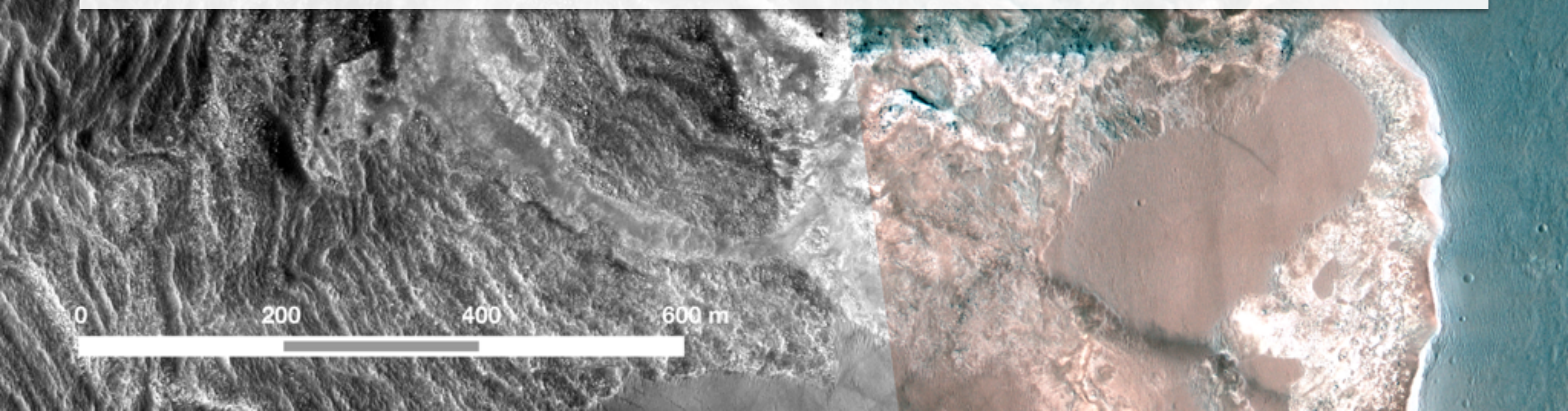
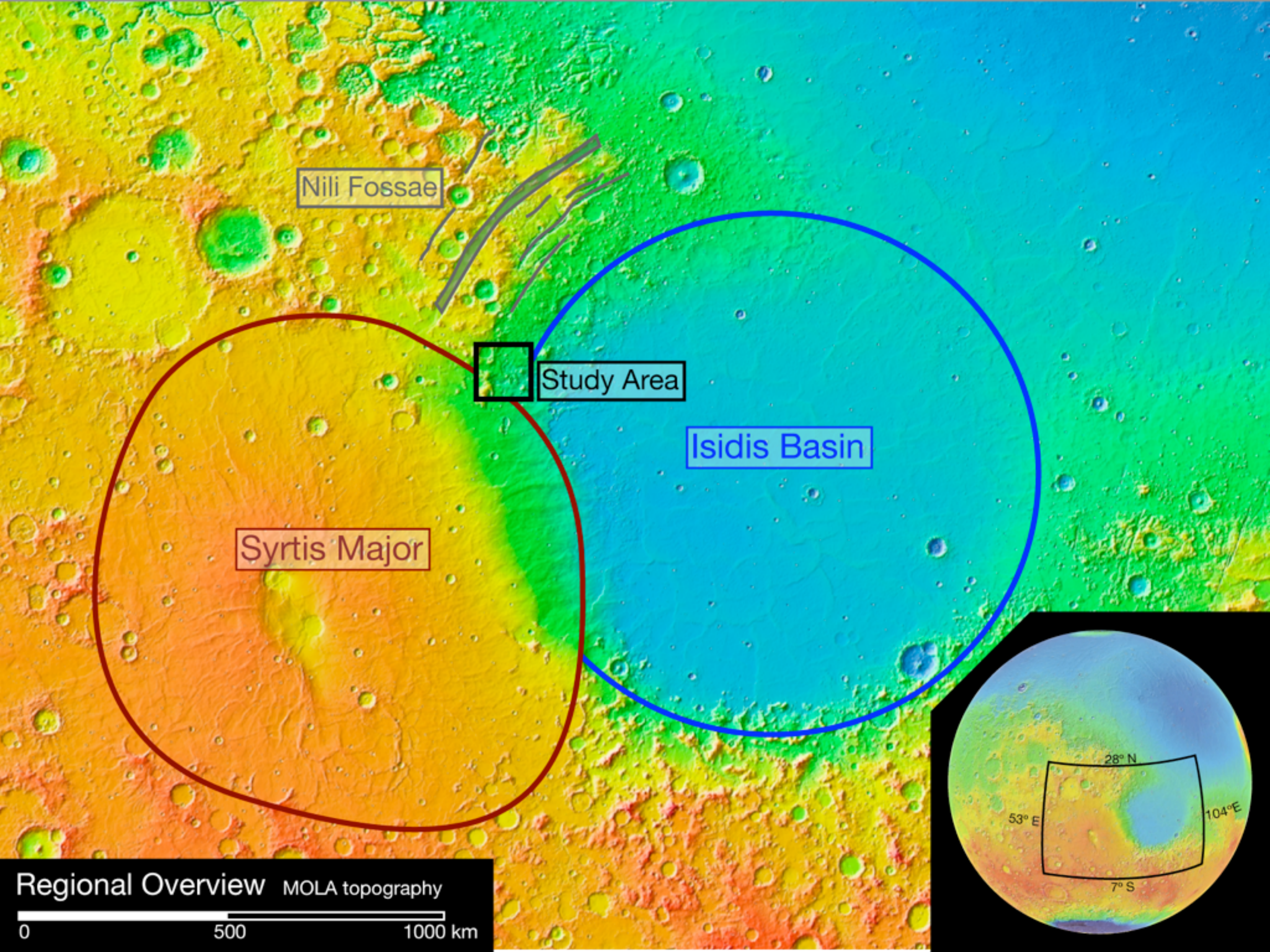
The deposition and alteration history of the northeast Syrtis layered sulfates

Daven Quinn[1] and Bethany Ehlmann[1,2]

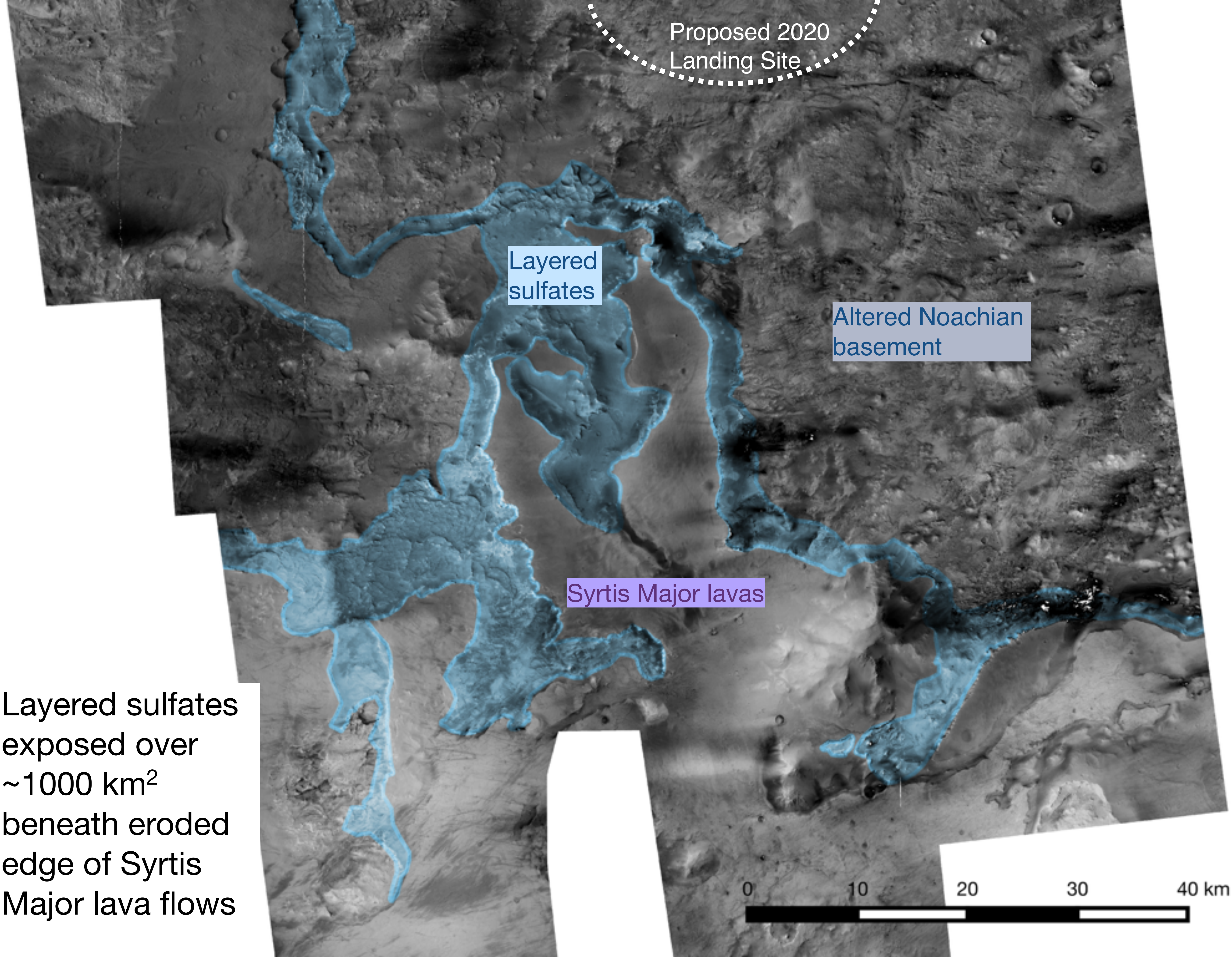
[1] California Institute of Technology
[2] Jet Propulsion Laboratory

GSA 2015





Nili Fossae
Study Area
Isidis Basin
Syrtis Major
Regional Overview
MOLA topography
0
500
1000 km
28° N
53° E
104°E
7° S

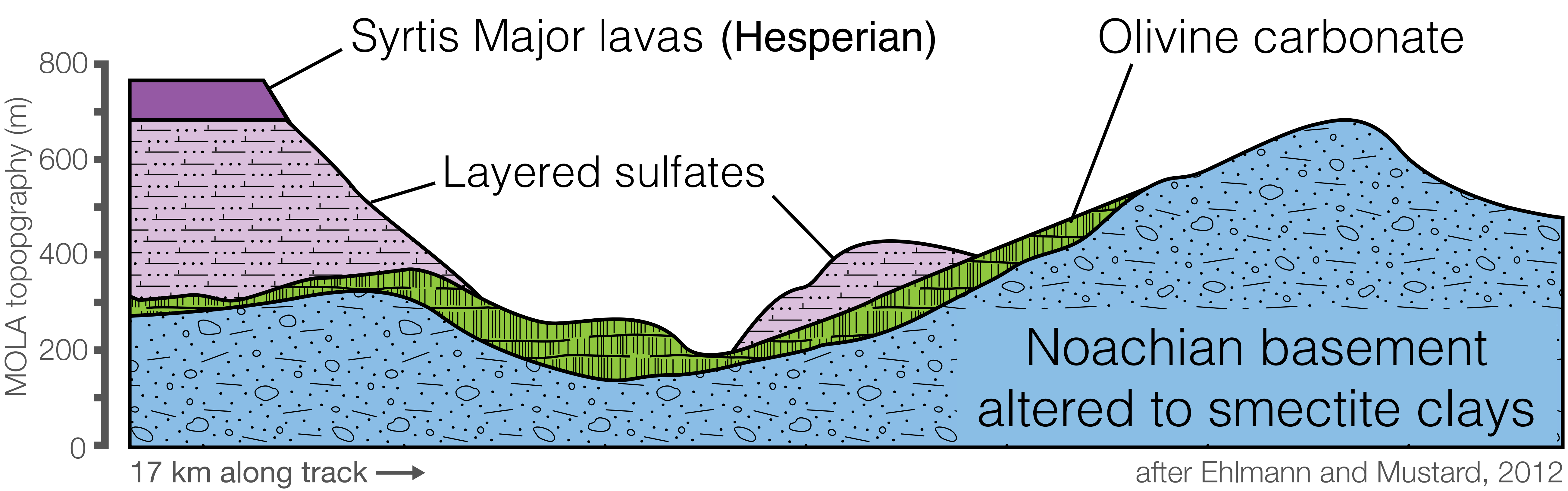


Layered sulfates exposed over ~1000 km^2 beneath eroded edge of Syrtis Major lava flows

