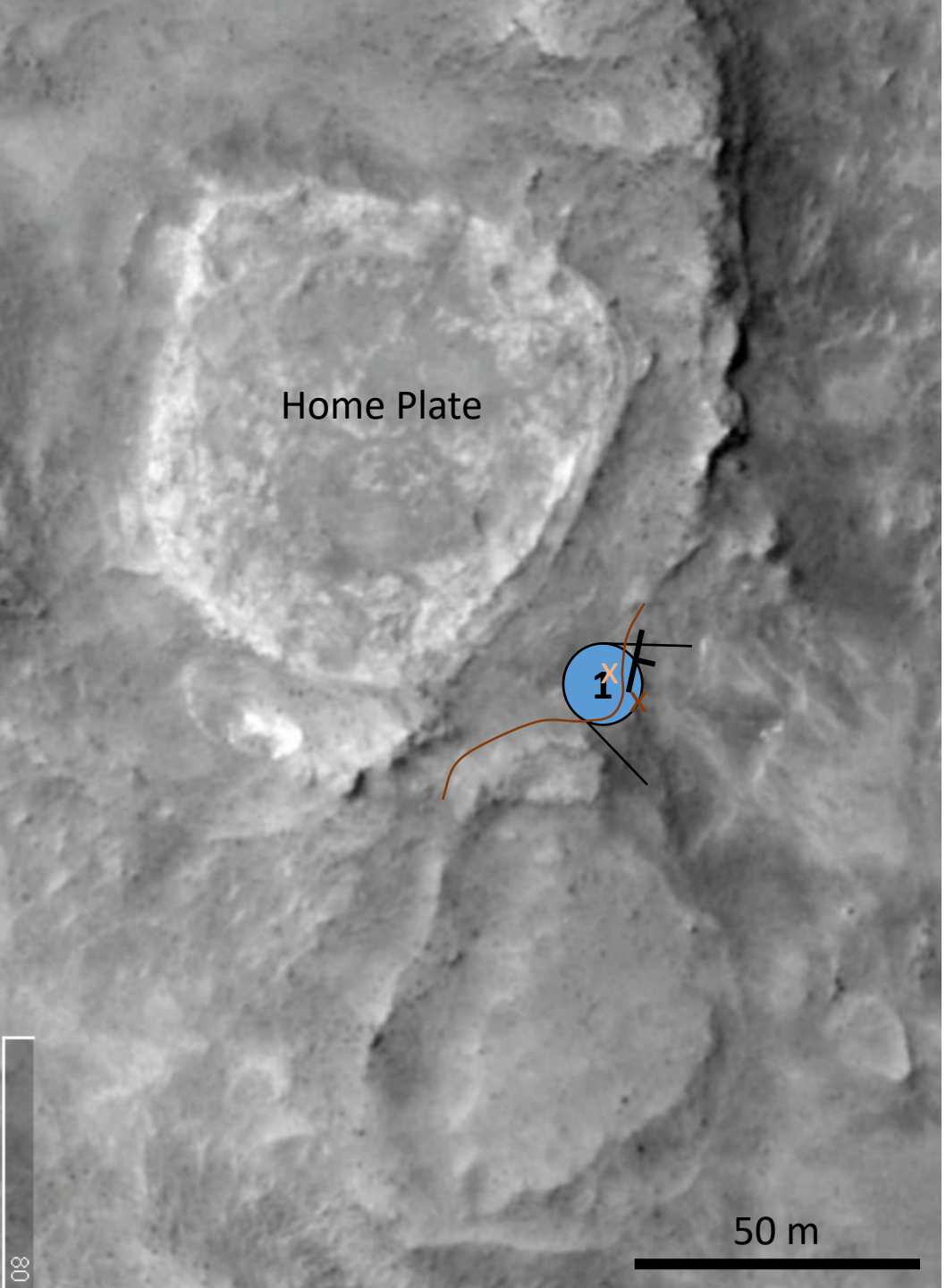
"A Mars 2020 Mission to Columbia Hills: Risk minimization through ground truth"

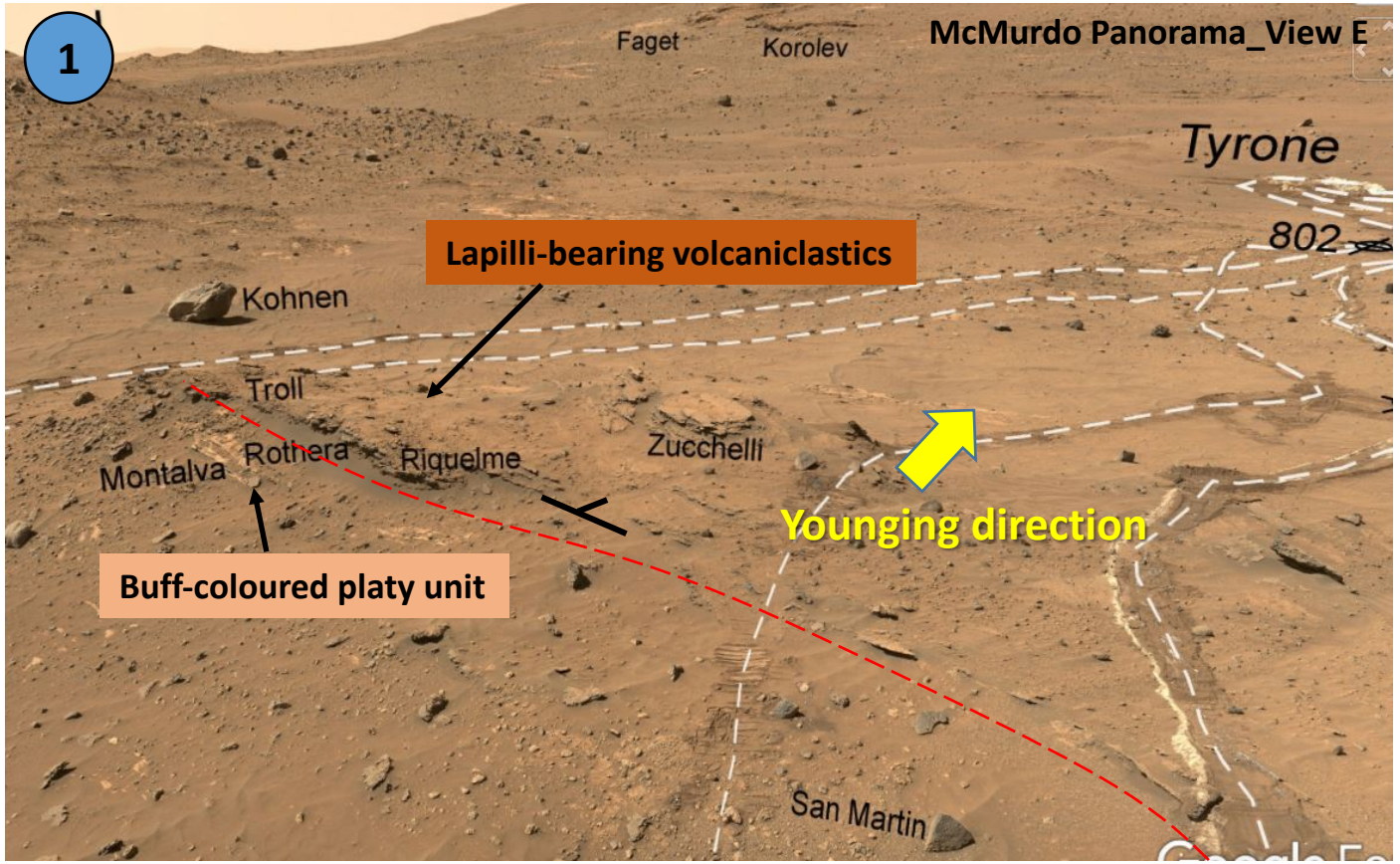
Martin J. Van Kranendonk[1], Steve Ruff[2], Tara Djokic[1], Kathleen A. Campbell[3]

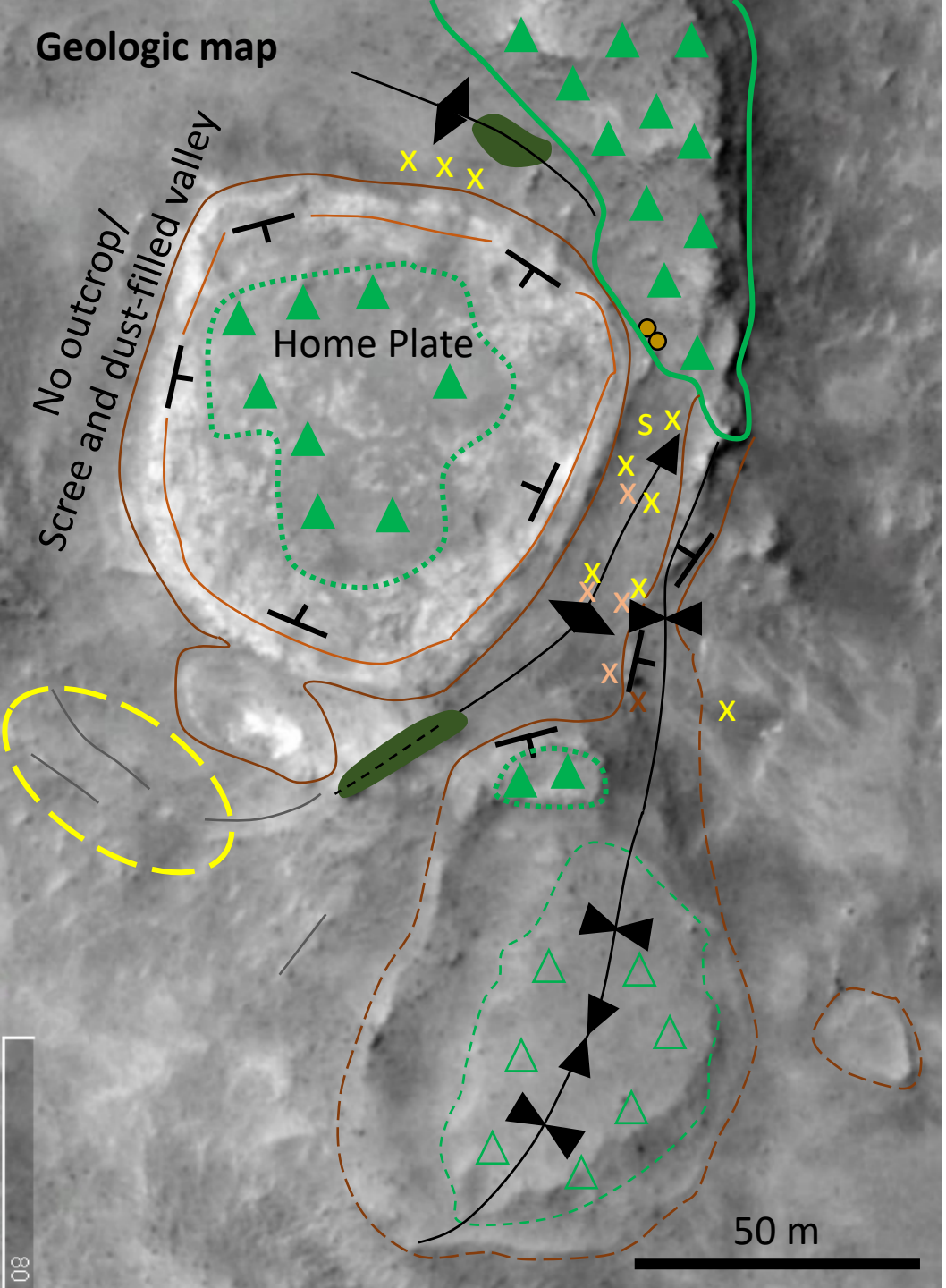
1. Australian Centre for Astrobiology, University of New South Wales Sydney, Australia
2. Arizona State University, U.S.A.
3. University of Auckland, New Zealand

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)

