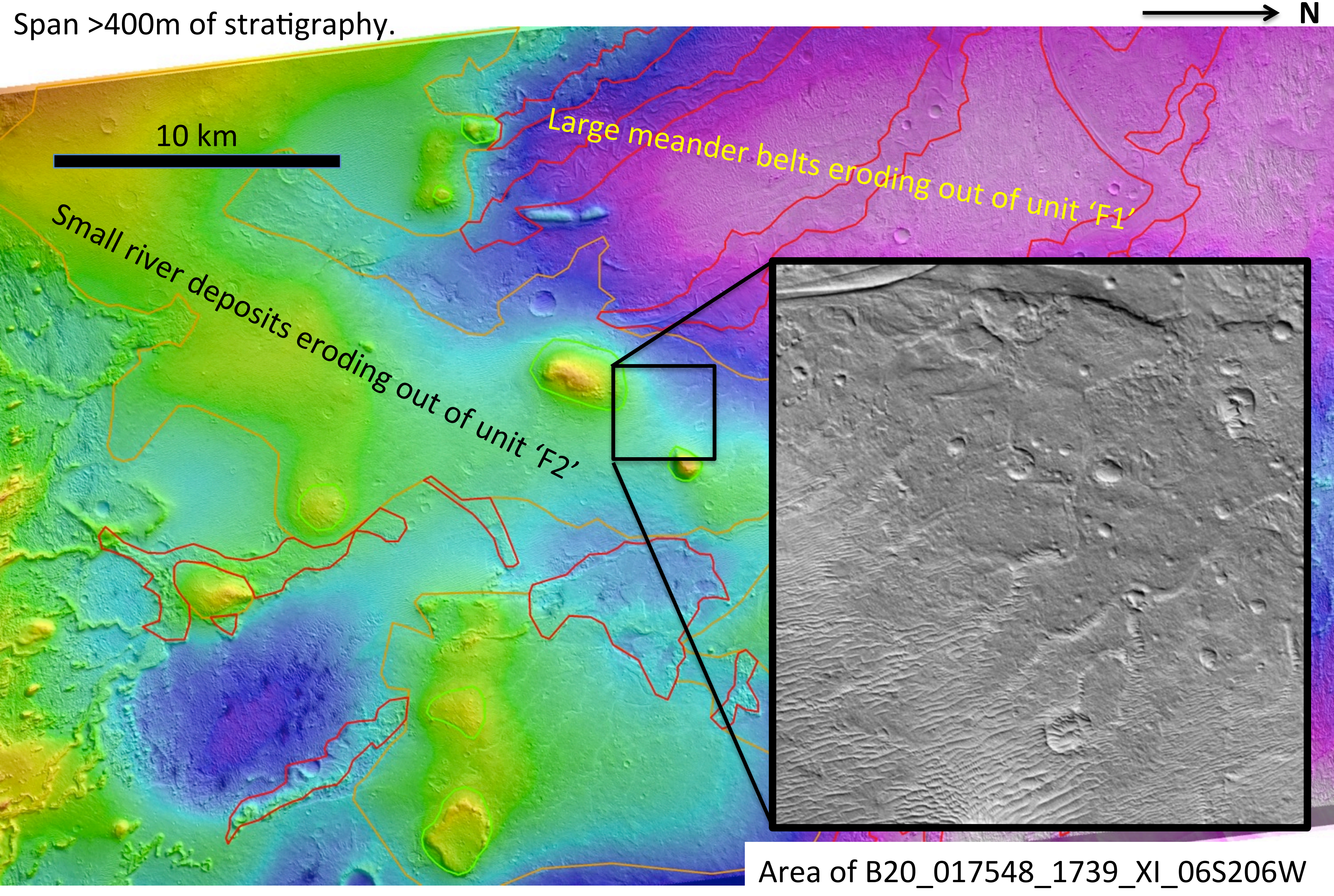
Cause of alternation between deposition and erosion: **Global sea-level change** (plate tectonics), **dynamic topography** (plate tectonics)

On Mars, unconformities within layered strata appear uncommon

Edgett (Mars J. 2005), Wiseman et al. (JGR-Planets 2007), Milliken et al. (GRL 2010), Holt et al. (Nature 2010)

River deposits are eroding out of mappable geologic units

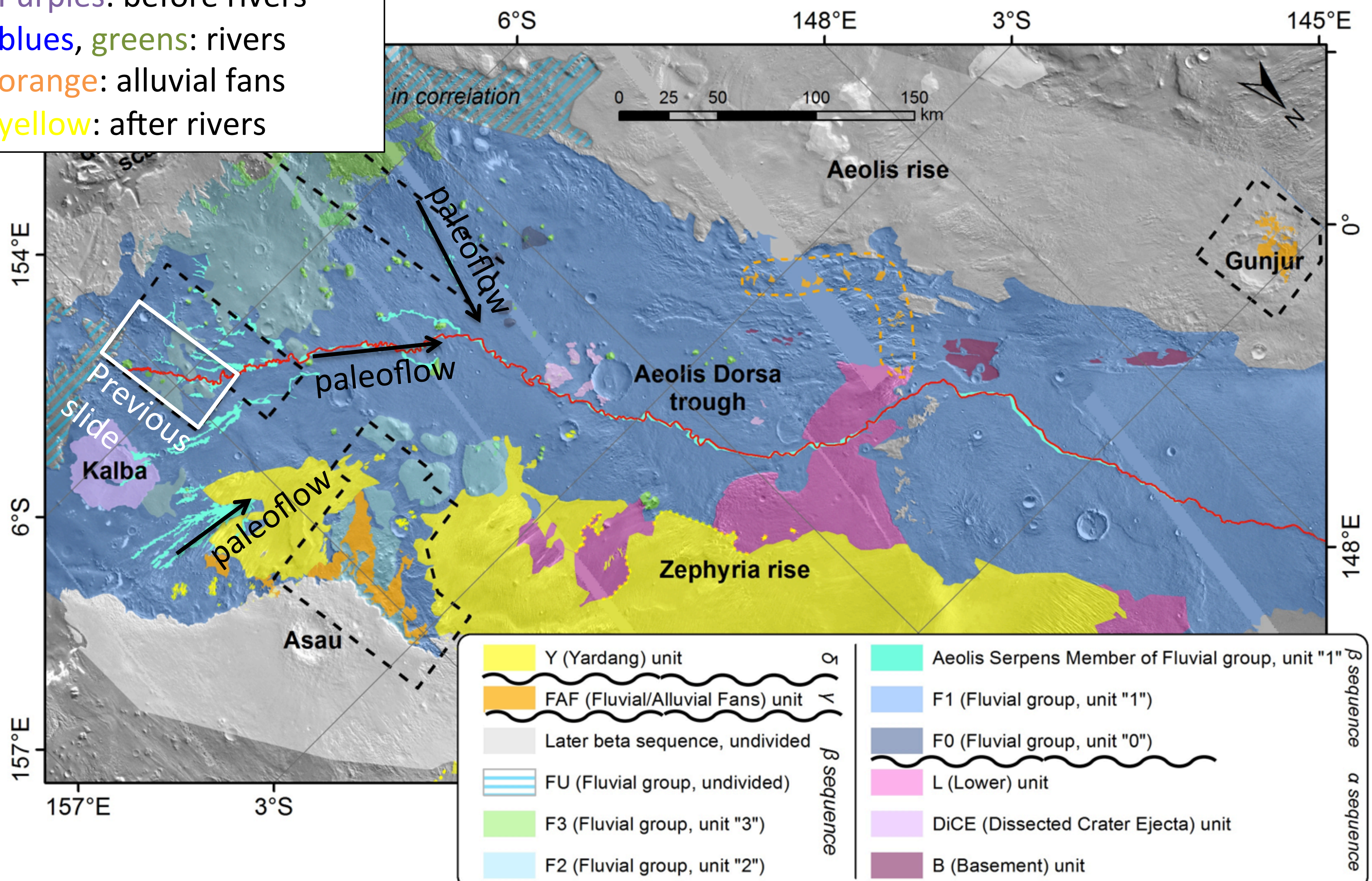
Span >400m of stratigraphy.



