# *"A Mars 2020 Mission to Columbia Hills: Risk minimization through ground truth"*

**Martin J. Van Kranendonk[1], Steve Ruff[2], Tara Djokic[1], Kathleen A. Campbell[3]**

1. Australian Centre for Astrobiology, University of New South Wales Sydney, Australia
2. Arizona State University, U.S.A.
3. University of Auckland, New Zealand

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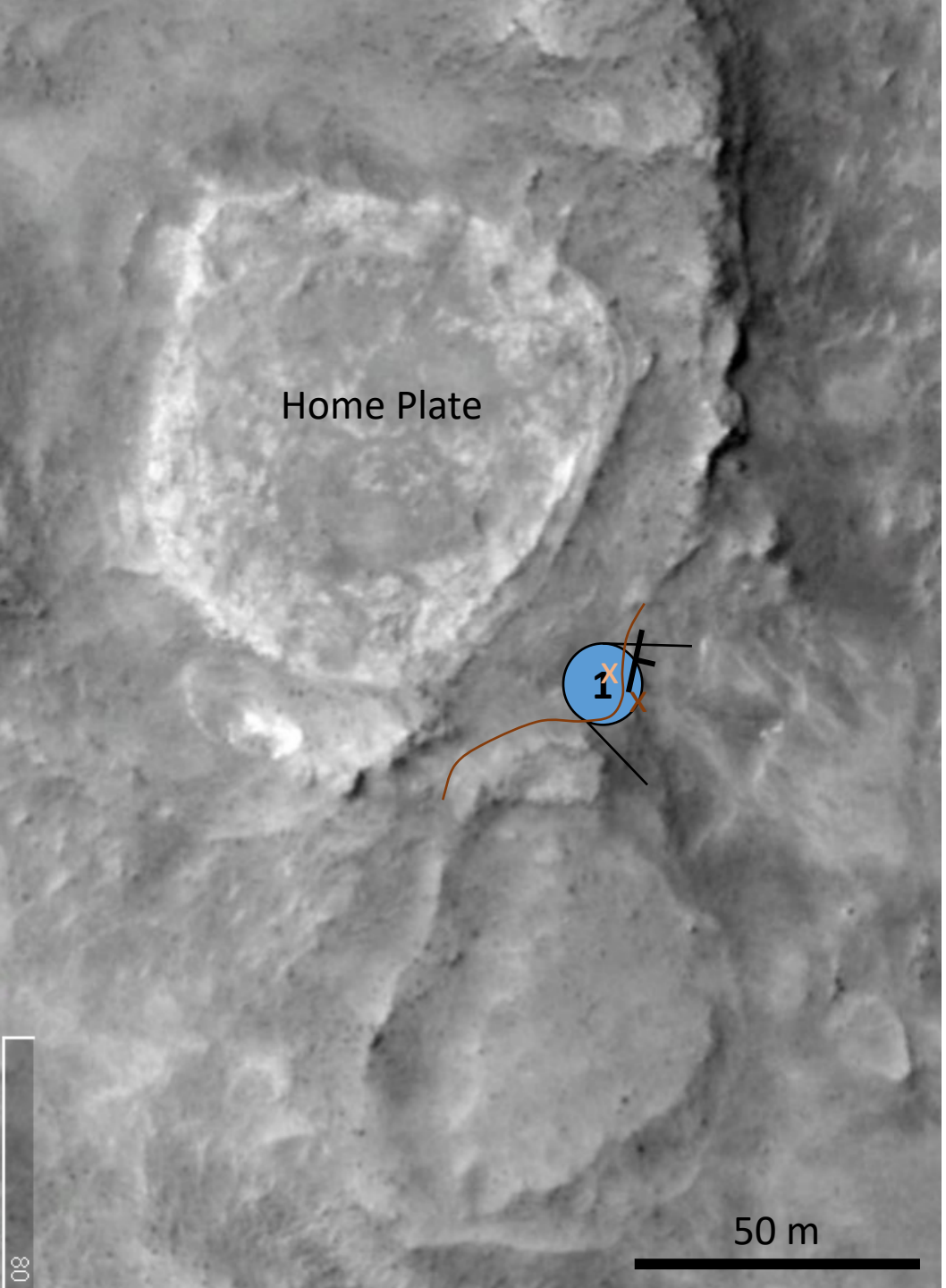
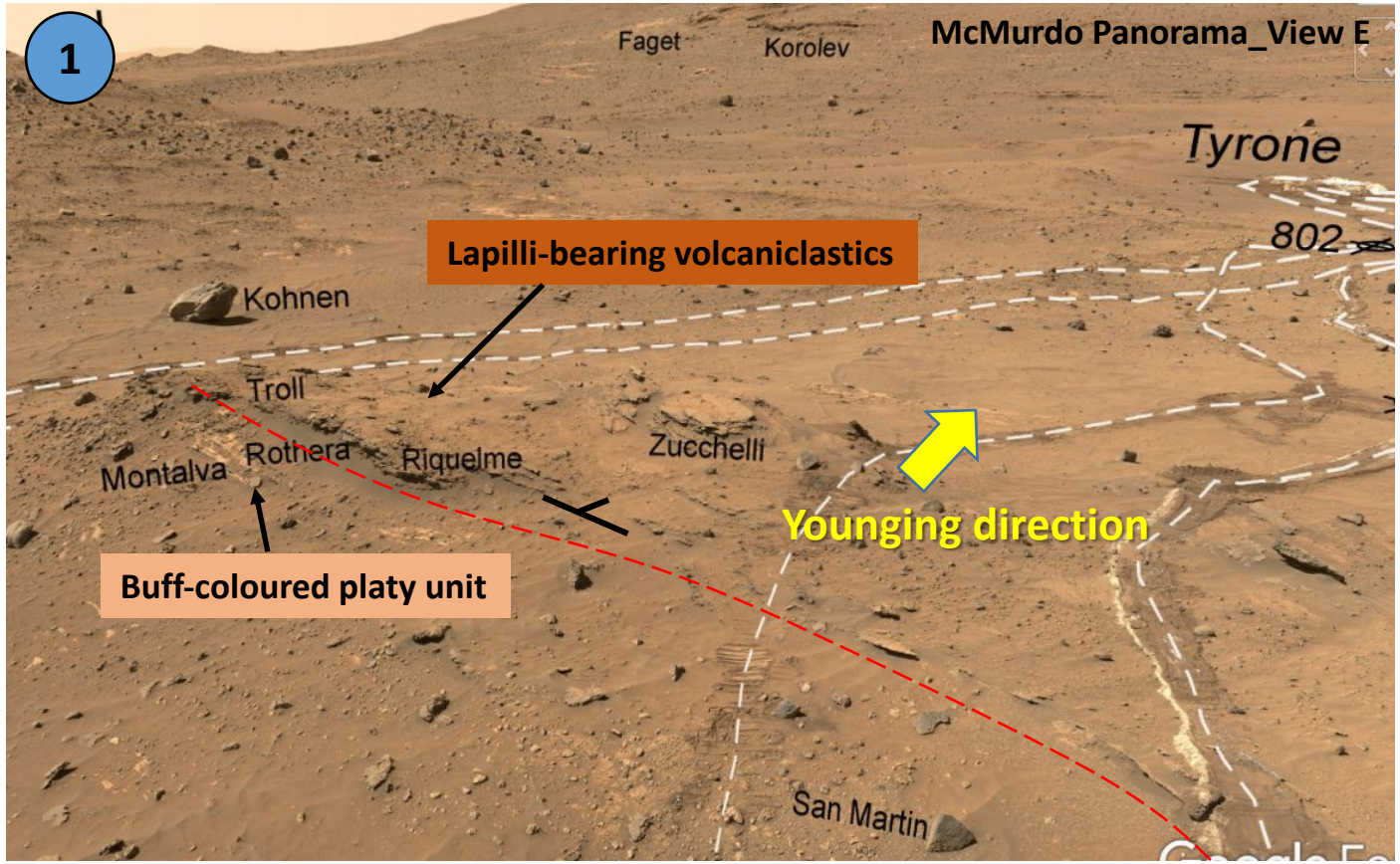
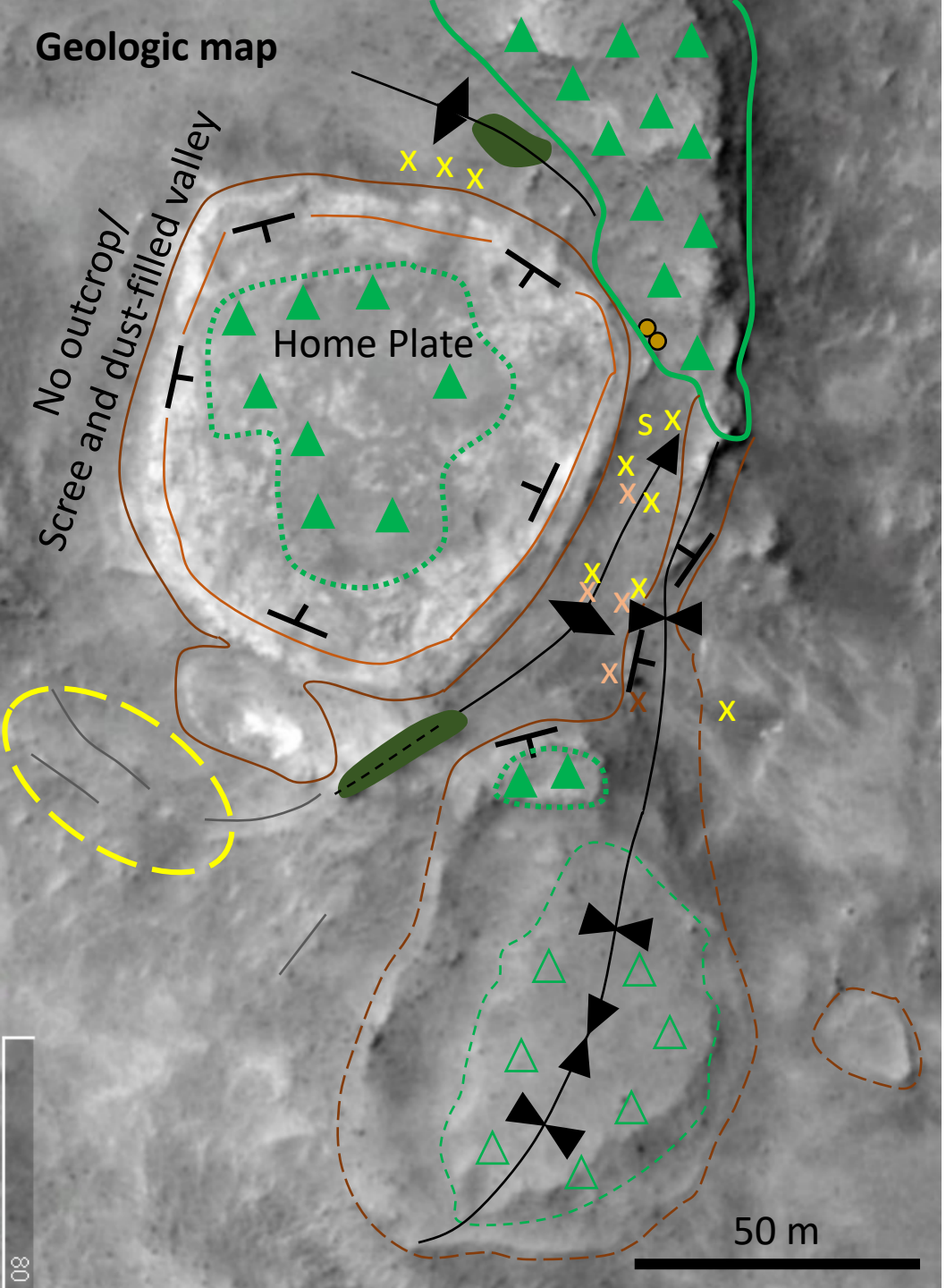
*Seminole Panorama by the Spirit rover*

# Spirit imagery from Columbia Hills allow ground-truthed mapping of contacts and strikes and dips of varied strata

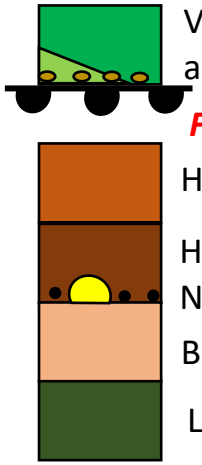





# Spirit analyses allow ground-truthed identification of rock compositions

## Stratigraphic column



Vesicular basalt (Irvine Class), with basal polymict conglomerate and volcaniclastic sandstone/tuff

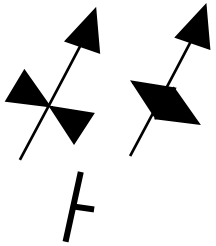
***Folding***

HP2: Fine-grained, planar to cross-bedded, Aeolian sandstone

HP1: Medium- to coarse-grained pyroclastics
Nodular/digitate opaline silica (local, as elongate ridges)

Buff-colored platy unit

Light-toned, fine-grained, vesicular, olivine basalt

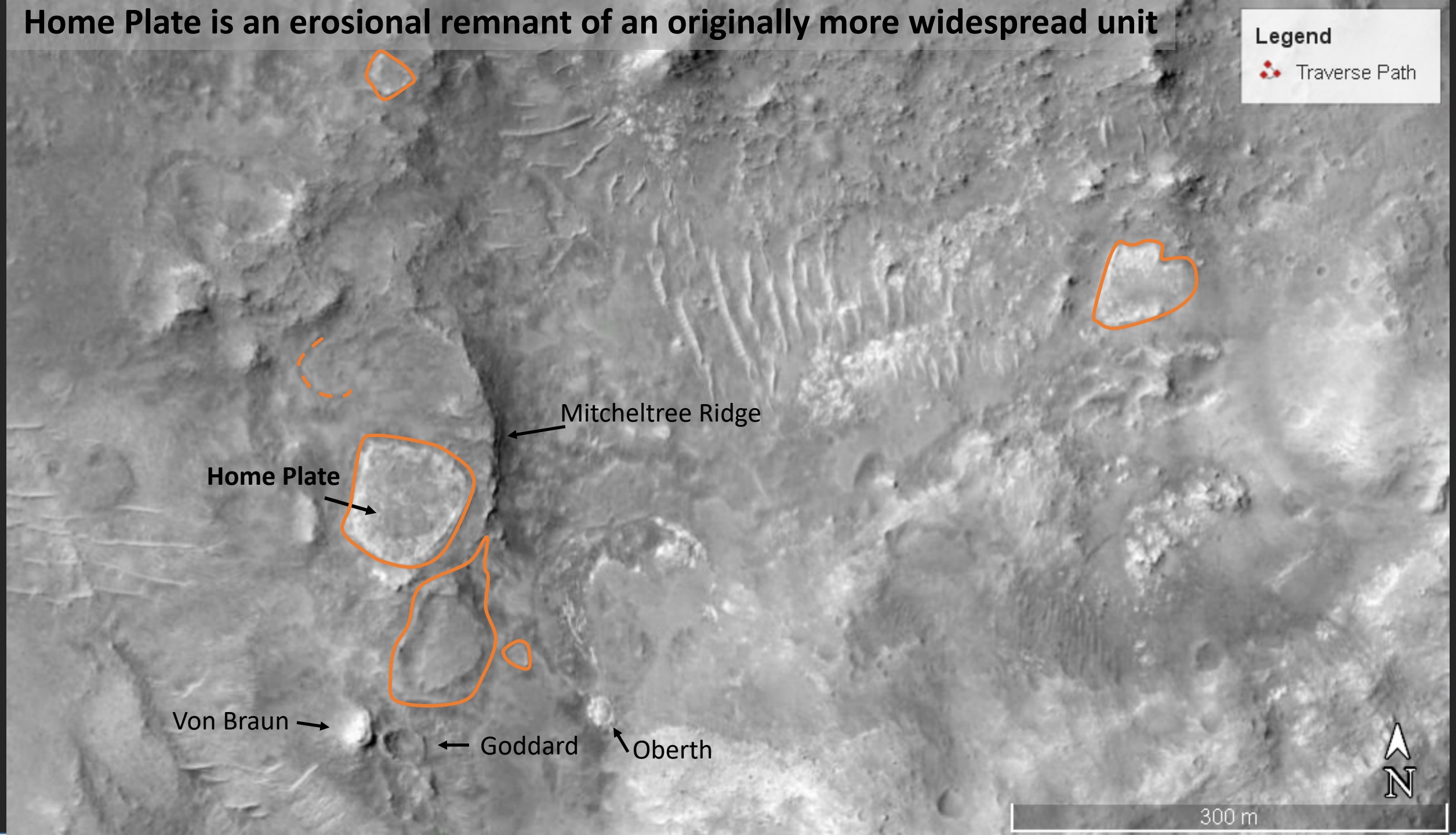


Plunging syncline, anticline

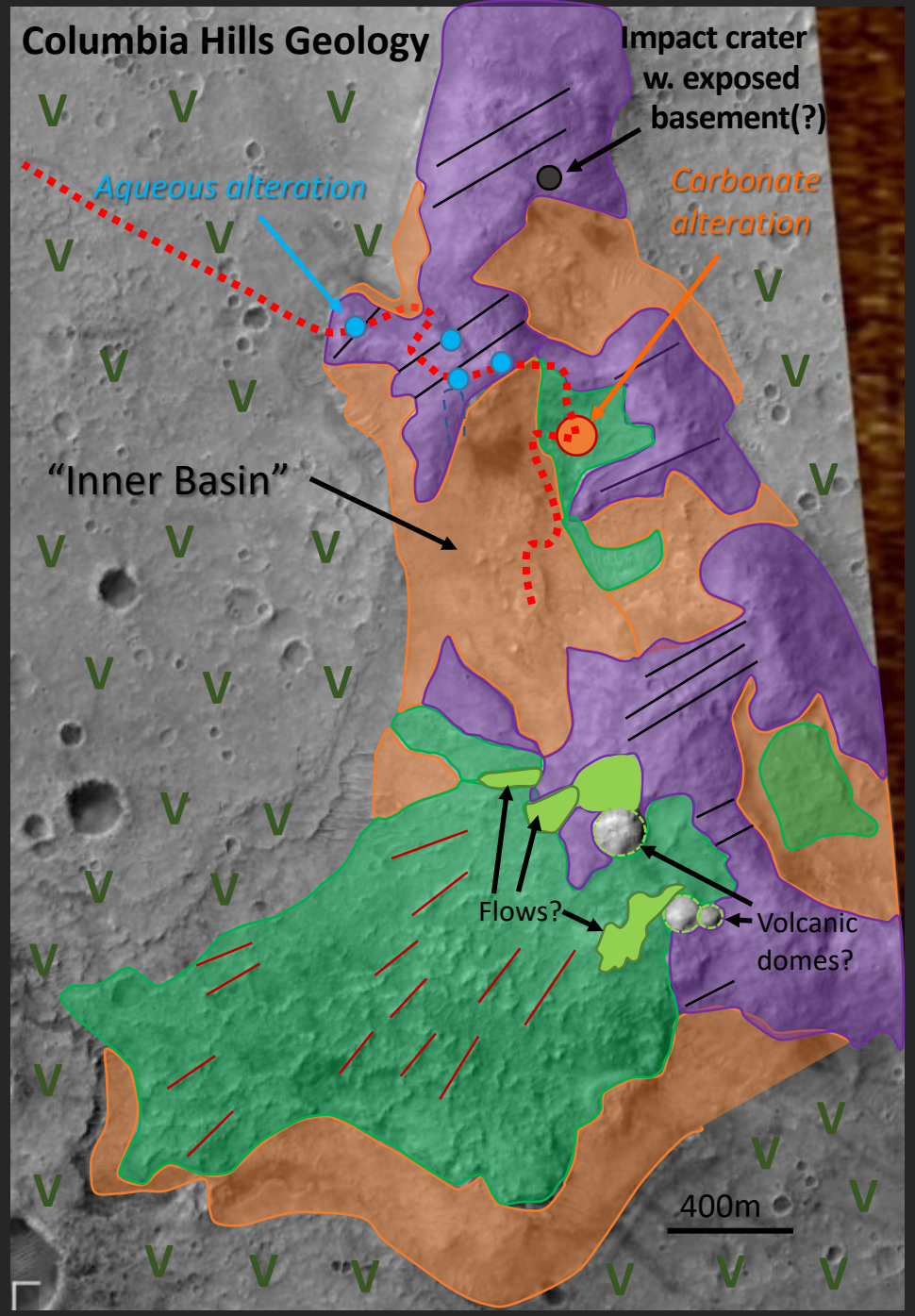
Strike and dip direction of bedding

Includes observations from
Squyres et al., 2007: Science
Arvidson et al., 2008: JGR
Crumpler et al., 2011: JGR
Ruff et al., 2011: JGR
and others

# Home Plate is an erosional remnant of an originally more widespread unit



# Event stratigraphy of the Columbia Hills




Spirit analyses provided ground-truthed identification of major units and their relationships, which can be extrapolated across whole area

*Minor hydrous alteration (atmospheric)*

V — Adirondack Class (Plains basalt west): Olivine picrobasalt (3.6 Ga)

Inner Basin: mixed volcanic, volcaniclastic and sedimentary units

*carbonate alteration (Comanche Class)*

***Erosion***

Algonquin Class: Olivine-bearing picritic tephra (north and south)