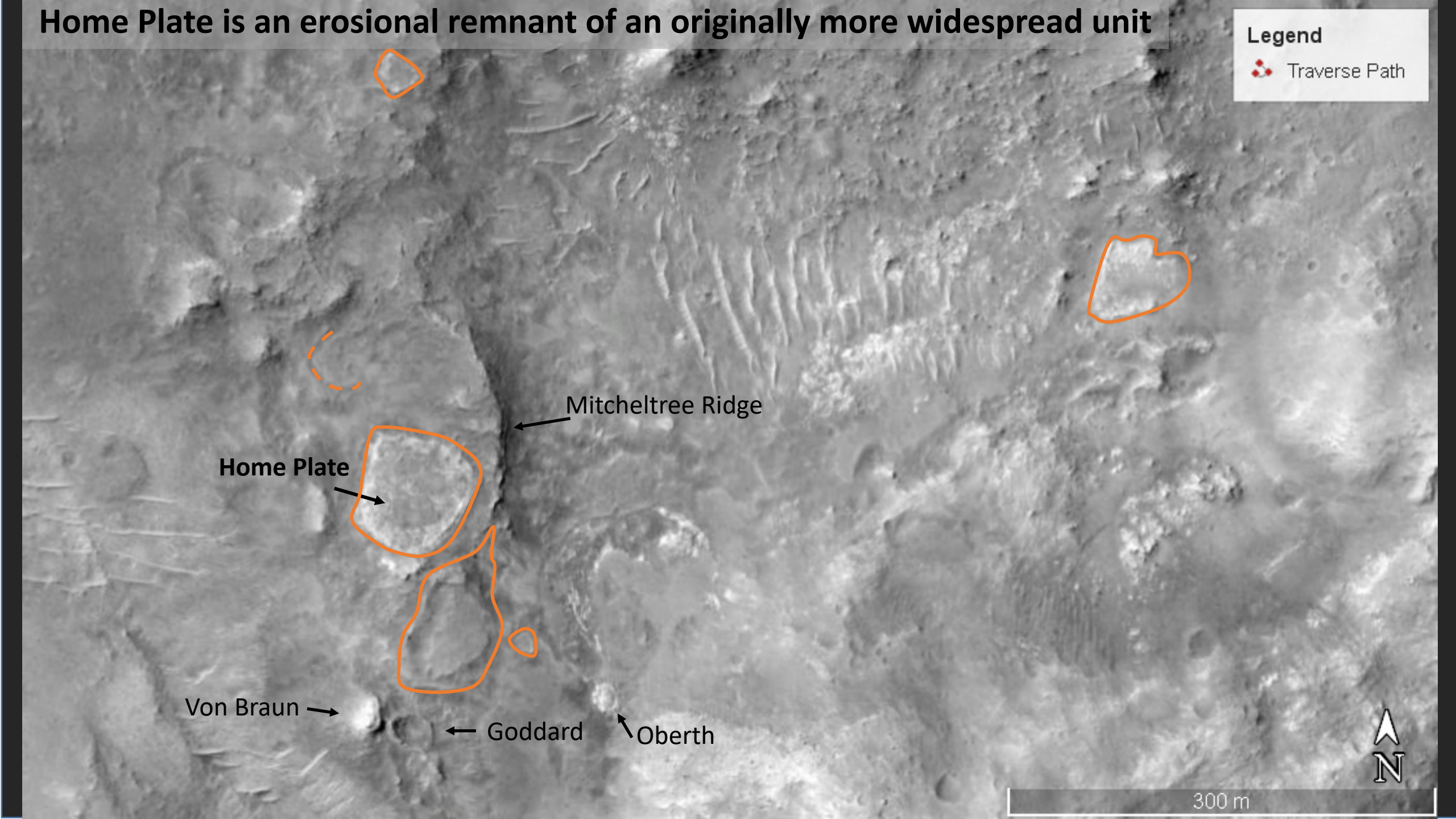
Buff-colored platy unit

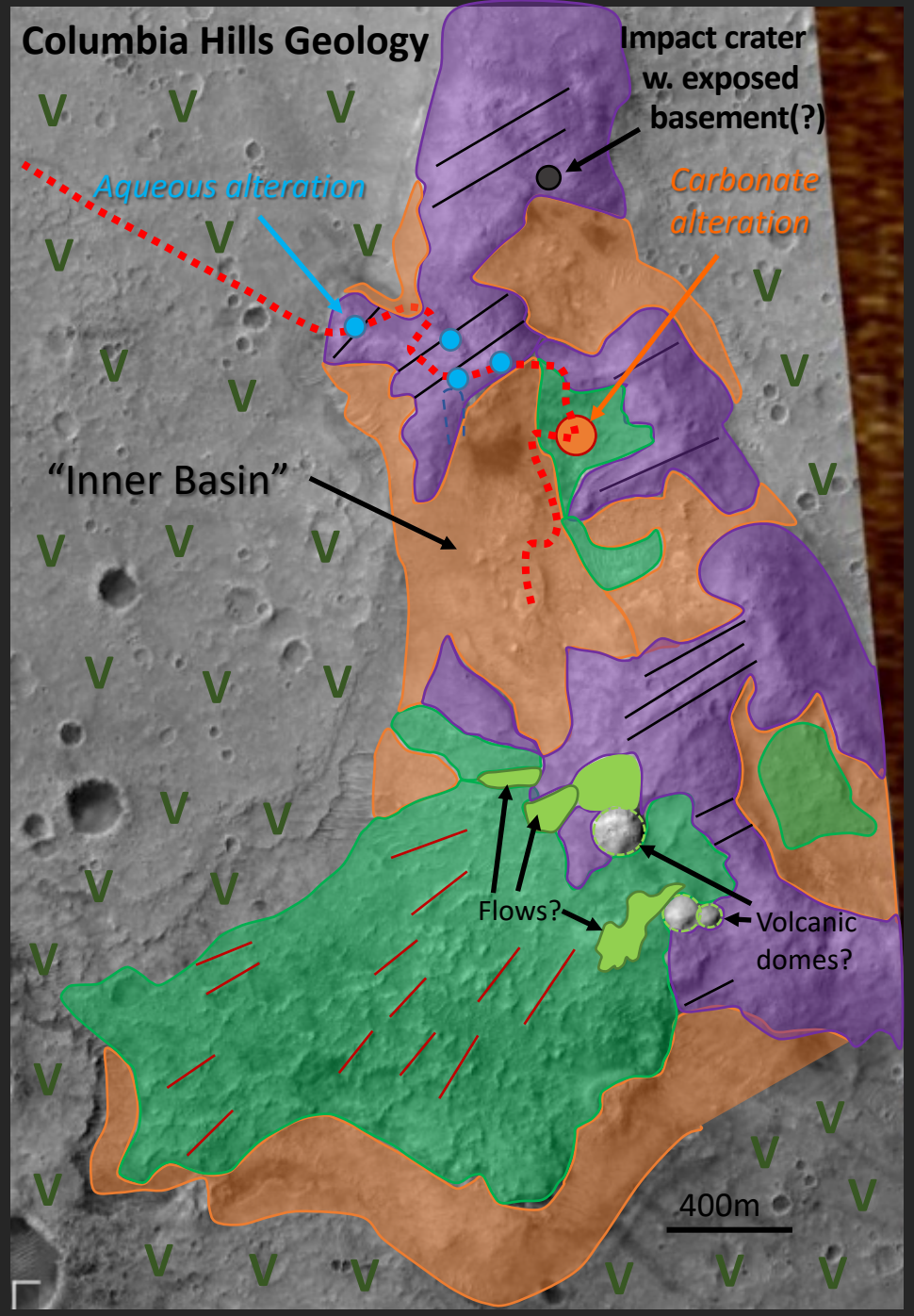
Light-toned, fine-grained, vesicular, olivine basalt

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
Legend
Traverse Path
Mitcheltree Ridge
Home Plate
Von Braun
Goddard
Oberth
N
300 m



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)

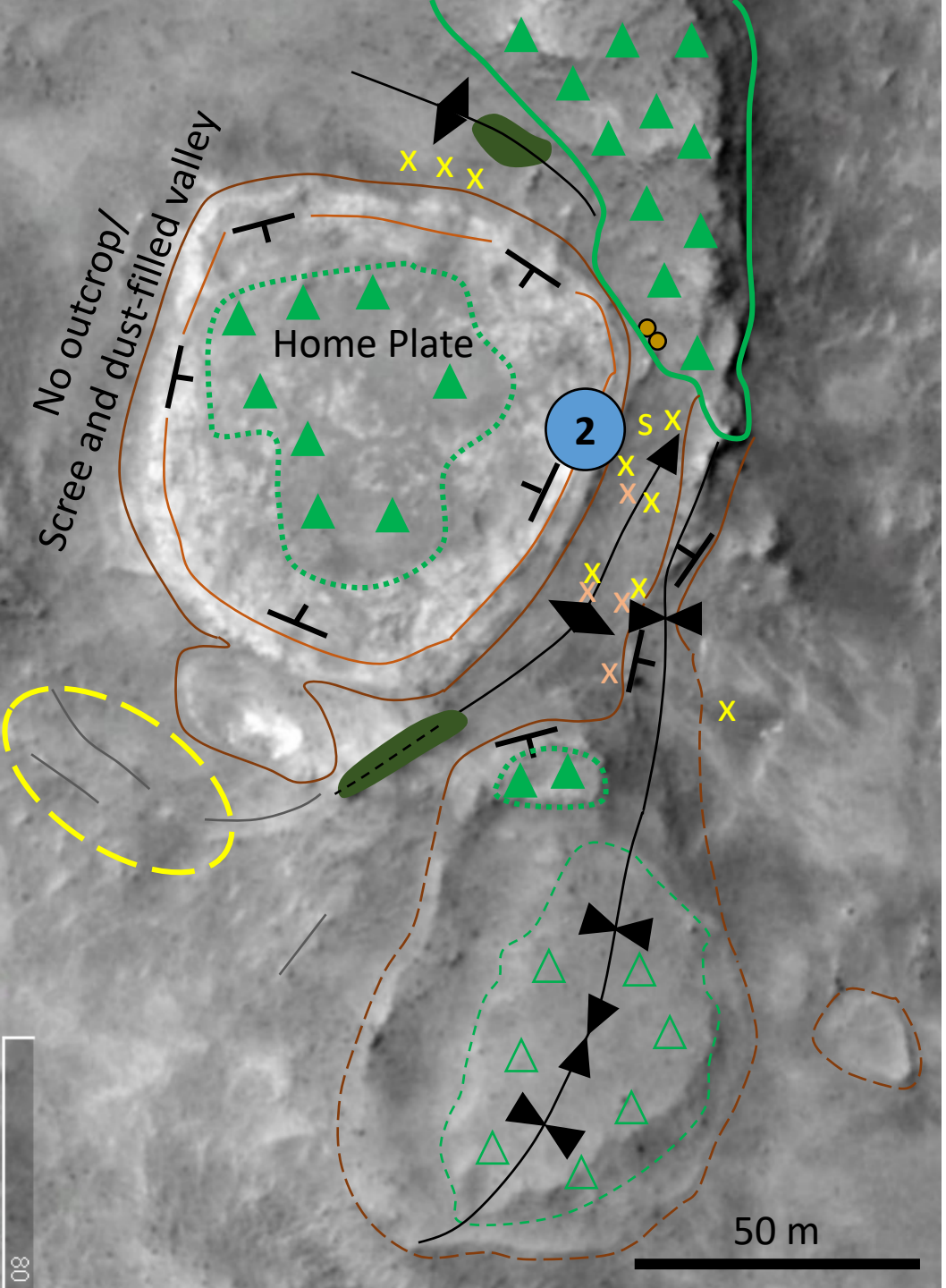
Erosion

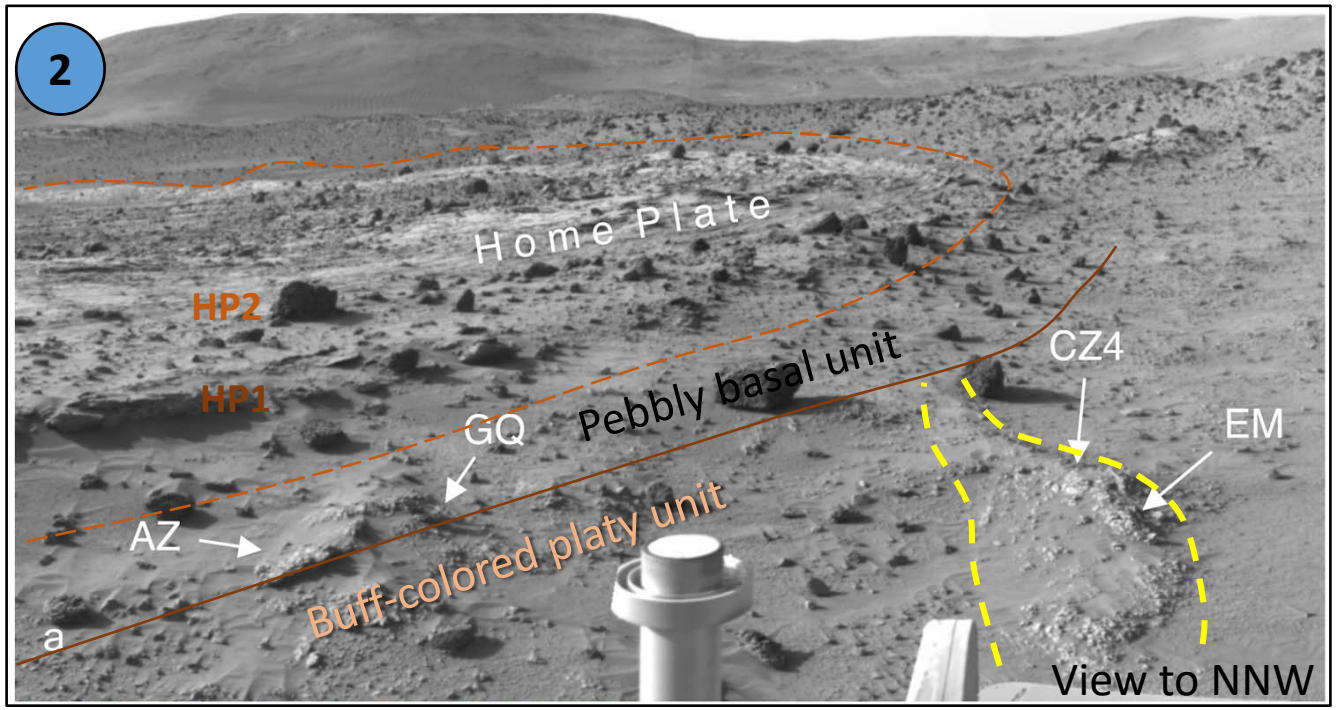
Wishstone Class: Hawaiite tephra with NE-SW bedding strike: *(and associated other classes)*;