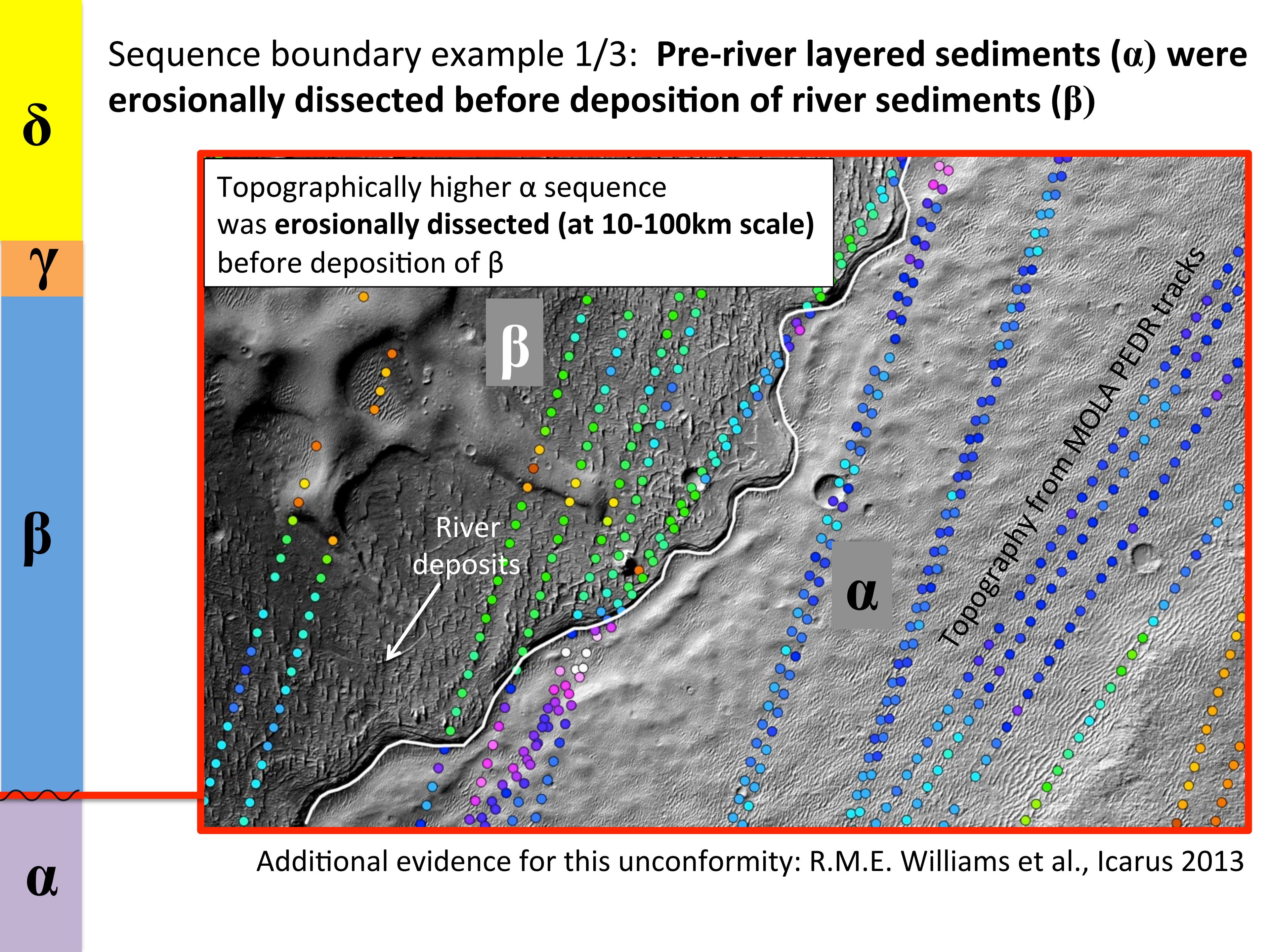
River deposits are eroding out of mappable geologic units

In time order:
Purples: before rivers
blues, greens: rivers
orange: alluvial fans
yellow: after rivers

Coherent paleoflow direction (n = 281 meanders picked)