*aqueous and sulfate alteration (Watchtower Class)*

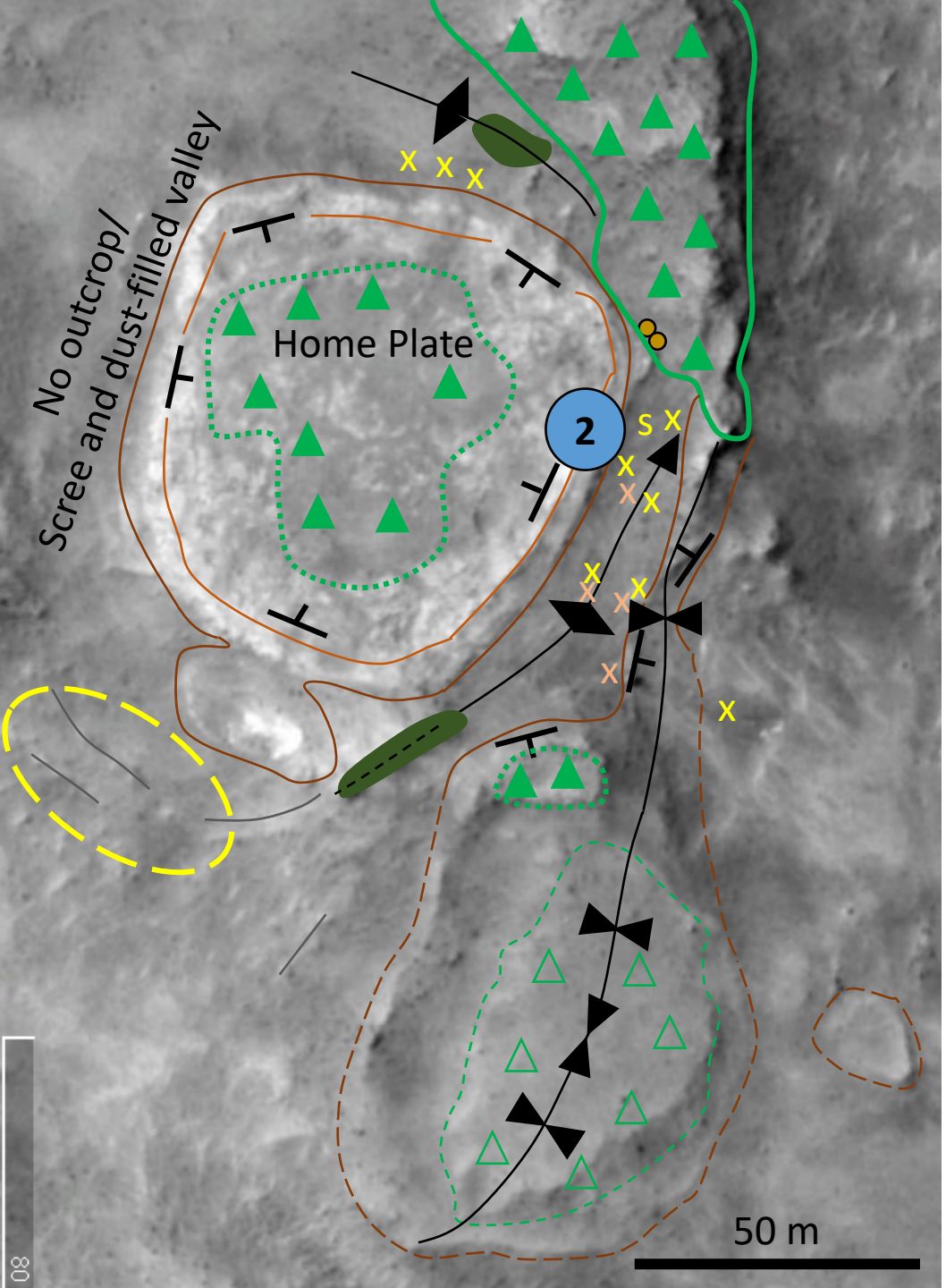
***Erosion***

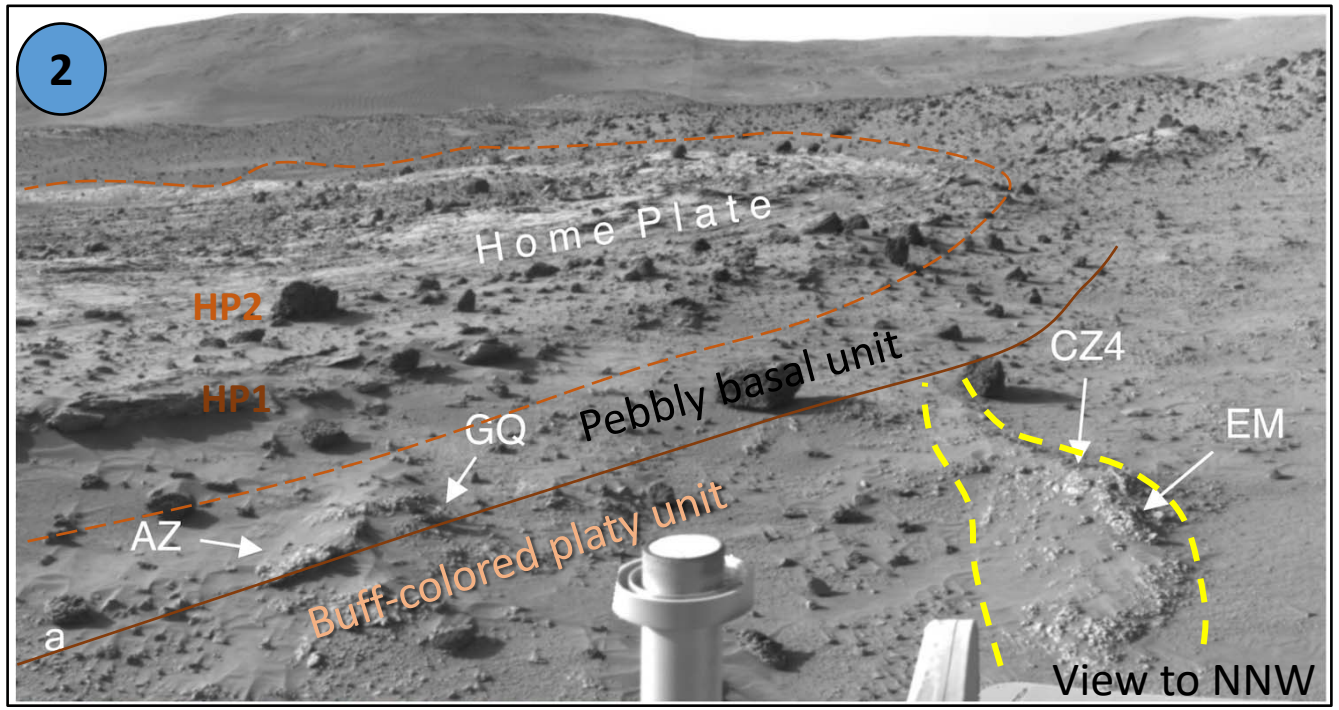
Wishstone Class: Hawaiite tephra with NE-SW bedding strike: *(and associated other classes)*;

***Uplift and erosion***

Possible basement in floor of impact crater

# What is the age of the nodular/digitate opaline silica deposits around Home Plate?

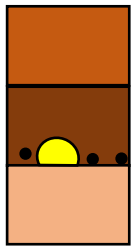



1 **OR** 2

Opaline silica: older than HP

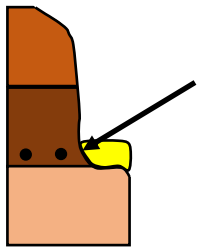
Opaline silica: younger than HP



HP2: Aeolian sandstone

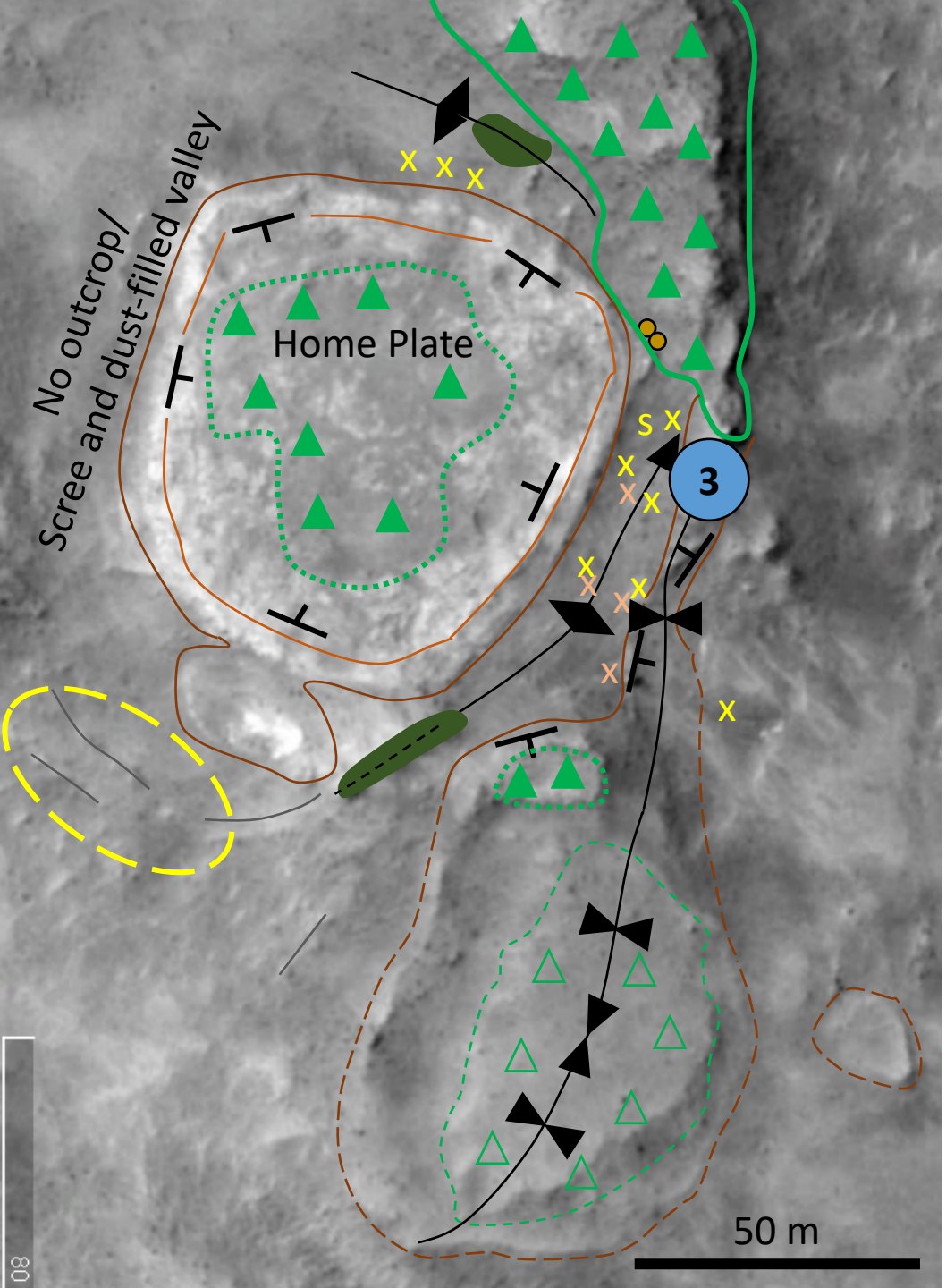
HP1: Volcanoclastics

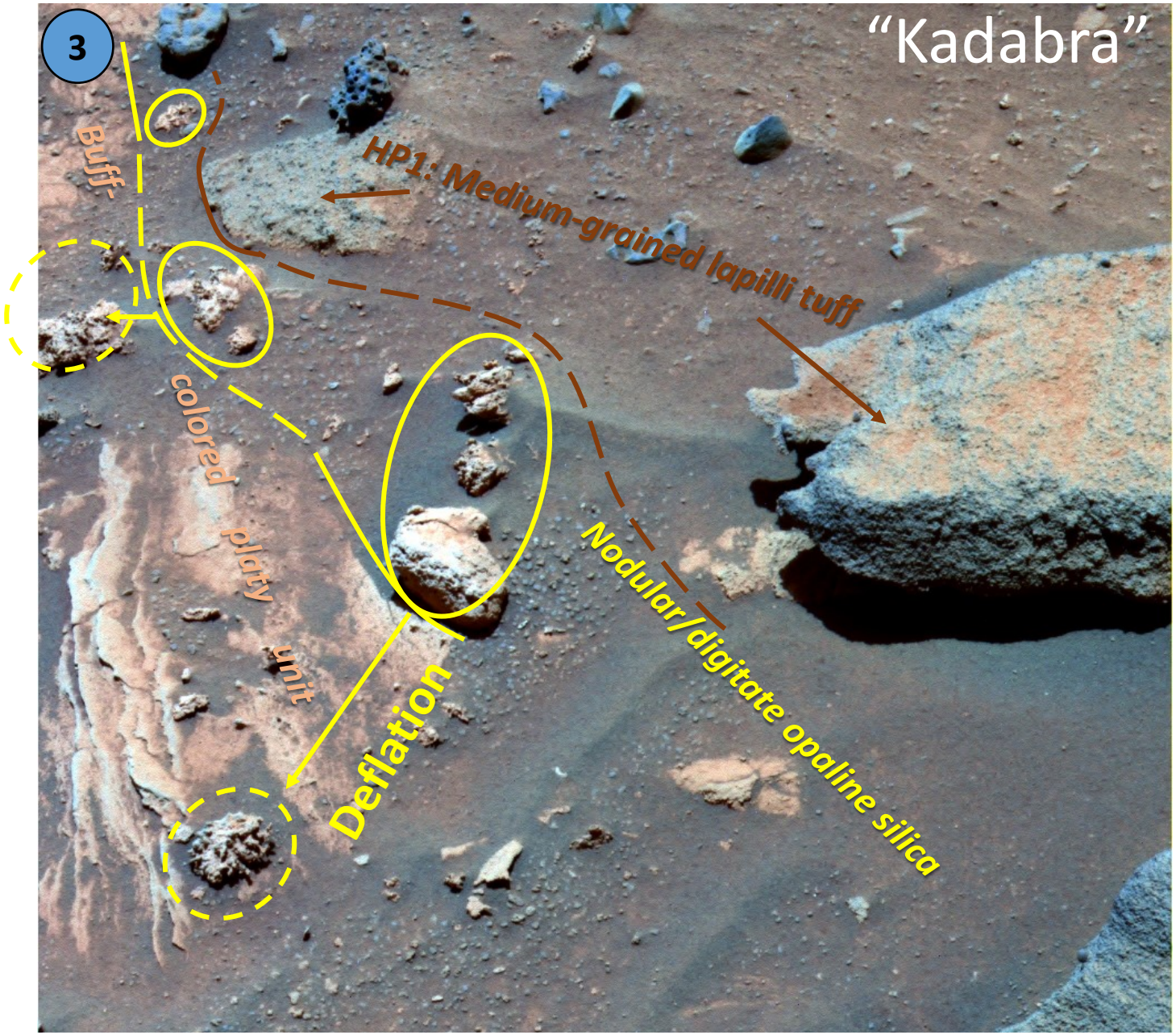
Buff-colored platy unit

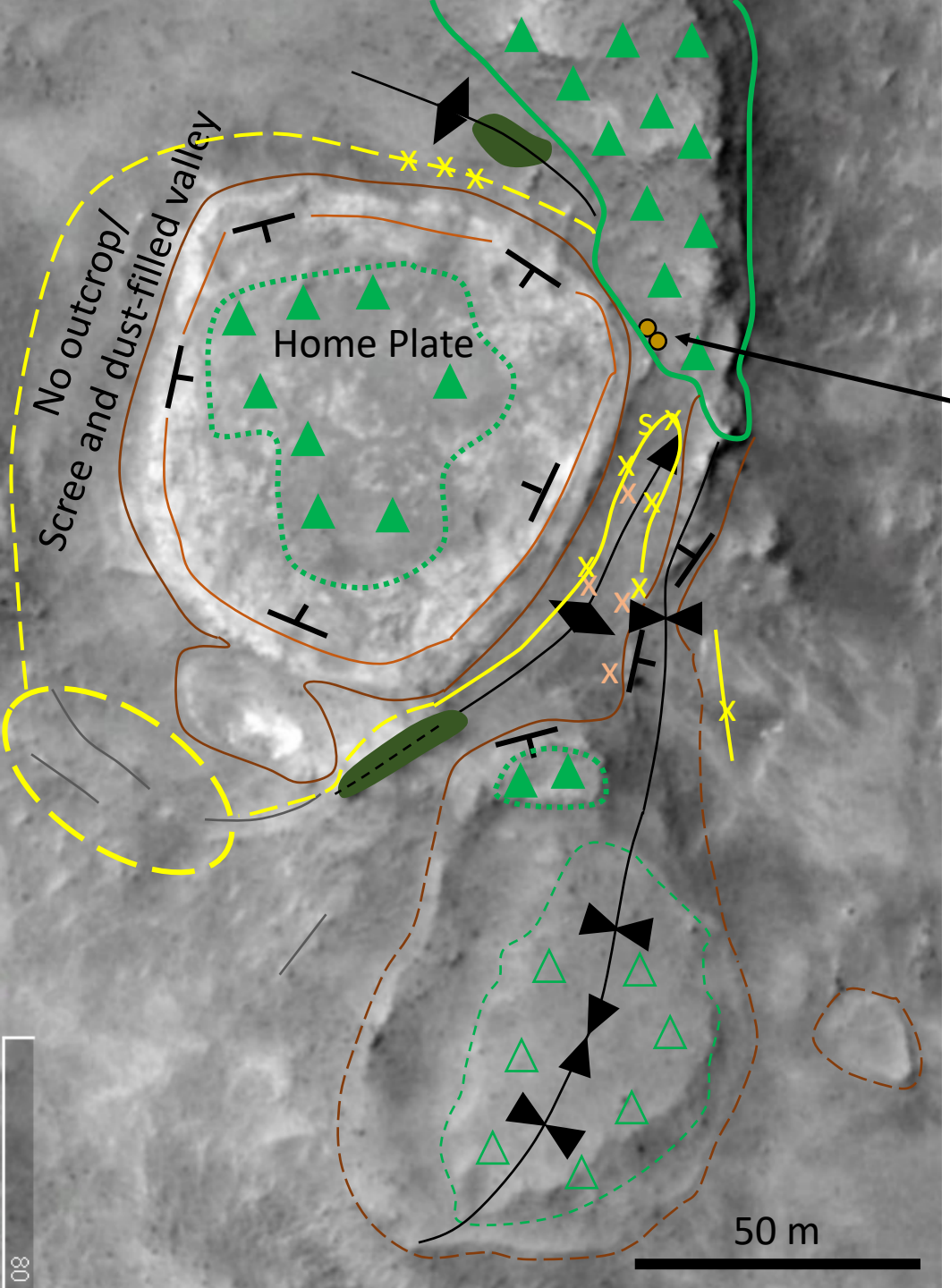


Silicify HP1

HP1 is not altered when adjacent to the nodular/digitate opaline silica; thus the opaline silica is *younger* than BHPU and *older* than HP1.



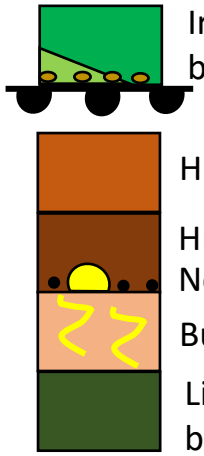



Nodular/digitate opaline silica occurrences are consistent with their being part of the stratigraphy, as it is folded together with the other bedded units.