Uplift and erosion

Possible basement in floor of impact crater

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

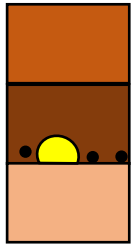




1 **OR** 2

Opaline silica: older than HP

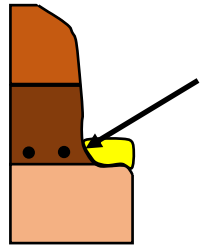
Opaline silica: younger than HP



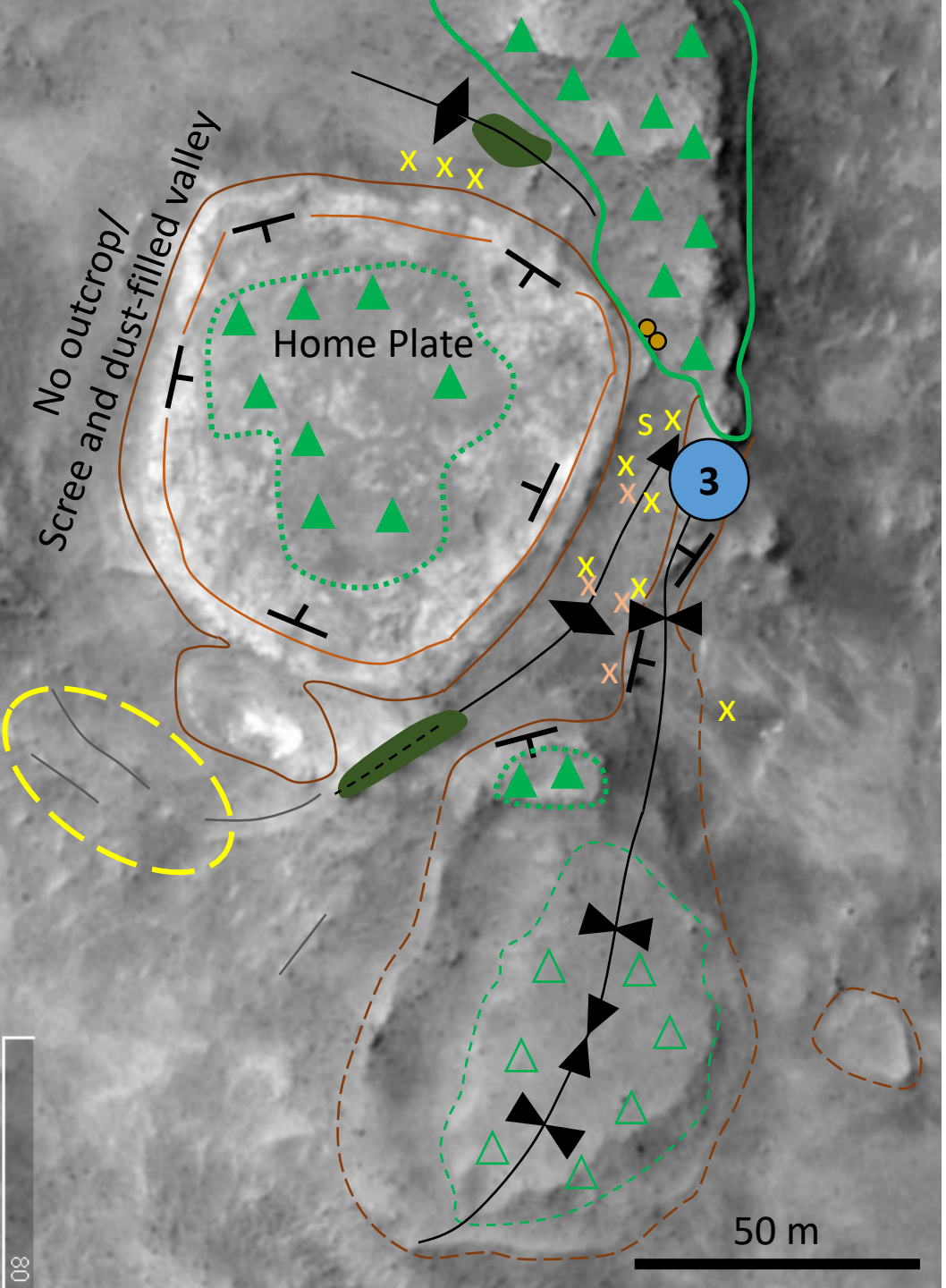
HP2: Aeolian sandstone

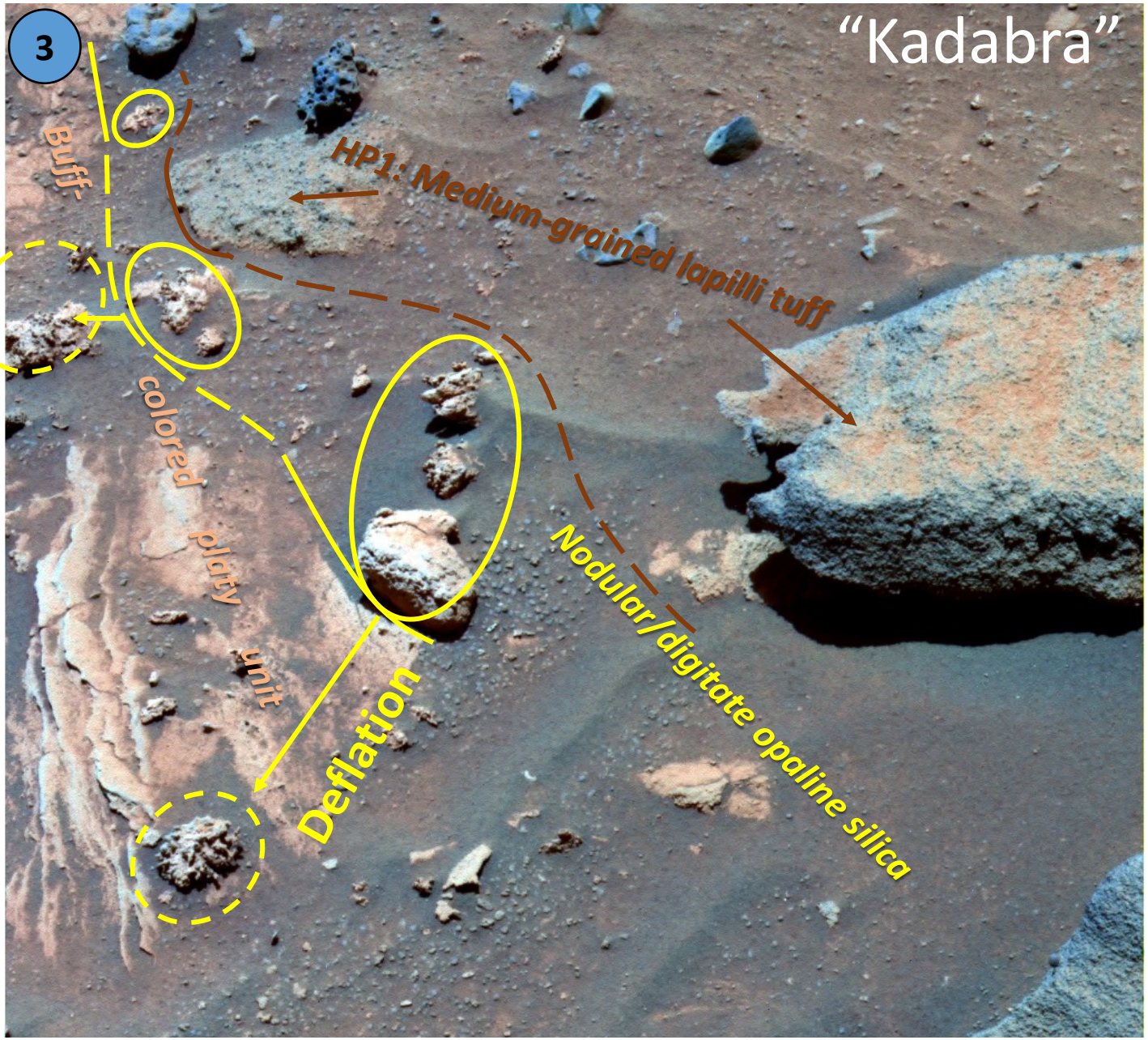
HP1: Volcanoclastics

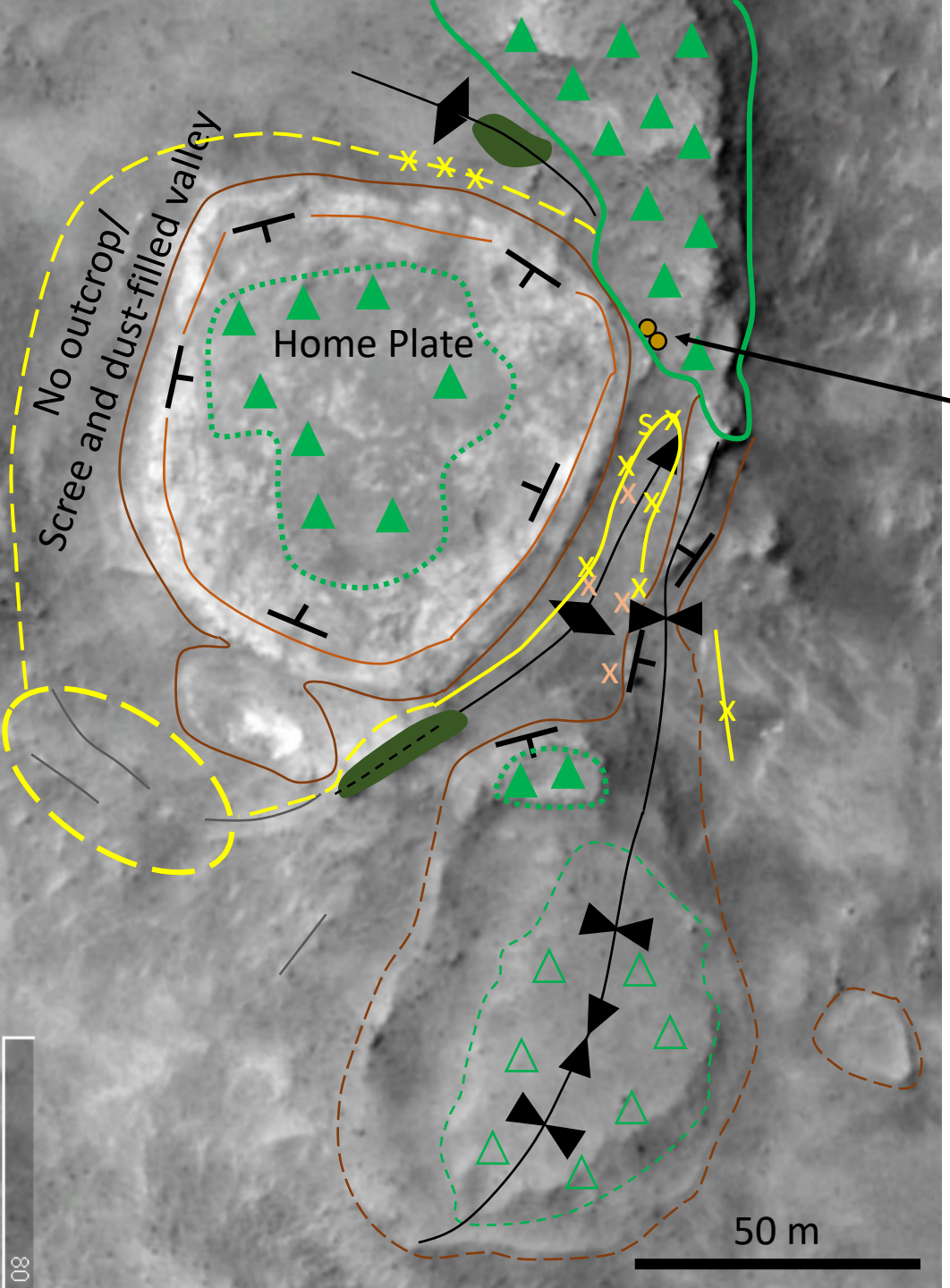
Buff-colored platy unit



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





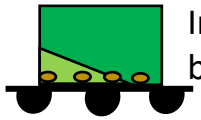


Nodular/digitate opaline silica occurrences are consistent with their being part of the stratigraphy, as it is folded together with the other bedded units.

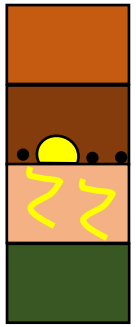
This relationship is also consistent with the acid-sulfate alteration observed for the buff-colored platy unit

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

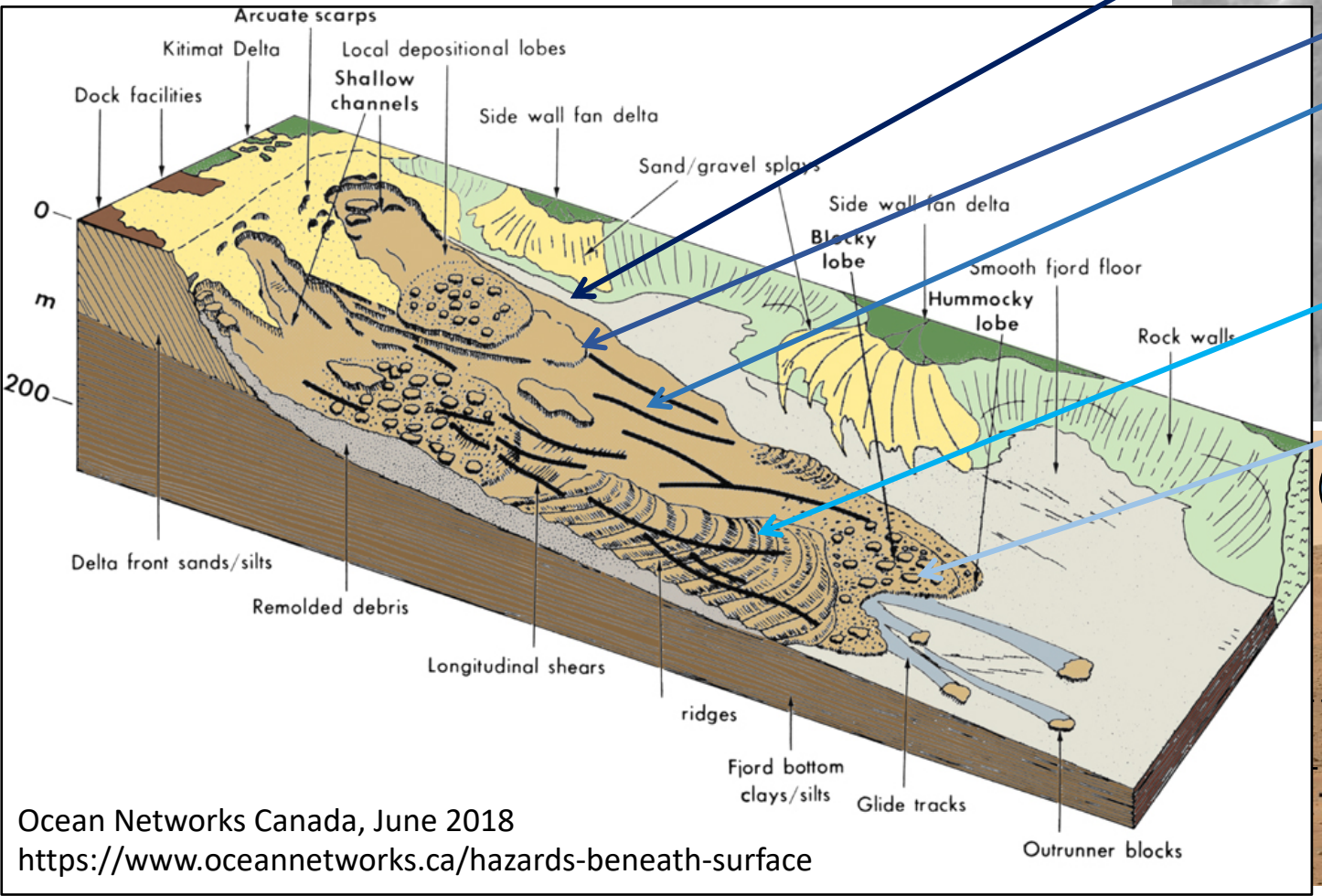
Nodular/digitate opaline silica

Buff-colored platy unit (ash)