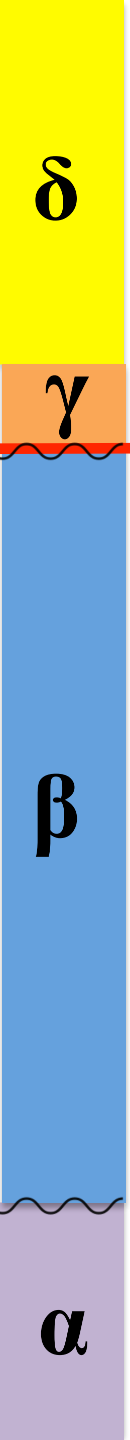


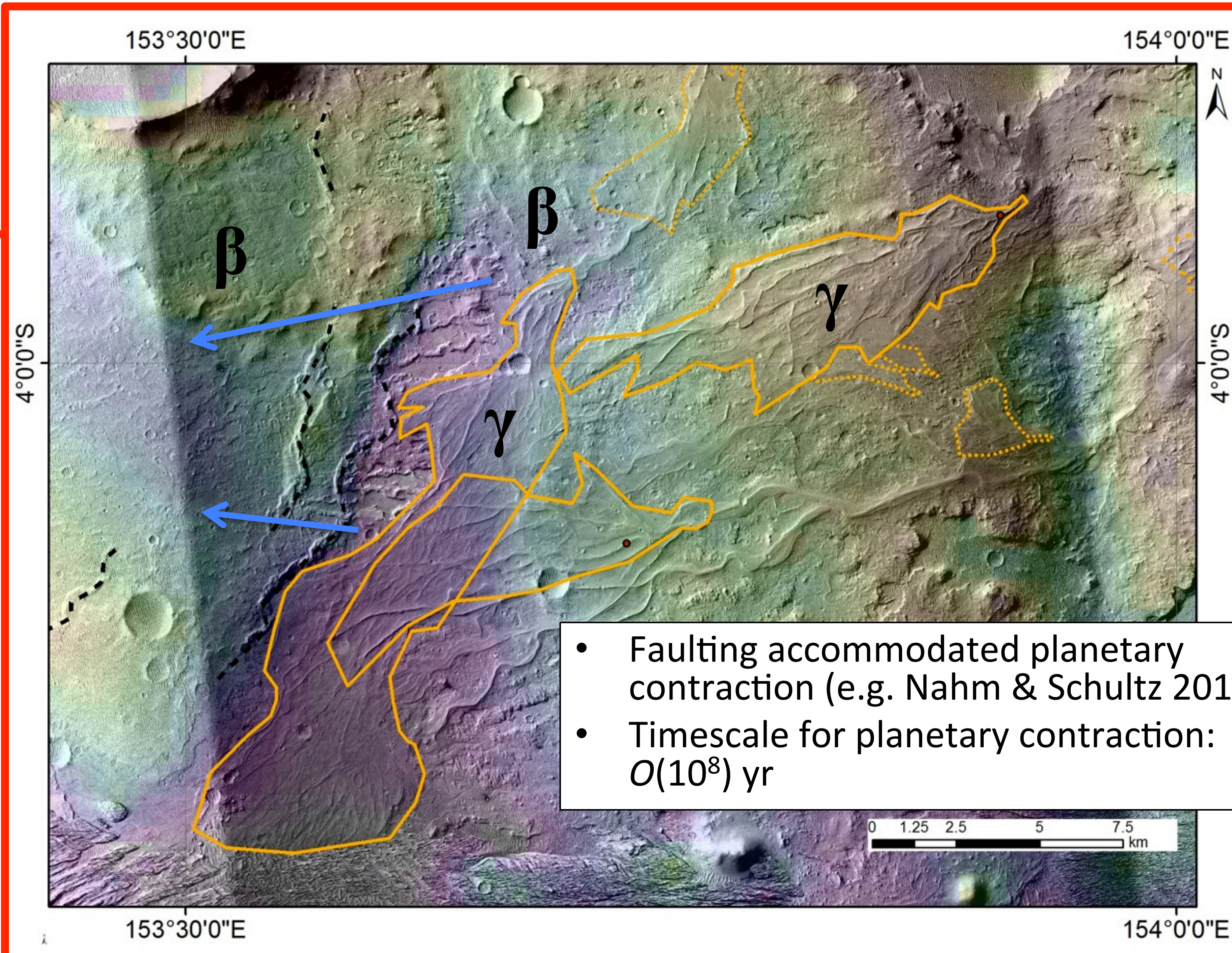
Sequence boundary example 1/3: **Pre-river layered sediments (α) were erosionally dissected before deposition of river sediments (β)**



Additional evidence for this unconformity: R.M.E. Williams et al., Icarus 2013

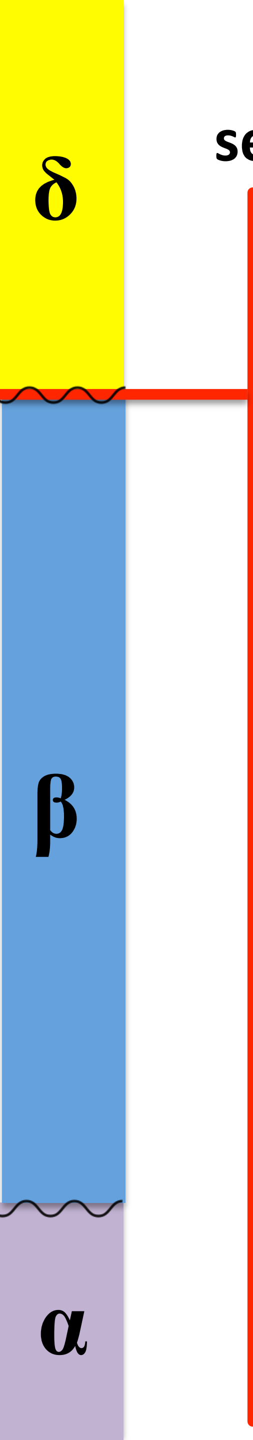
Sequence boundary example 2/3: **Thrust faulting postdates river deposits (β) and predates alluvial fans (γ)** *- At least in E of Aeolis Dorsa*