This relationship is also consistent with the acid-sulfate alteration observed for the buff-colored platy unit

Its absence from “Backstop” area is consistent with an overlying unconformity of flat-lying Irvine Class vesicular basalt

**Stratigraphic column**



Irvine Class vesicular alkaline basalt, with basal conglomerate

HP2: Aeolian sandstone

HP1: volcaniclastic rocks

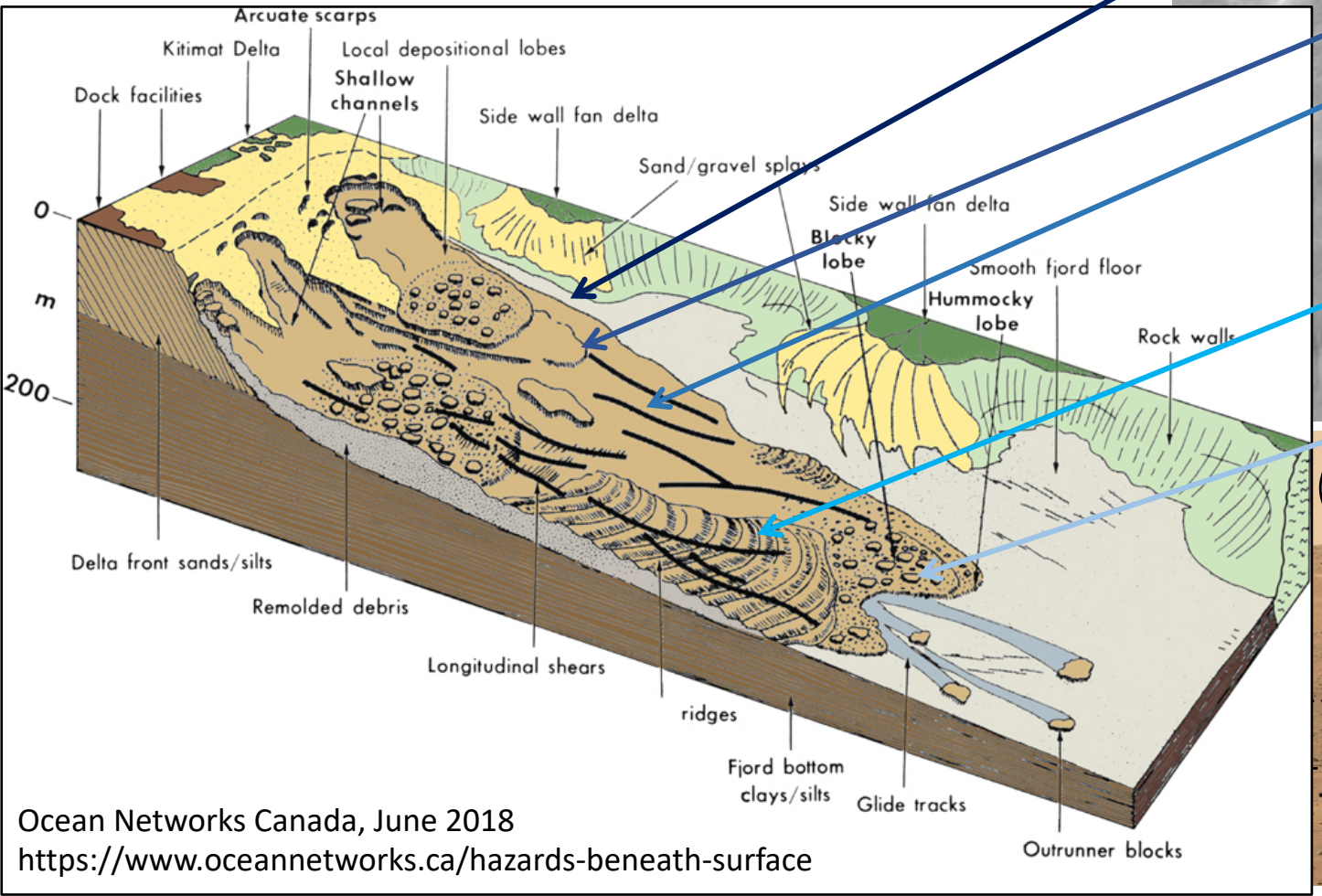
Nodular/digitate opaline silica

Buff-colored platy unit (ash)

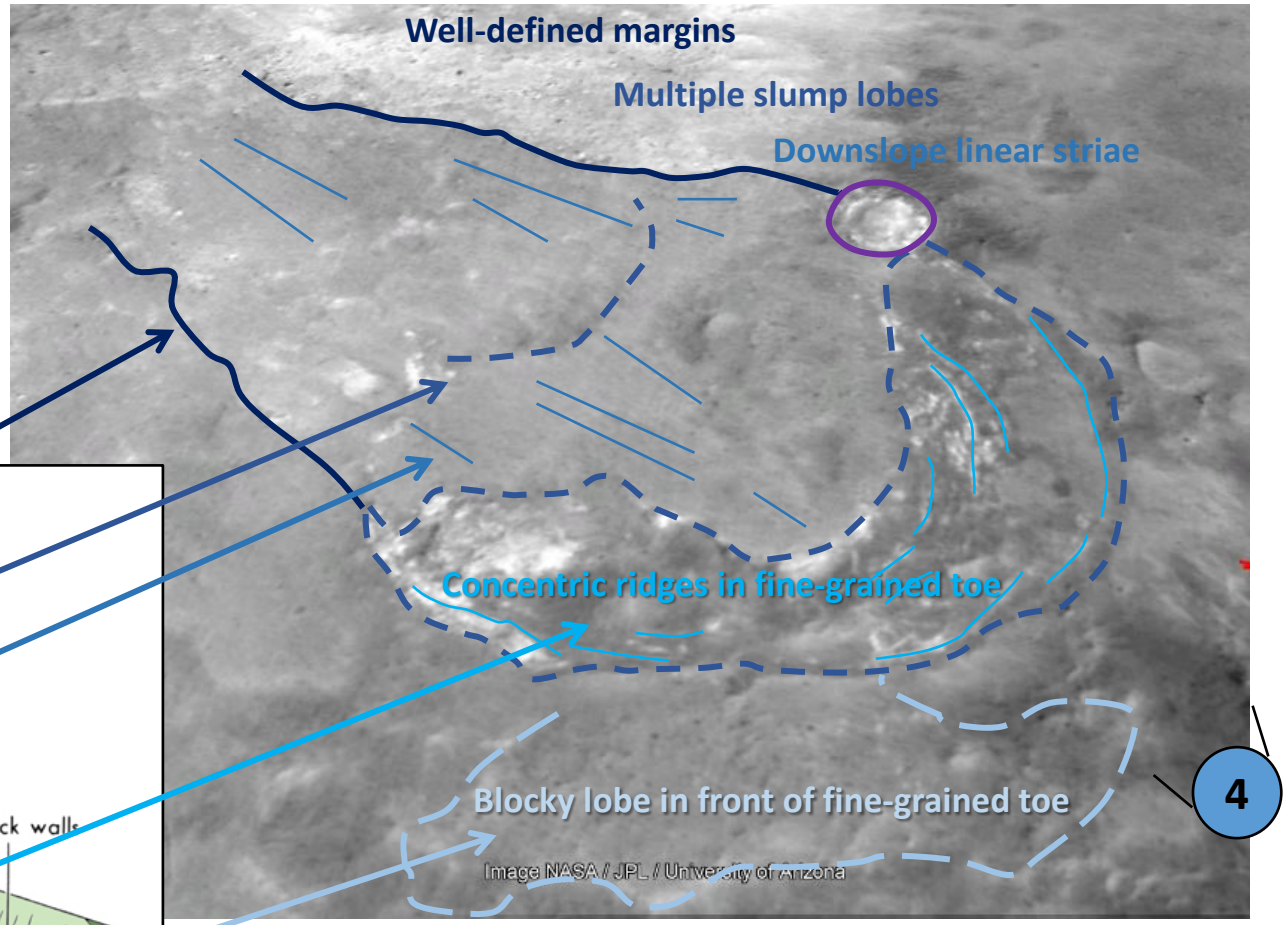
Light-toned, fine-grained, vesicular, olivine basalt

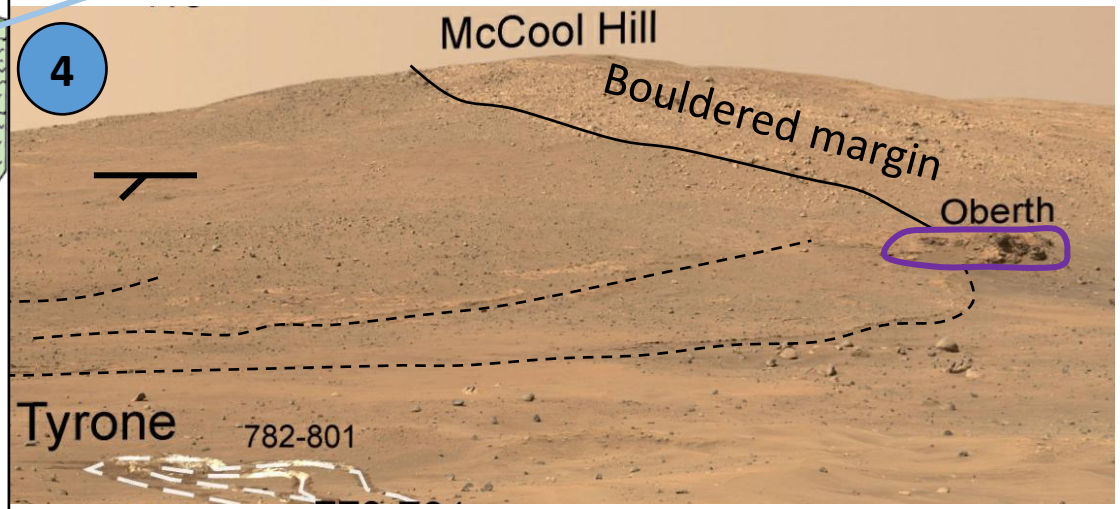
# McCool Hill mass waste deposit: A *subaqueous* landslide

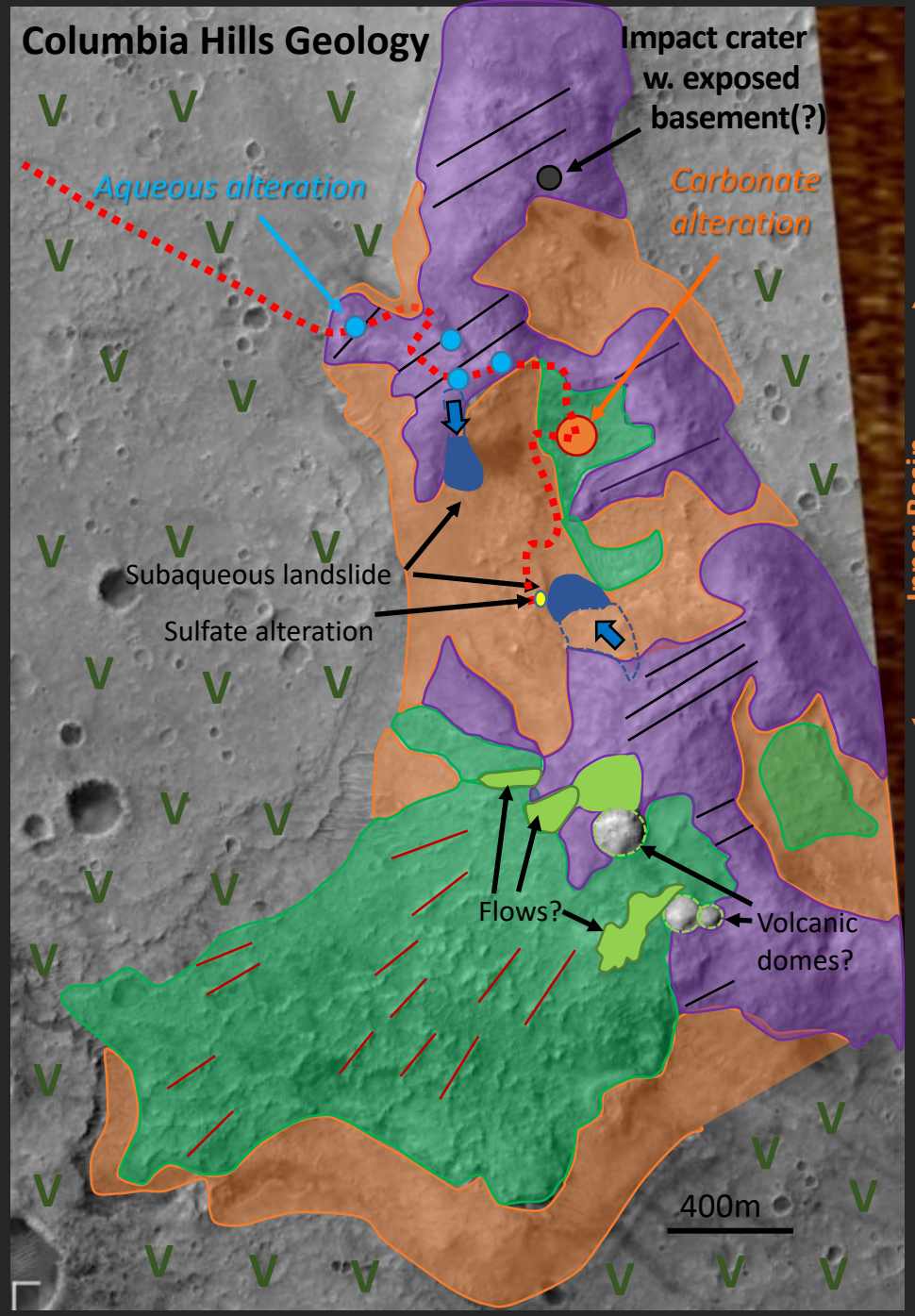
## Oldest unit of the Inner Basin




Ocean Networks Canada, June 2018
https://www.oceannetworks.ca/hazards-beneath-surface






# Event stratigraphy of the Columbia Hills

Minor hydrous alteration (atmospheric)

V — Adirondack Class (Plains basalt west): Olivine picrobasalt (3.6 Ga)

Inner Basin

-Irvine Class: Vesicular alkali basalt; with basal conglomerate

*Folding*

-Aeolian sandstone

-Barnhill Class: alkaline volcaniclastics

-Nodular/digitate opaline silica — *low water/rock, sulfate alteration*

-Halley Class Buff-coloured platy unit

-Vesicular basalt

-Sediments, with subaqueous landslide: Ma'Adim Vallis flooding?

*Erosion*

Algonquin Class: Olivine-bearing picritic tephra (north and south)

*carbonate alteration (Comanche Class)*

*Erosion*

Wishstone Class: Hawaiite tephra with NE-SW bedding strike: *(and associated other classes);*

*Uplift and erosion*

*aqueous and sulfate alteration (Watchtower Class)*

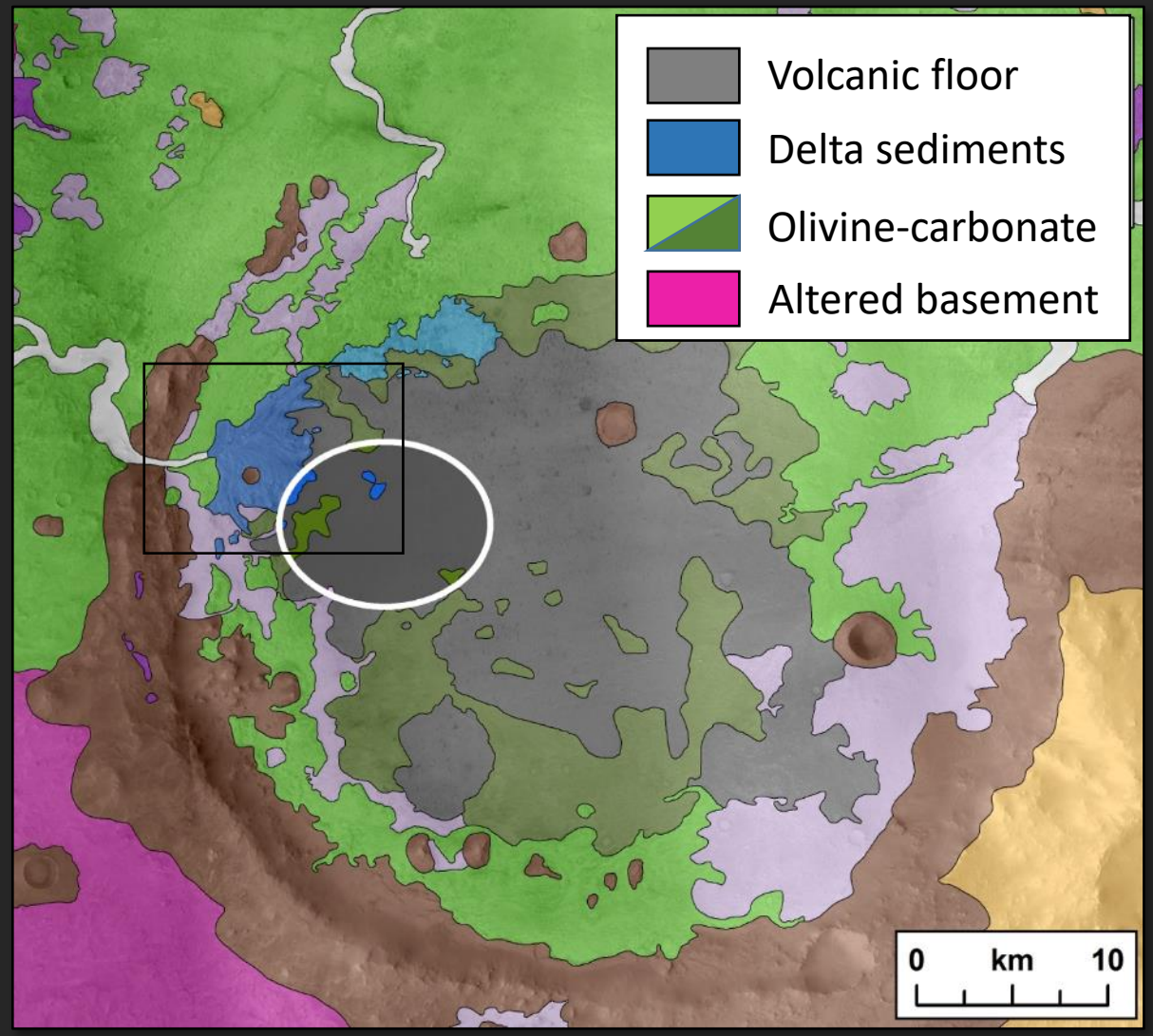
Possible basement in floor of impact crater

Subaerial

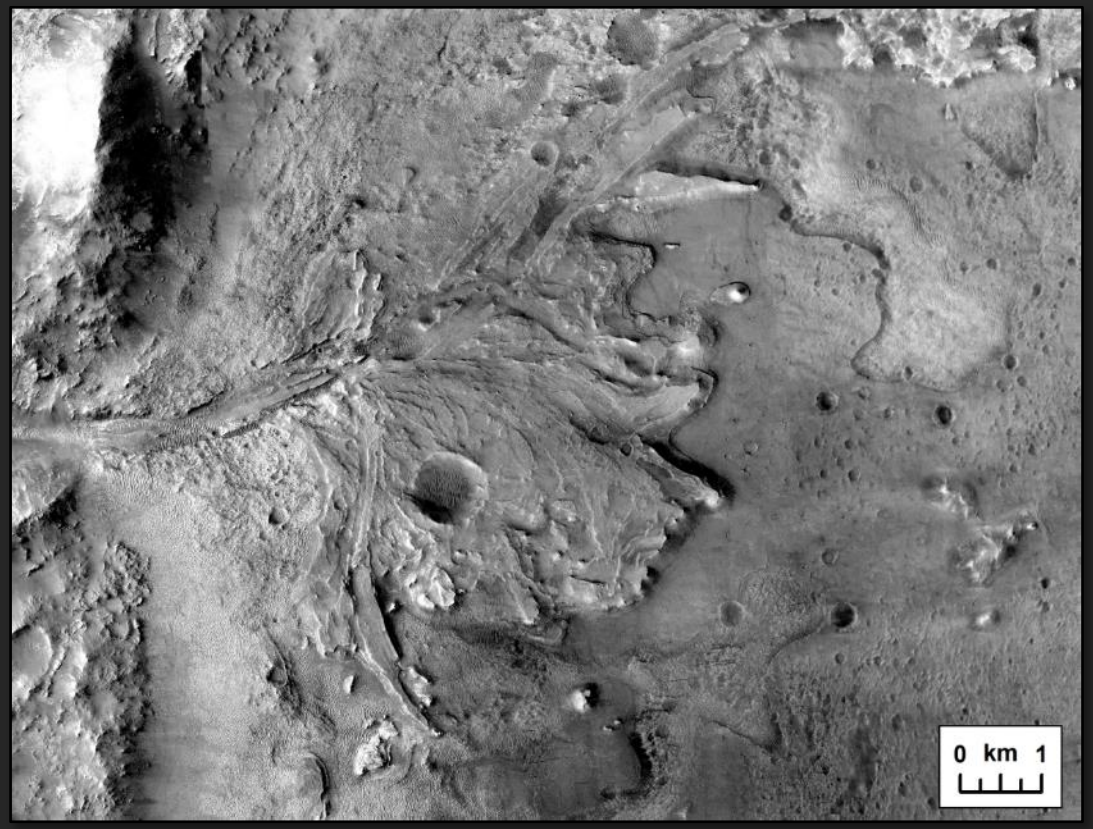
Aqueous alteration

# Jezero: A fluvial-deltaic system

- **Diverse geologic units *in clear stratigraphic context*** (*Ehlmann et al.,* 2008a; *Goudge et al.,* 2015).
- ***Long-lived* delta**
- **Fe-Mg smectite clays may contain organics**

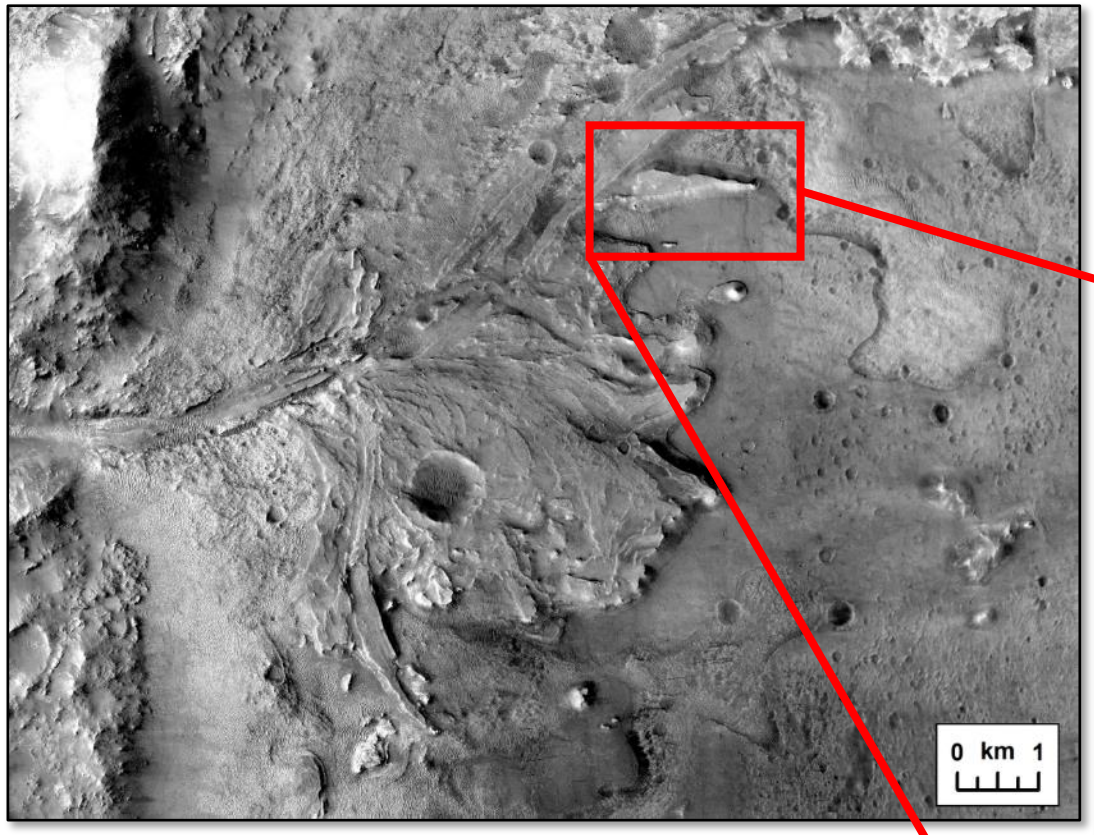



*Goudge et al.* [2015]