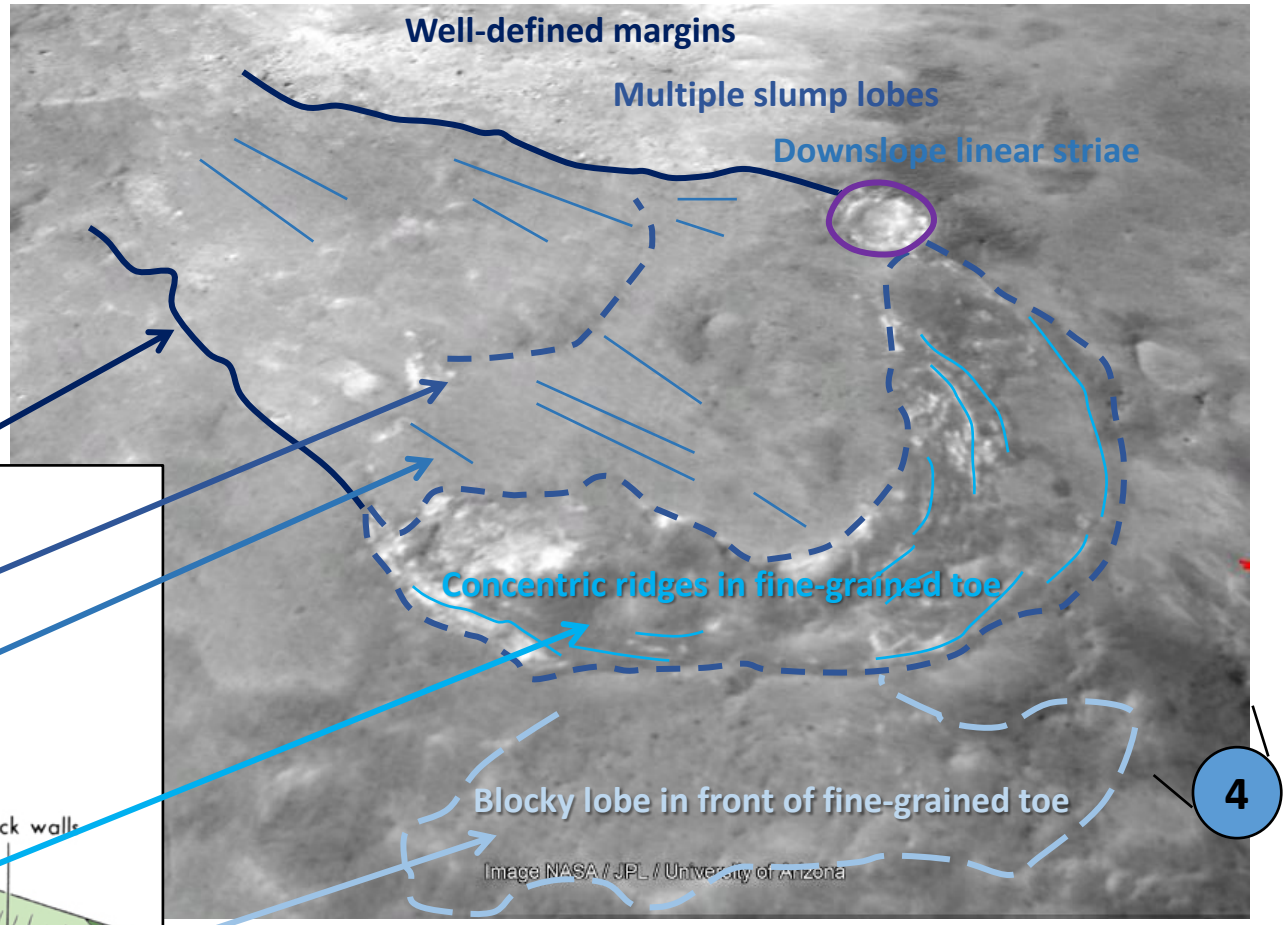
Light-toned, fine-grained, vesicular, olivine basalt

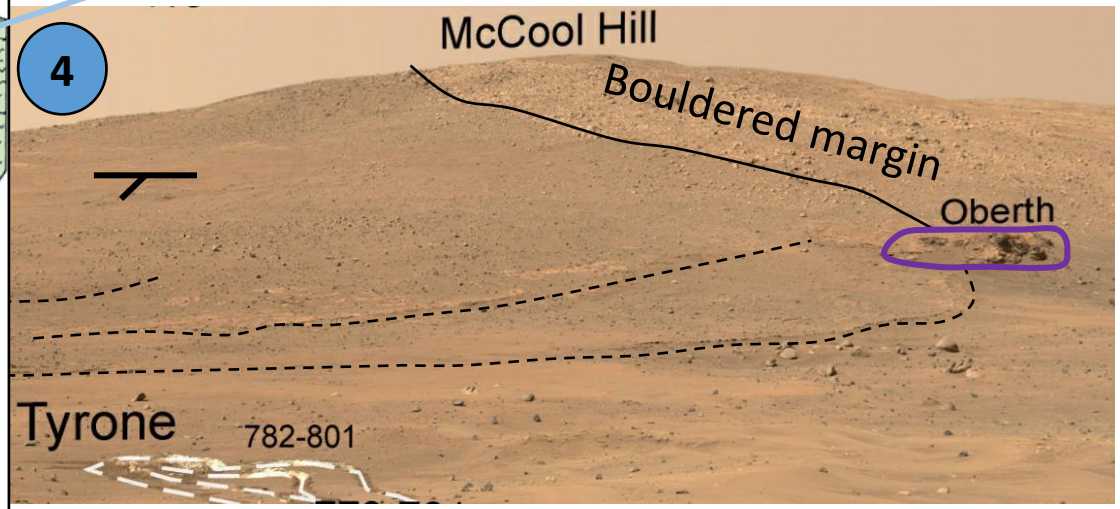
McCool Hill mass waste deposit:
A *subaqueous* landslide

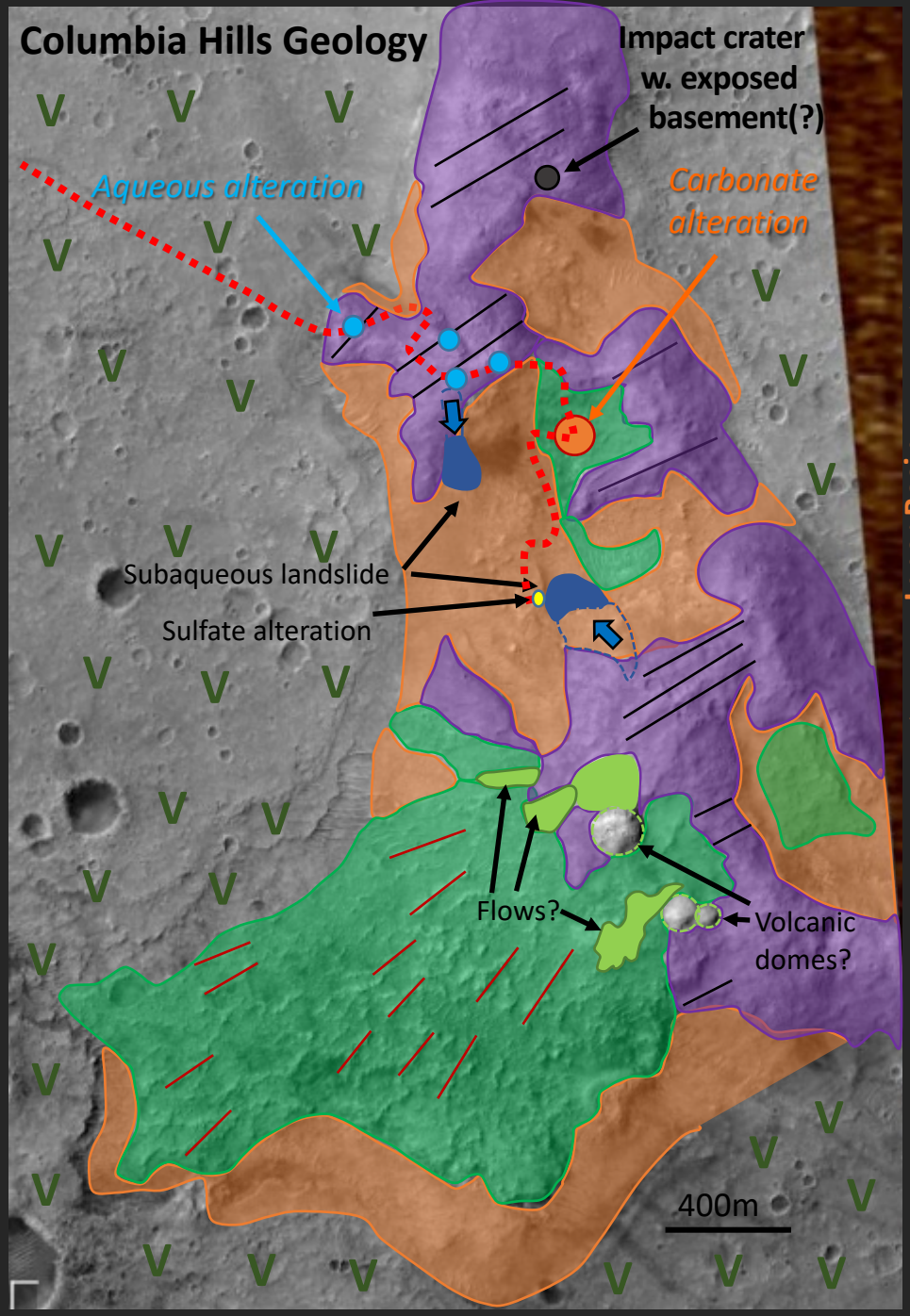
Oldest unit of the Inner Basin



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







Event stratigraphy of the Columbia Hills

Minor hydrous alteration (atmospheric)

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)

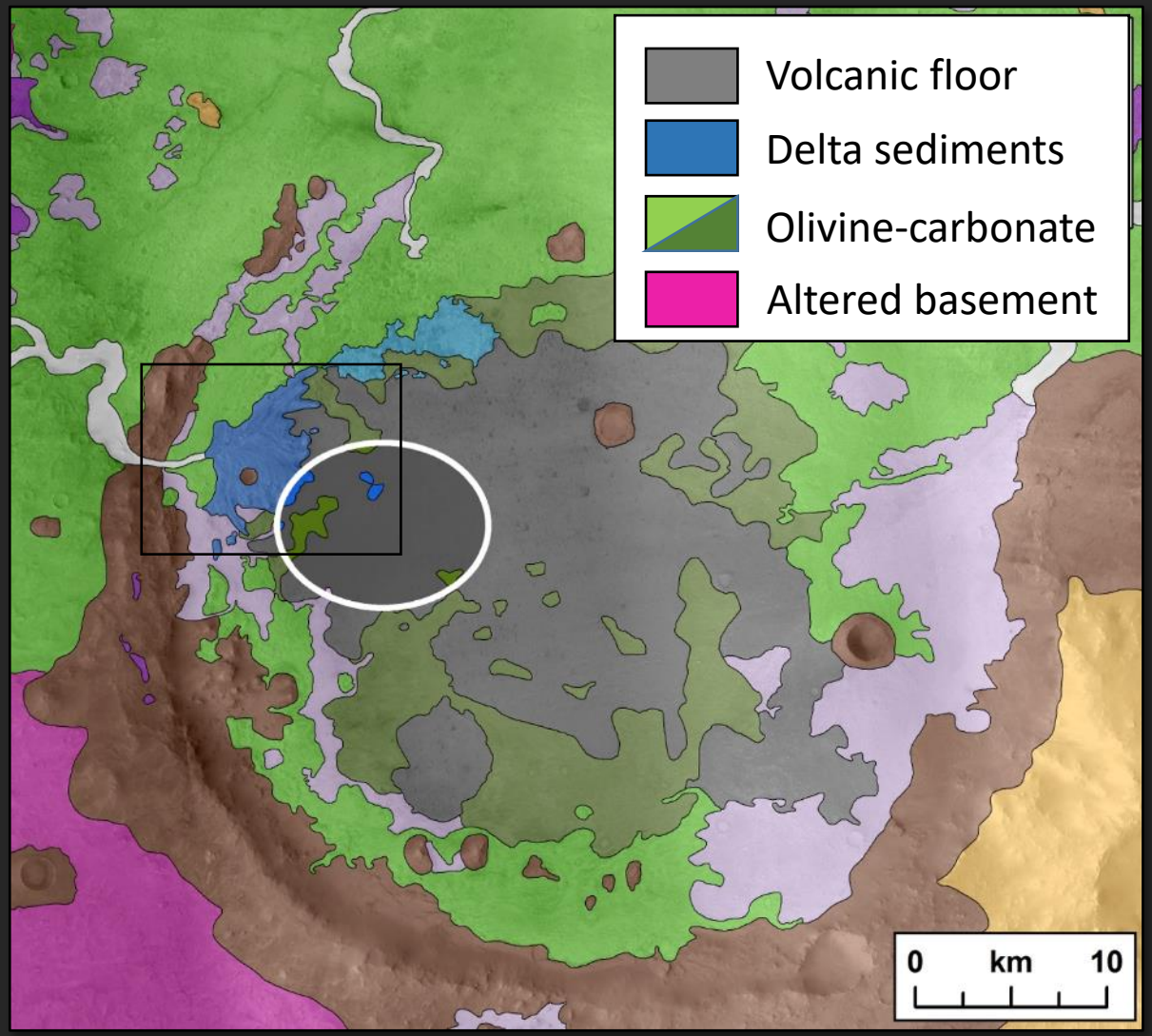
Possible basement in floor of impact crater