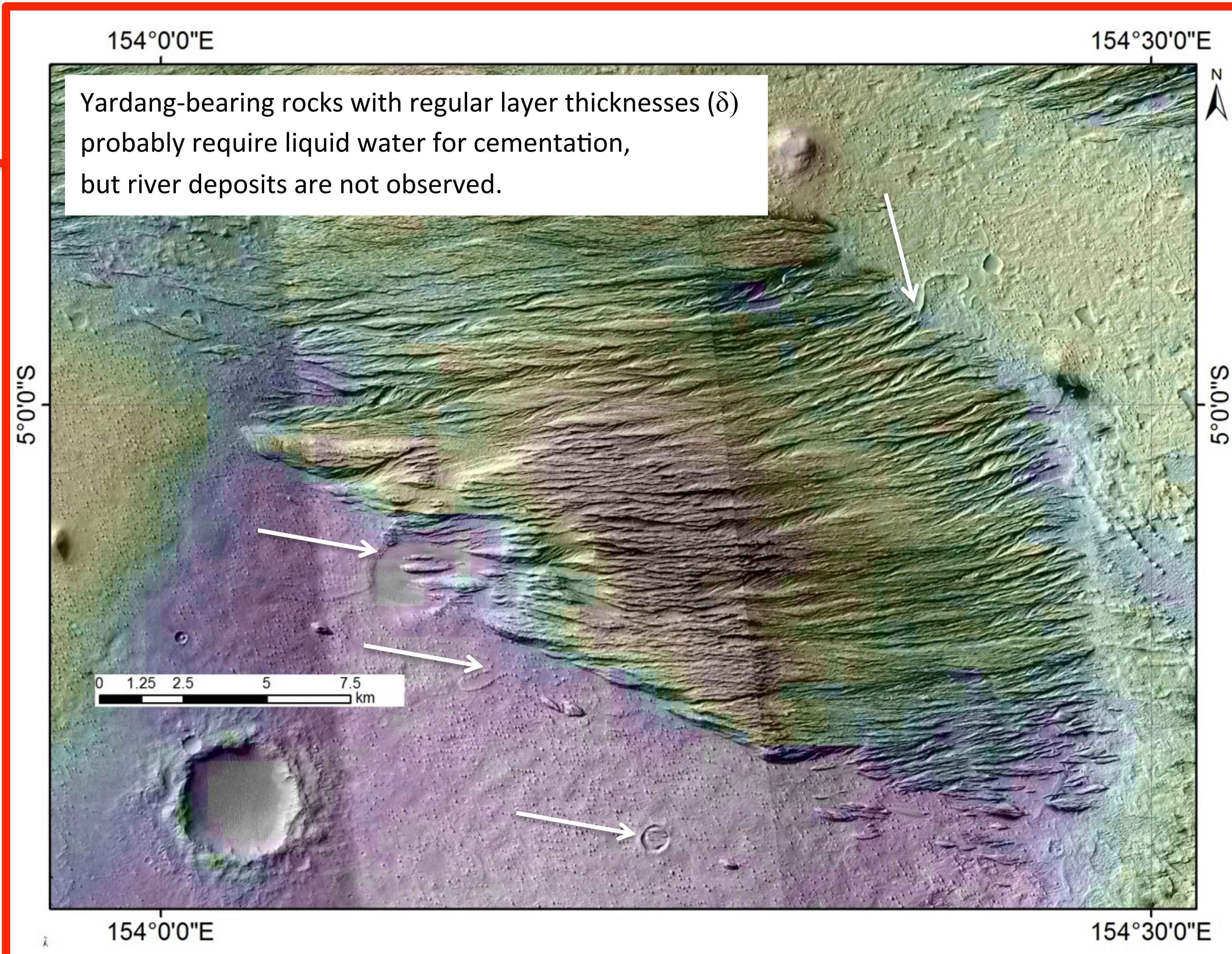




- Faulting accommodated planetary contraction (e.g. Nahm & Schultz 2011)
- Timescale for planetary contraction: $O(10^8)$ yr

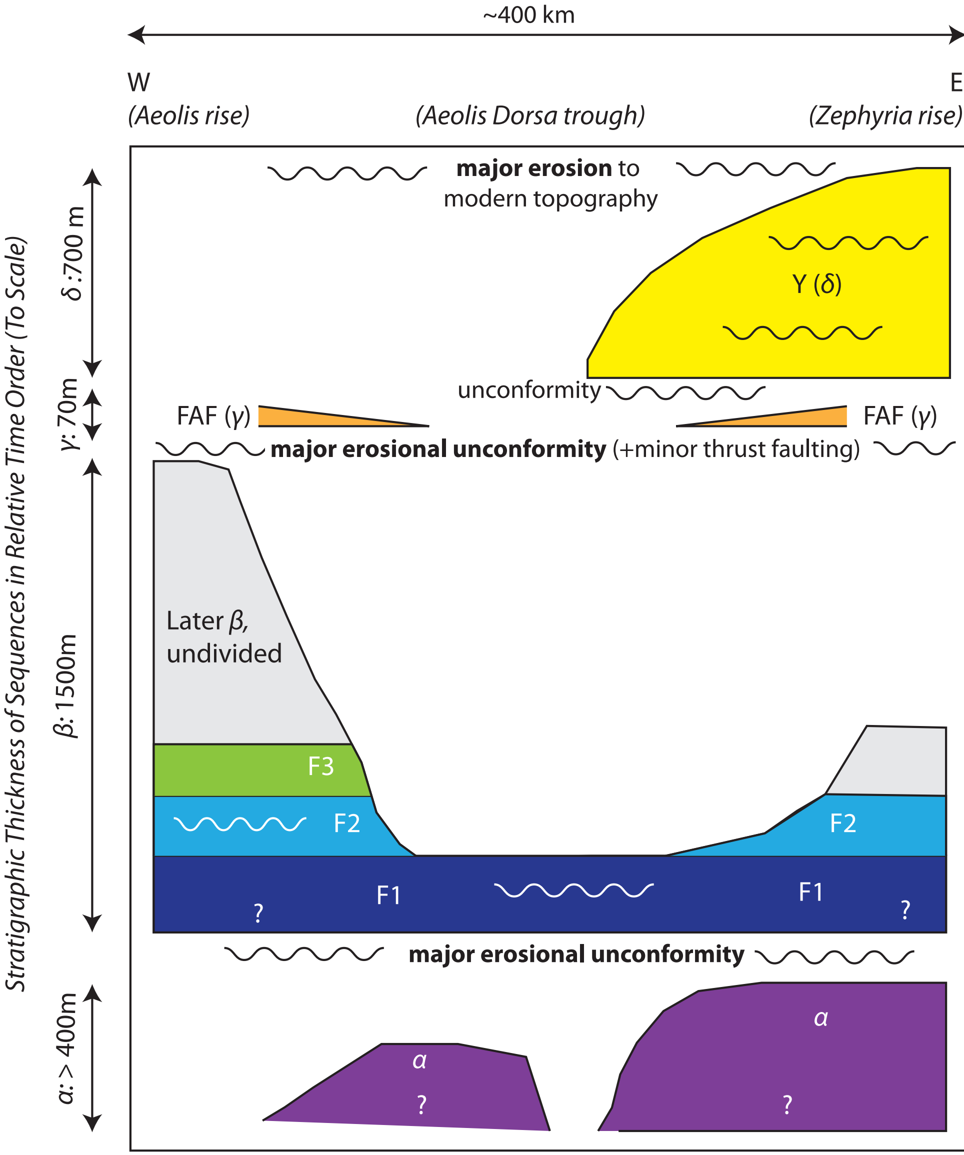
Sequence boundary example 3/3: **Densely cratered surface separates river deposits (β) from yardang-bearing materials (δ)**