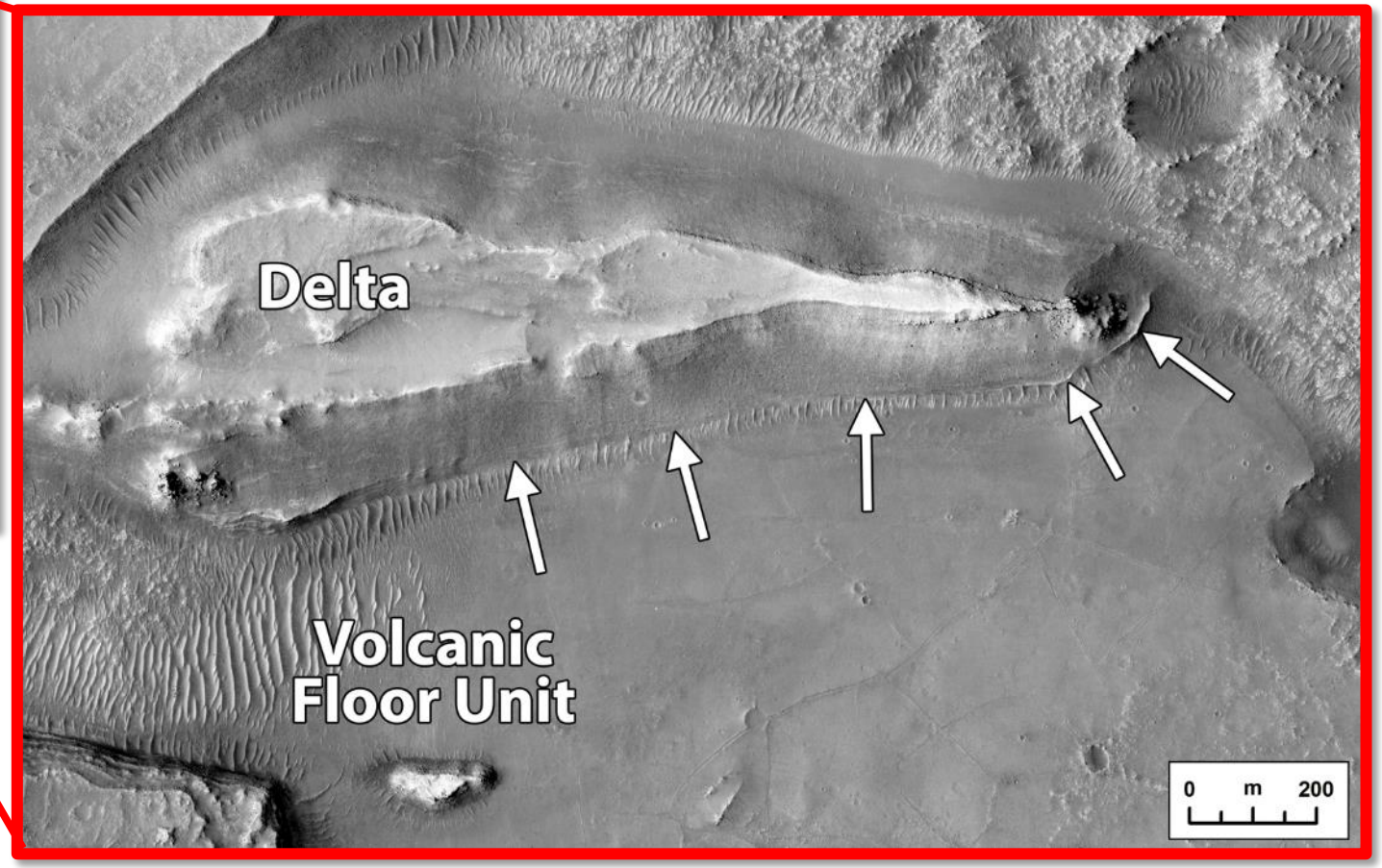
# Clear stratigraphic context…

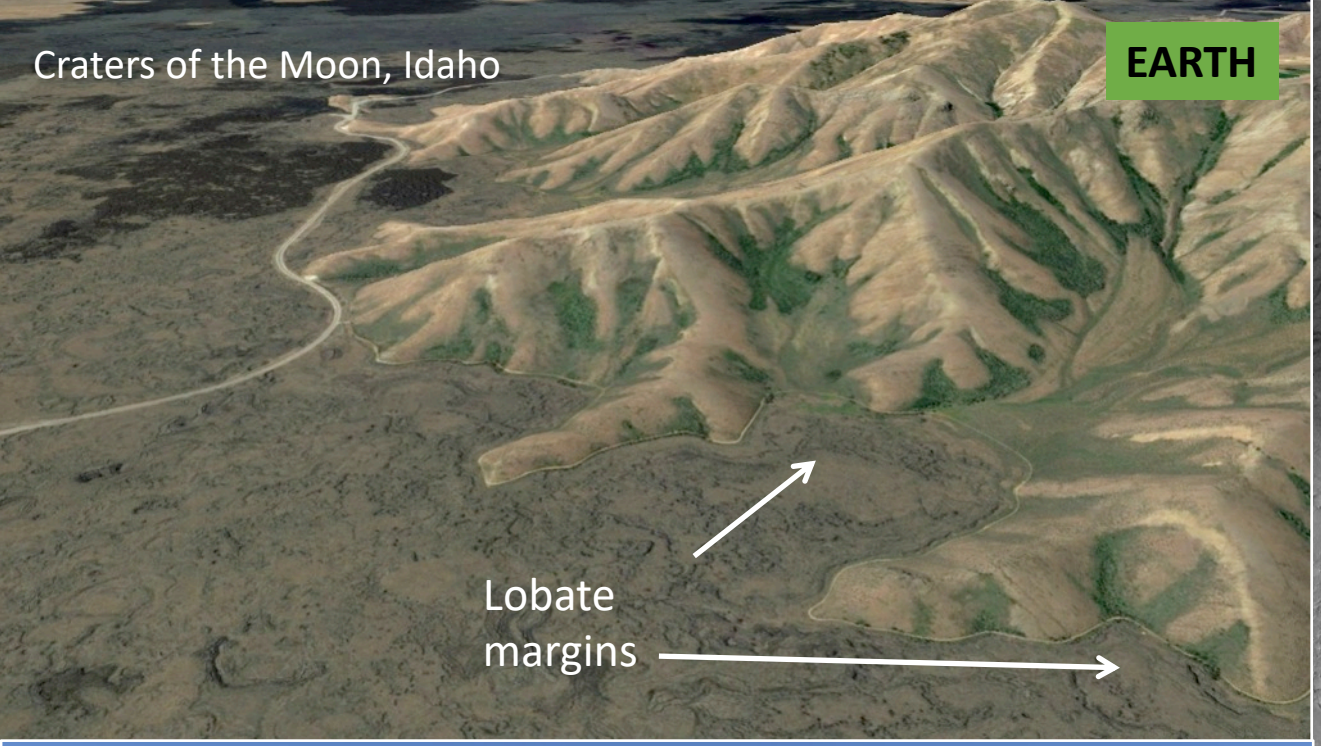
## Volcanic floor unit interpreted as *younger than* the delta

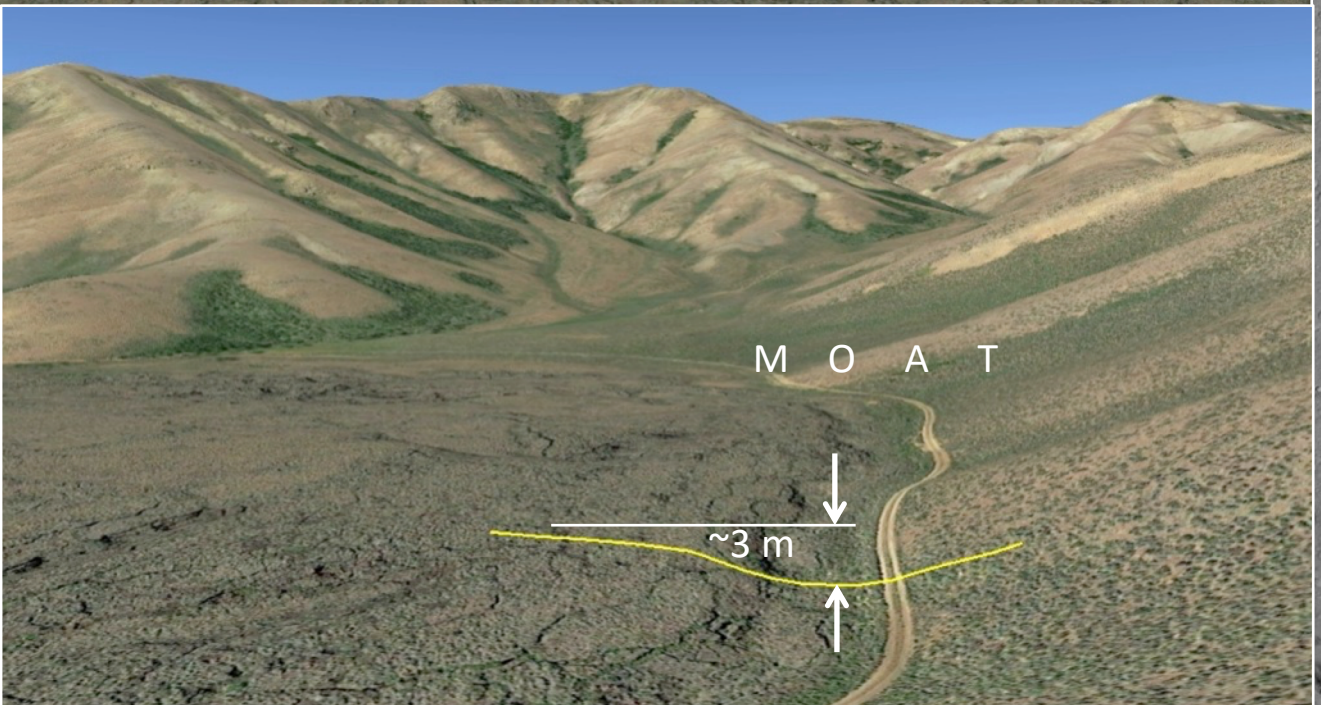


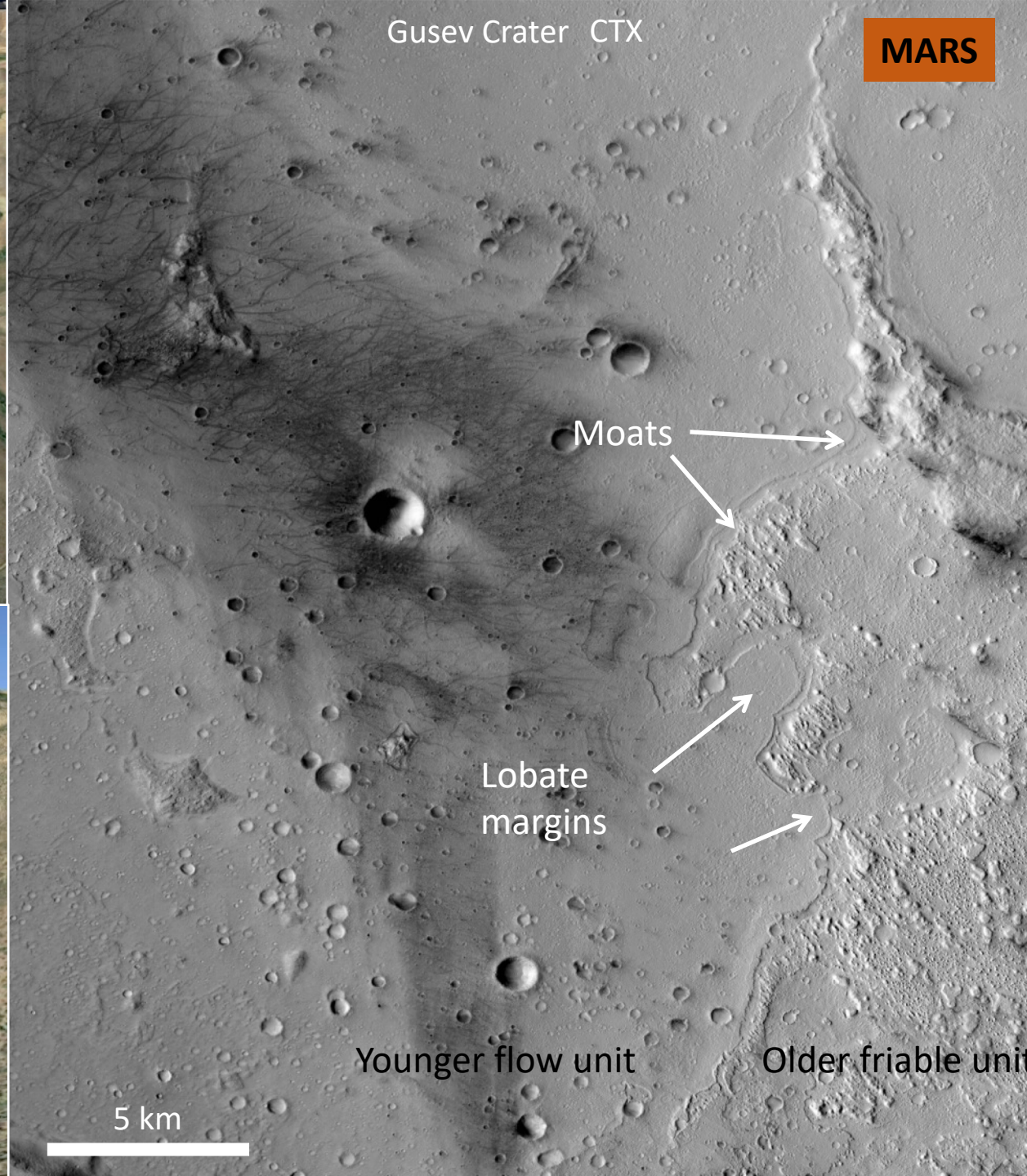

Volcanic floor unit embays delta deposit.

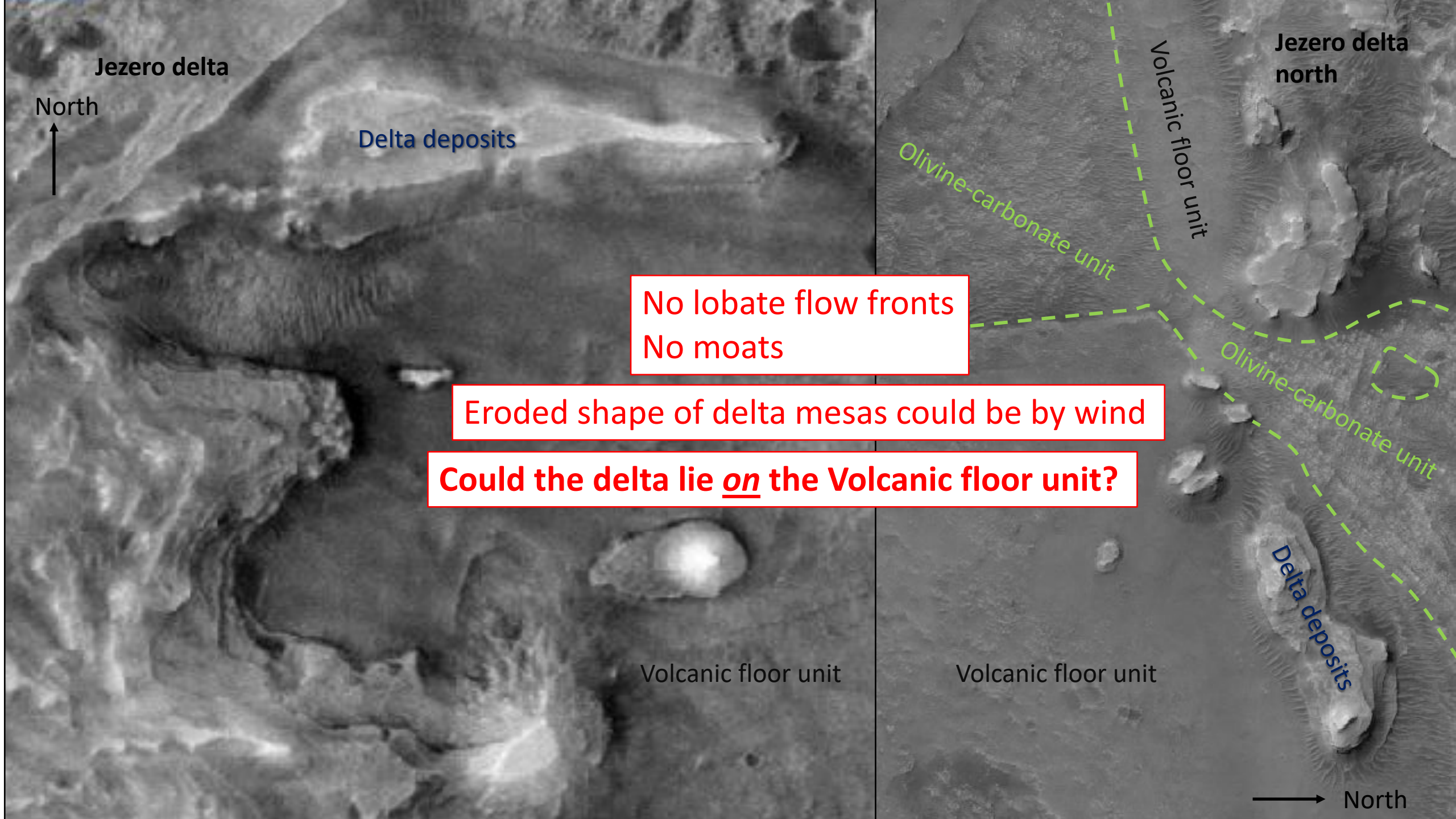
*Goudge et al.* [2012, 2015]




Craters of the Moon, Idaho
EARTH
Lobate
margins


M O A T
~3 m

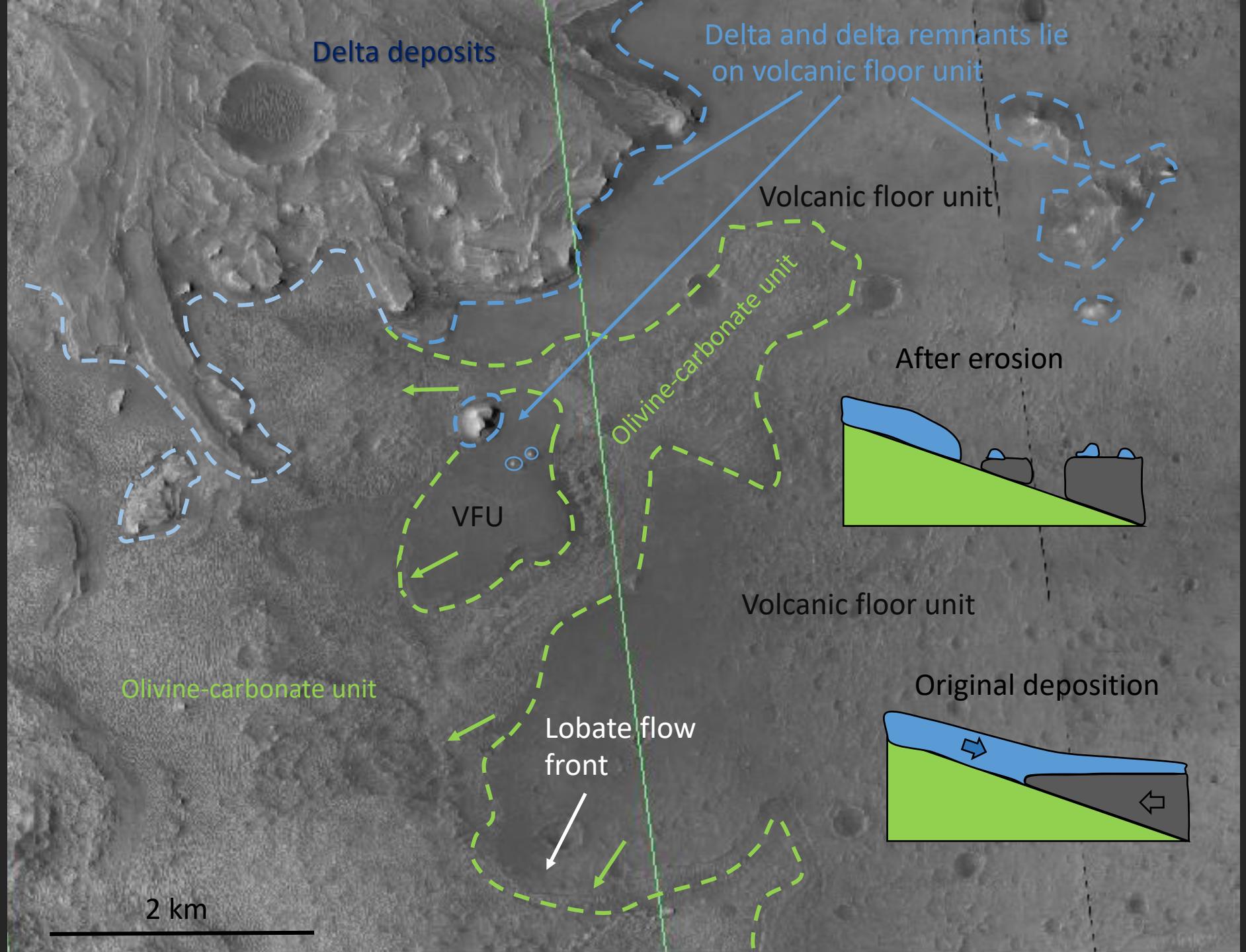

Gusev Crater CTX
MARS
Moats
Lobate
margins
Younger flow unit
Older friable unit
5 km