Subaerial

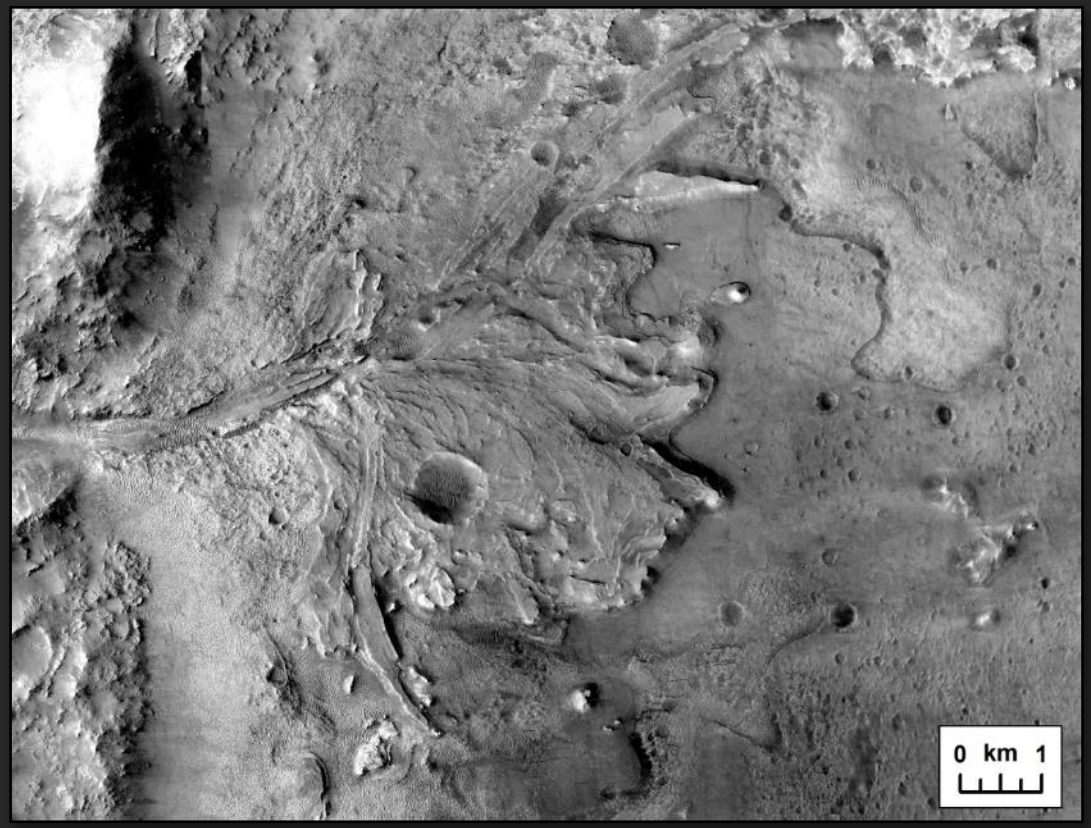
Aqueous alteration

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**

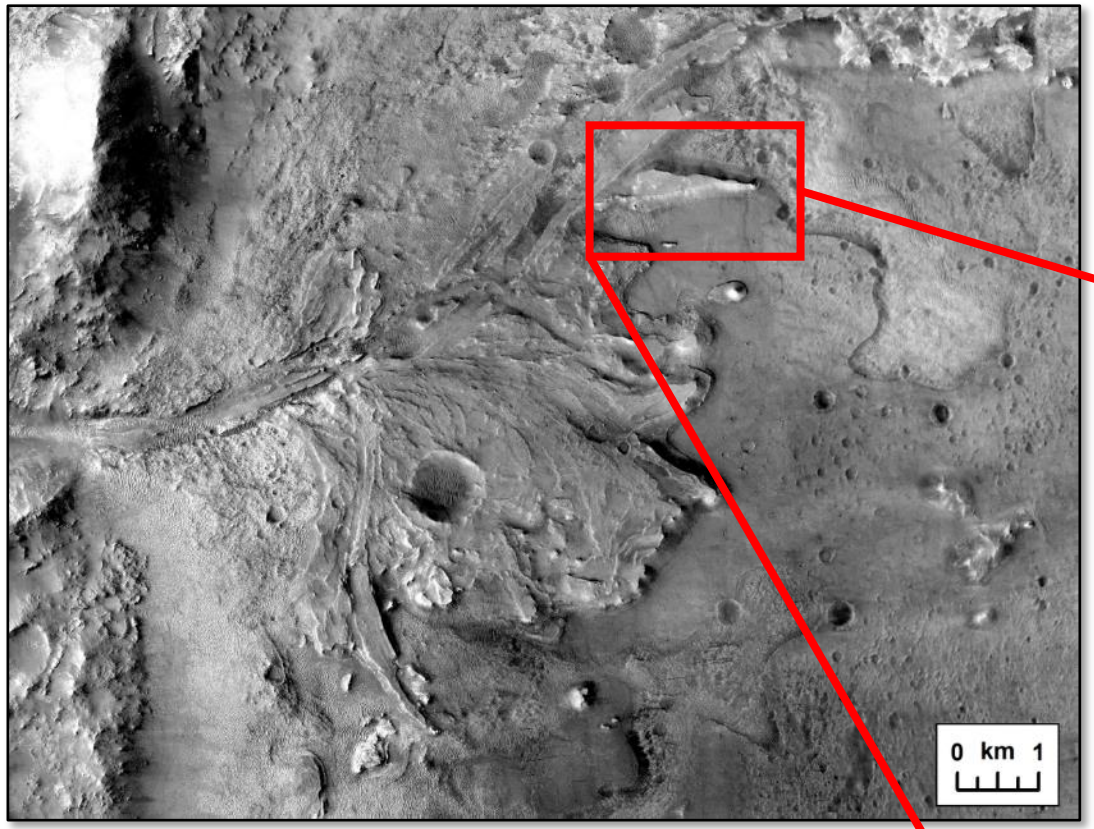


Goudge et al. [2015]

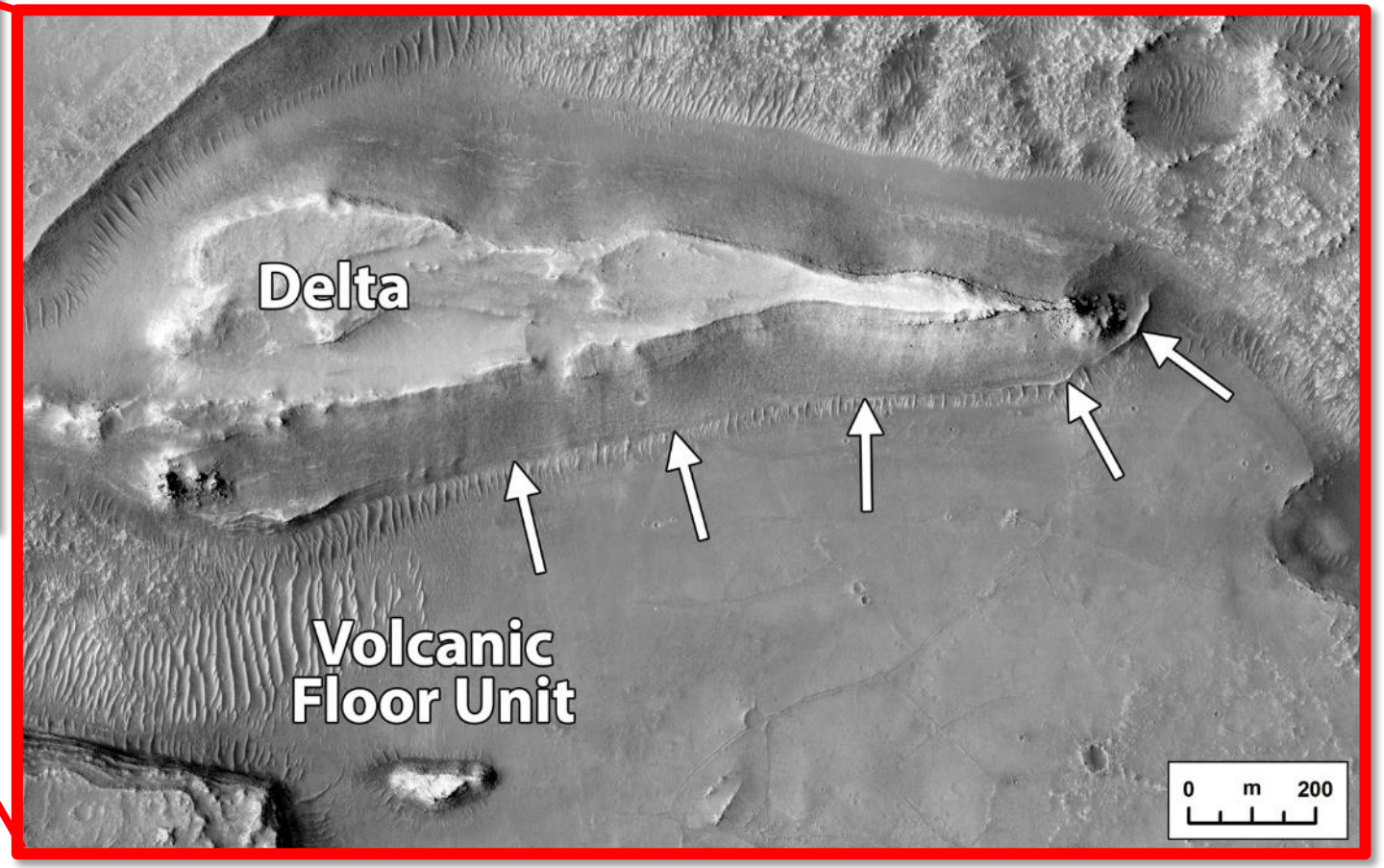


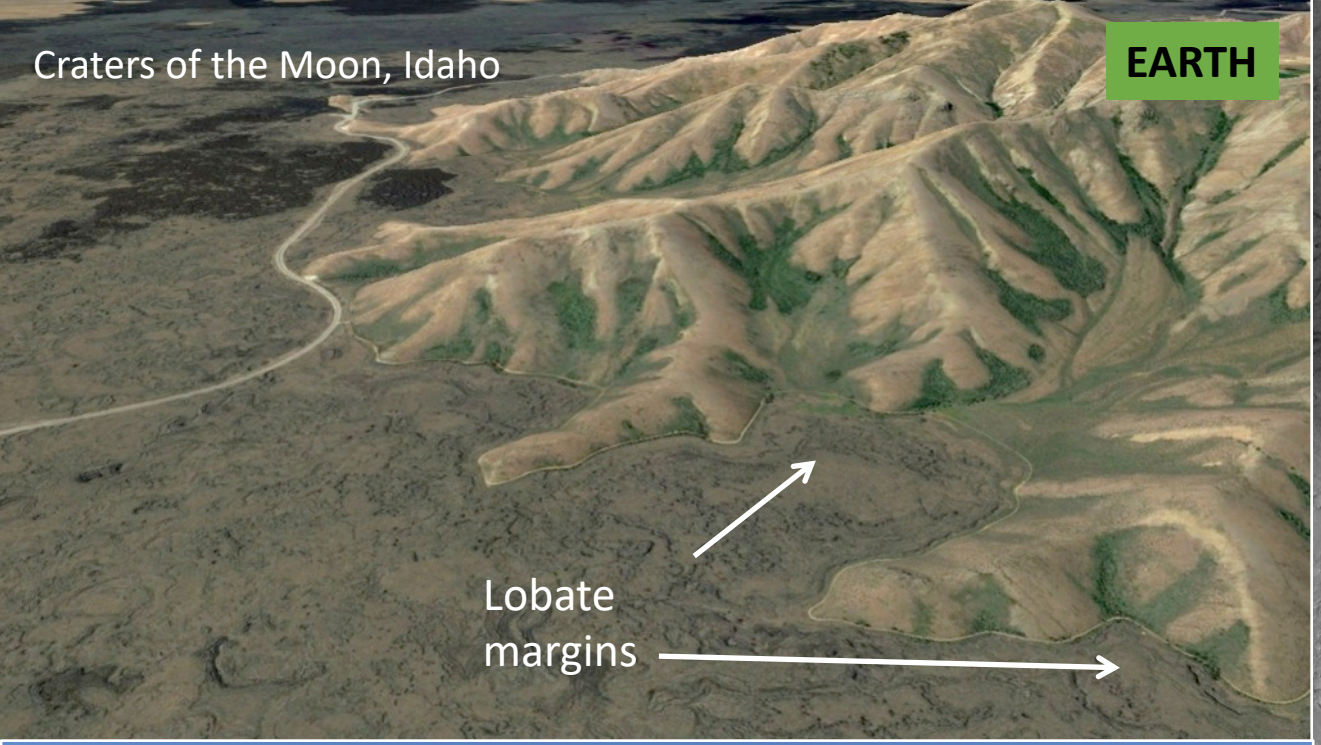
Clear stratigraphic context…

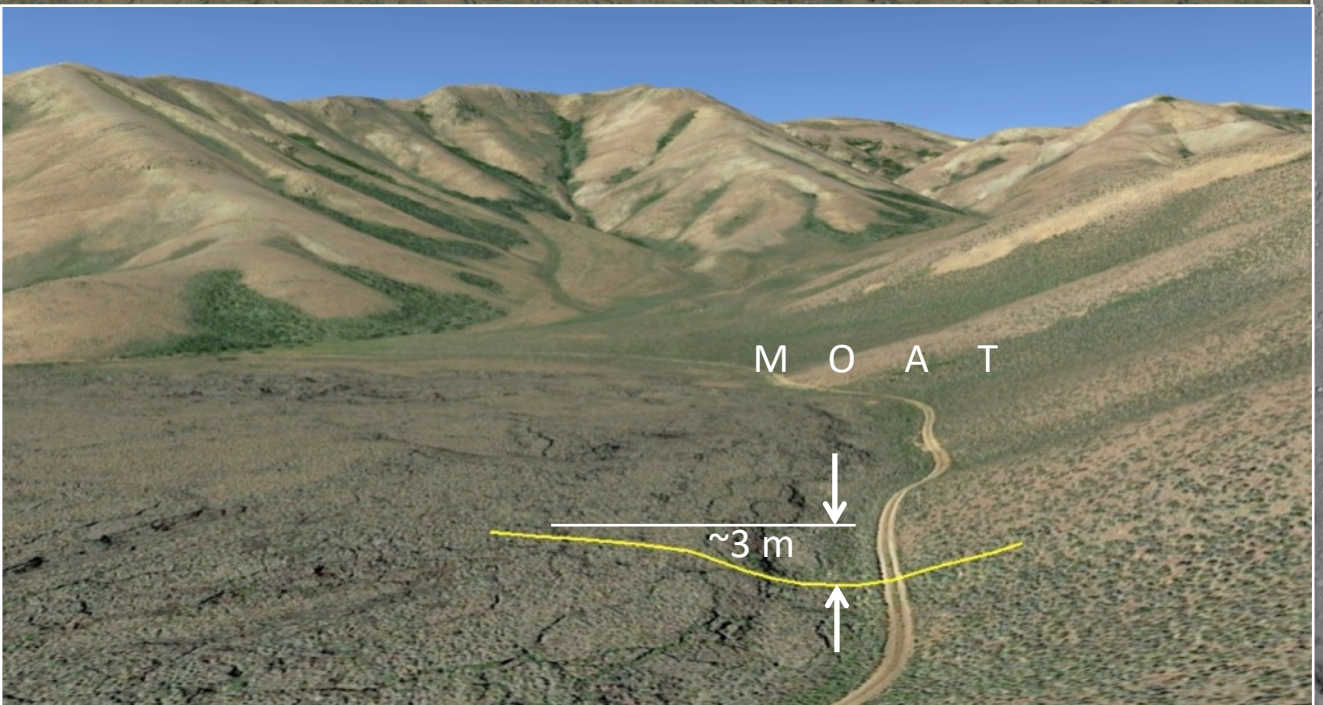
Volcanic floor unit interpreted as *younger than* the delta