Climate proxies show that the great drying of Mars was not steady

Preliminary



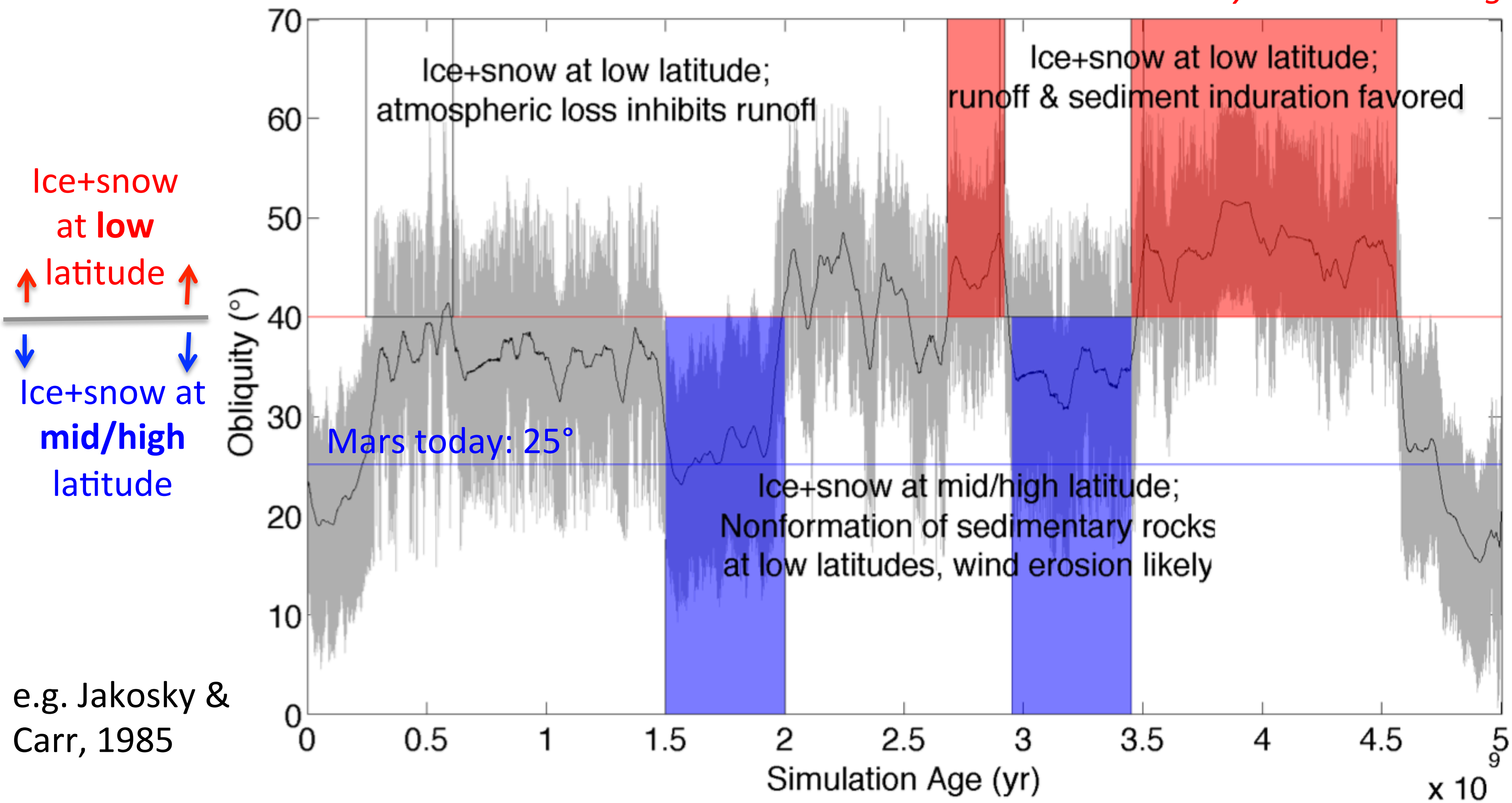
Epoch	Max. river network length (km)	Mean channel/ river deposit width (m)	*Interpretation:* Climate conditions
Deflation to modern topography	Wind erosion, dry conditions		**Dry**
δ	Aqueous cementation inferred. River deposits not found.		**Damp**
Sub-δ unconformity	Wind erosion, dry conditions		**Dry**
FAF	40	30	**Wet**
Sub-γ unconformity	Major planar erosion Wind erosion Possible minor river erosion		**Dry**
Later β	Gap in fluvial-deposit record		**?**
F3	60	60	**Very wet**
F2	20	40	**Less wet**
F1	>500	100	**Very wet**
Sub-β unconformity	Major dissectional erosion Possible fluvial or glacial		**?**
α	River deposits not found.		**?**

Next: quantify using ISEE-Mars framework - Kite et al., "Seasonal melting ...," Icarus 2013

Mean-obliquity shifts are a plausible **driving mechanism** of observed shifts between erosion and deposition.

- Plate tectonics & eustasy unlikely
- Implies signal should be **global**

Shown: one of many possible Mars obliquity histories.
Calculation by John Armstrong



e.g. Jakosky & Carr, 1985

Conclusions

- Stratigraphy consistent with Aeolis Dorsa recording an unusually complete history of Early Mars fluvial environments.

  (candidate global reference section)

- Drying-out of Mars climate was not steady.

  Goal: extract enough constraints to resolve disagreements about the cause and duration of warm/wet climates.

  Requires quantitative models linking sed./strat. to climate.