No lobate flow fronts
No moats

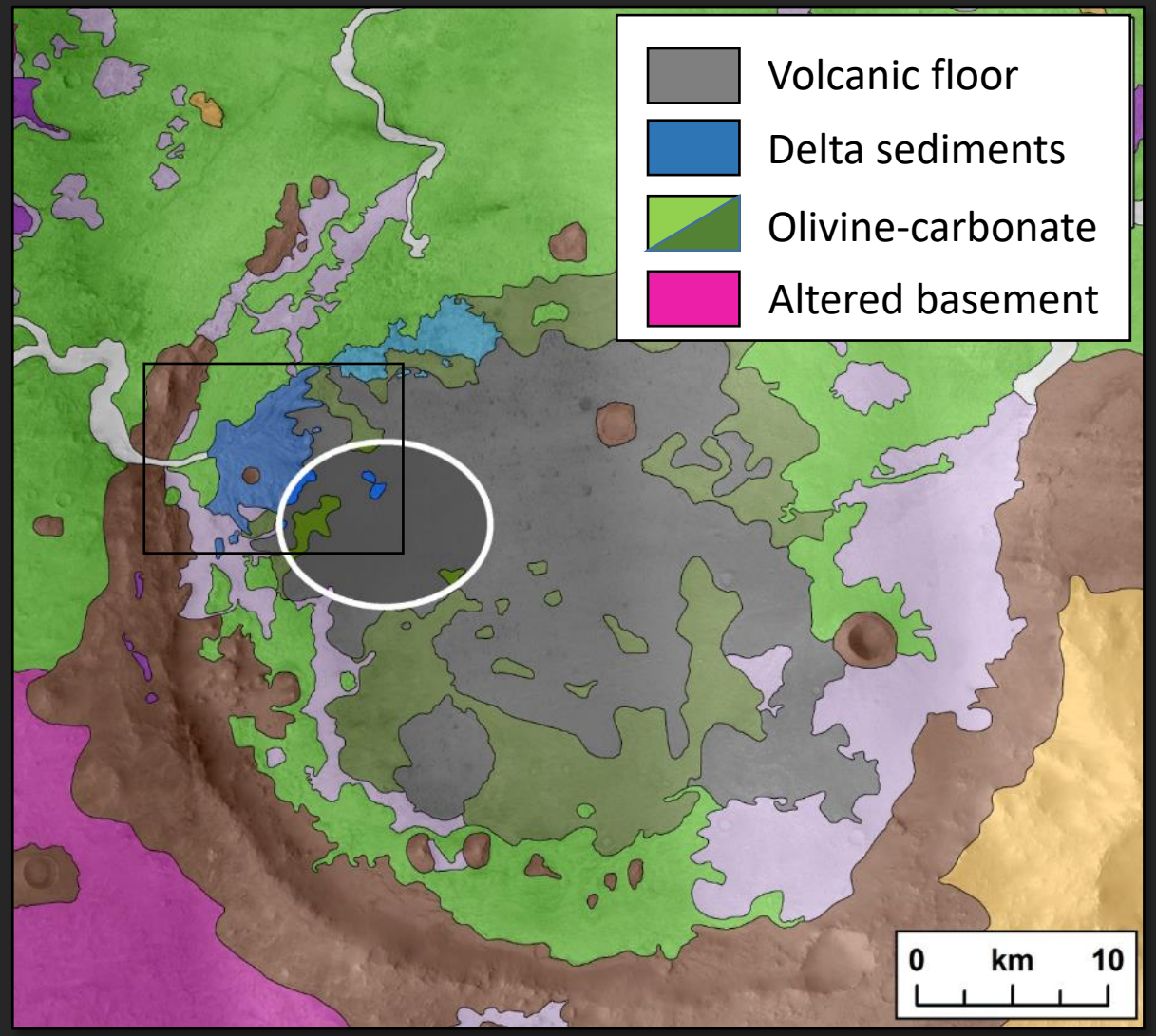
Eroded shape of delta mesas could be by wind

**Could the delta lie *on* the Volcanic floor unit?**

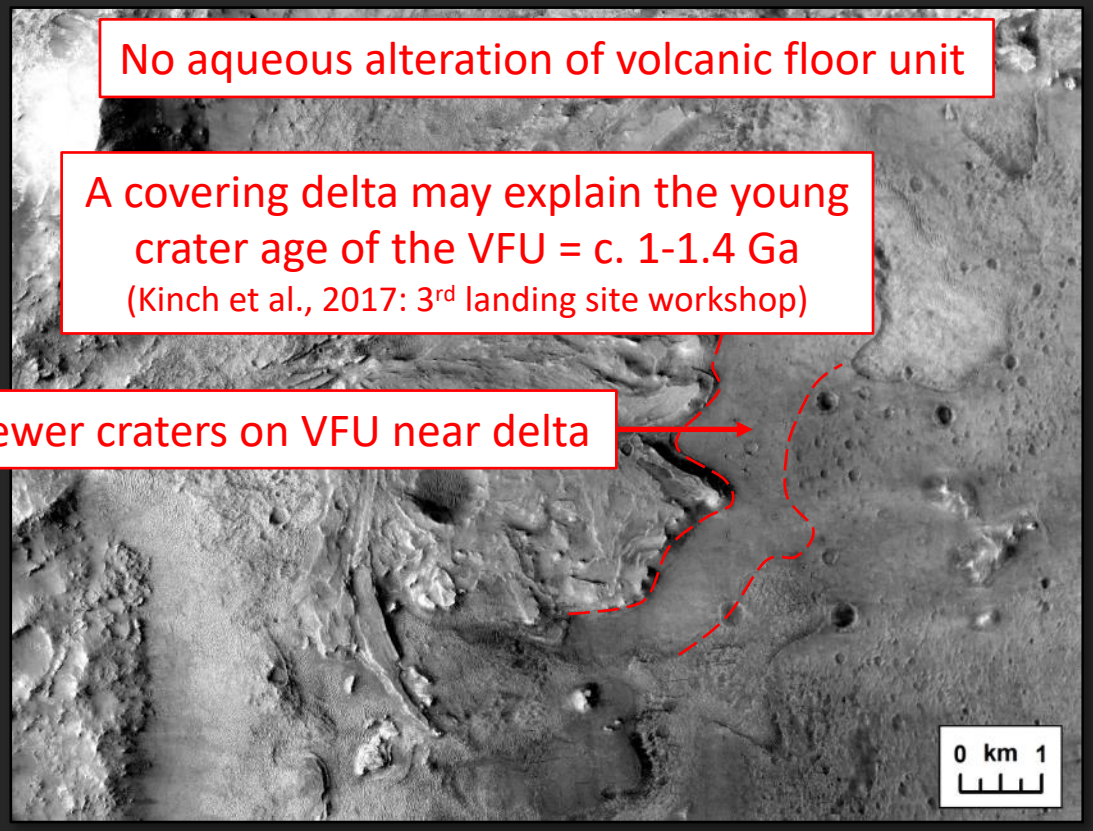

Delta deposits
Delta and delta remnants lie on volcanic floor unit
Volcanic floor unit
Olivine-carbonate unit
After erosion
VFU
Volcanic floor unit
Olivine-carbonate unit
Original deposition
Lobate flow front
2 km

# Jezero: A fluvial-deltaic system

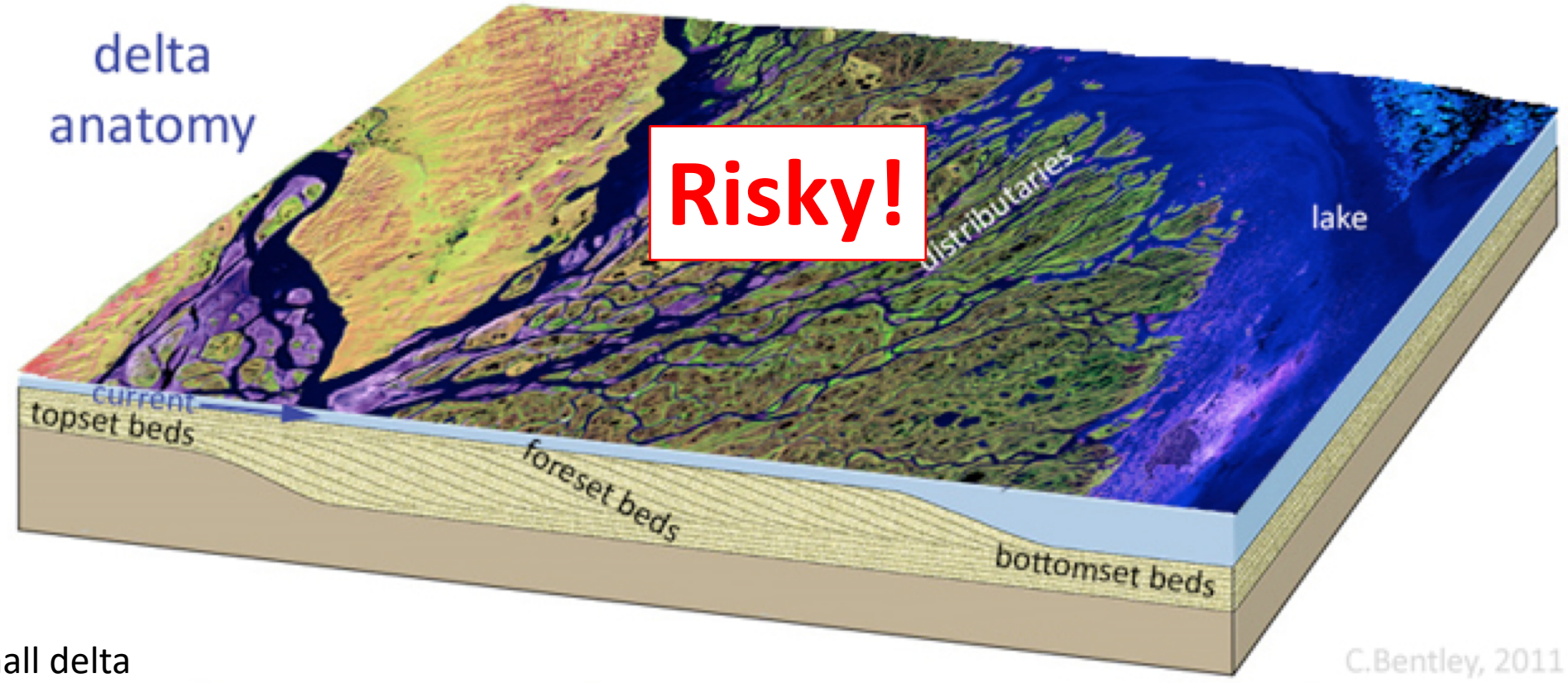
- **Diverse geologic units *in clear stratigraphic context*** (*Ehlmann et al.*, 2008a; *Goudge et al.*, 2015).
- ***Long-lived* delta?**
- **Fe-Mg smectite clays; derived through transport from basement hinterland**




*Goudge et al.* [2015]

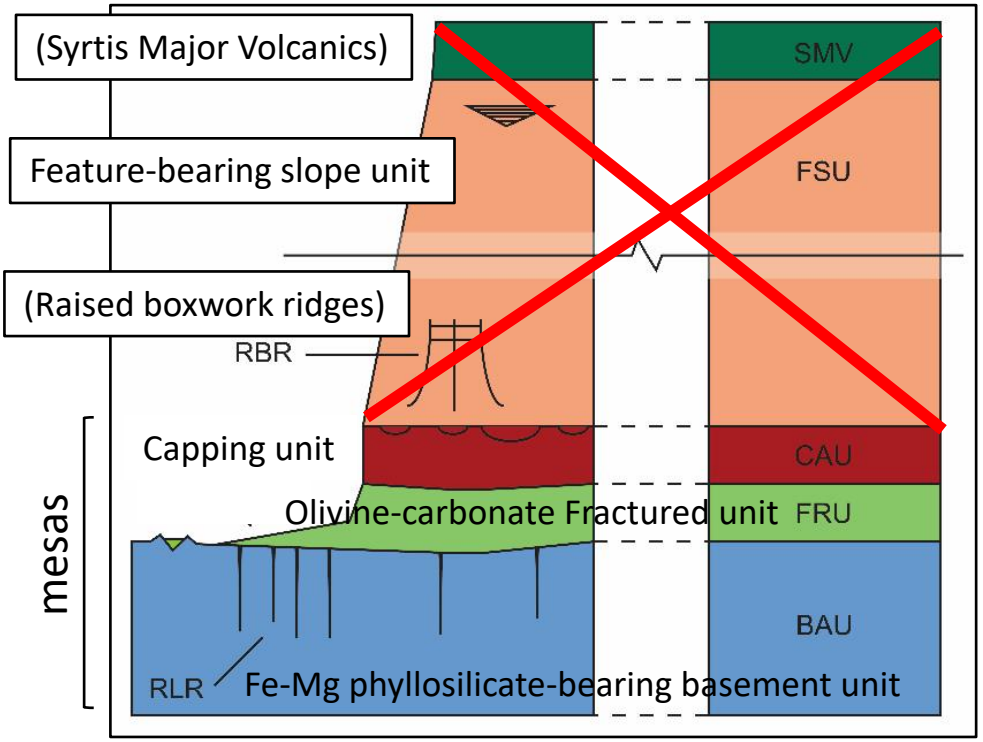


# Thus, a reliance on this model is…

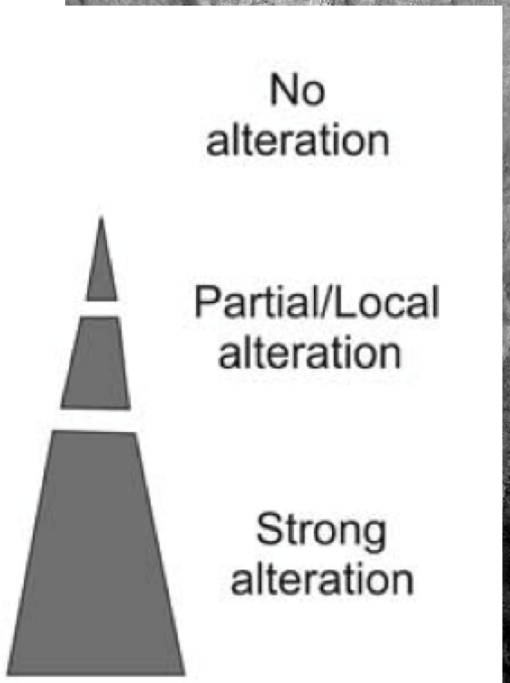



Small delta
Long-lived?
Type of metabolism? Phototrophic unlikely…
Low organic concentration?
Youngest unit, thus susceptible to radiation damage…

# NE Syrtis Major – land of many mesas




Bramble et al., 2017: Icarus

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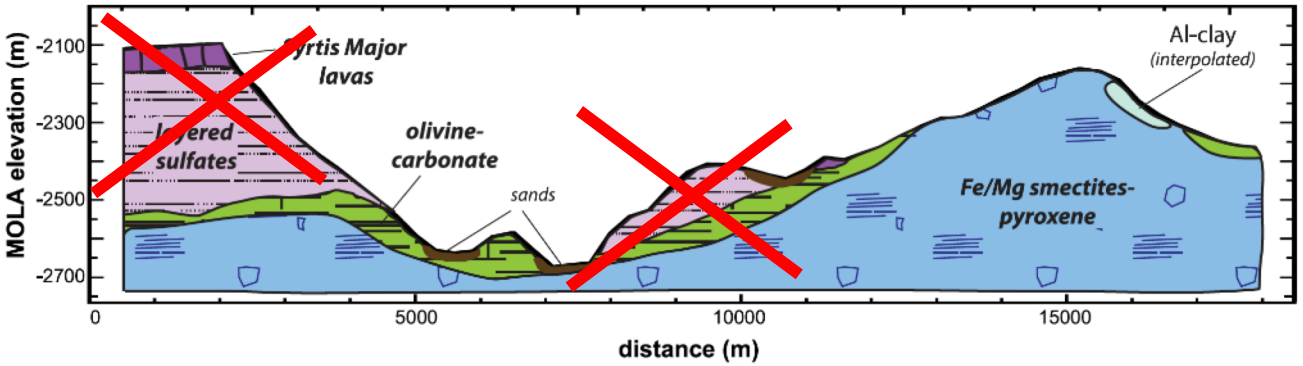
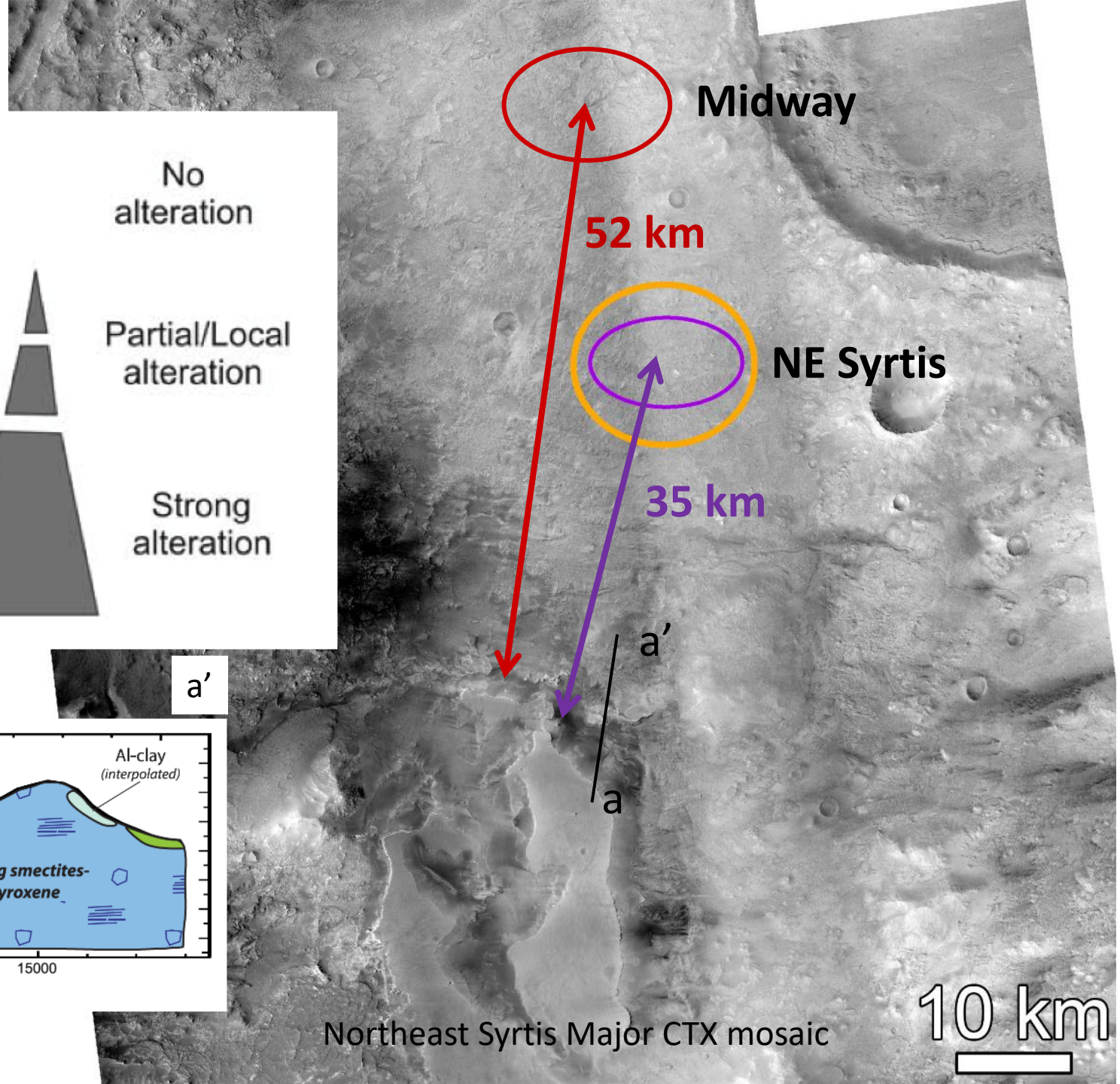