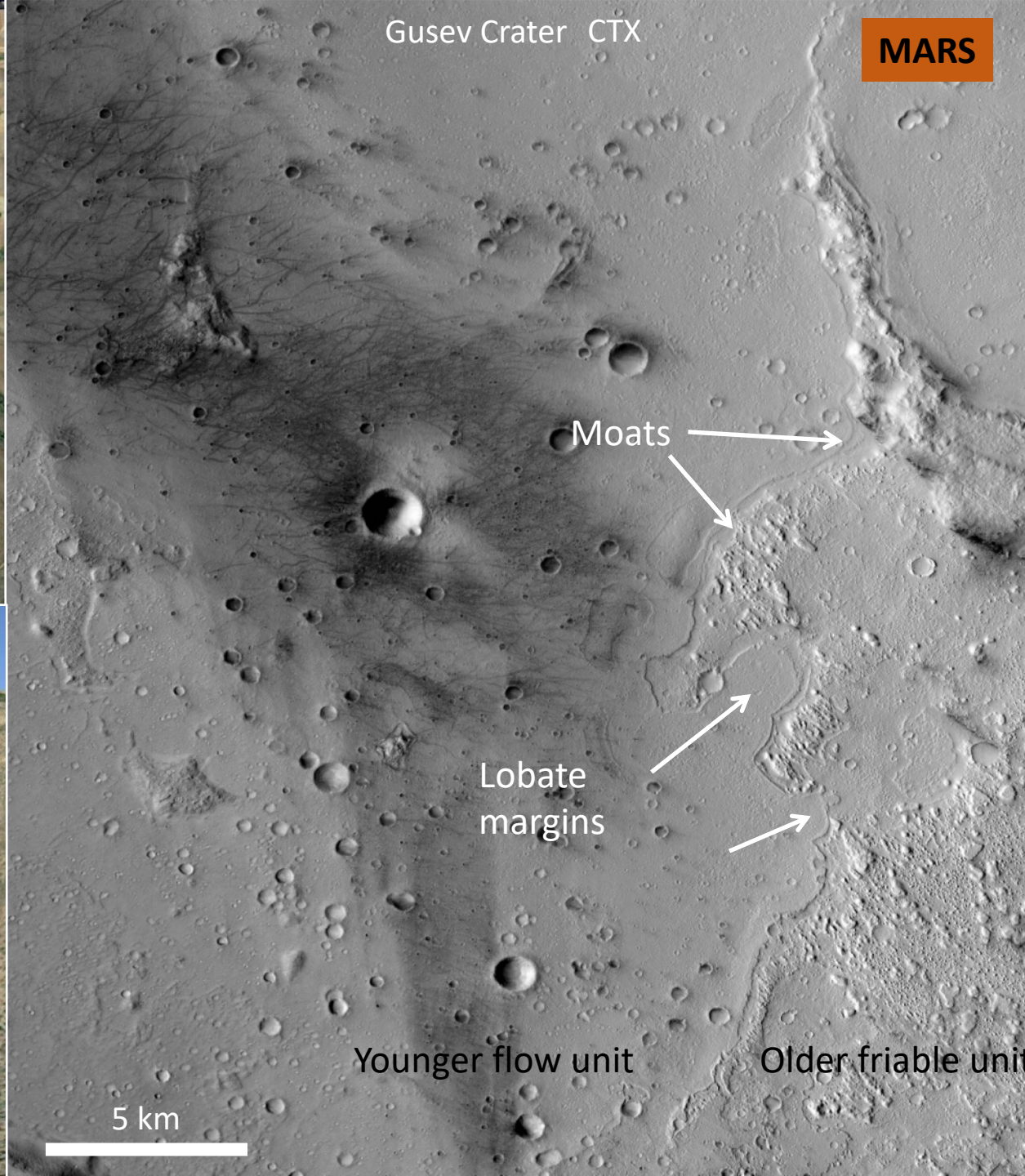


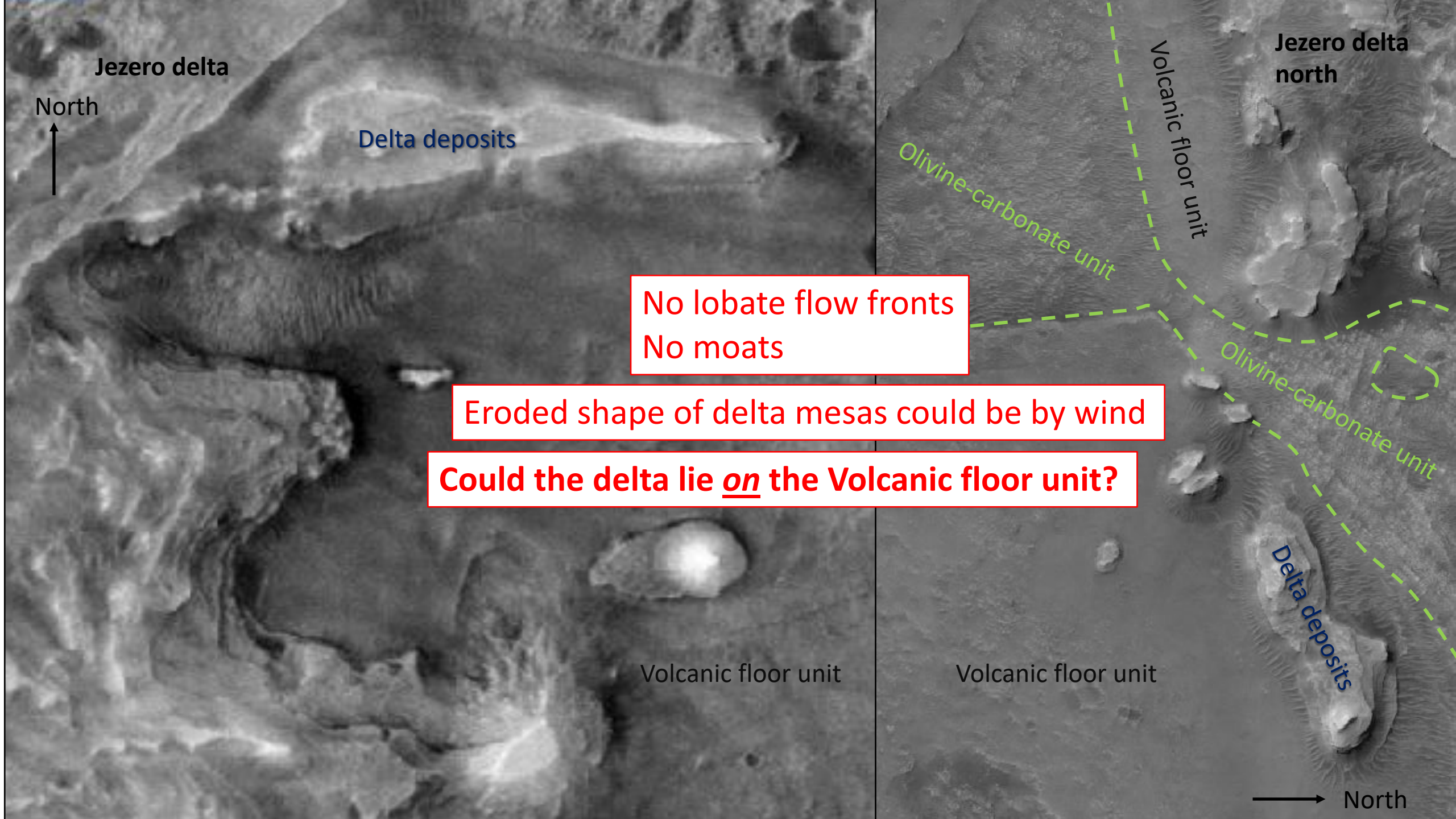
Volcanic floor unit embays delta deposit. *Goudge et al.* [2012, 2015]

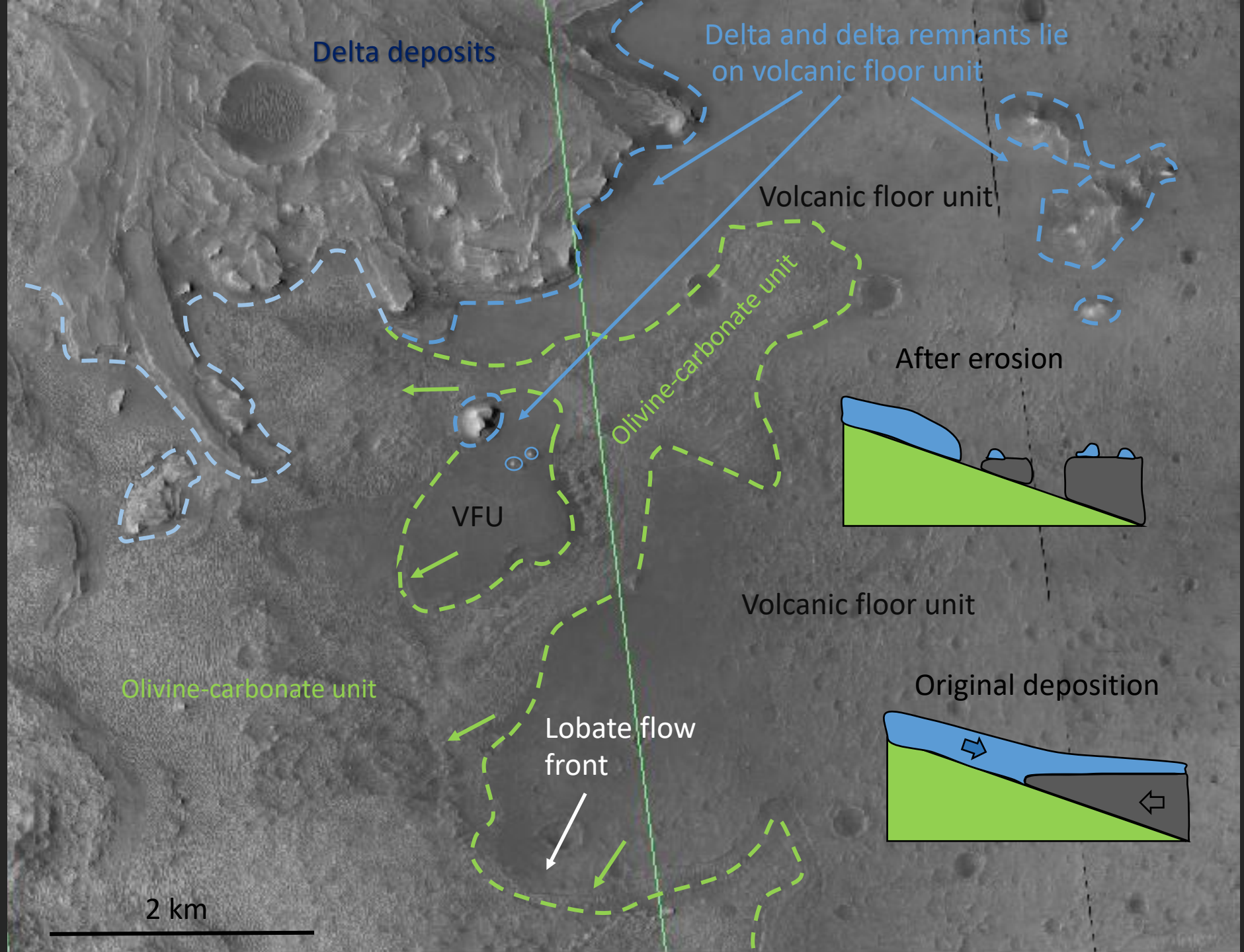



Craters of the Moon, Idaho
EARTH
Lobate
margins


M O A T
~3 m

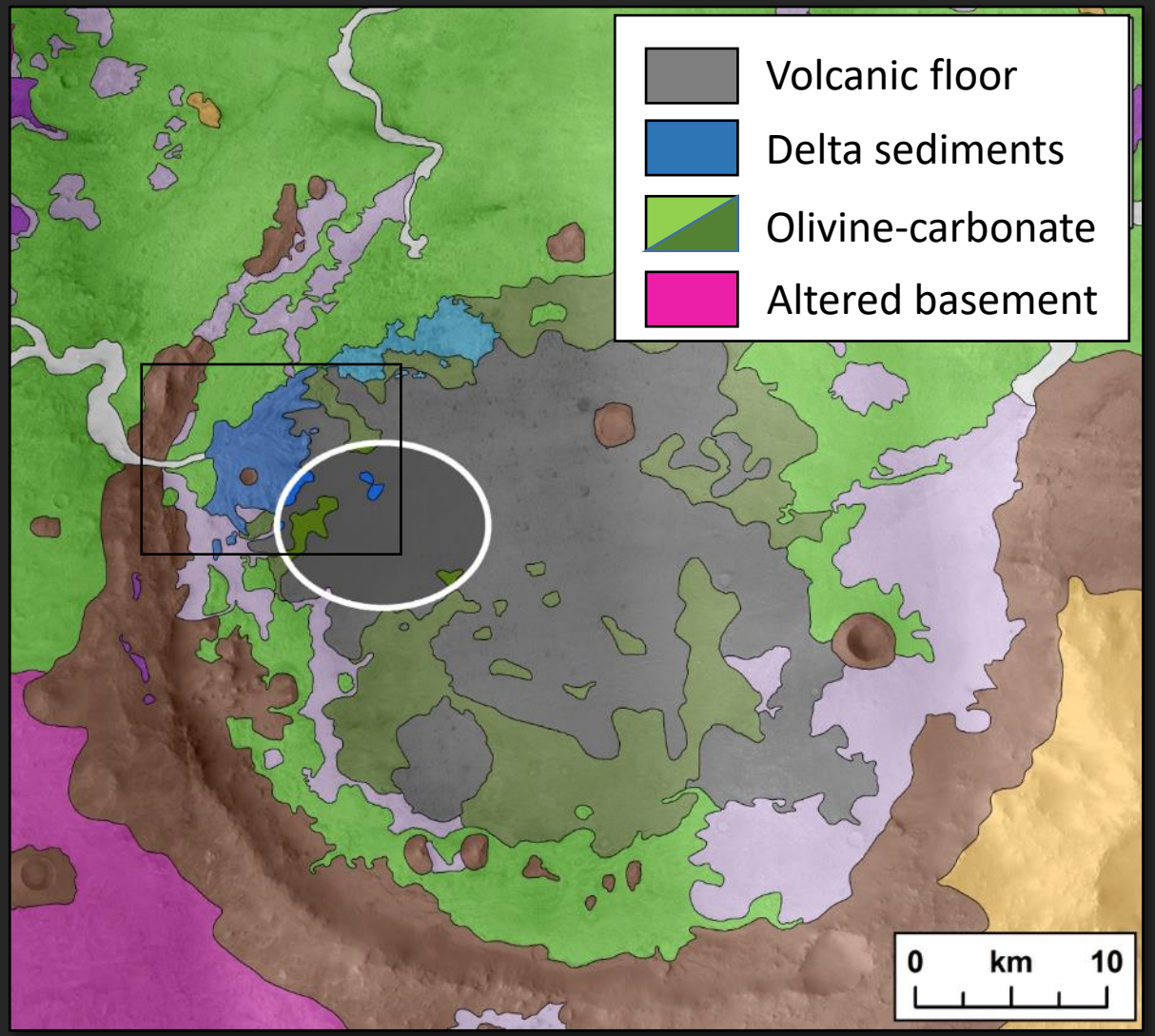

Gusev Crater CTX
MARS
Moats
Lobate
margins
Younger flow unit
Older friable unit
5 km