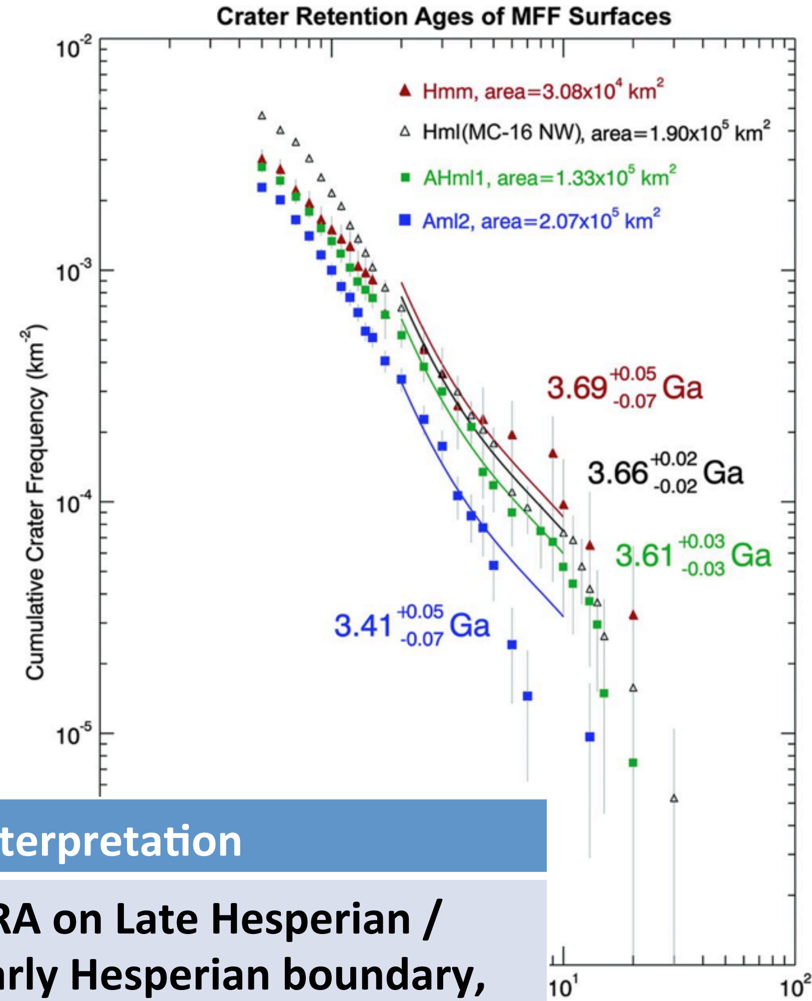
More information: Kite et al., 'Seasonal melting …' *Icarus* 2013,
Kite et al., 'Growth and form …' *Geology* 2013,
Kite et al., 'Pacing fluvial …' *Icarus* 2013,
Kite et al., 'Paleopressure …' *Nature Geoscience,* 'accepted in principle,' arxiv:1304.4043
gps.caltech.edu/~kite

With thanks to: Mike Lamb, Woody Fischer, Devon Burr, Robert Jacobsen, Rebecca Williams, Roman diBiase, Or Bialik, and all the participants in Caltech's Mars Fluvial Geomorphology Reading Group

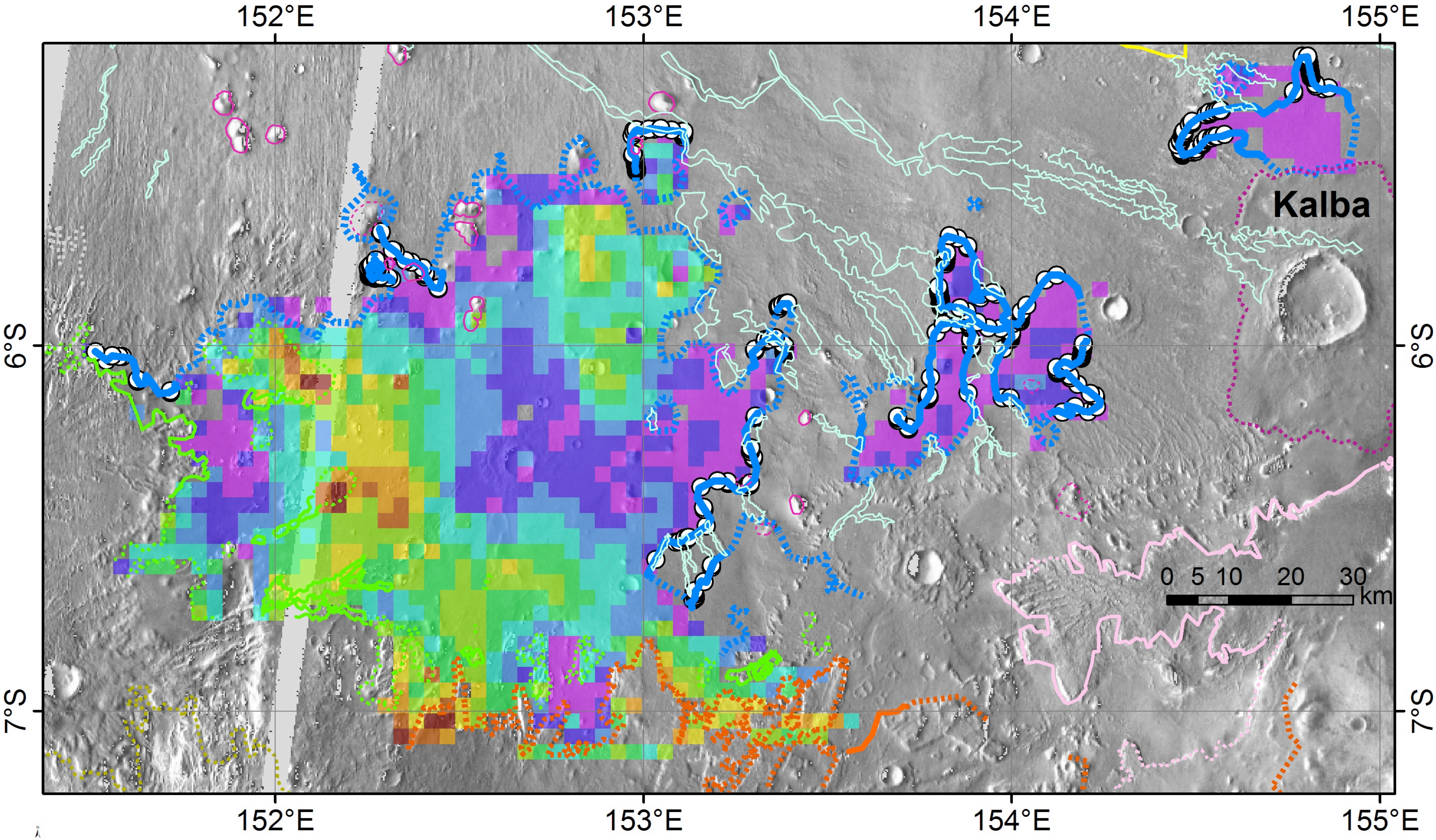
End of presentation

Crater density consistent with Noachian/Hesperian boundary – and density of rivers suggests that