Northeast Syrtis sequence spans first billion years of Mars history

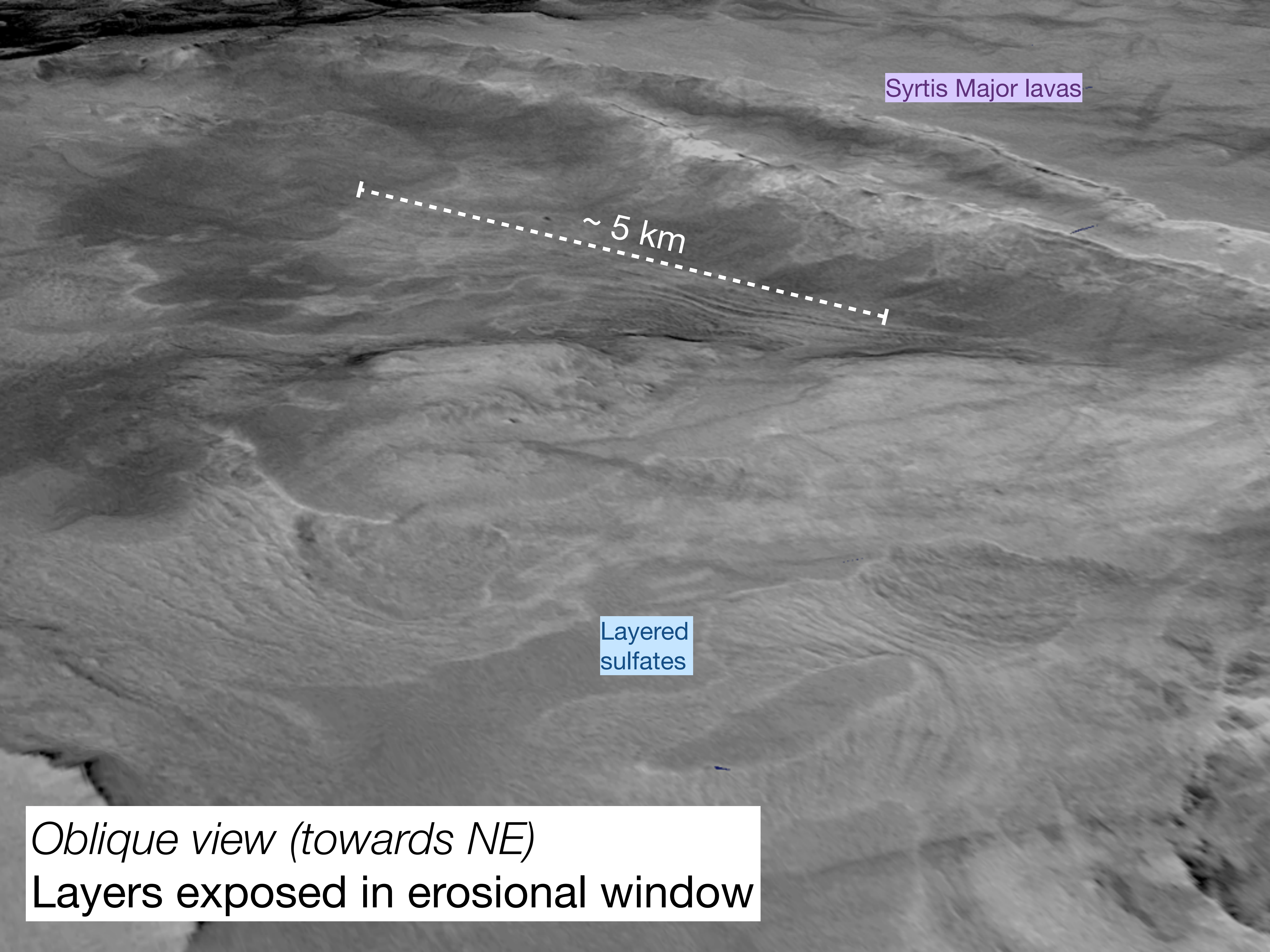
Layered sulfates record major environmental change during Noachian—Hesperian transition

- More acidic style of alteration
- Capped by un-altered Syrtis Major lavas
- Proxy for global change

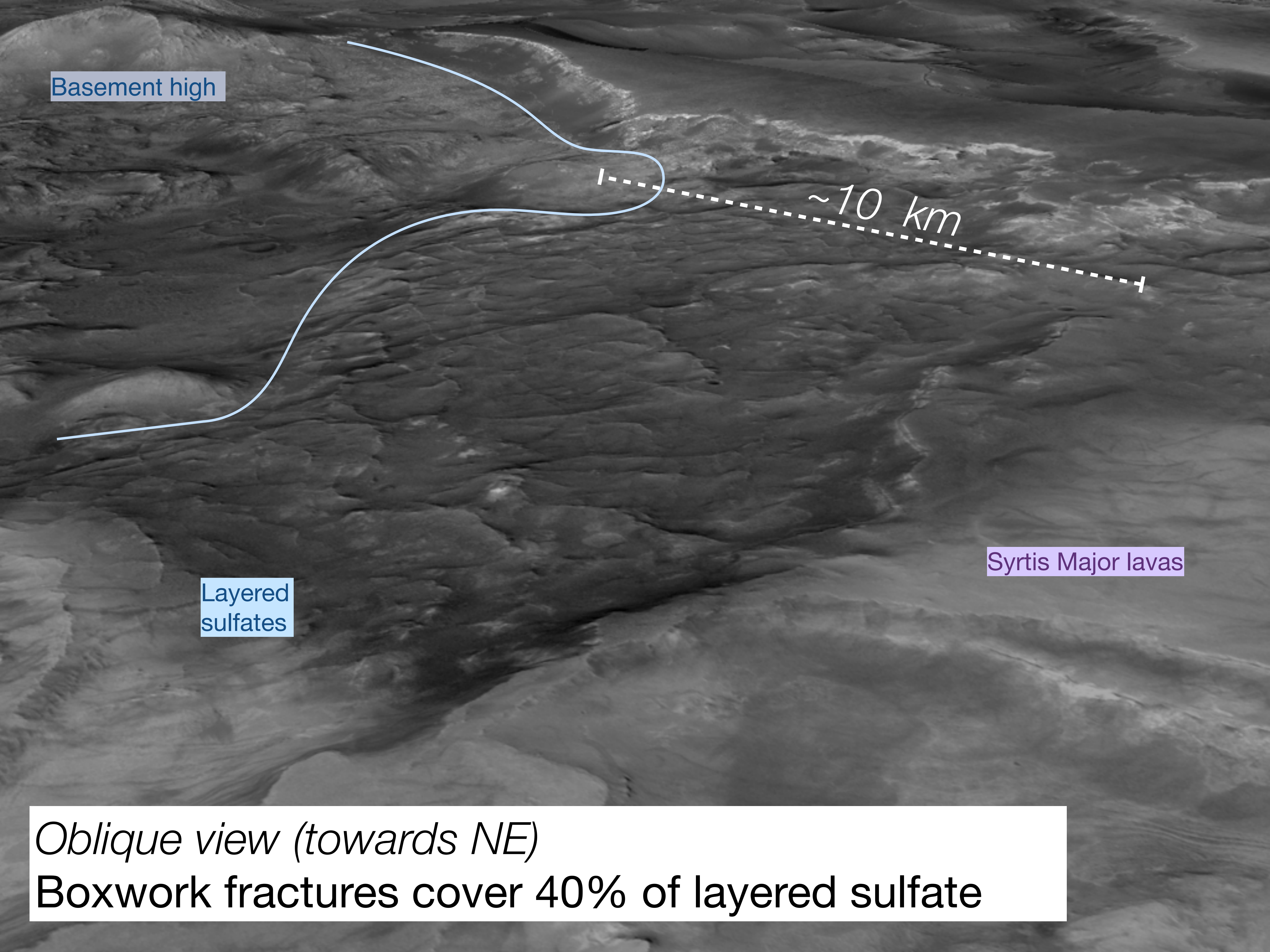


Layered sulfates ~ 300m thick atop basement

PSP_009217_1975 - ESP_027625_1975
View to the northwest

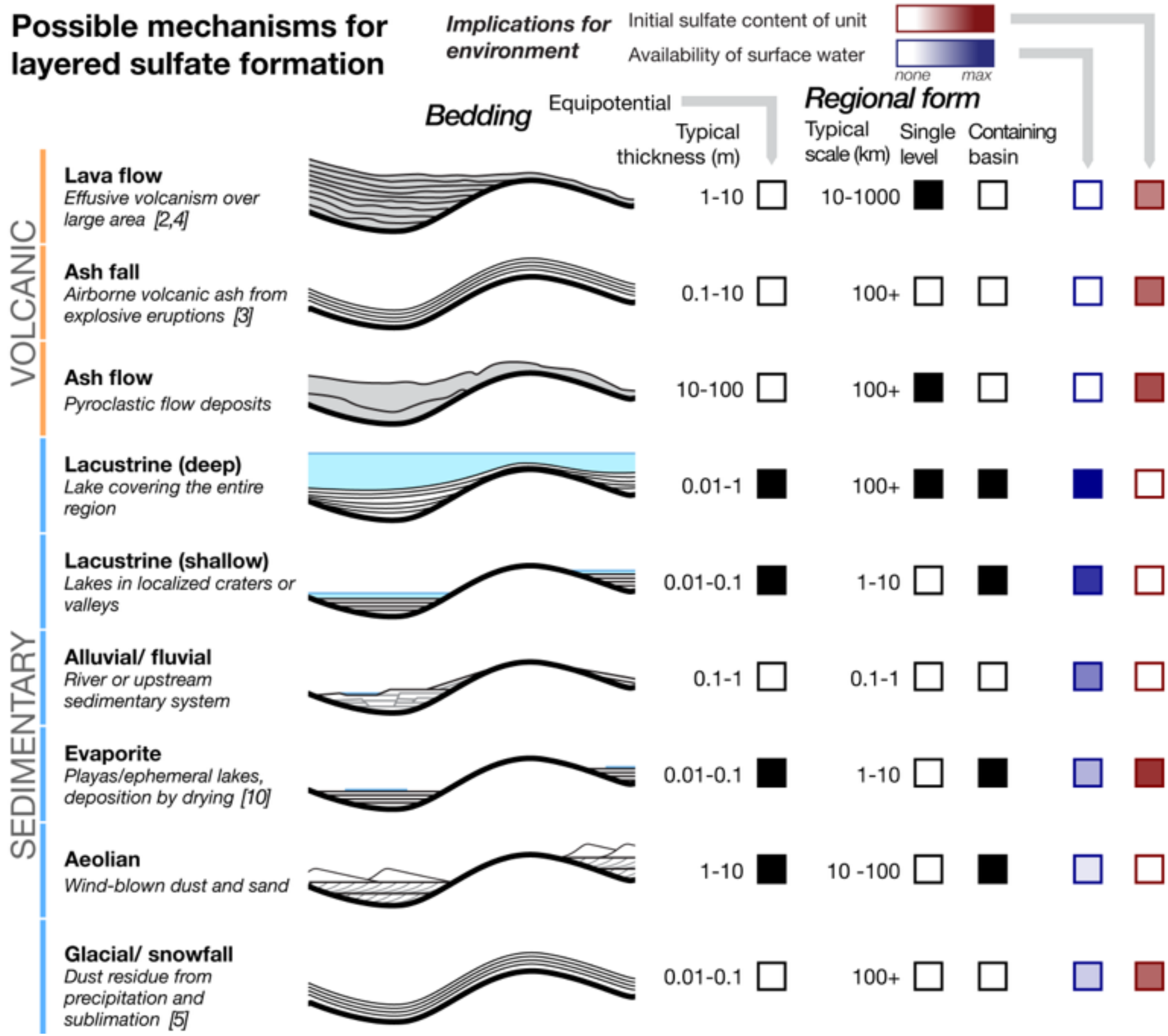


Syrtis Major lavas
~ 5 km
Layered
sulfates
Oblique view (towards NE)
Layers exposed in erosional window

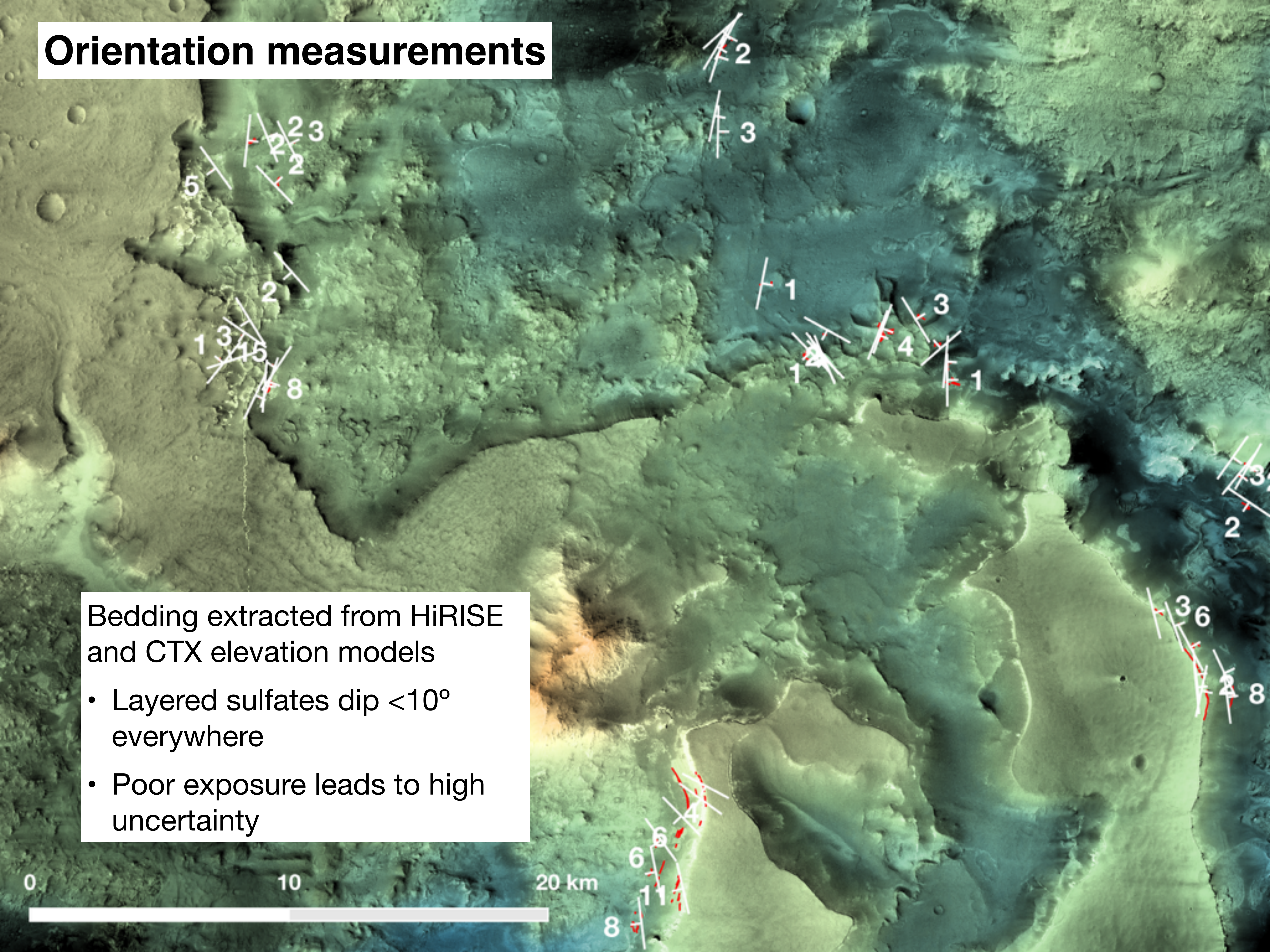


Oblique view (towards NE)