Jezero delta
North
Delta deposits
Jezero delta north
Volcanic floor unit
Olivine-carbonate unit
No lobate flow fronts
No moats
Eroded shape of delta mesas could be by wind
Could the delta lie on the Volcanic floor unit?
Olivine-carbonate unit
Delta deposits
Volcanic floor unit
Volcanic floor unit
North

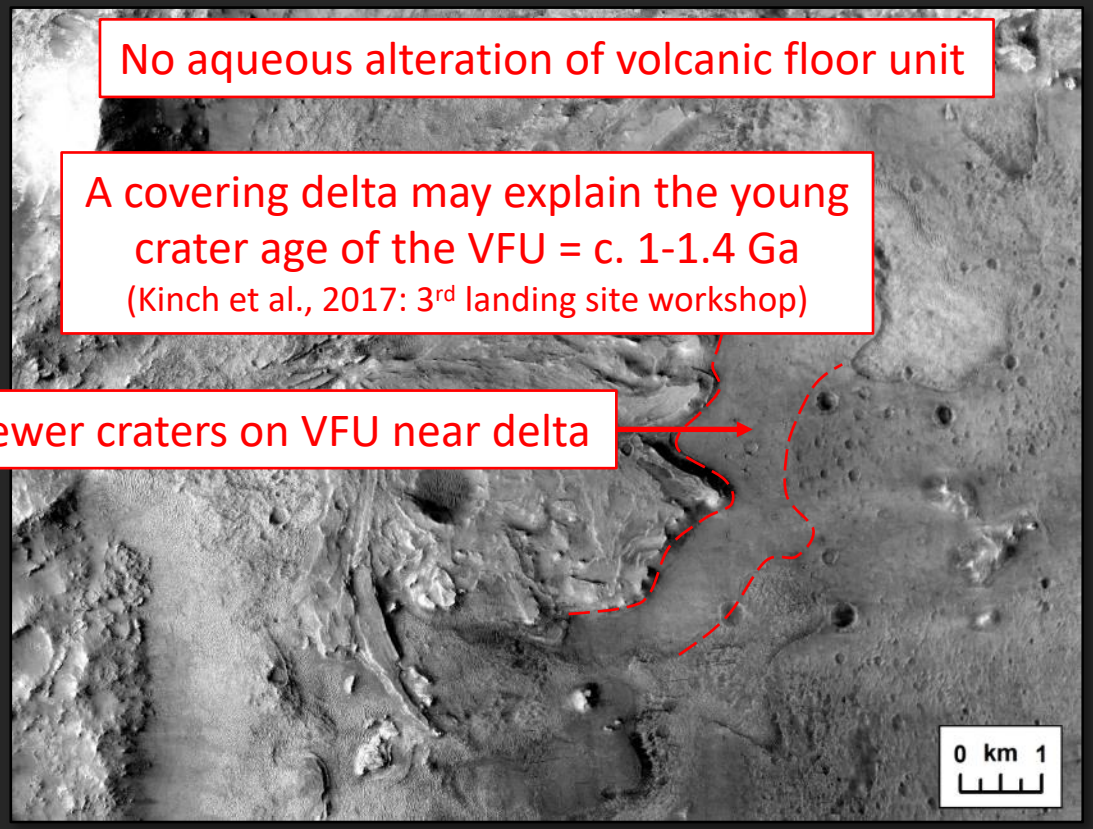

Delta deposits
Delta and delta remnants lie on volcanic floor unit
Volcanic floor unit
Olivine-carbonate unit
After erosion
VFU
Volcanic floor unit
Olivine-carbonate unit
Original deposition
Lobate flow front
2 km

Jezero: A fluvial-deltaic system

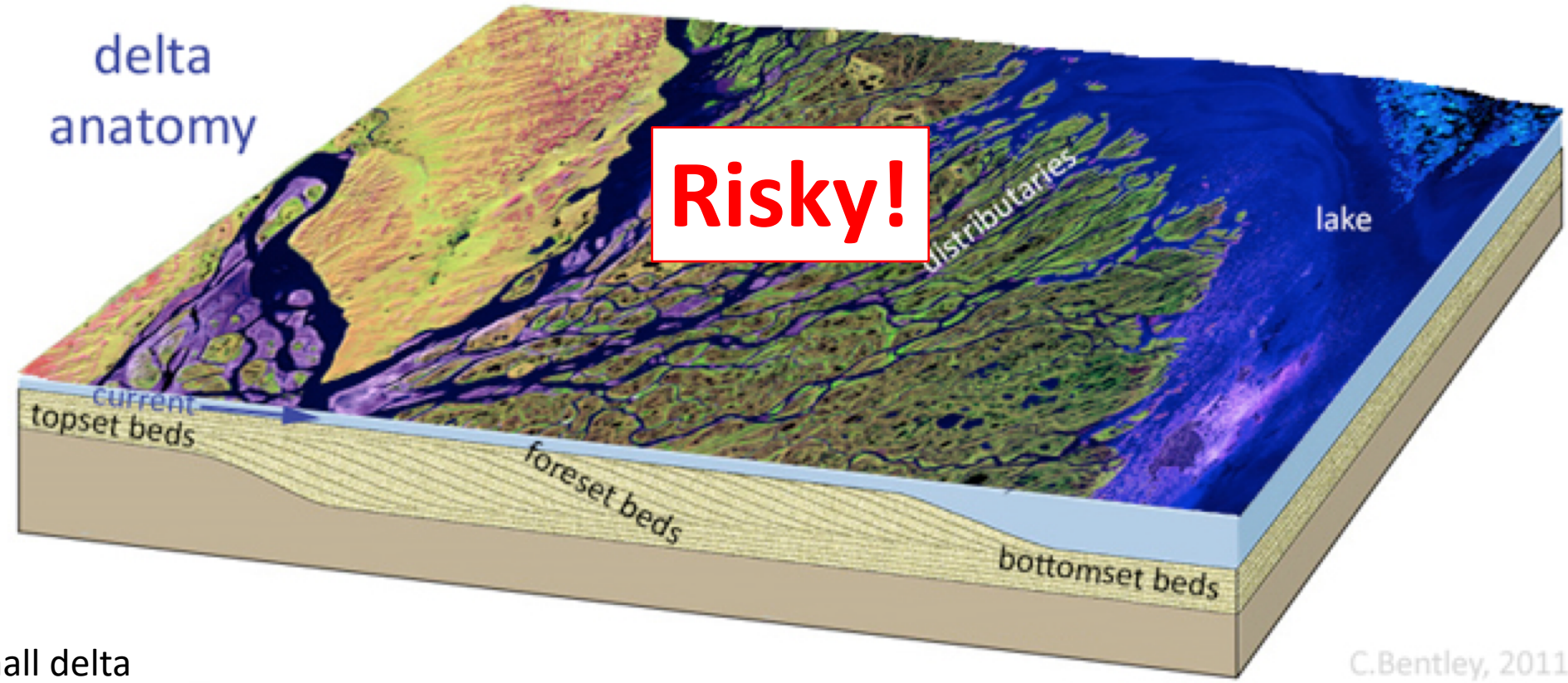
- **Diverse geologic units *in clear stratigraphic context*** (*Ehlmann et al.*, 2008a; *Goudge et al.*, 2015).
- ***Long-lived* delta?**
- **Fe-Mg smectite clays; derived through transport from basement hinterland**



Goudge et al. [2015]

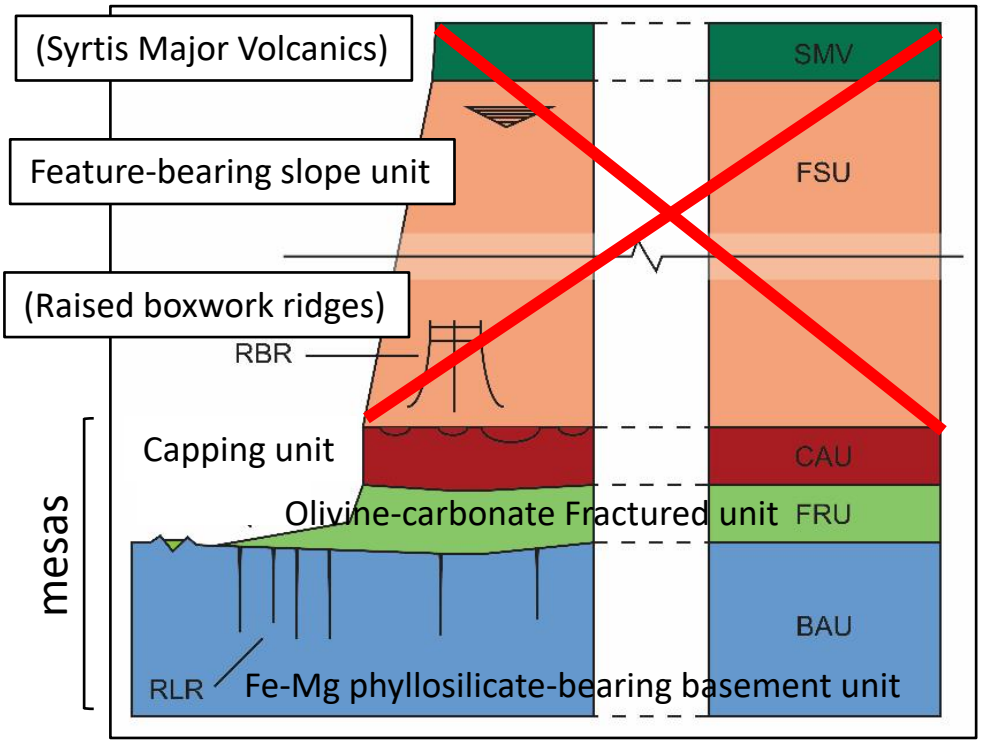


Thus, a reliance on this model is…

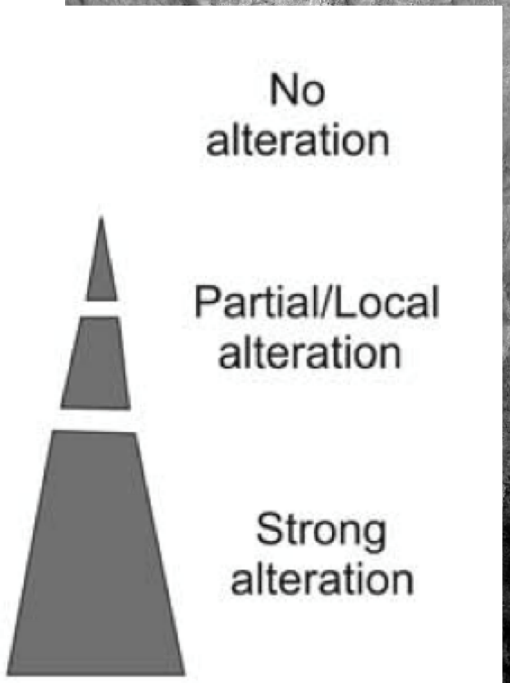


Small delta
Long-lived?
Type of metabolism? Phototrophic unlikely…
Low organic concentration?
Youngest unit, thus susceptible to radiation damage…

NE Syrtis Major – land of many mesas

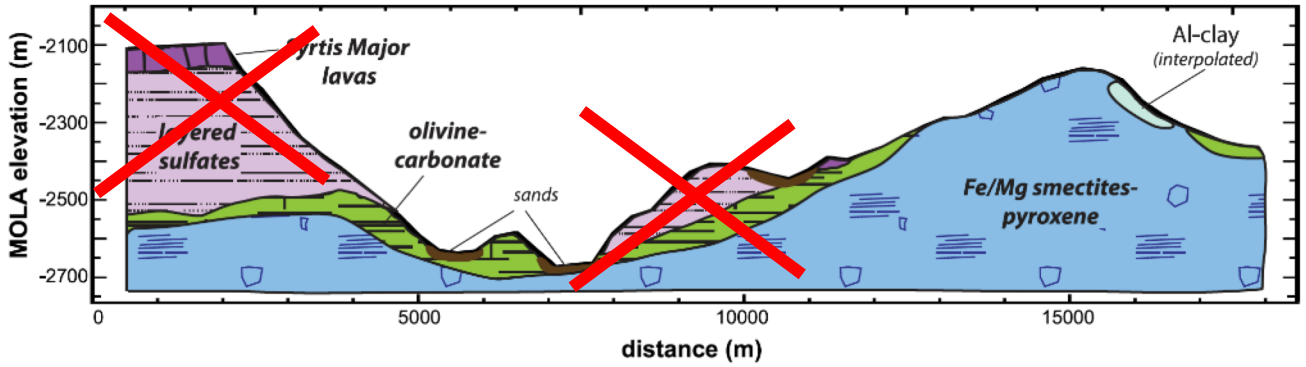


Bramble et al., 2017: Icarus



a

a’