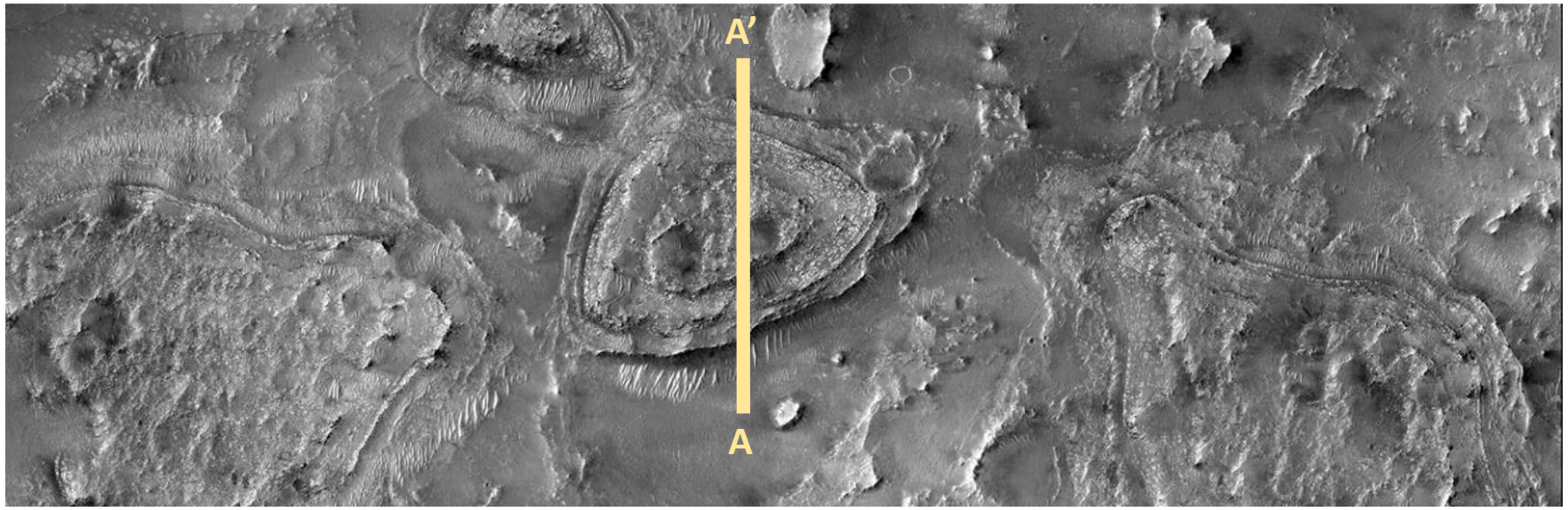

Ehlmann and Mustard, 2012

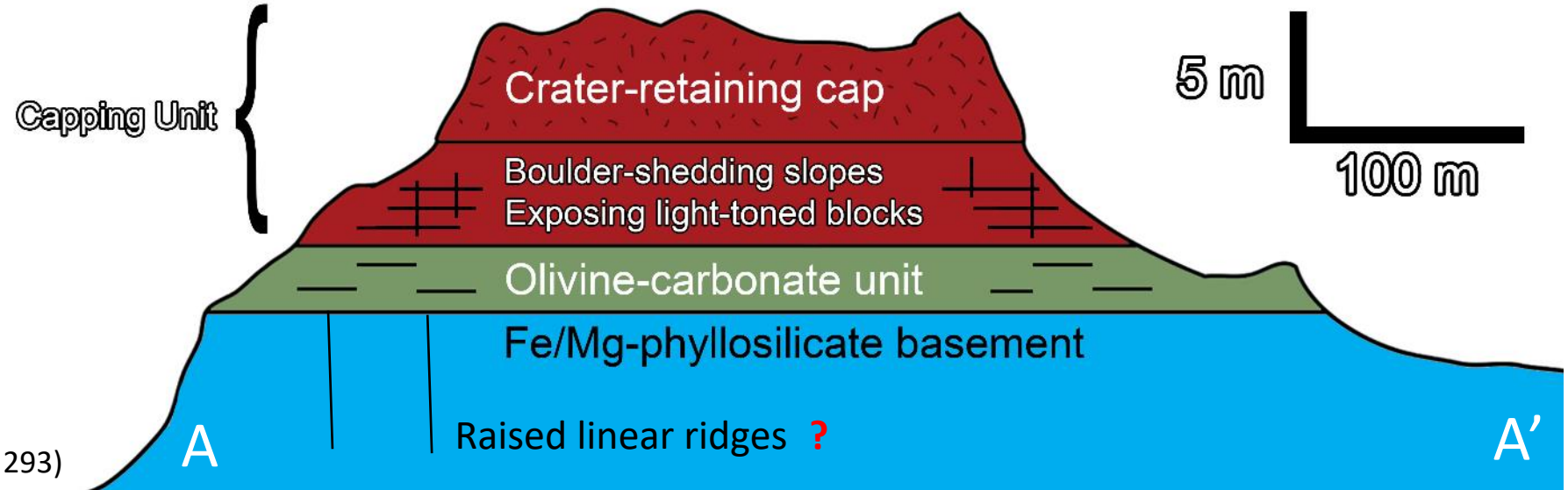



Northeast Syrtis Major CTX mosaic

Clear stratigraphy of *3* main units, *but all mesas show the same units*:

***low geological diversity***




(Bramble et al., 2017: Icarus 293)

# Noachian Crust

Investigation of megabreccia will gain information on the “magnetic field, geochronology, and petrogenesis” of pre-Isidis basement.

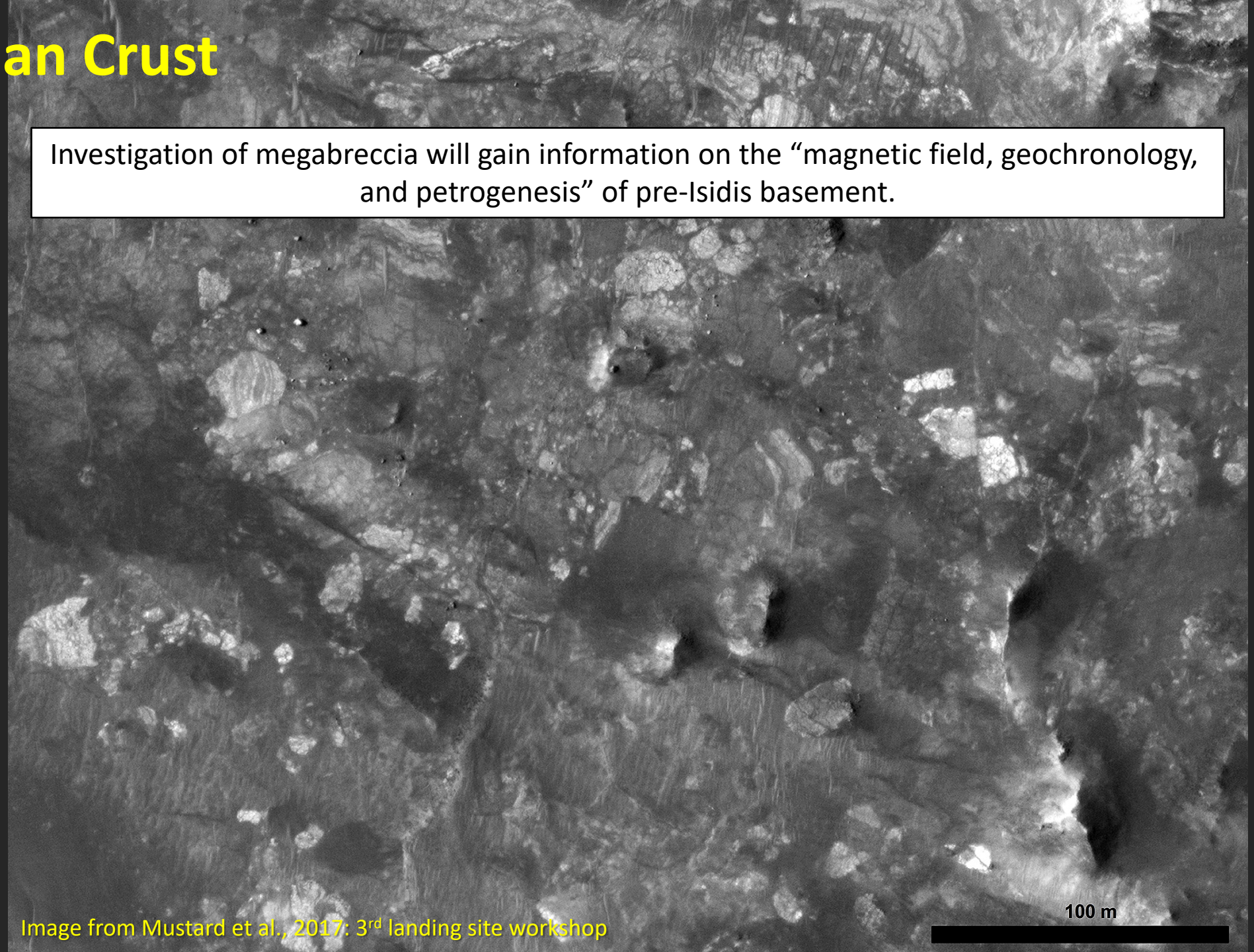



Image from Mustard et al., 2017: 3rd landing site workshop

Sudbury Impact, Canada

130 km

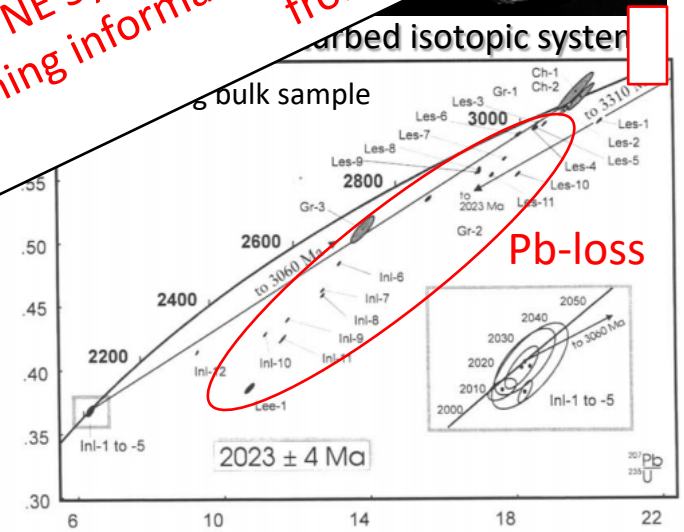
**Pseudotachylyte-hosted breccia**

**Shattercones**

Vredefort Impact Structure, S. Africa

(largest on Earth)

300 km




Kamo et al. 1996: EPSL

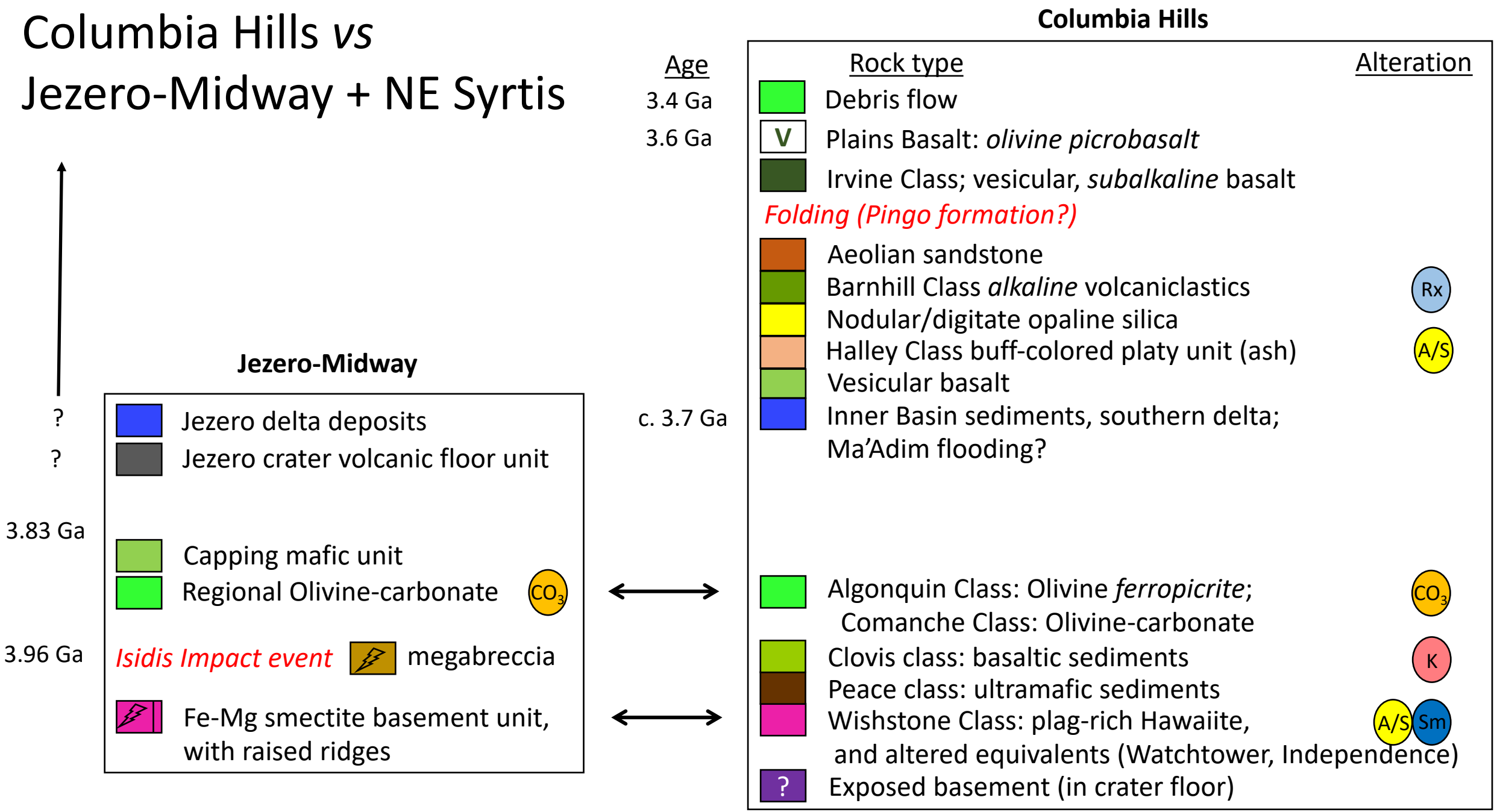
Isidis Basin, Mars

km

Mustard et al., 2009: JGR 114

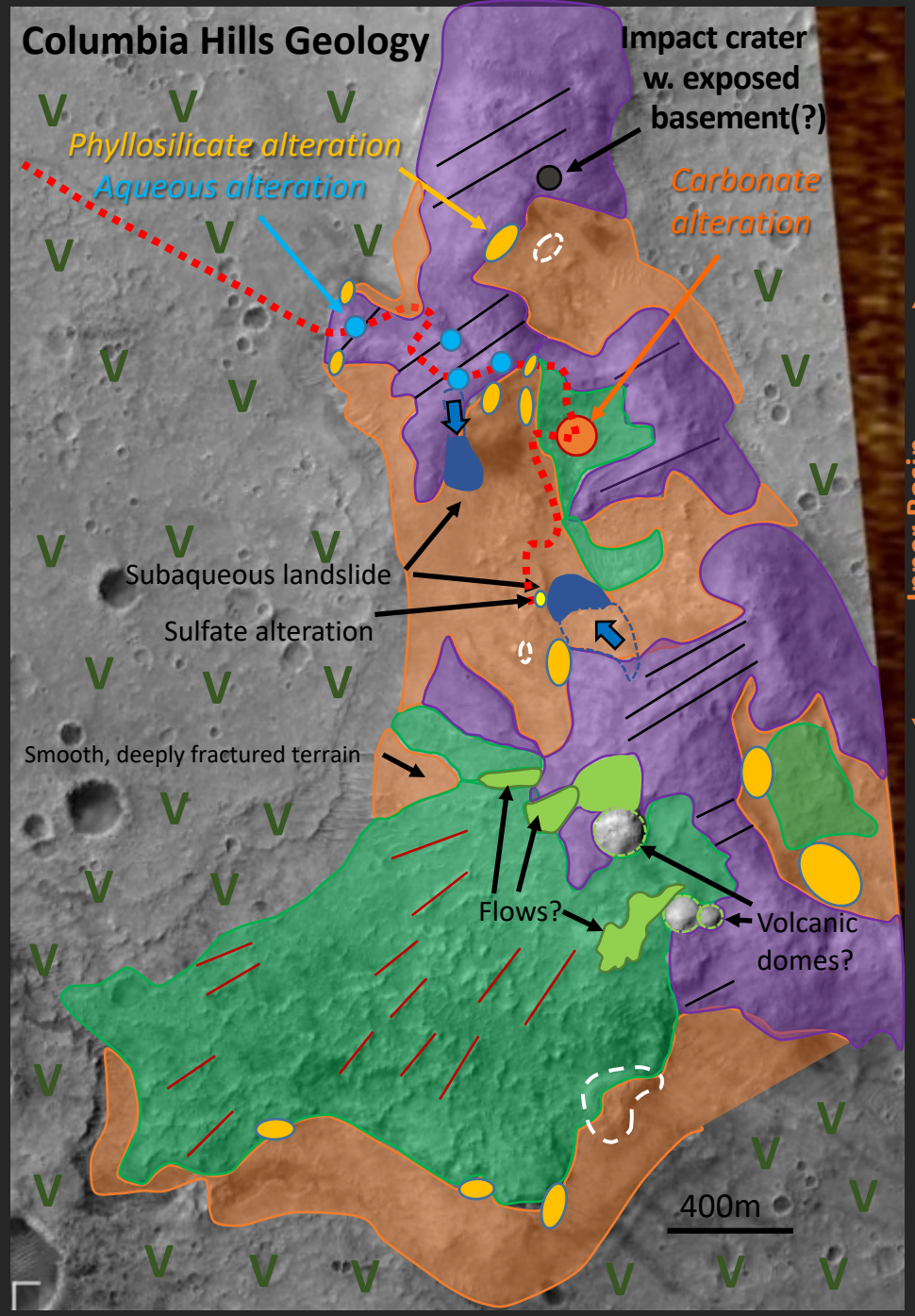
Pre-Isidis "basement" at NE Syrtis, Midway, Jezero will be *significantly* compromised by the Isidis impact event:
The stated goals of gaining information on the "magnetic field, geochronology, and petrogenesis" of basement from Isidis breccia blocks is ***RISKY!***

# Columbia Hills *vs* Jezero-Midway + NE Syrtis

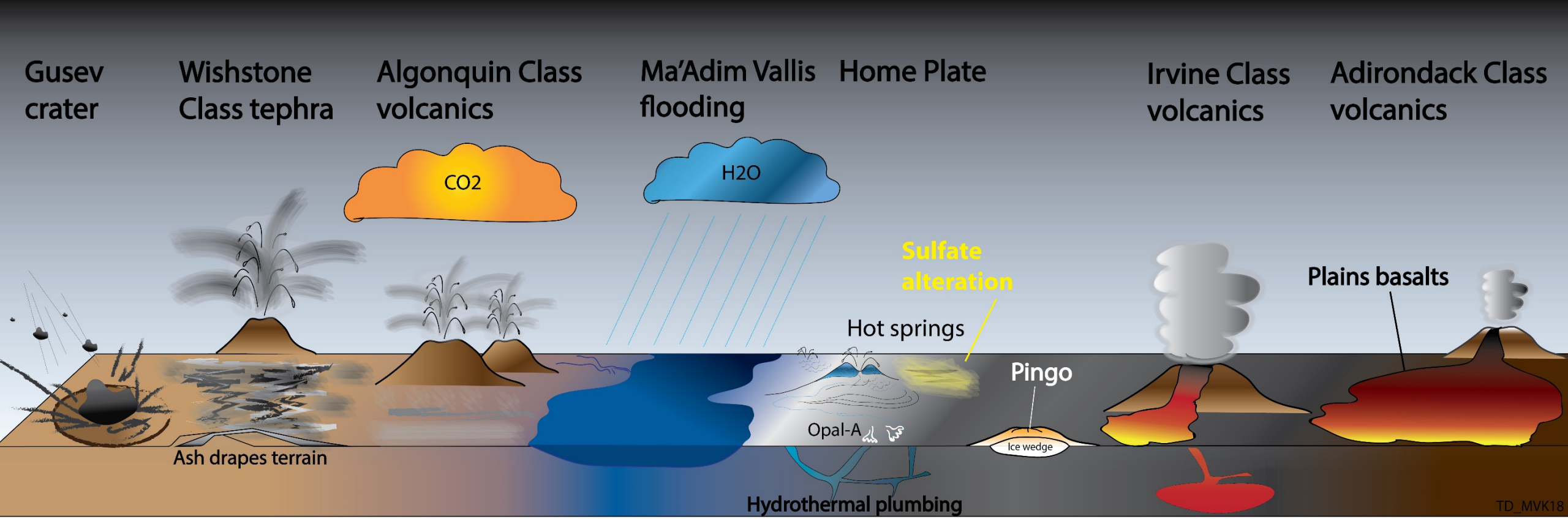


COLUMBIA HILLS
"So much more to explore"