Boxwork fractures cover 40% of layered sulfate


Possible mechanisms for layered sulfate formation
Implications for environment
Initial sulfate content of unit
Availability of surface water
none
max
Bedding
Equipotential
Typical thickness (m)
Regional form
Typical scale (km)
Single level
Containing basin
VOLCANIC
SEDIMENTARY
Lava flow
Effusive volcanism over large area [2,4]
1-10
10-1000
Ash fall
Airborne volcanic ash from explosive eruptions [3]
0.1-10
100+
Ash flow
Pyroclastic flow deposits
10-100
100+
Lacustrine (deep)
Lake covering the entire region
0.01-1
100+
Lacustrine (shallow)
Lakes in localized craters or valleys
0.01-0.1
1-10
Alluvial/ fluvial
River or upstream sedimentary system
0.1-1
0.1-1
Evaporite
Playas/ephemeral lakes, deposition by drying [10]
0.01-0.1
1-10
Aeolian
Wind-blown dust and sand
1-10
10 -100
Glacial/ snowfall
Dust residue from precipitation and sublimation [5]
0.01-0.1
100+

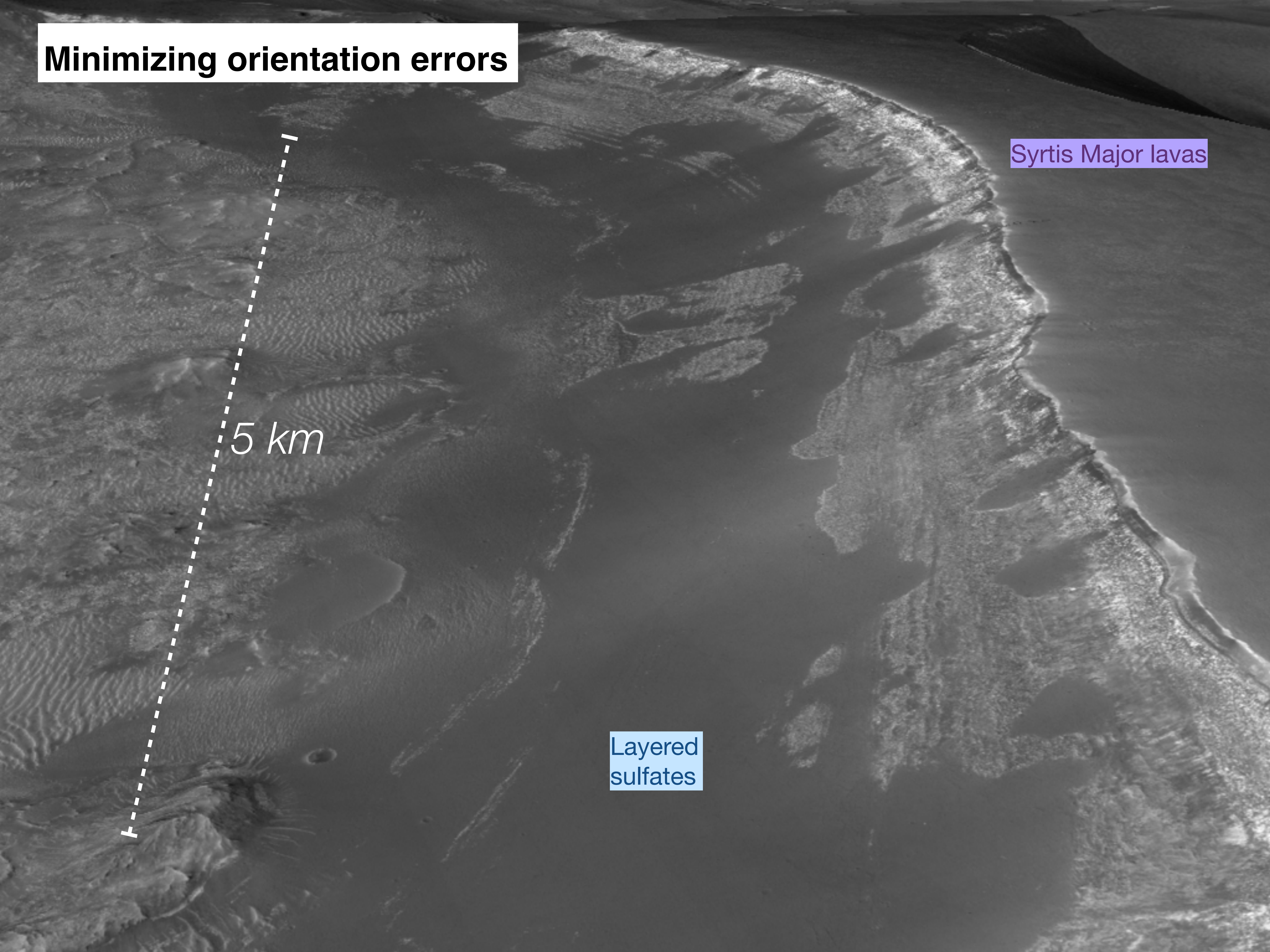
Orientation measurements



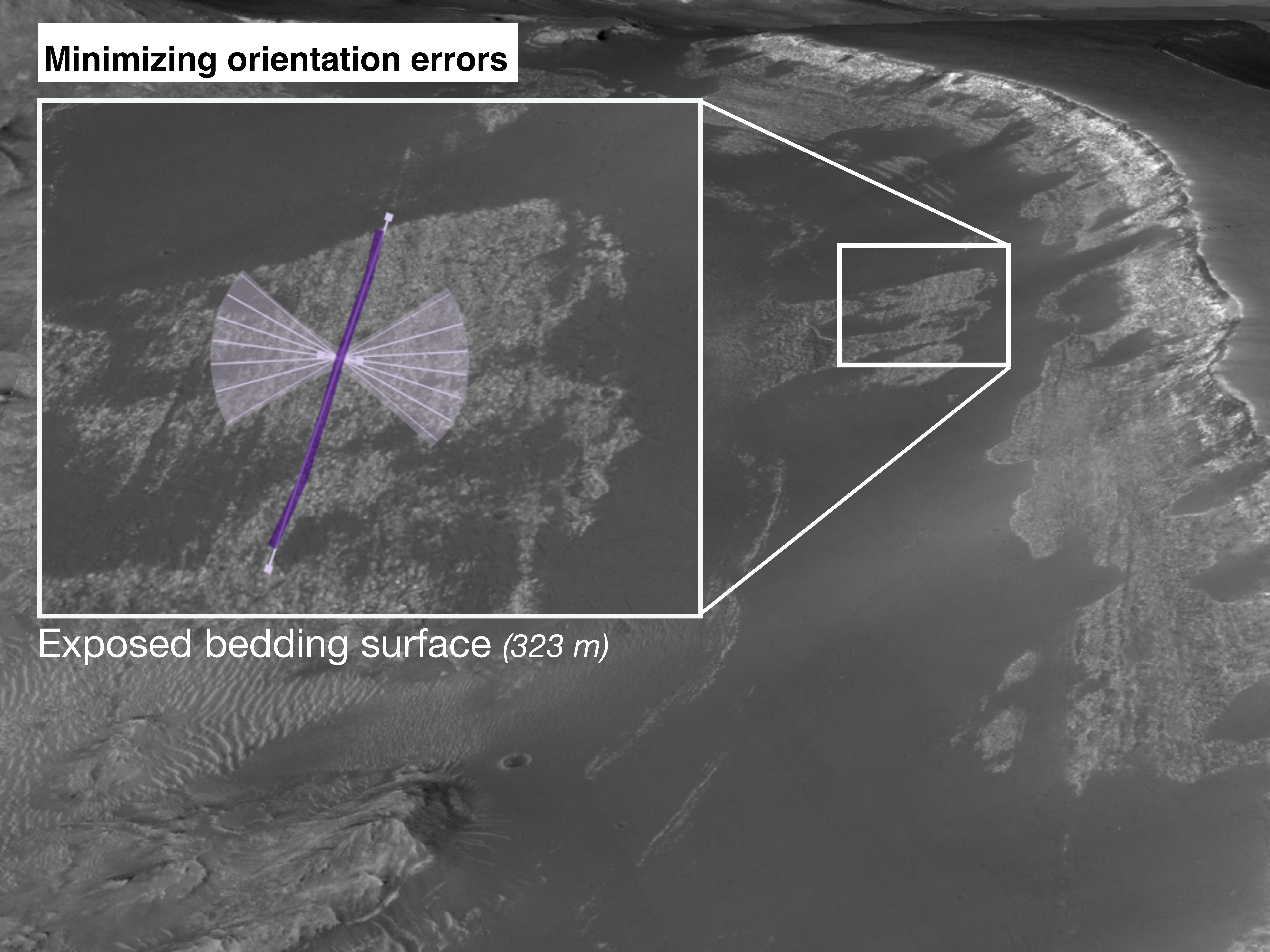
Bedding extracted from HiRISE and CTX elevation models

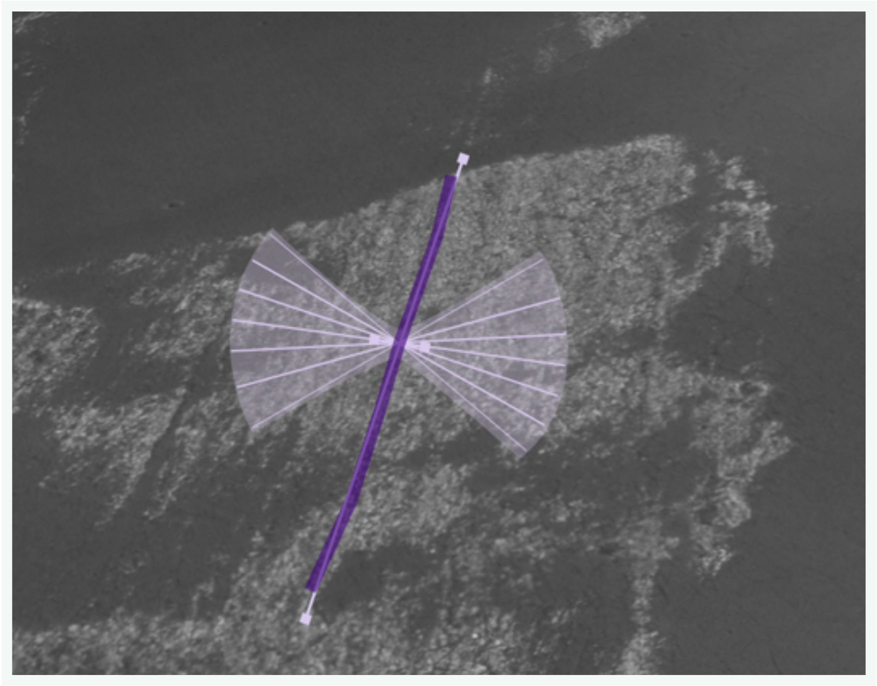
- Layered sulfates dip <10° everywhere
- Poor exposure leads to high uncertainty