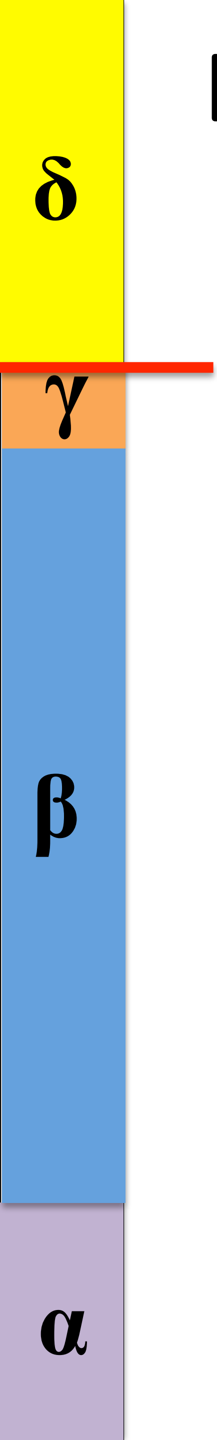
- Major Amazonian erosion has occurred (mesas)
- Zimbelman & Scheidt (Science), 2012 "craters on a nearby exposure of middle-member material (**superposed on the [rivers]**) indicate a late Hesperian age
- CRA of rivers is on Late Hesperian/ Early Amazonian boundary



	N(1)	N(2)	N(5)	Interpretation
Postfluvial + Undetermined	**2049±158**	**634±88**	**37±21**	**CRA on Late Hesperian / Early Hesperian boundary, consistent with overall correlation to Noachian/ Hesperian boundary**
Postfluvial only	1049±113	415±71	37±21	
Synfluvial				