# Event stratigraphy of the Columbia Hills



# Geological history of Columbia Hills, Gusev Crater

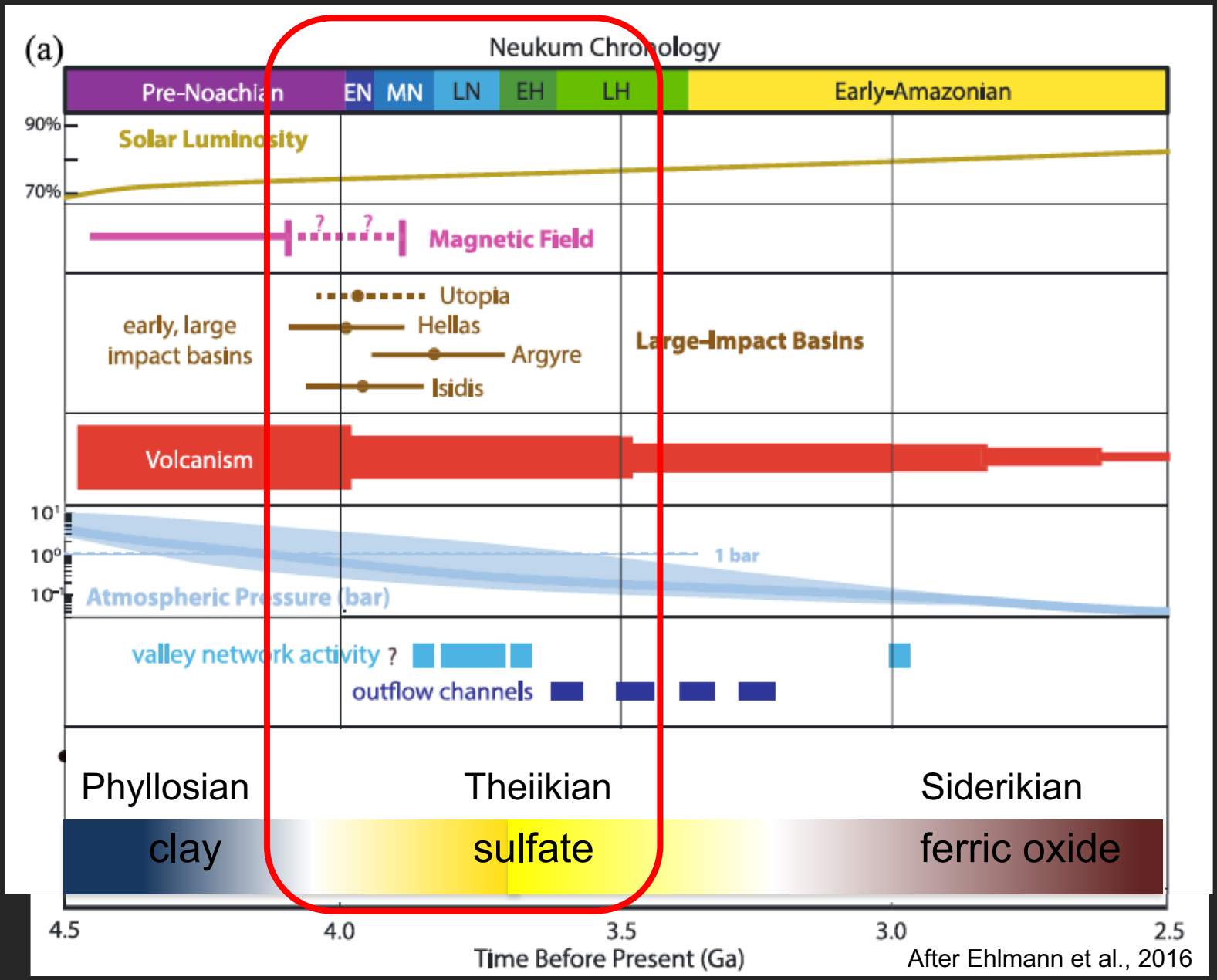



~4 Ga
Early Noachian

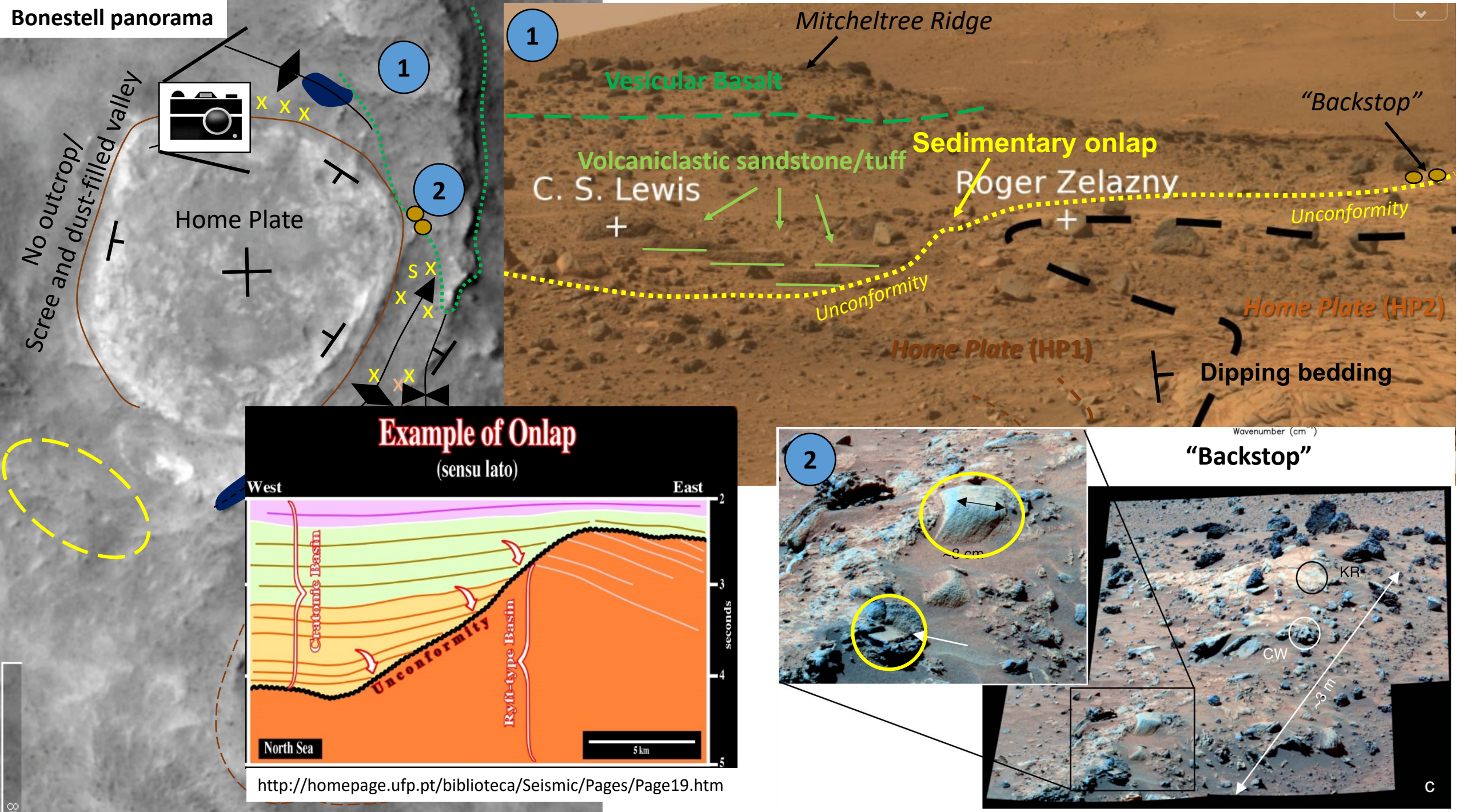
~3.8 Ga
Warm/wet period

~3.6 - 3.5 Ga
Late Hesperian

# Tara's diagram

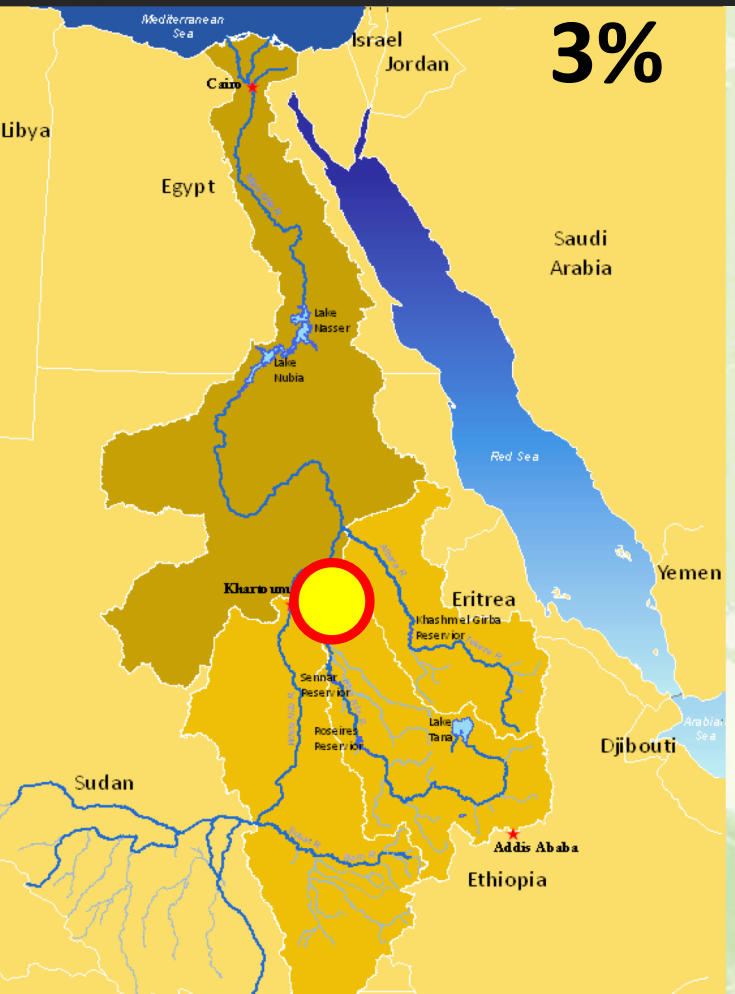


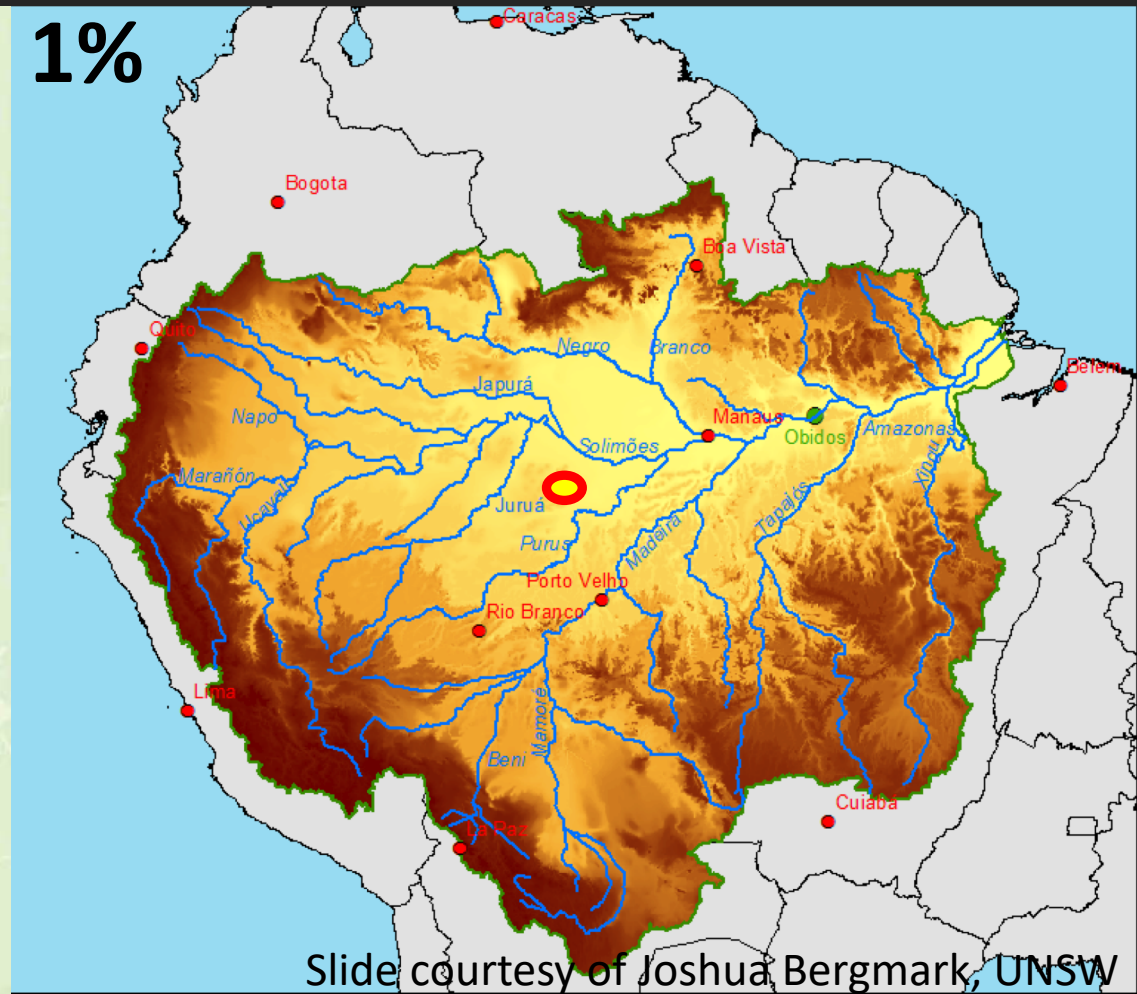

After Ehlmann et al., 2016




http://homepage.ufp.pt/biblioteca/Seismic/Pages/Page19.htm

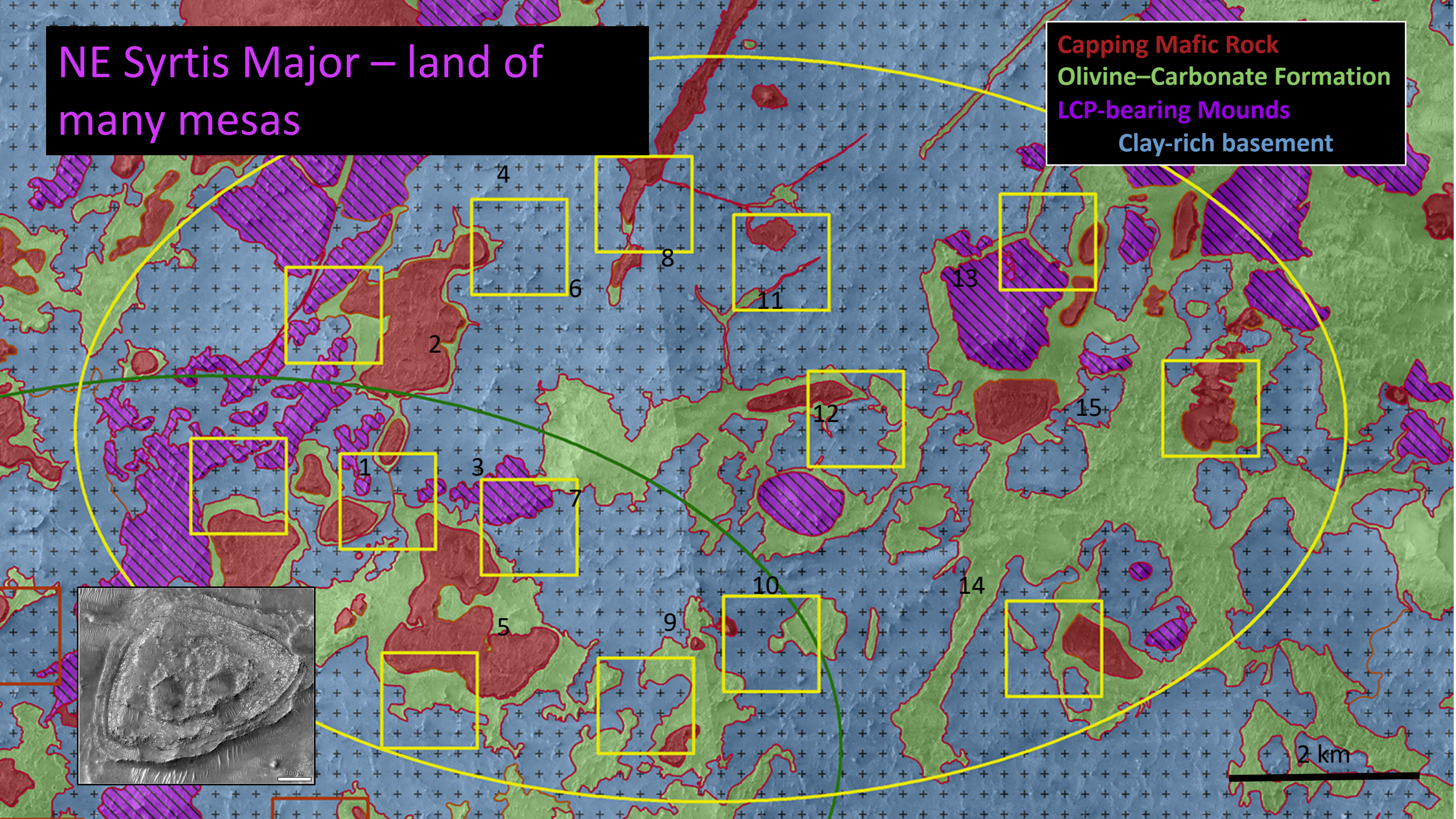
# Jezero delta is *small*: it ain't no Amazon

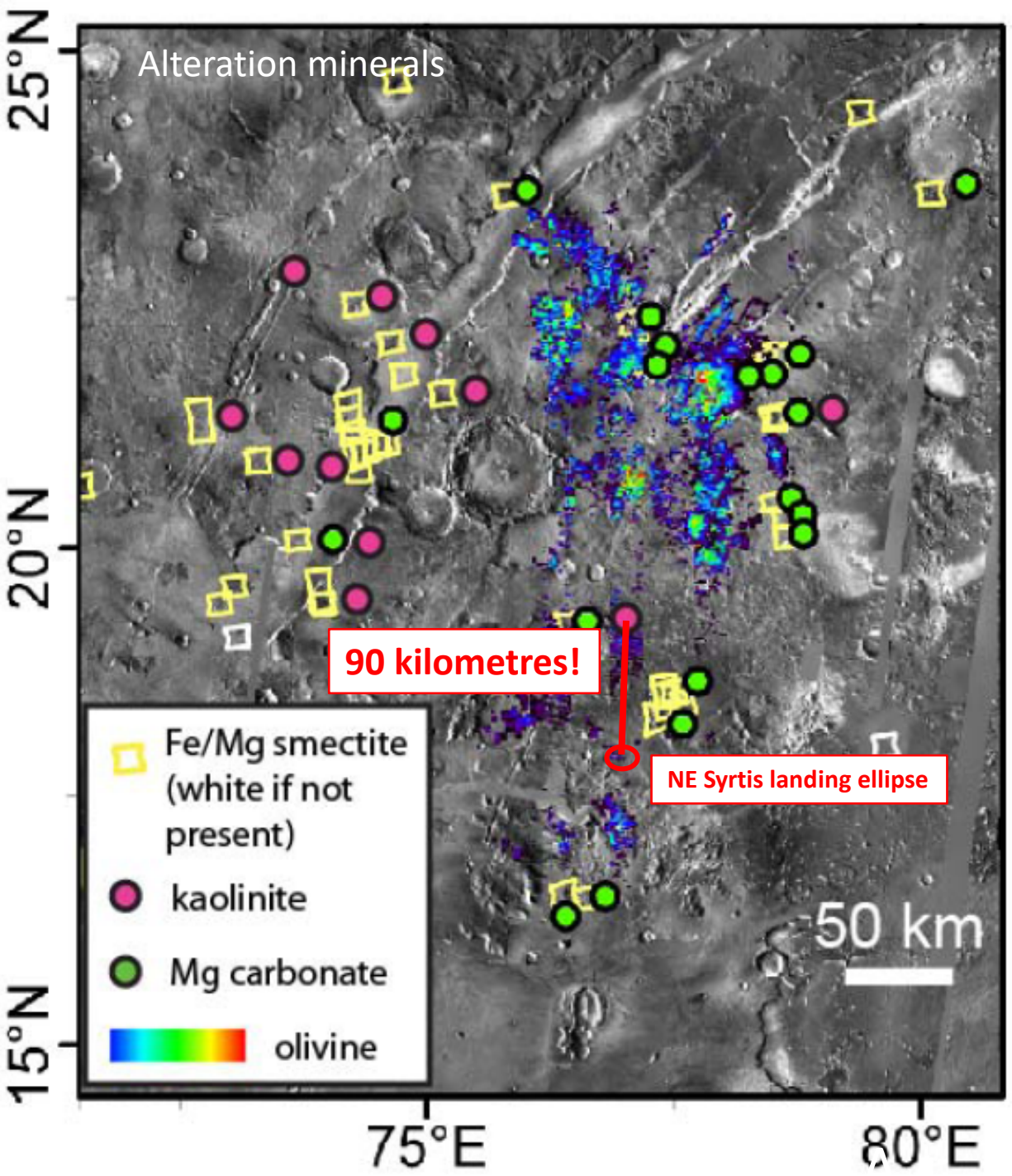





Slide courtesy of Joshua Bergmark, UNSW

# NE Syrtis Major – land of many mesas



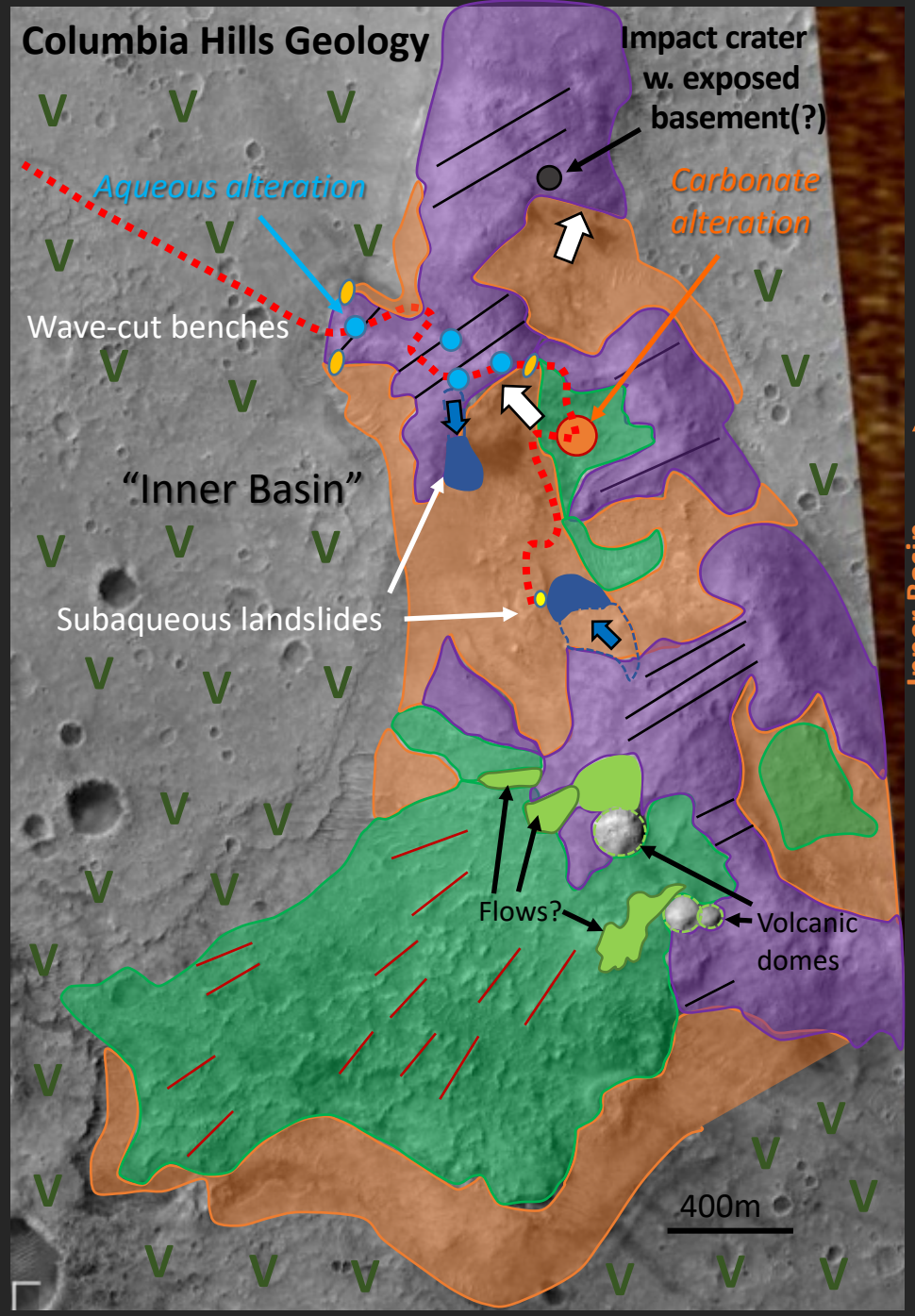



**Kaolinite may *NOT* be a realistic target**

Ehlmann et al., 2008: Science
Ehlmann et al., 2009: *JGR*

# Event stratigraphy of the Columbia Hills

## New analyses suggest period of standing water at onset of Inner Basin succession




*Minor hydrous alteration (atmospheric)*

V — Adirondack Class (Plains basalt west): Olivine picrobasalt (3.6 Ga)