Minimizing orientation errors



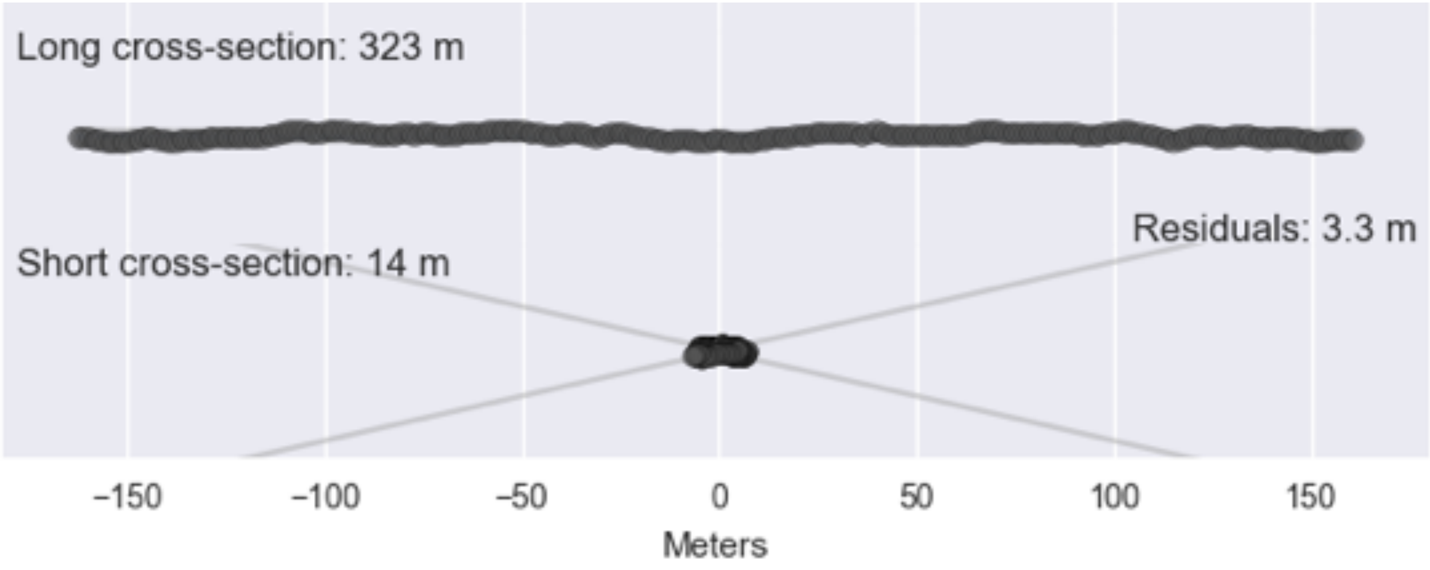
Minimizing orientation errors

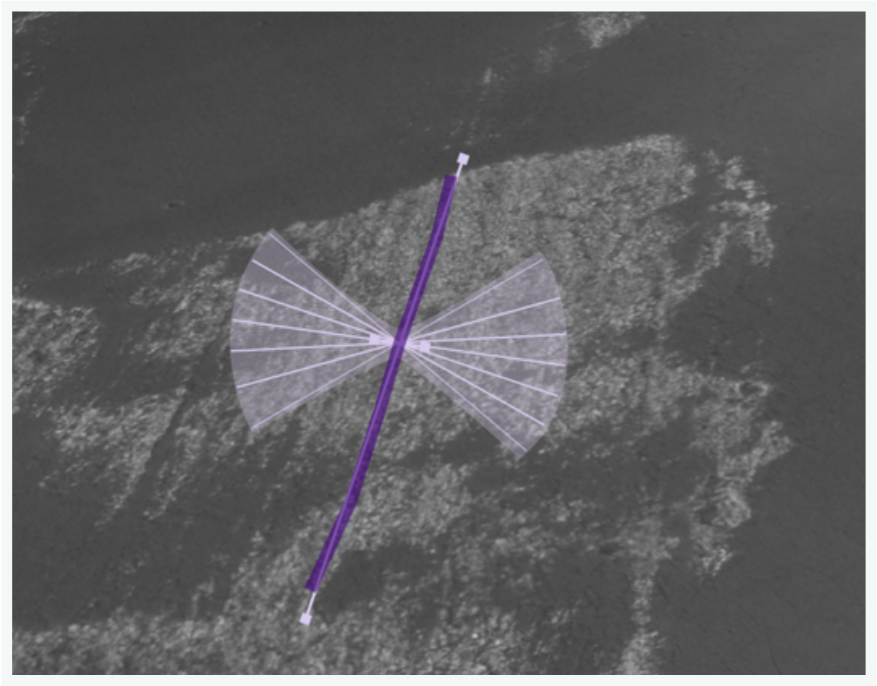




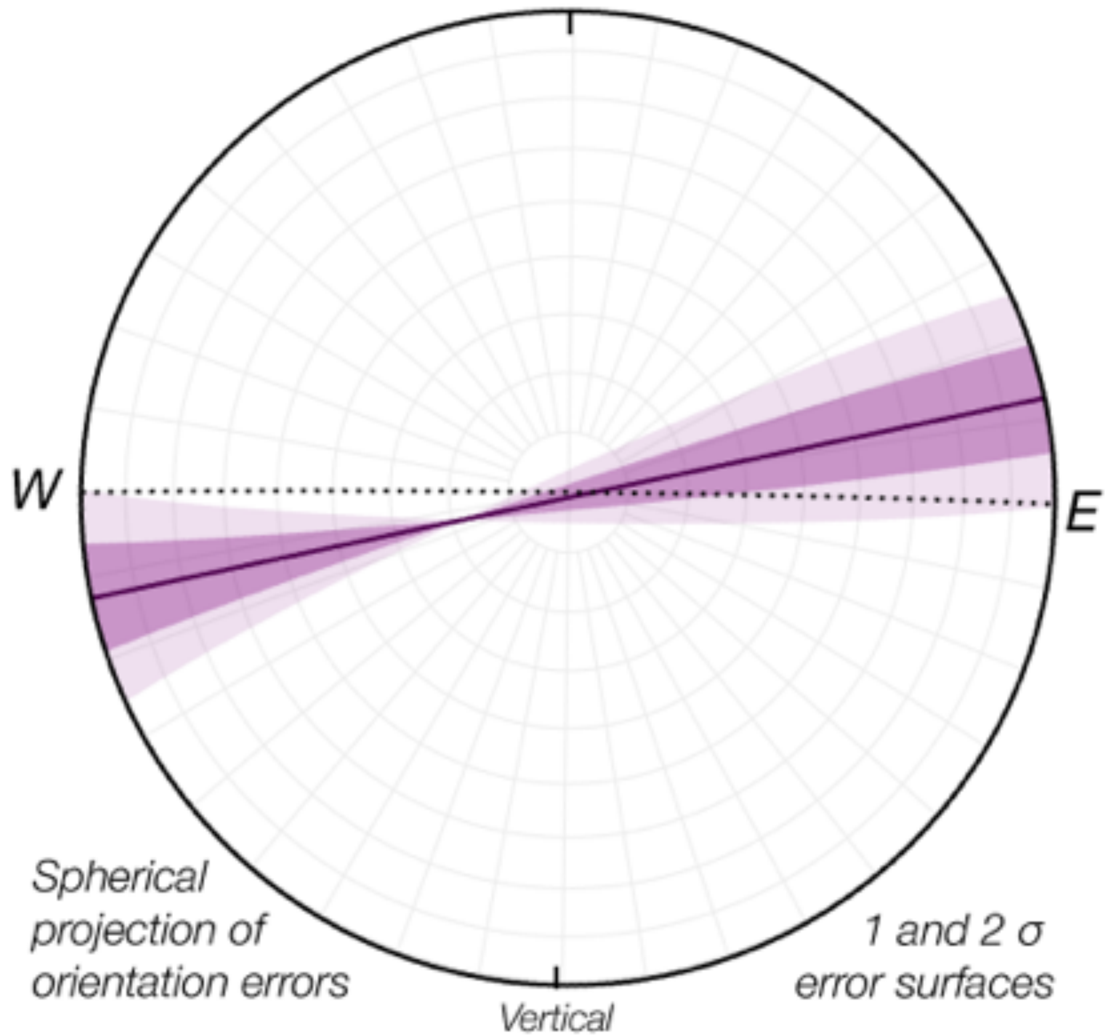
Principal component analysis

- Generalization of linear least squares
- Visualization of **shape of input data** and **residuals along major axes**
- Enables accounting for **arbitrarily oriented errors**

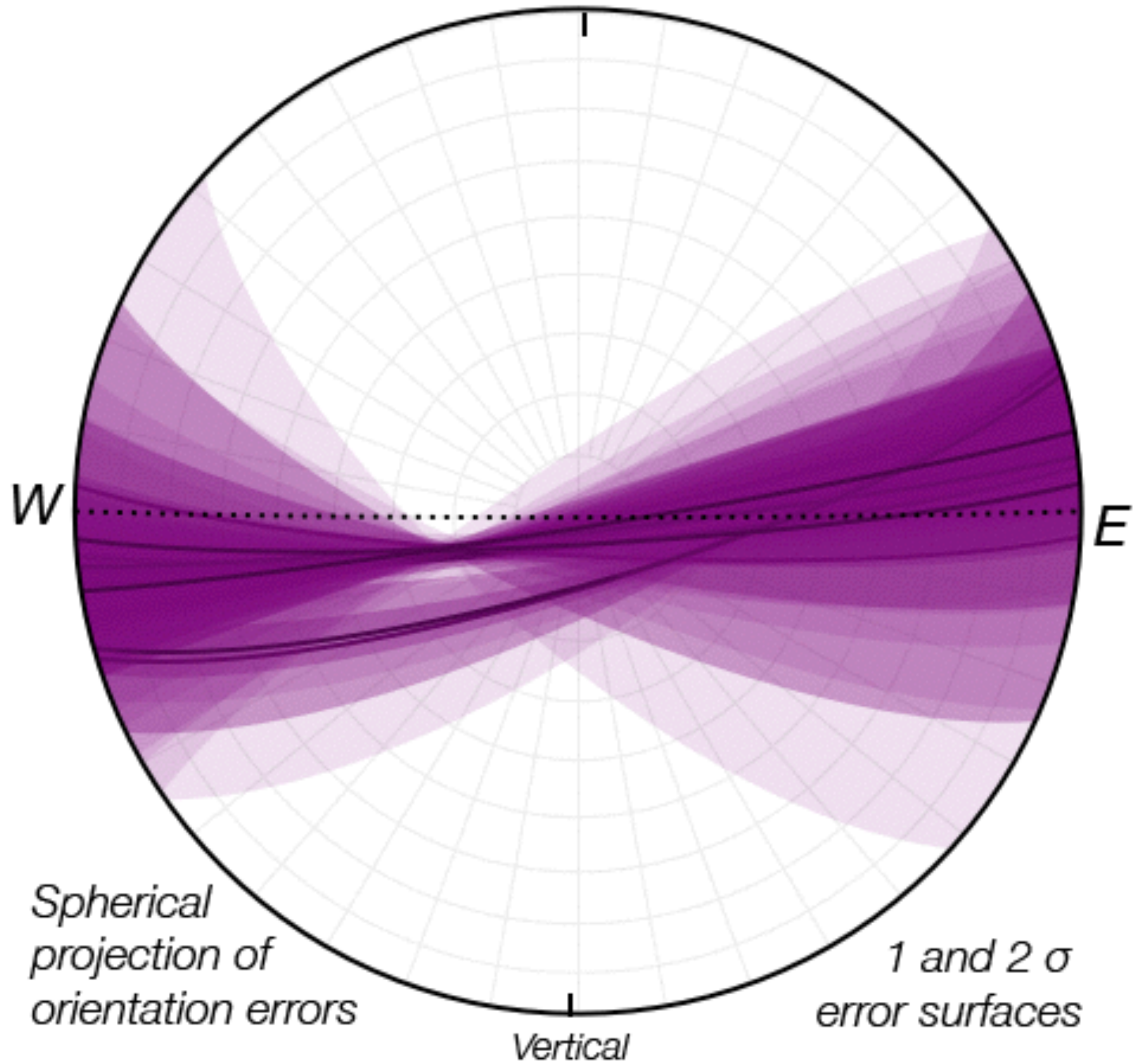




Orientation errors (spherical projection)