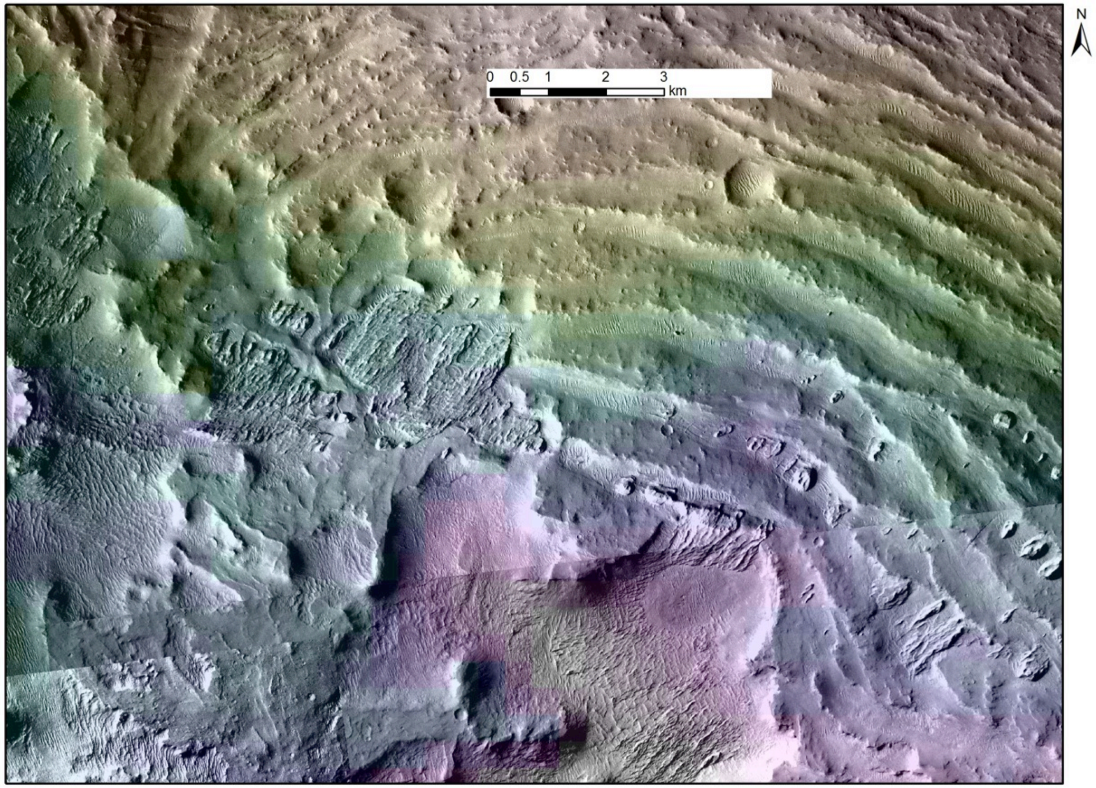


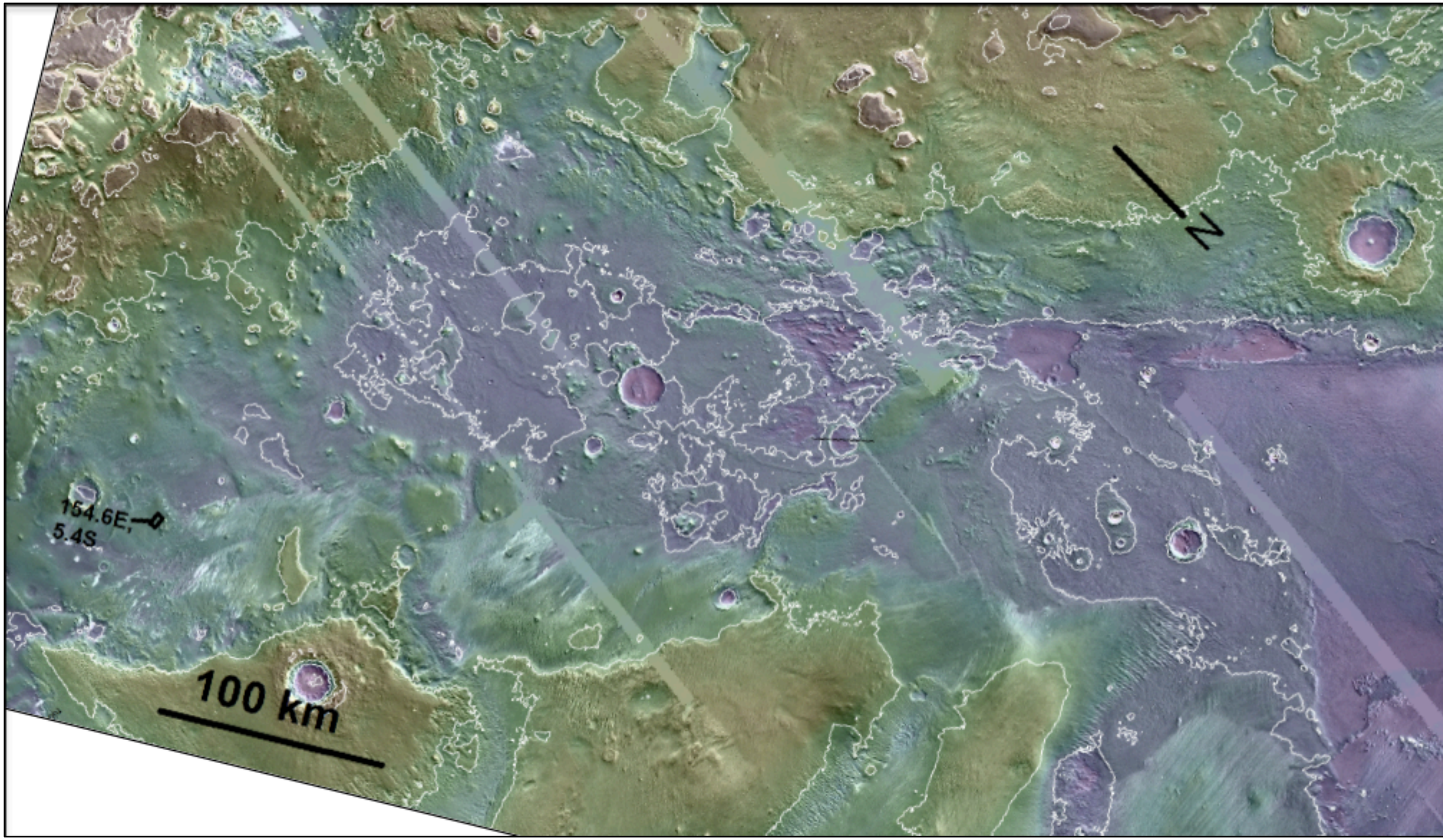
152°E
153°E
154°E
155°E
6°S
7°S
Kalba
0 5 10 20 30
km



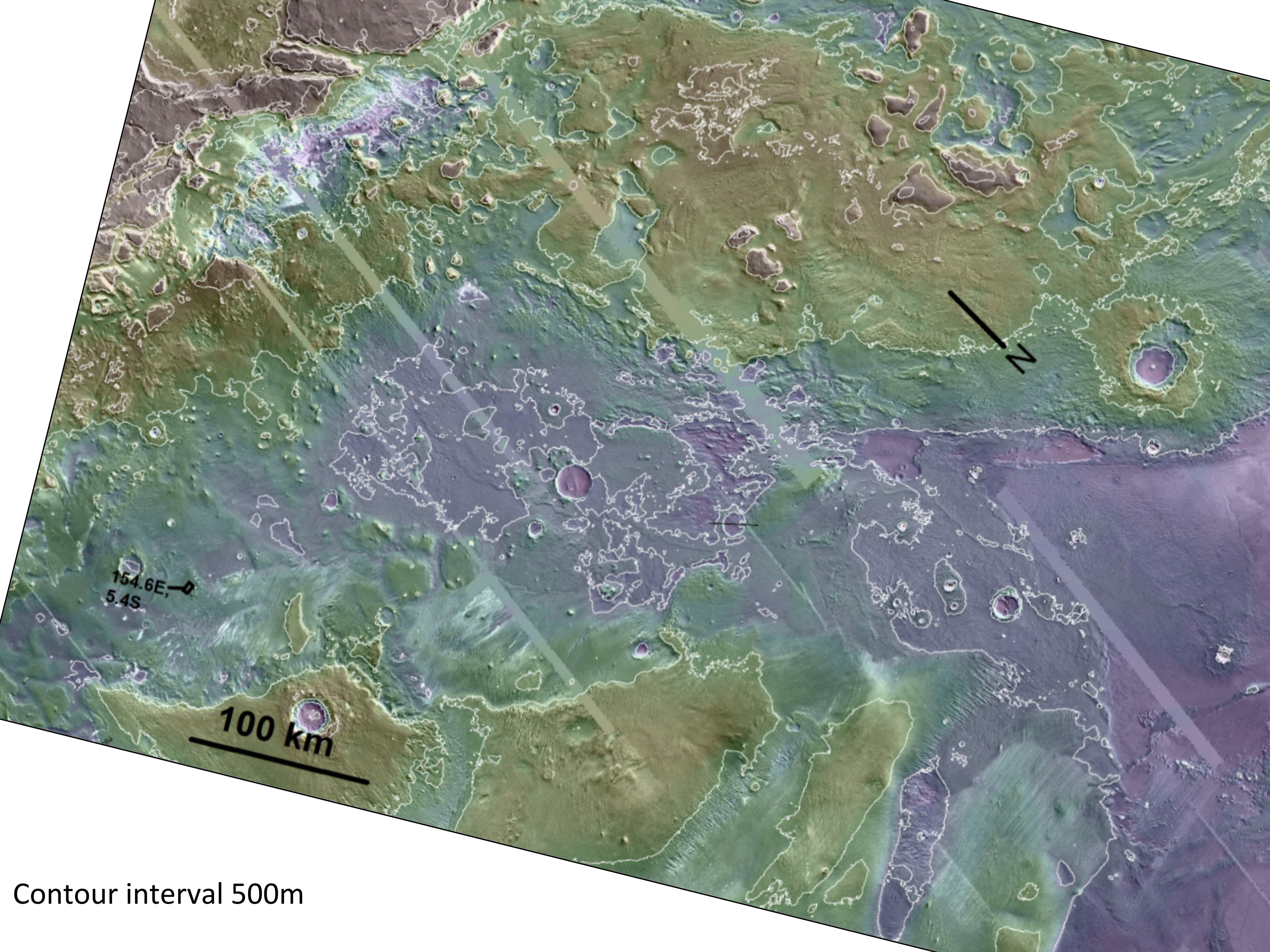
Evidence for additional unconformities

- Some evidence for unconformity separating alluvial fans and yardang-bearing materials
- Strong evidence for unconformities *within* fluvial deposits, at multiple scales





Contour interval 500m



Contour interval 500m