Inner Basin

-Irvine Class: Vesicular alkali basalt; with basal conglomerate

***Folding***

-Aeolian sandstone

-Barnhill Class: tuffaceous rocks

-Nodular/digitate opaline silica

*low water/rock, sulfate alteration*

-Halley Class Buff-coloured platy unit

-Vesicular basalt

***Erosion***

*carbonate alteration (Comanche Class)*

Algonquin Class: Olivine-bearing picritic tephra (north and south)

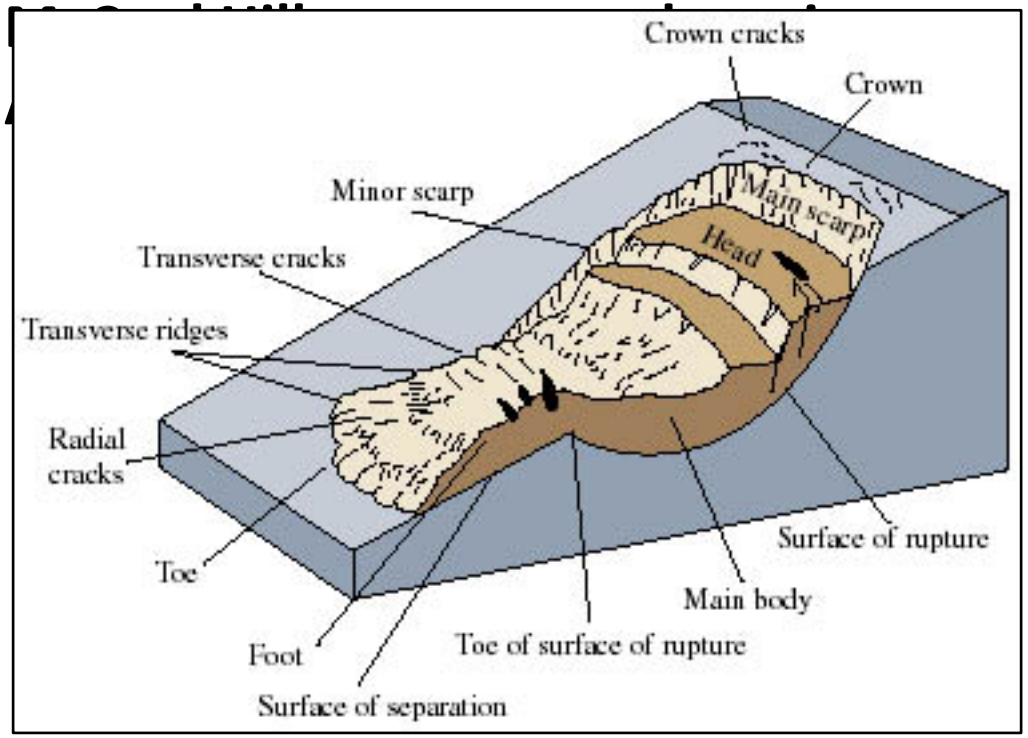
***Erosion***

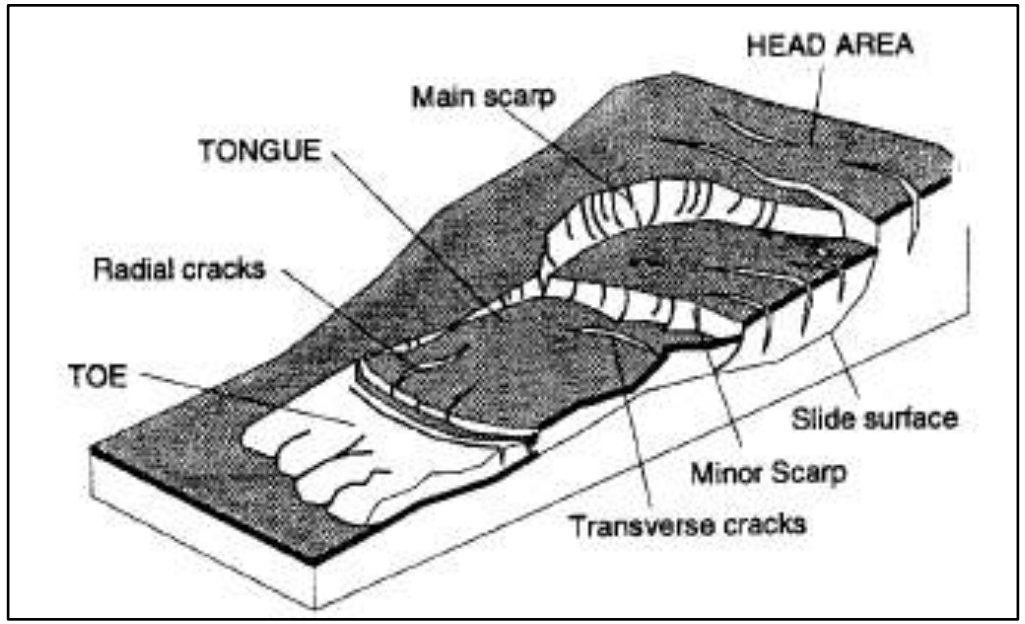
*aqueous and sulfate alteration (Watchtower Class)*

Wishstone Class: Hawaiite tephra with NE-SW bedding strike: *(and associated other classes)*;

***Uplift and erosion***

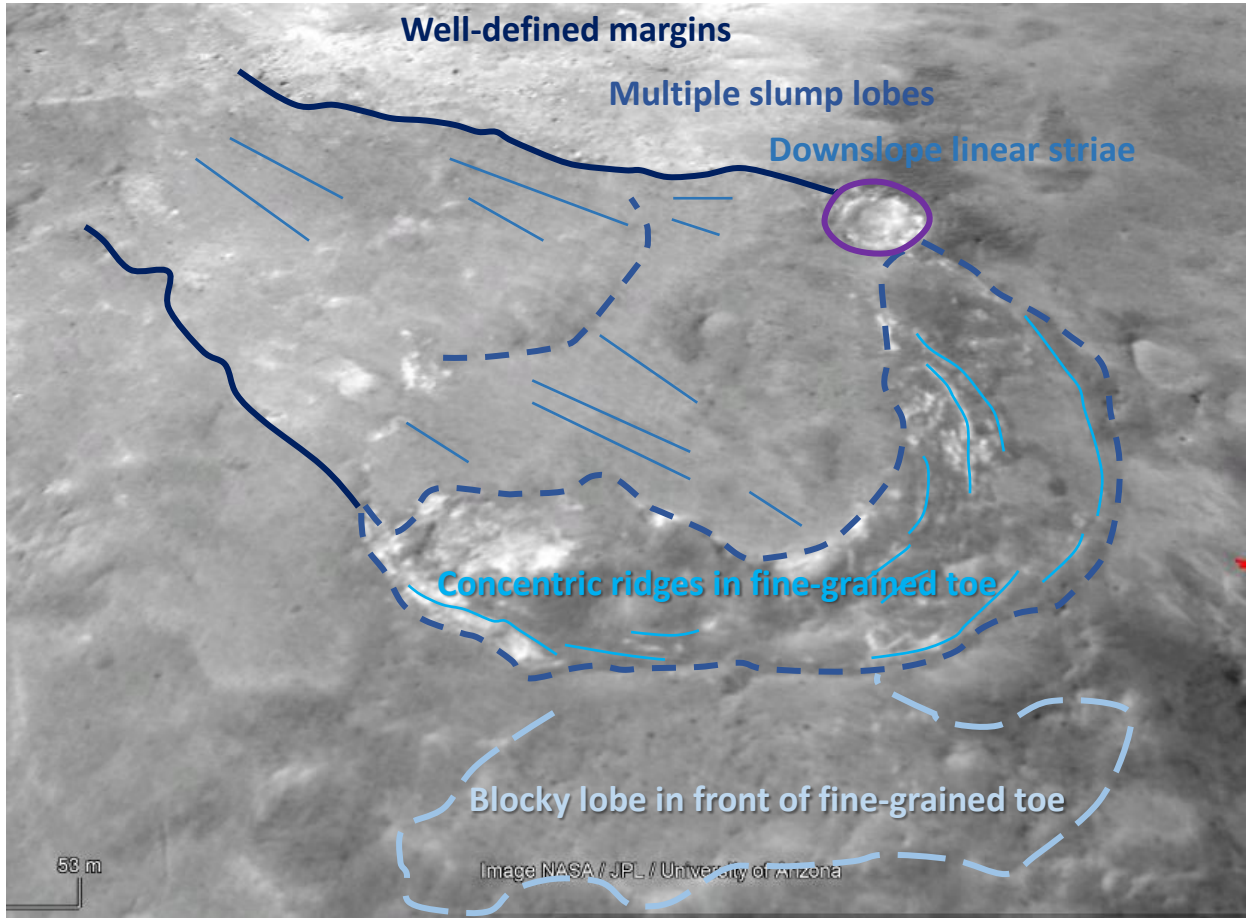
Possible basement in floor of impact crater



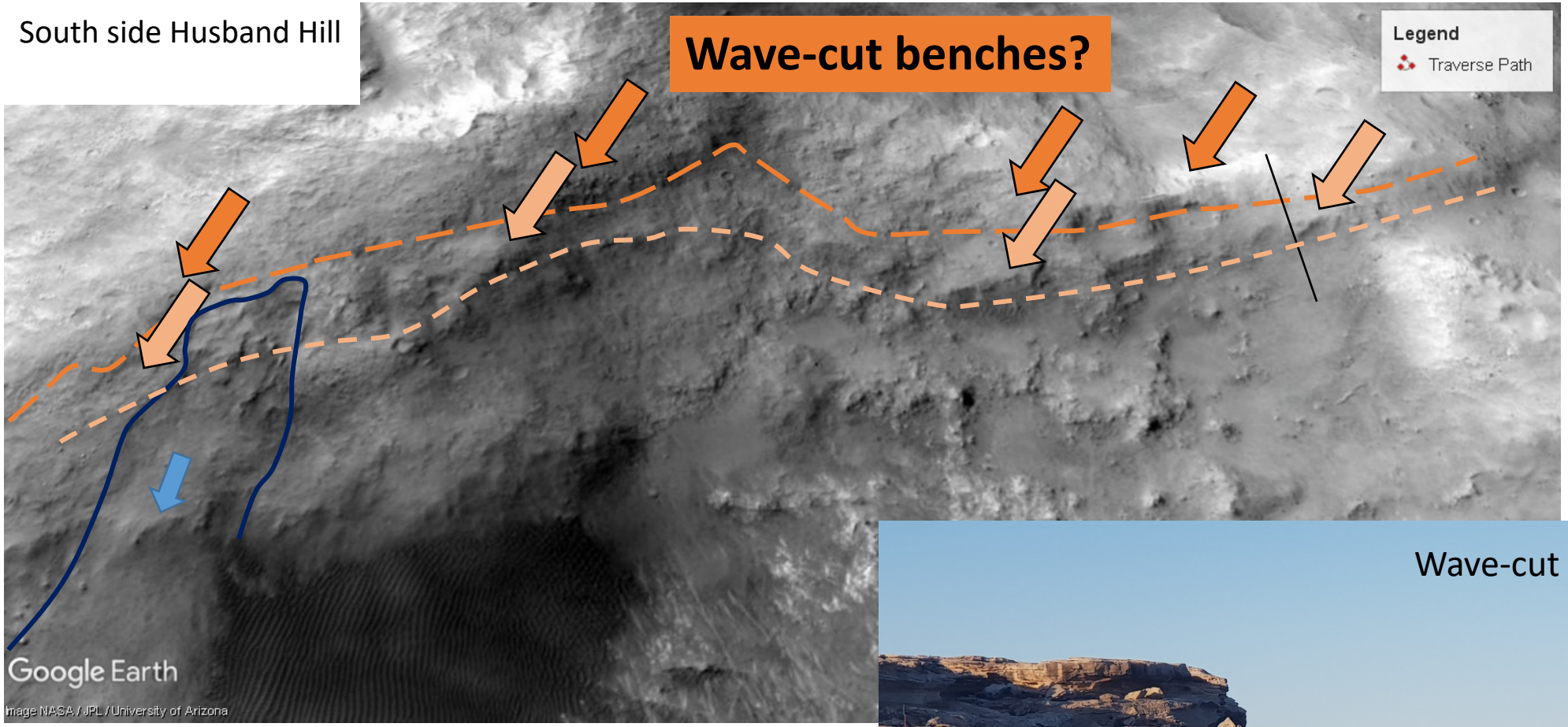




*Terrestrial* mass waste deposits have distinctly different features:

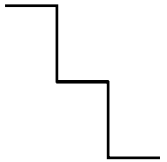
- Radial cracks
- Scarps
- Transverse cracks
- Toe lobes



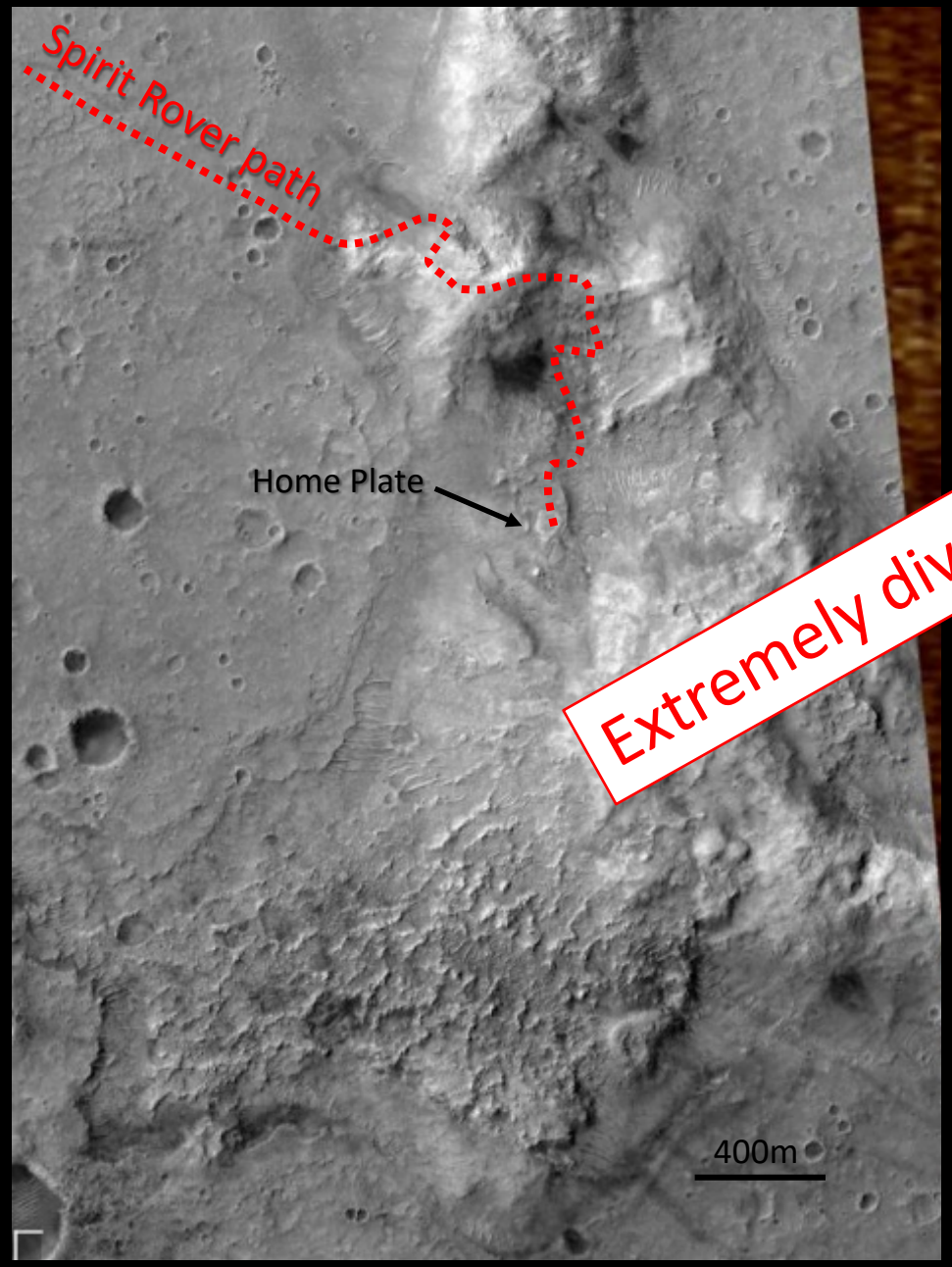
South side Husband Hill

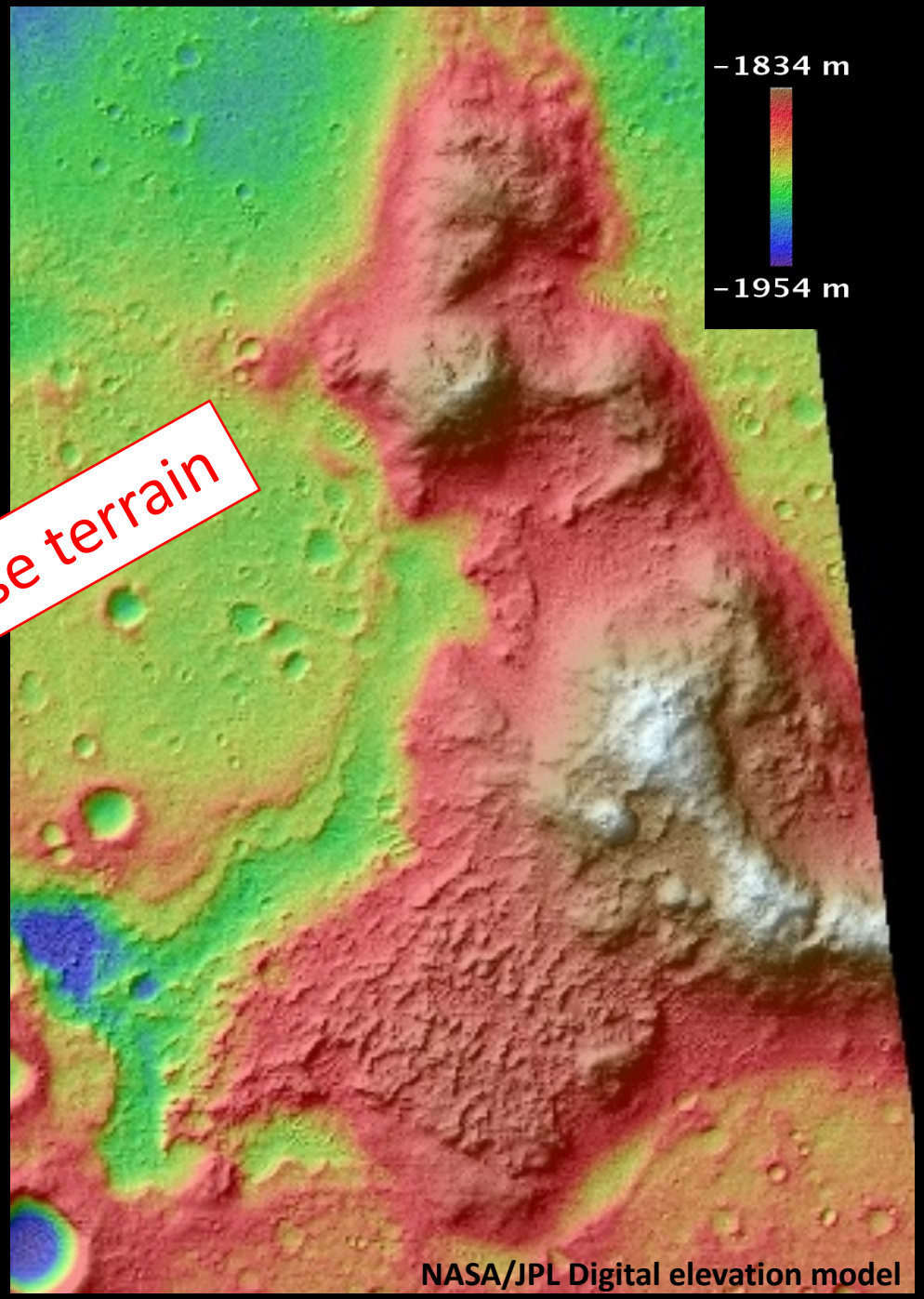



Cross-section



# Columbia Hills, Gusev Crater




Extremely diverse terrain