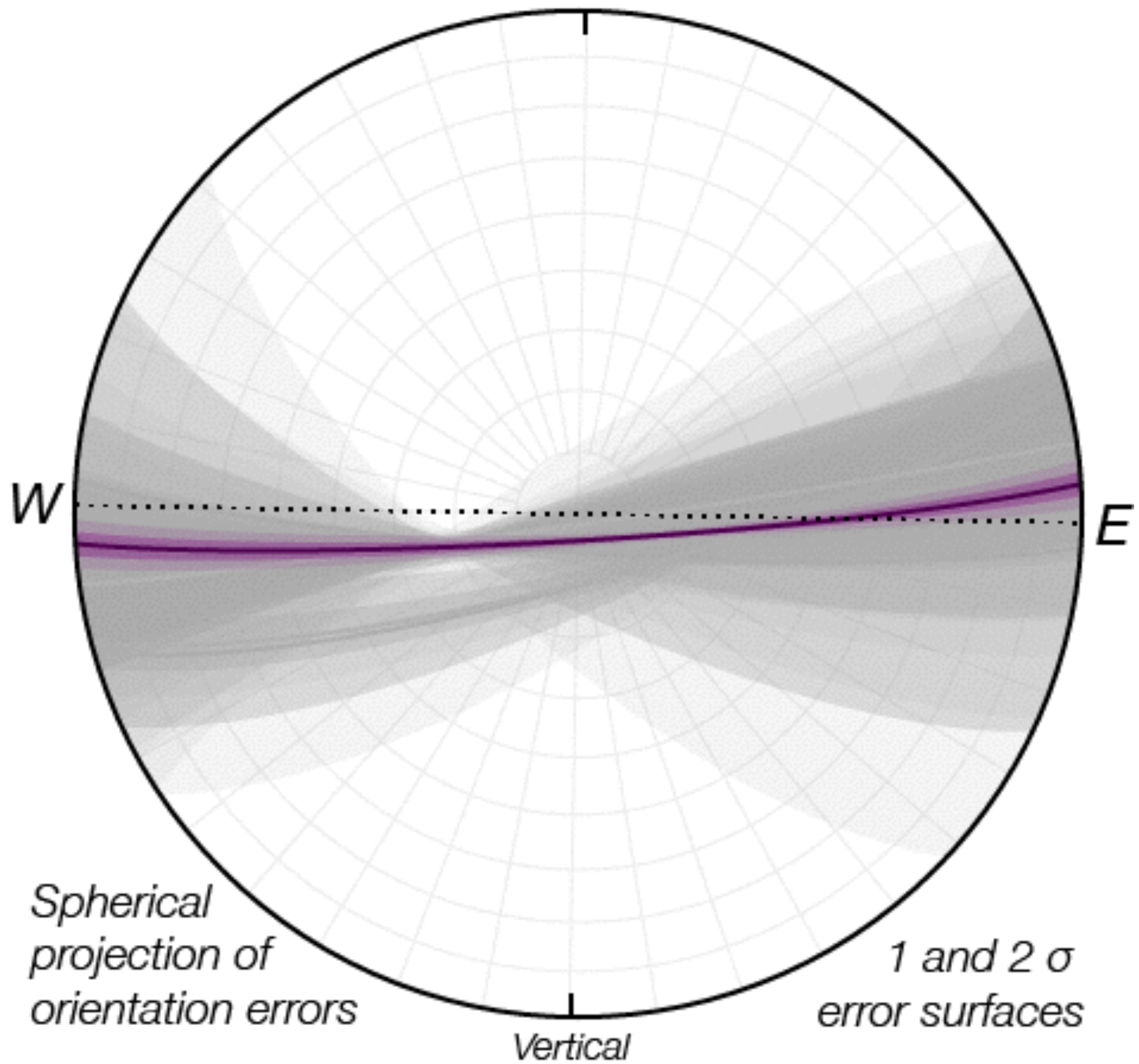


Poor fits from multiple orientation measurements



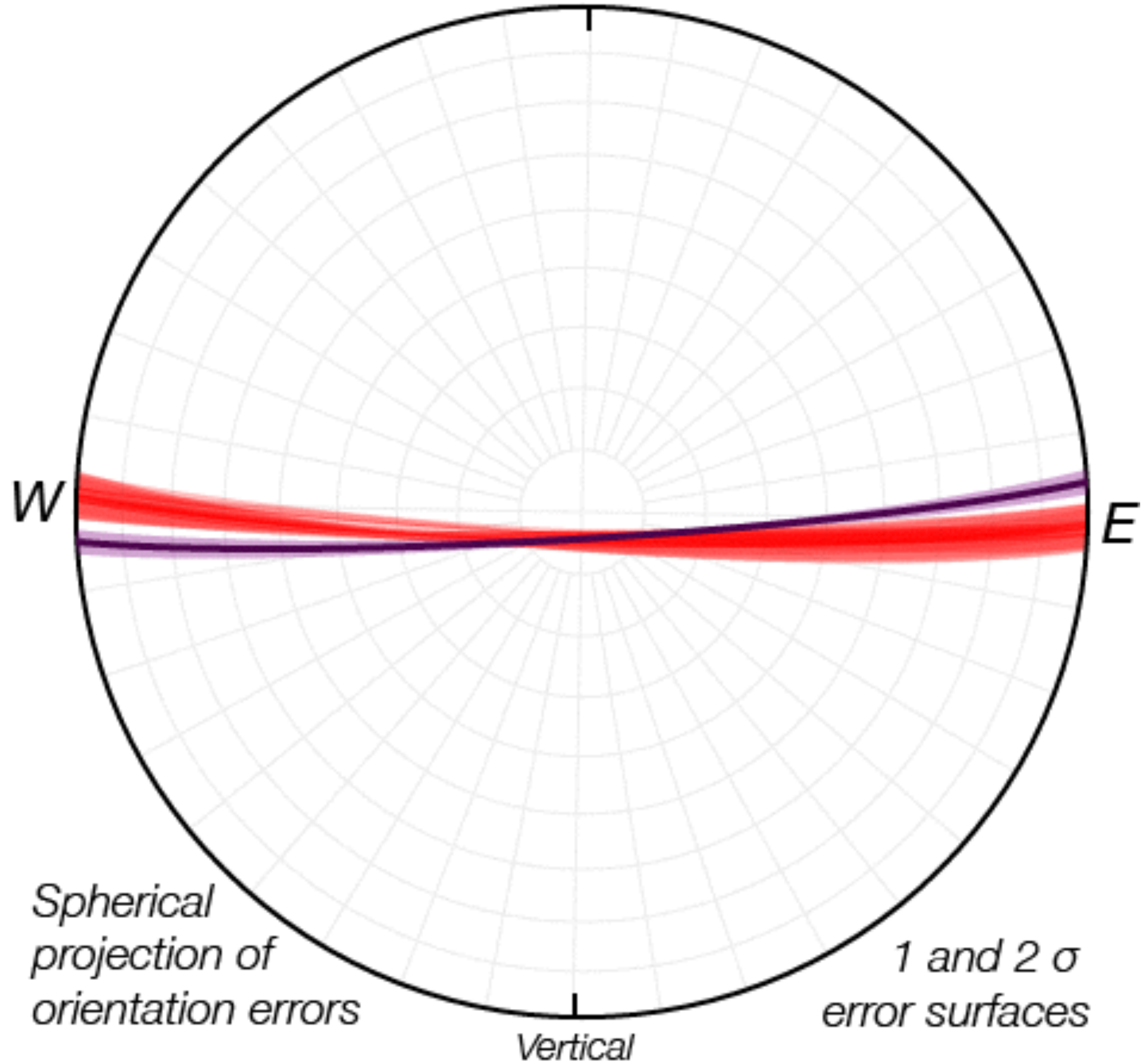
Test prior assumption that individual planes are part of a single stratigraphy…

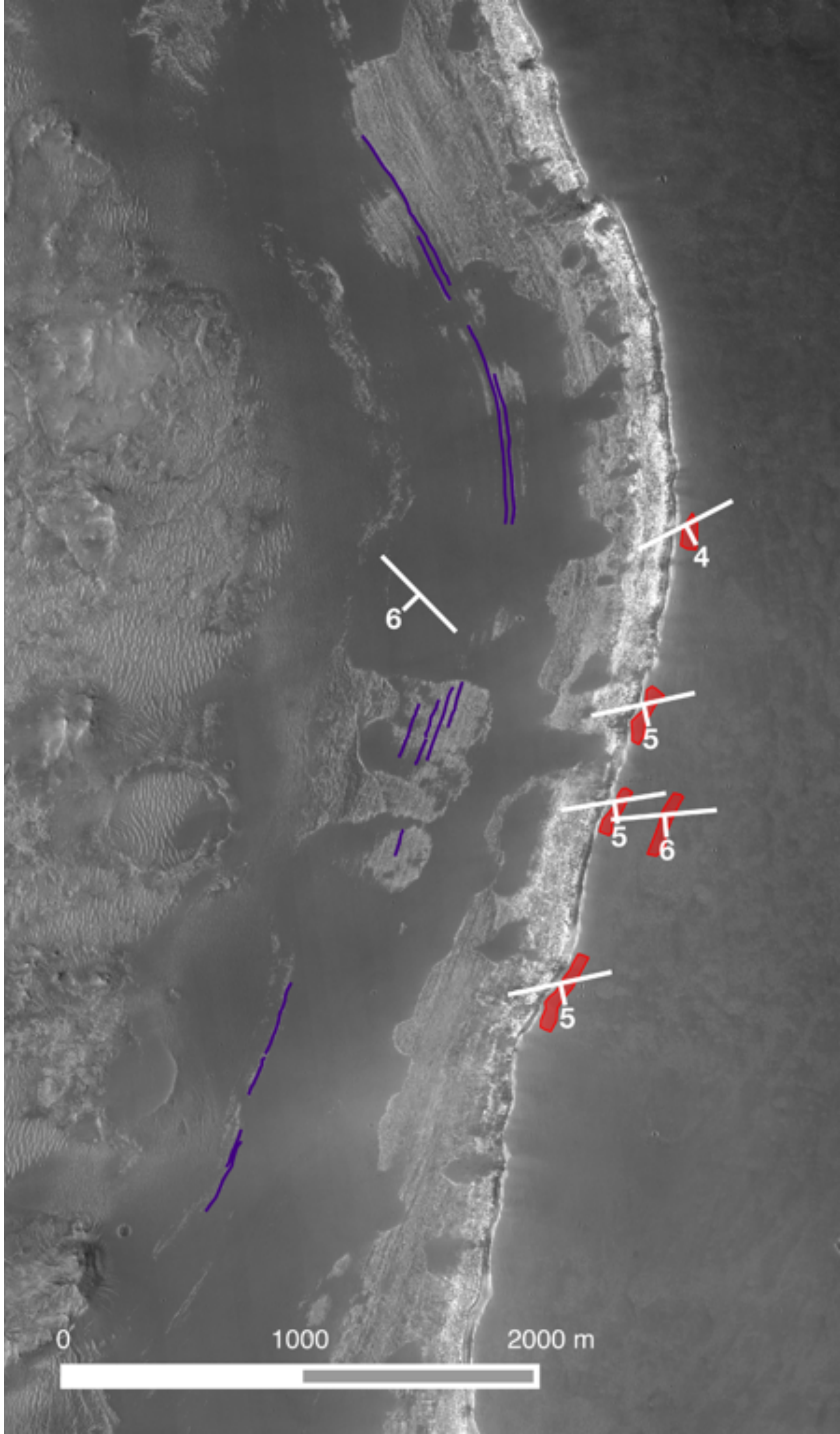
Combining multiple planes reduces error



- Single fit over 7 km of exposure
- Contains error minima of all component planes
- Maximum residual: 6.6 m

Unconformity with capping Syrtis Major lava flows

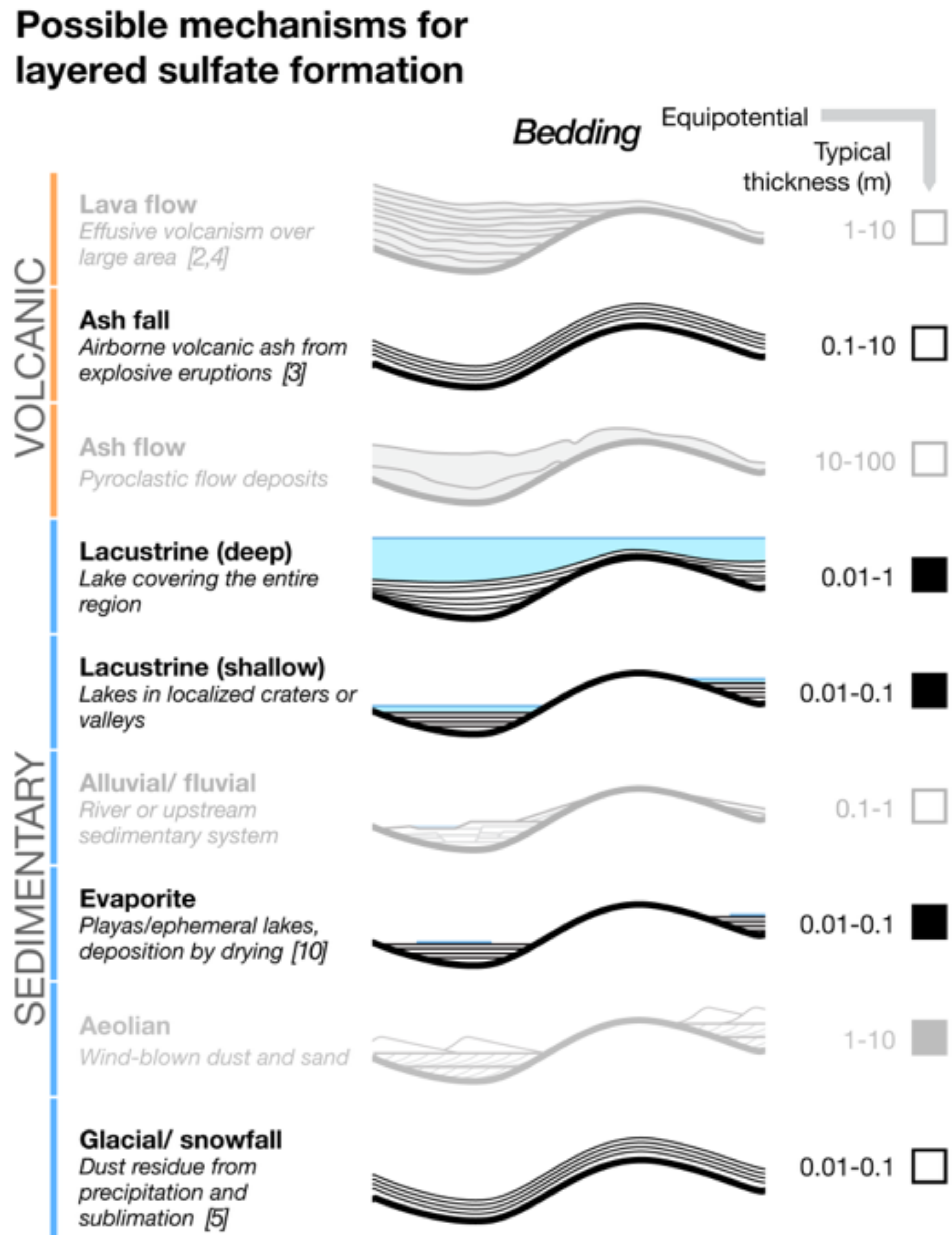




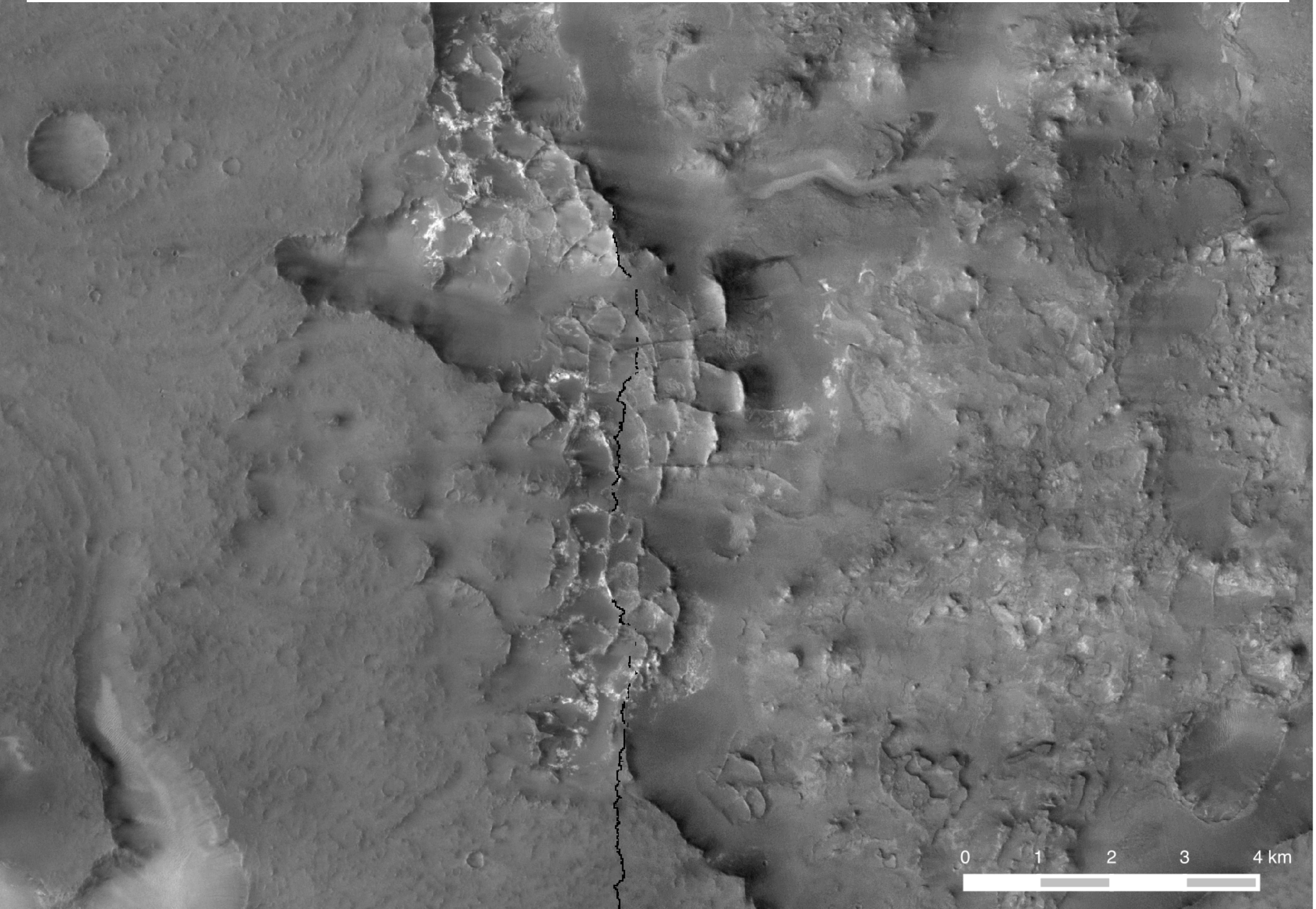
- Near-perfectly planar strata in layered sulfates
- Dipping differently at > 3 σ level

Bedding results
for layered sulfates

- Low-angle (<10º) dips everywhere
- Locally, **planar stratigraphy** (*homoclinal*) at 5-km scale
- **Unconformable with overriding lavas**
- Uncertain if deposited on flat surface (*equipotential*) or draping low-angle slope

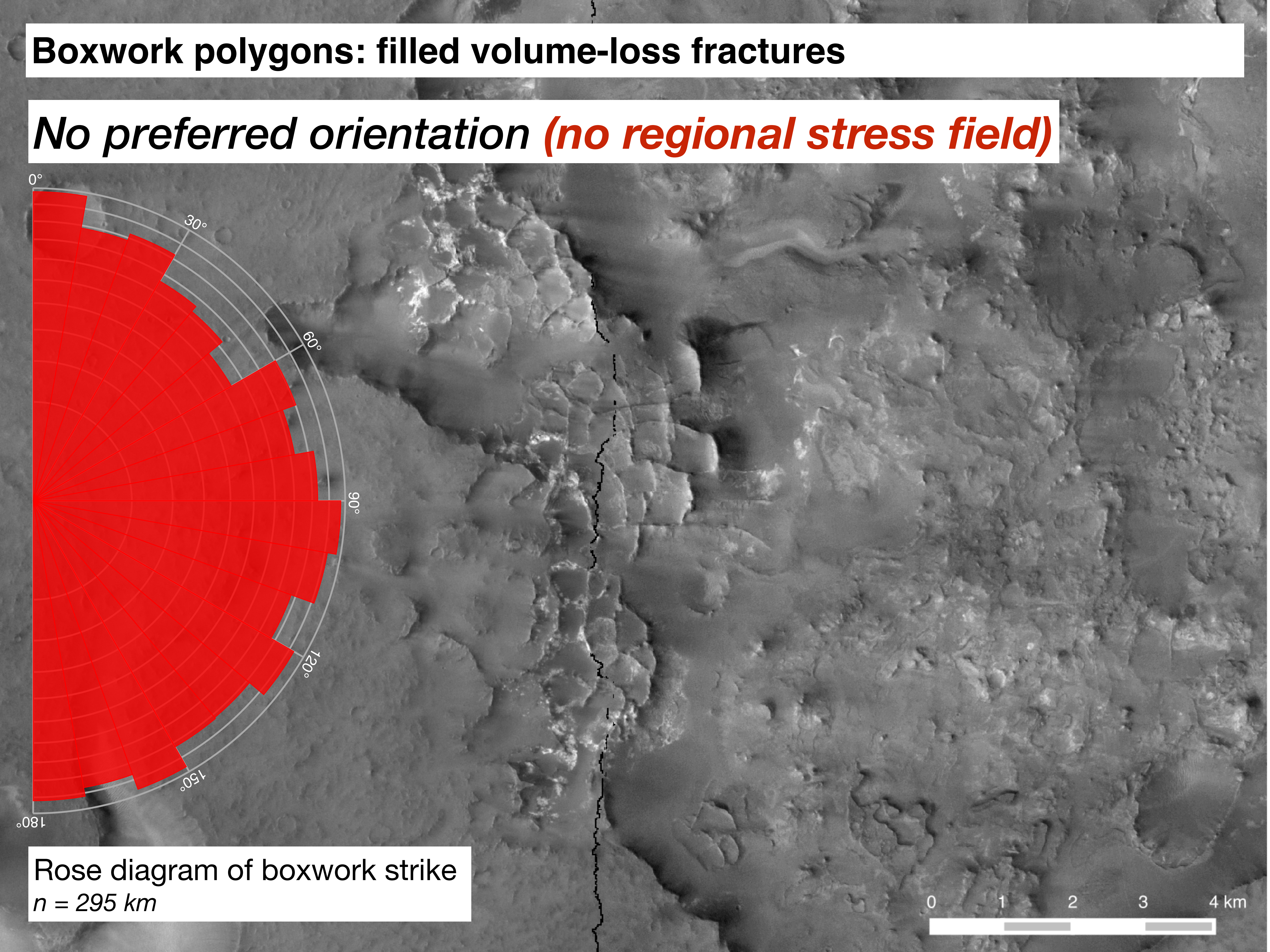


Boxwork polygons: key markers of alteration history



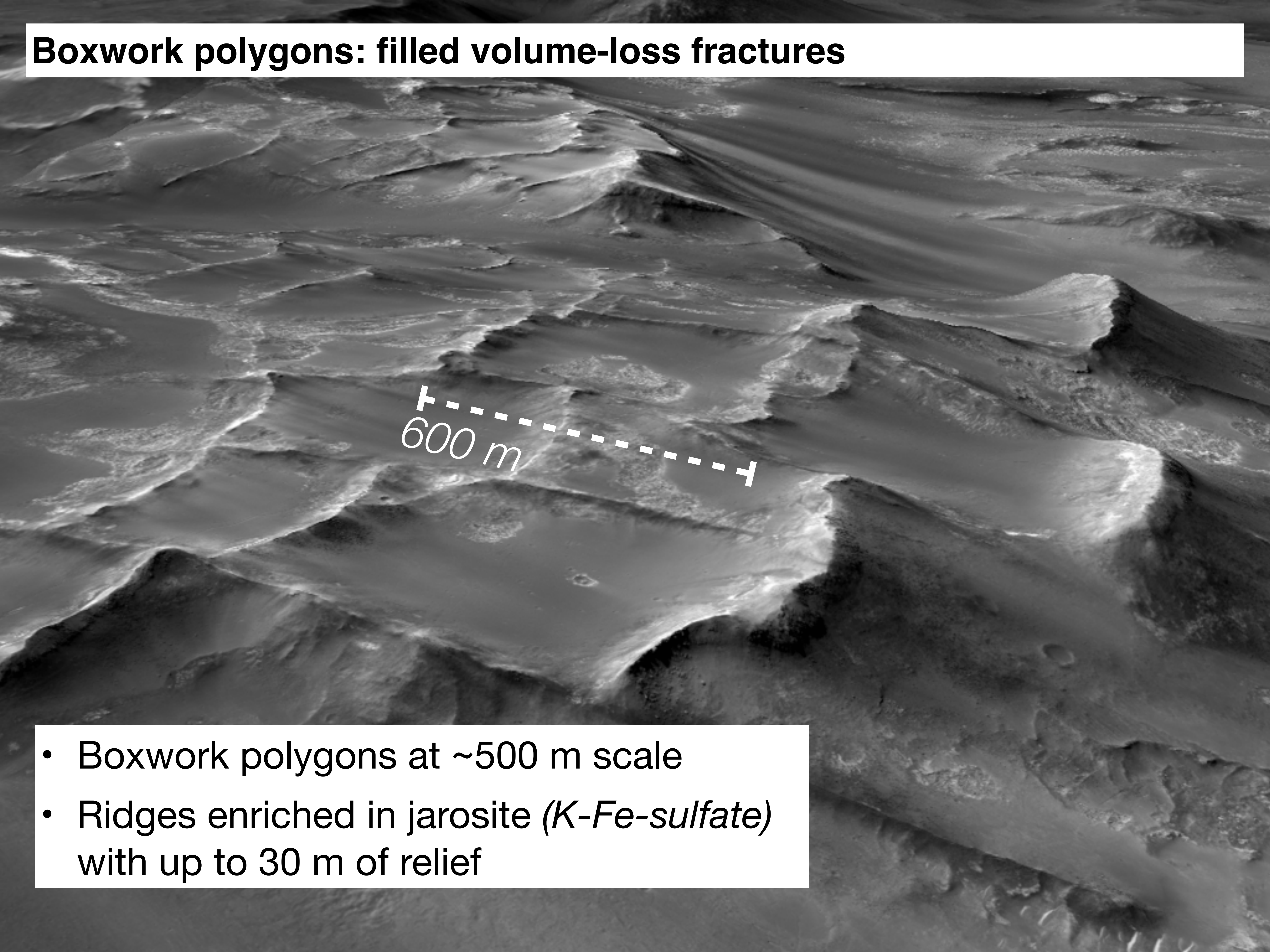
Boxwork polygons: filled volume-loss fractures

No preferred orientation (no regional stress field)



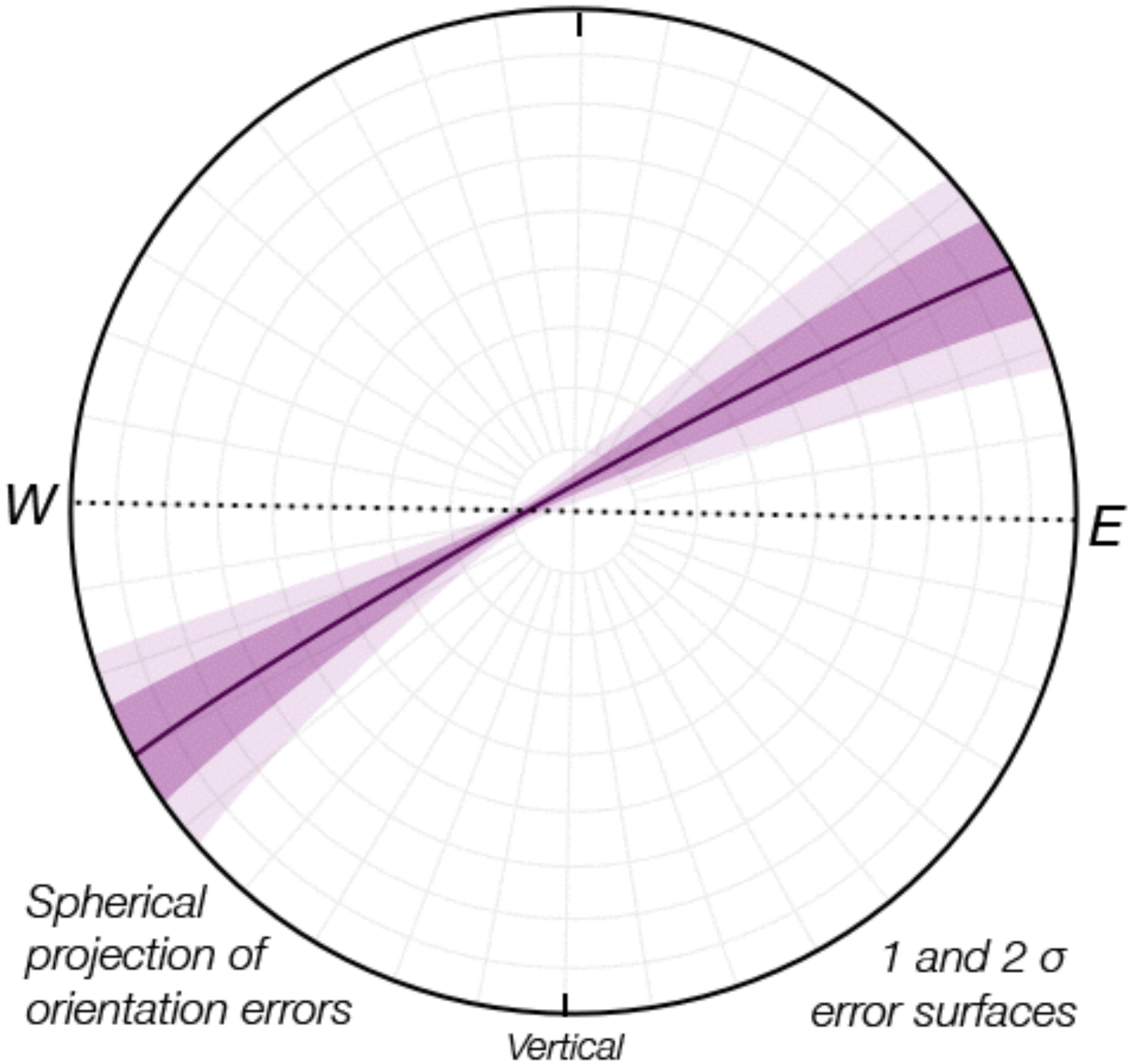
Rose diagram of boxwork strike
n = 295 km

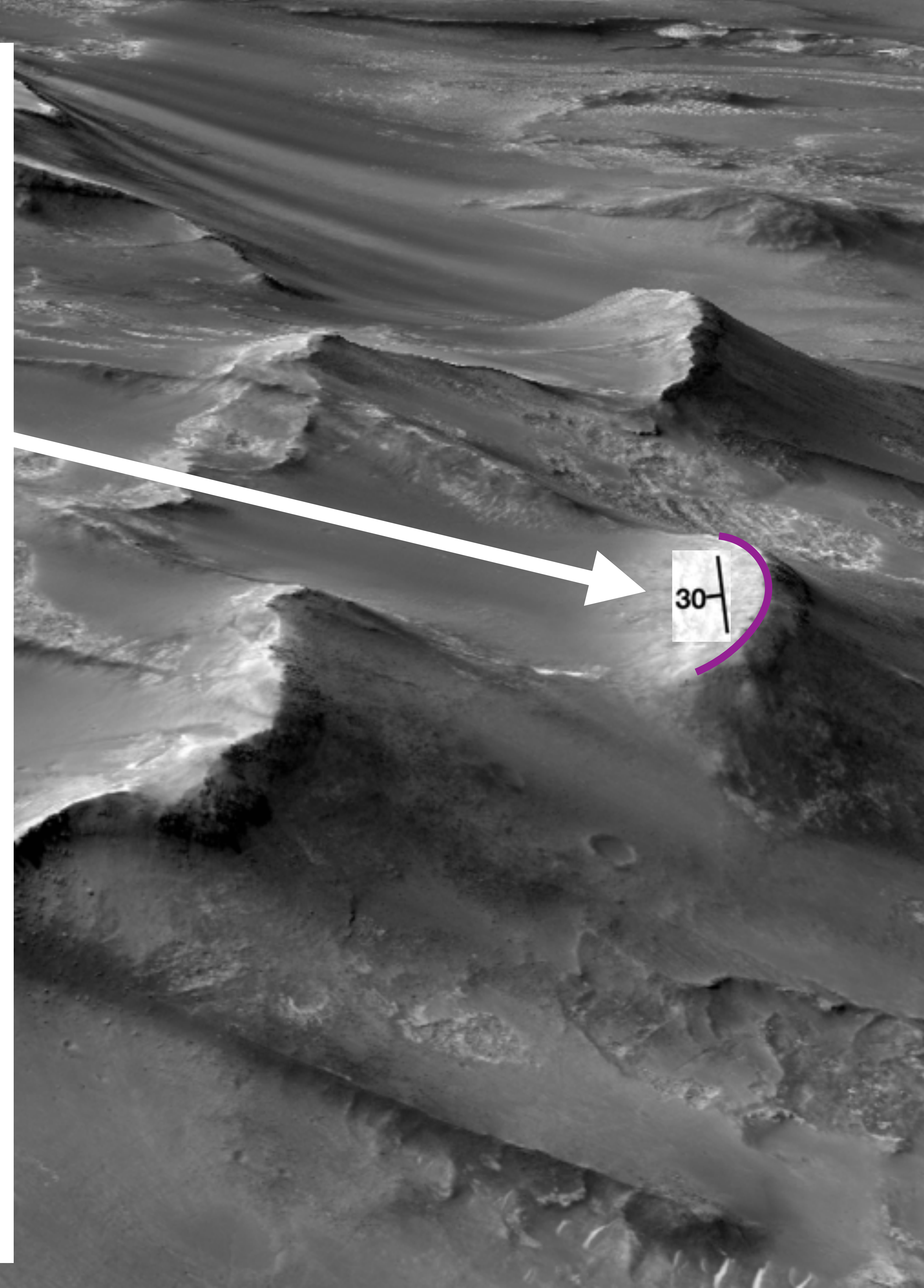
Boxwork polygons: filled volume-loss fractures



- Boxwork polygons at ~500 m scale
- Ridges enriched in jarosite *(K-Fe-sulfate)* with up to 30 m of relief

Boxwork polygons: filled volume-loss fractures





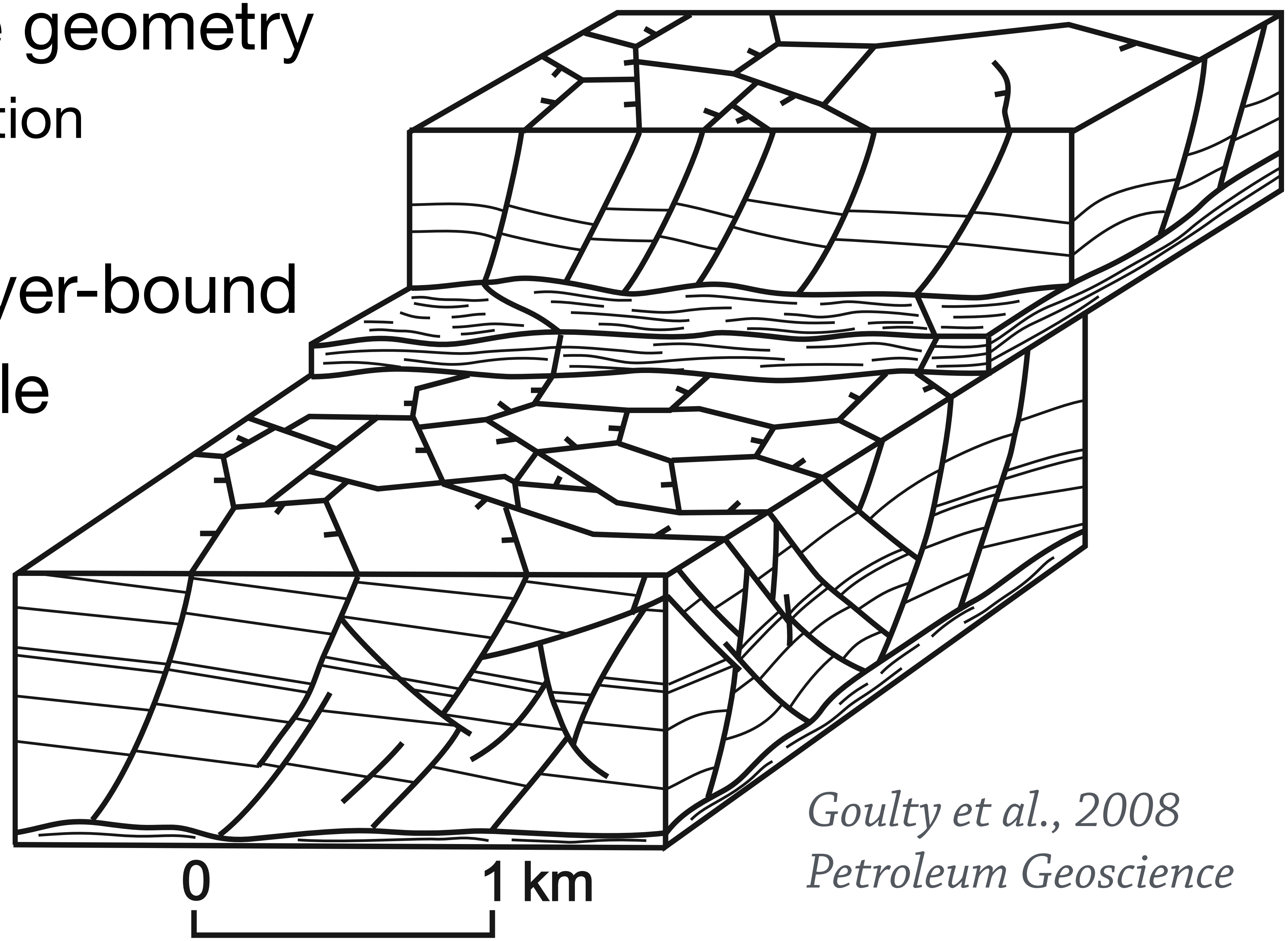
Often non–vertical

Can penetrate full exposed thickness of layered sulfate *(up to 200 m depth)*

Not formed at free surface

Polygonal faulting: an Earth analog?

- polygonal fracture geometry
  - no preferred orientation
  - non-vertical dips
- penetrative but layer-bound
- ~100–1000 m scale



Goulty et al., 2008
Petroleum Geoscience

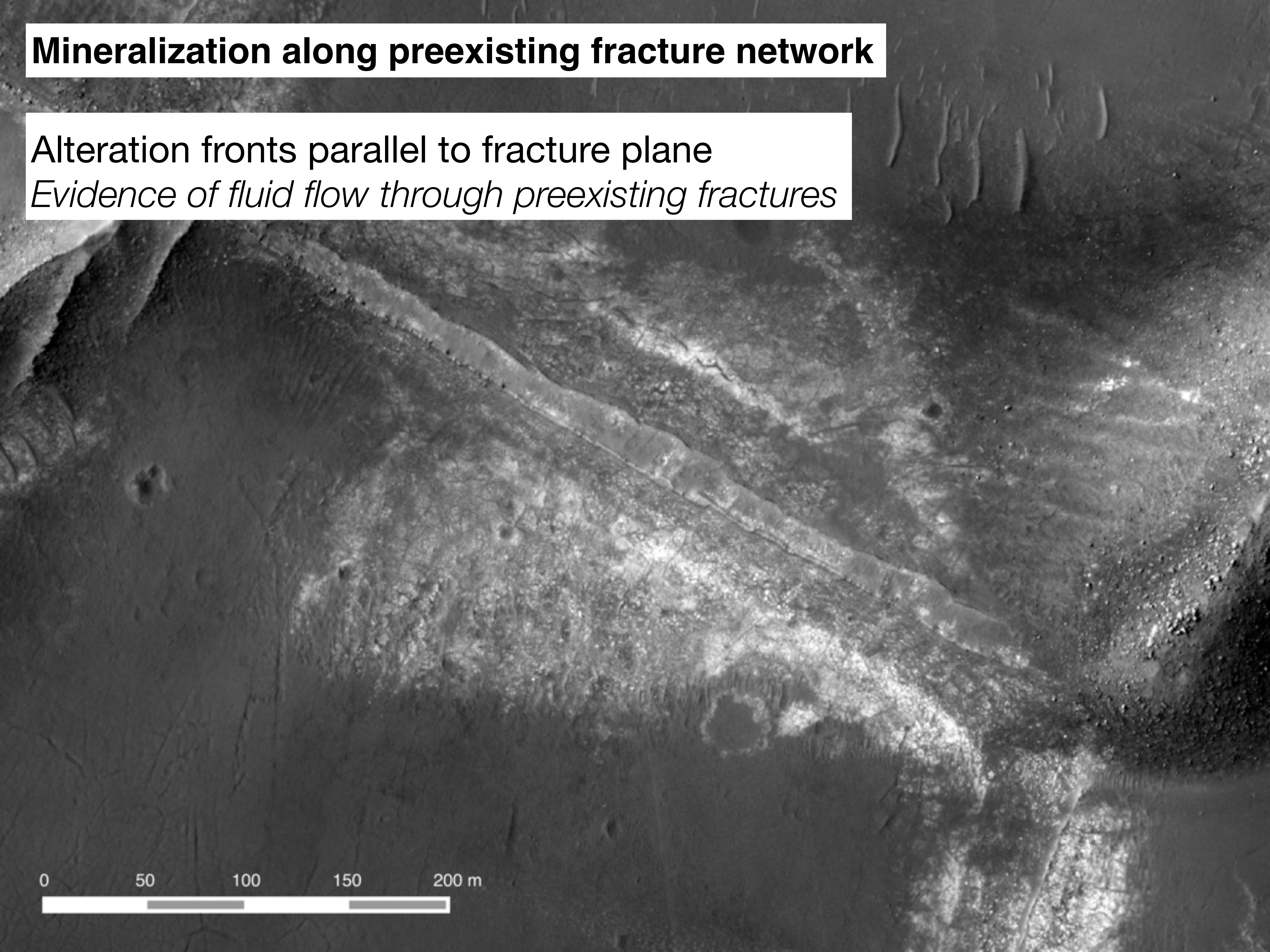
Mechanism

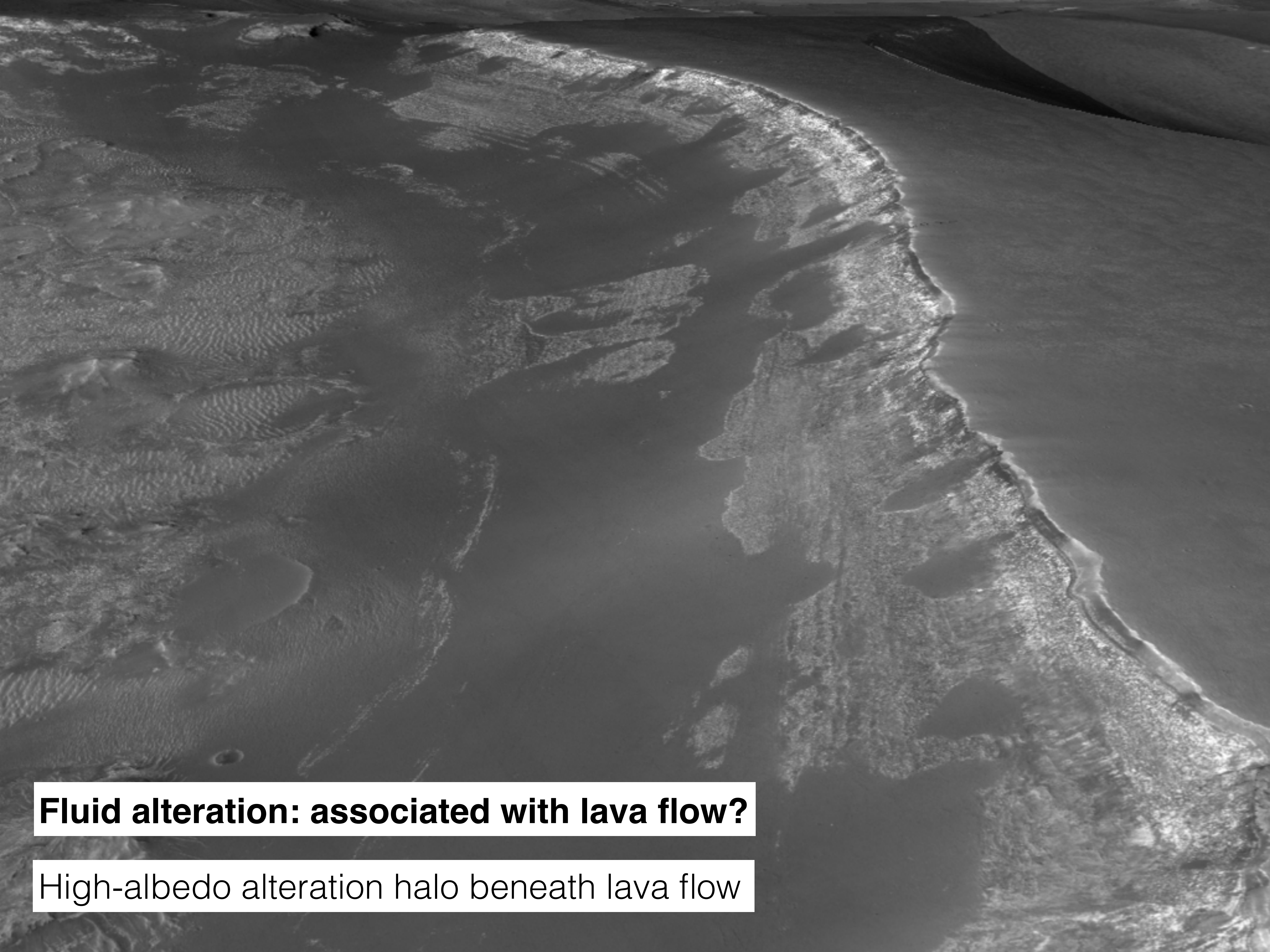
*Compaction of **clay-rich sediments** forms **layer-bound faults** during **diagenesis and shallow burial***

Mineralization along preexisting fracture network

Alteration fronts parallel to fracture plane

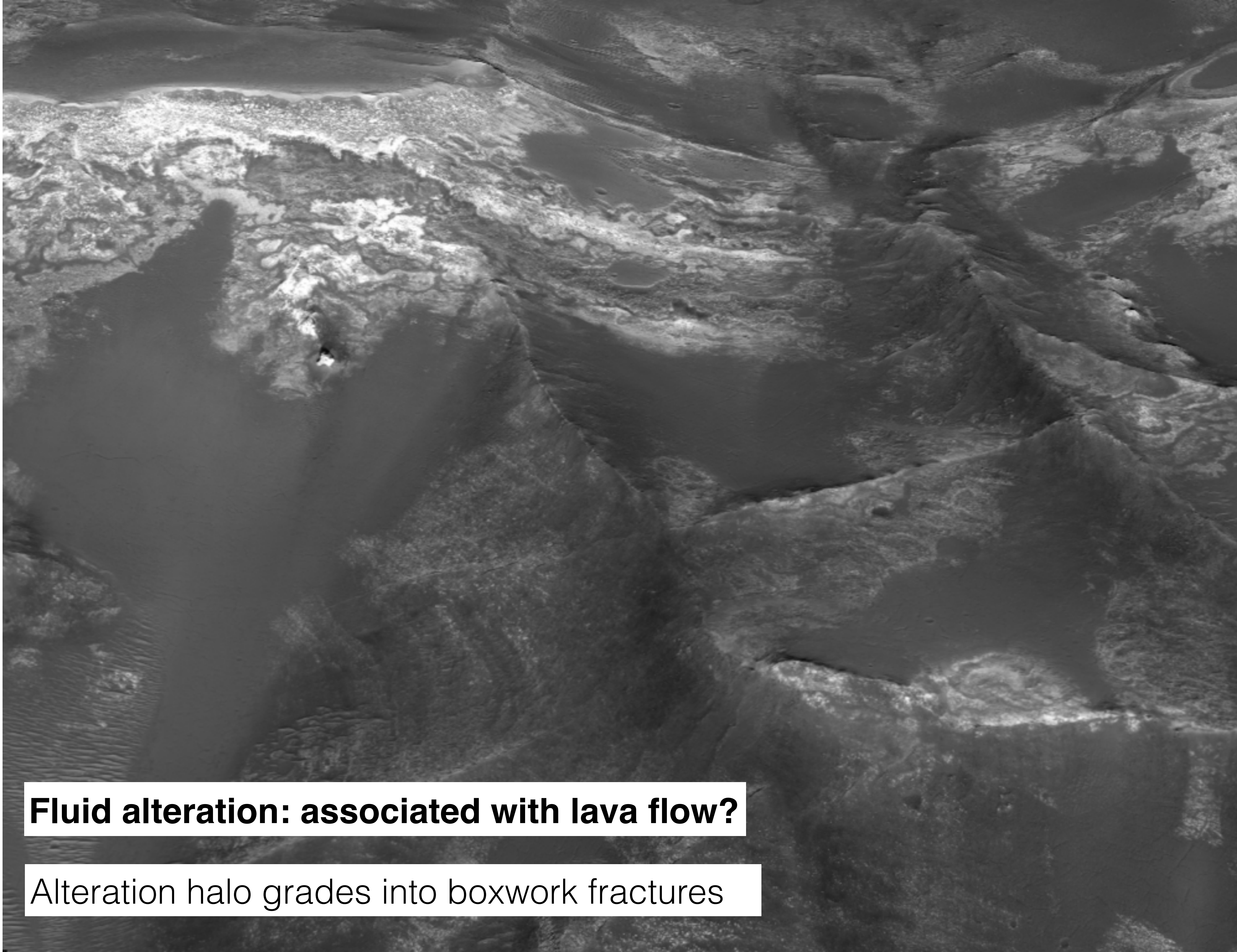
Evidence of fluid flow through preexisting fractures





Fluid alteration: associated with lava flow?

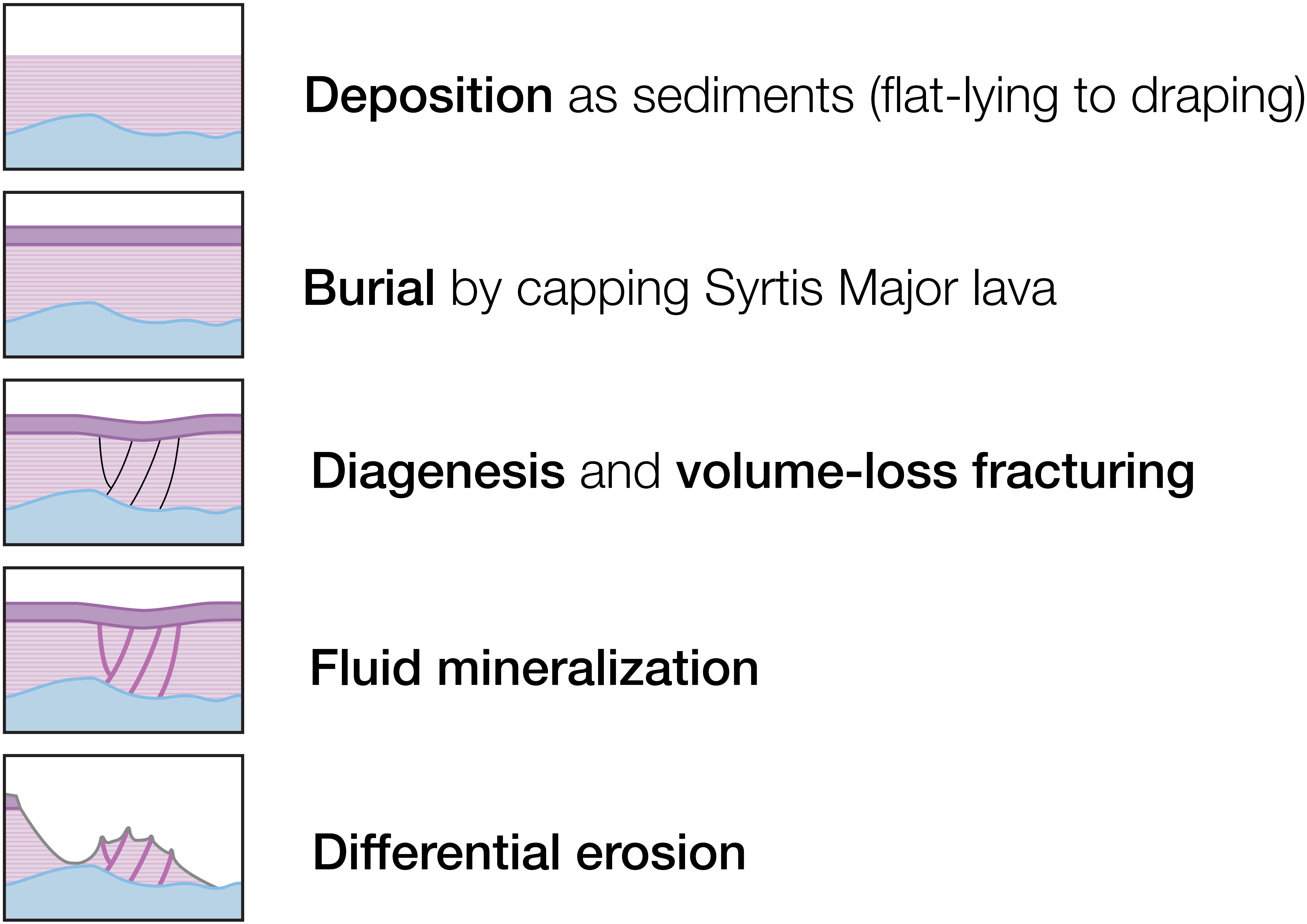
High-albedo alteration halo beneath lava flow



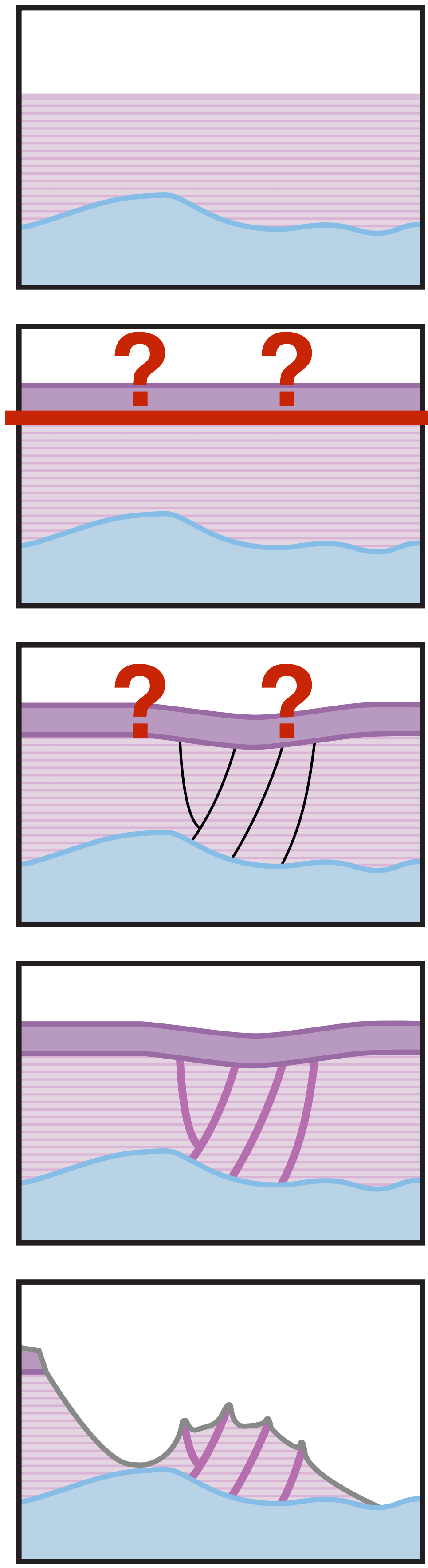
Fluid alteration: associated with lava flow?

Alteration halo grades into boxwork fractures

Model of deposition and alteration of layered sulfates



Model of deposition and alteration of layered sulfates



Deposition as sediments (flat-lying to draping)

Burial by lava

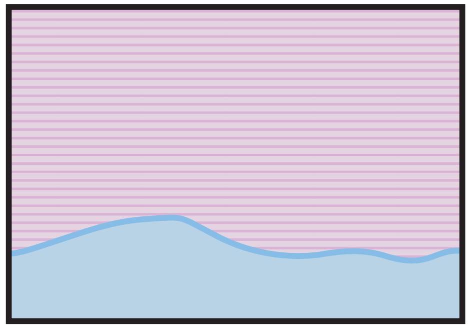
Unconformity masks potential history of deposition, erosion

Diagenesis and **volume-loss fracturing**

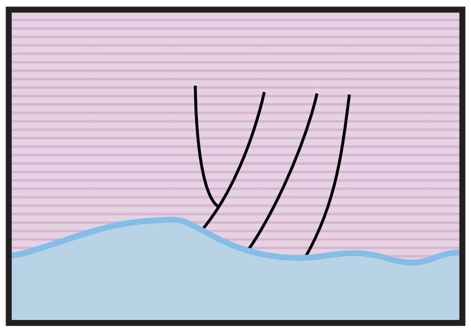
Fluid mineralization

Differential erosion

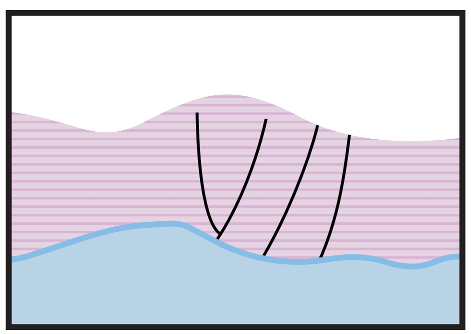
Alternative scenario with substantial early erosion



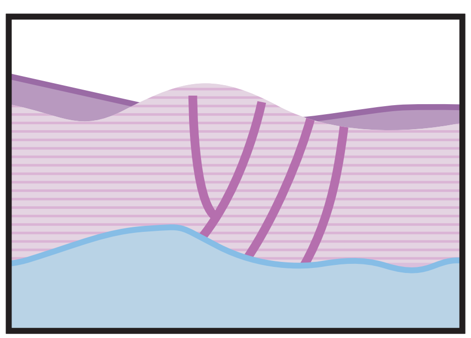
Deposition of sediments of unknown thickness (flat-lying to draping)



Diagenesis and **volume-loss fracturing**

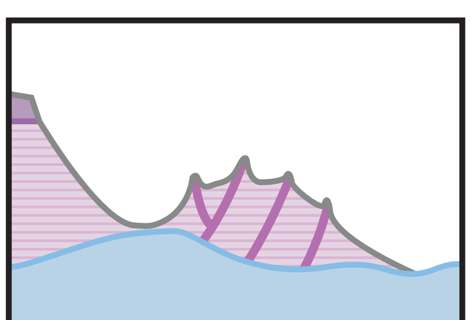


Period of erosion (±fluid alteration)



Burial by capping Syrtis Major lava

Fluid mineralization



Differential erosion

Conclusions

- Parallel bedding at km-scale: **flat or gently draping deposition** (e.g. lacustrine, evaporite, or ash fall)
- Layered sulfates **unconformable** with capping Syrtis Major lava
- Boxwork is formed by **volume-loss fracturing** followed by **fluid flow**
- Fluid alteration likely associated with overriding lava

Ongoing work

- Regionally constrain depositional dips with further analysis of orientation errors
- Finalize mapping (mineralogy, morphology)
- Examine timing of fracturing relative to lava emplacement