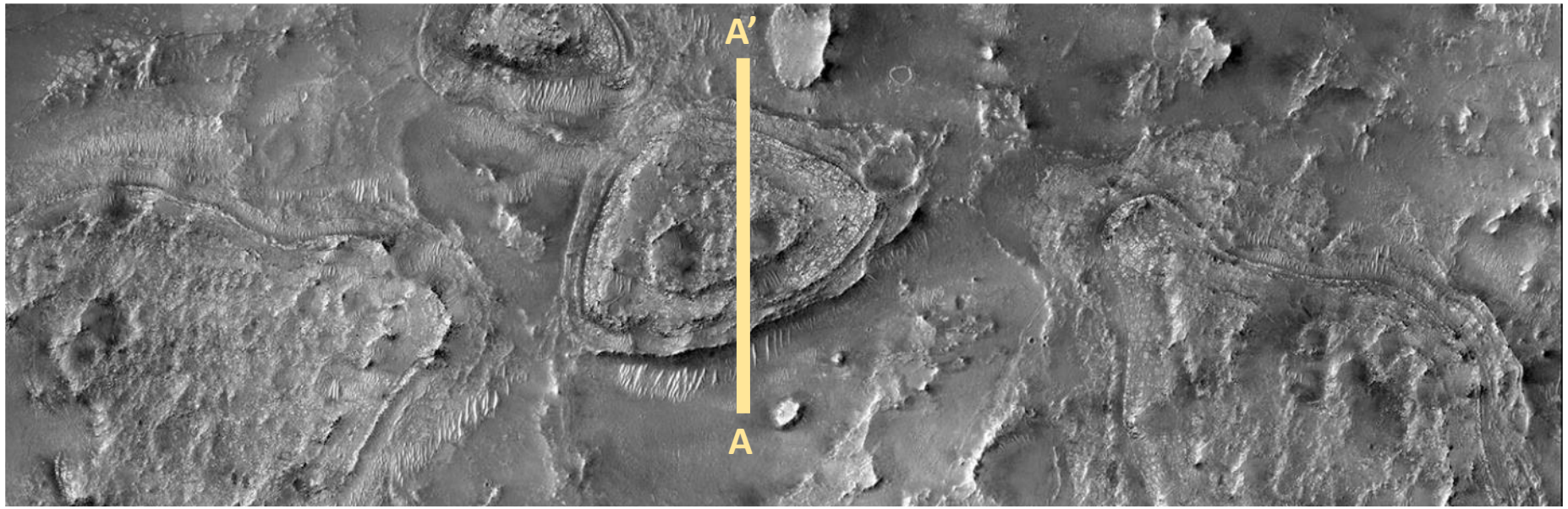


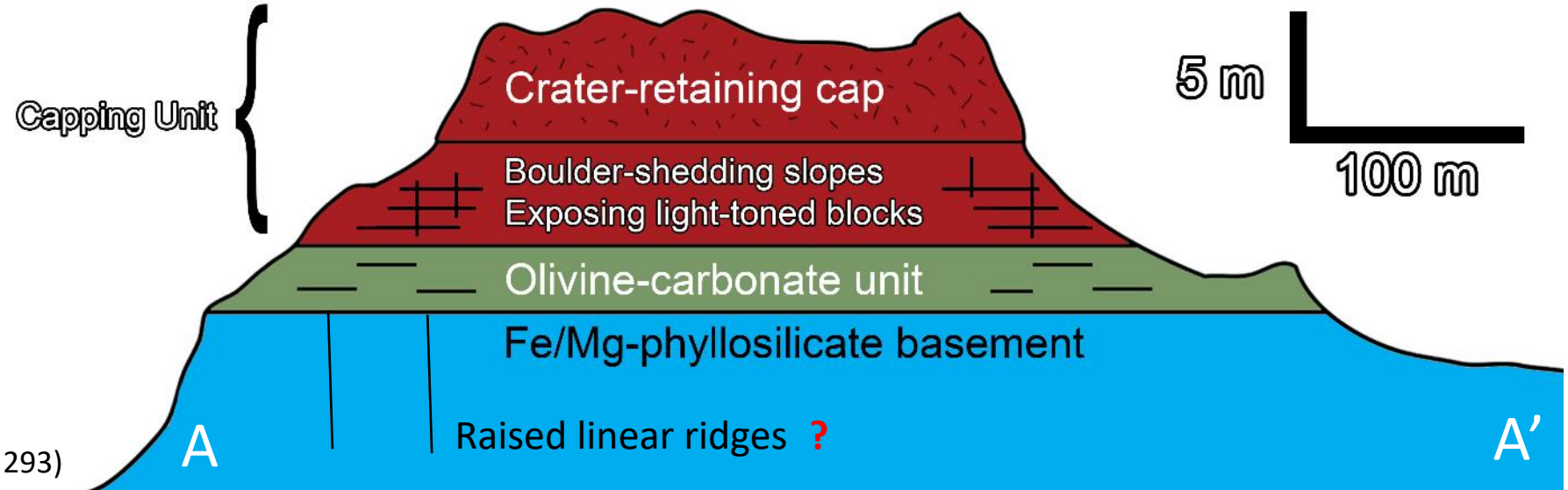
Ehlmann and Mustard, 2012

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.

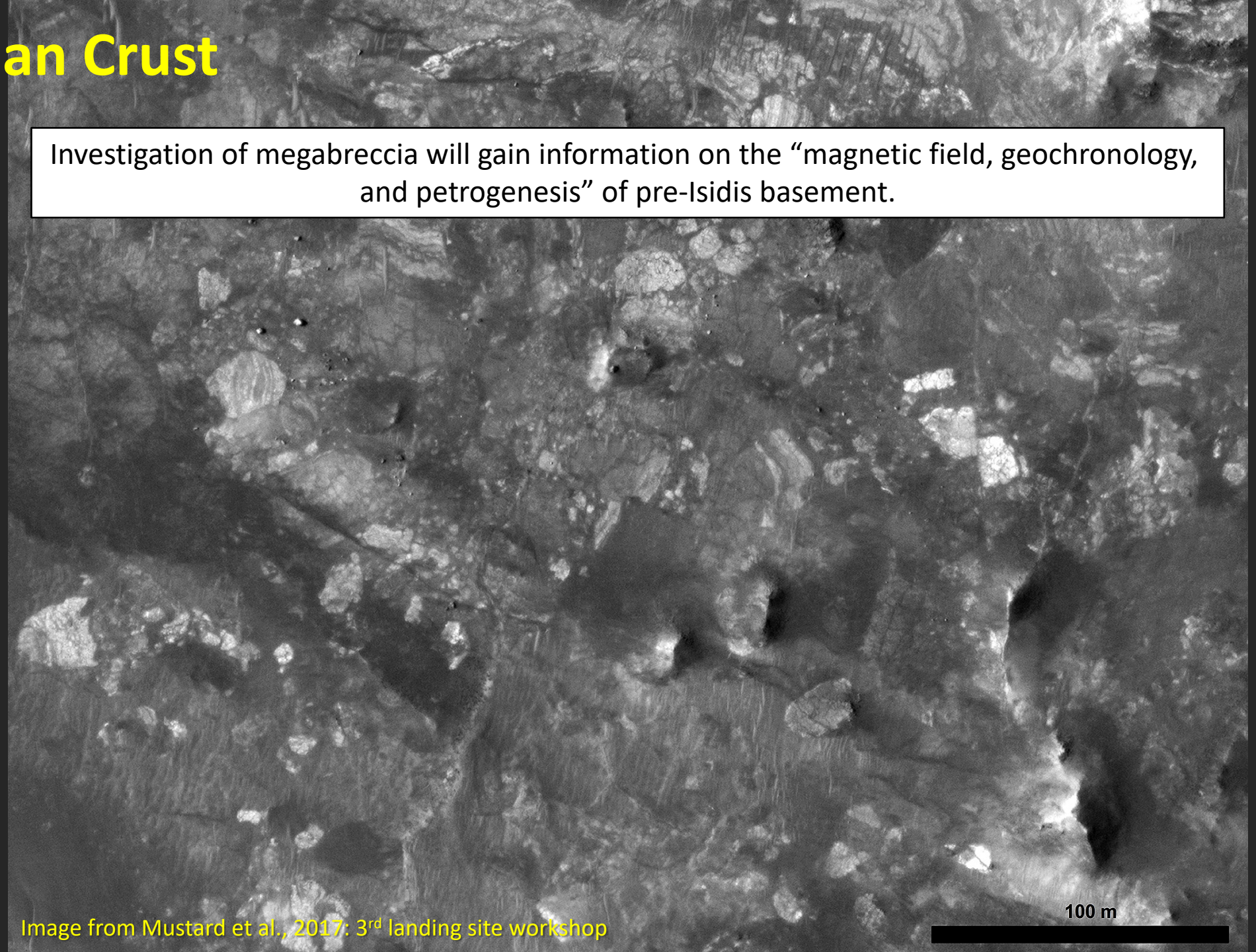


Image from Mustard et al., 2017: 3rd landing site workshop

Sudbury Impact, Canada

130 km

Pseudotachylyte-hosted breccia

Shattercones

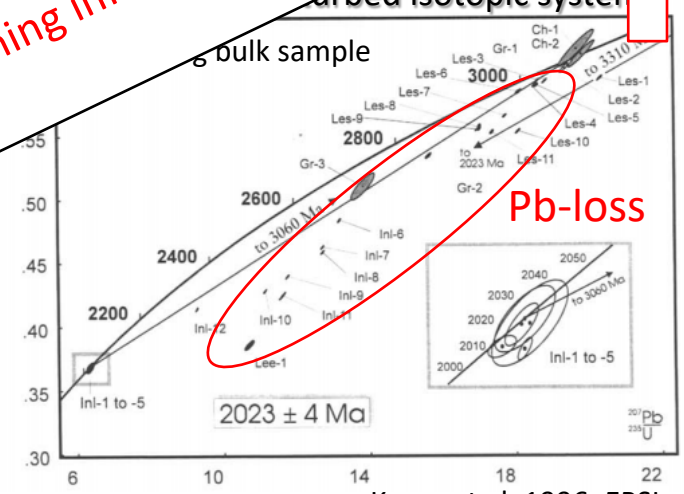
Vredefort Impact Structure, S. Africa

(largest on Earth)

300 km

arbed isotopic syster

bulk sample



Kamo et al. 1996: EPSL

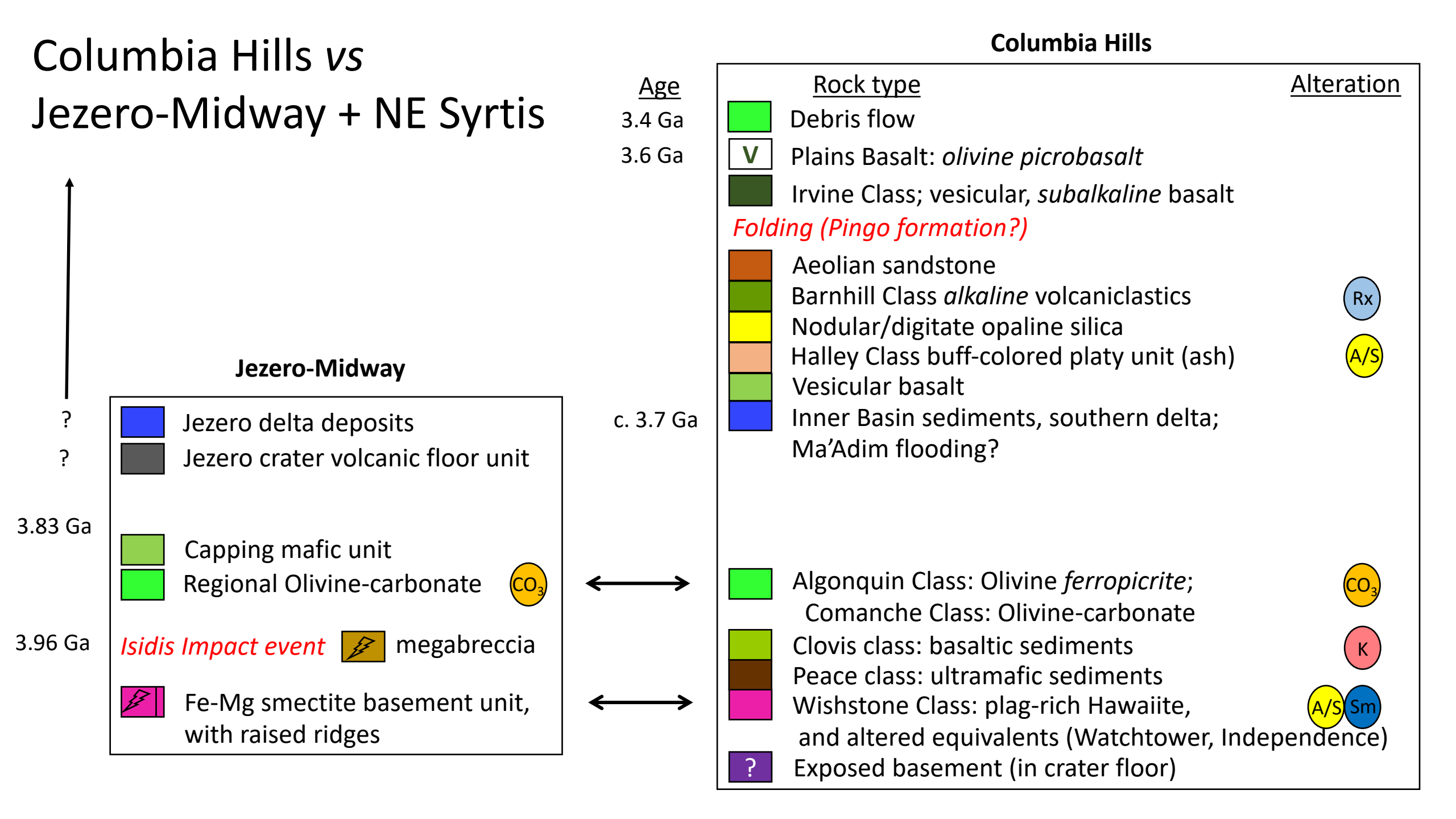
Isidis Basin, Mars

km

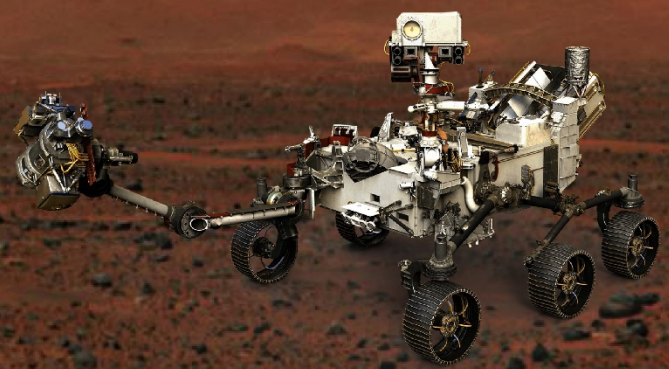
Mustard et al., 2009: JGR 114

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!***

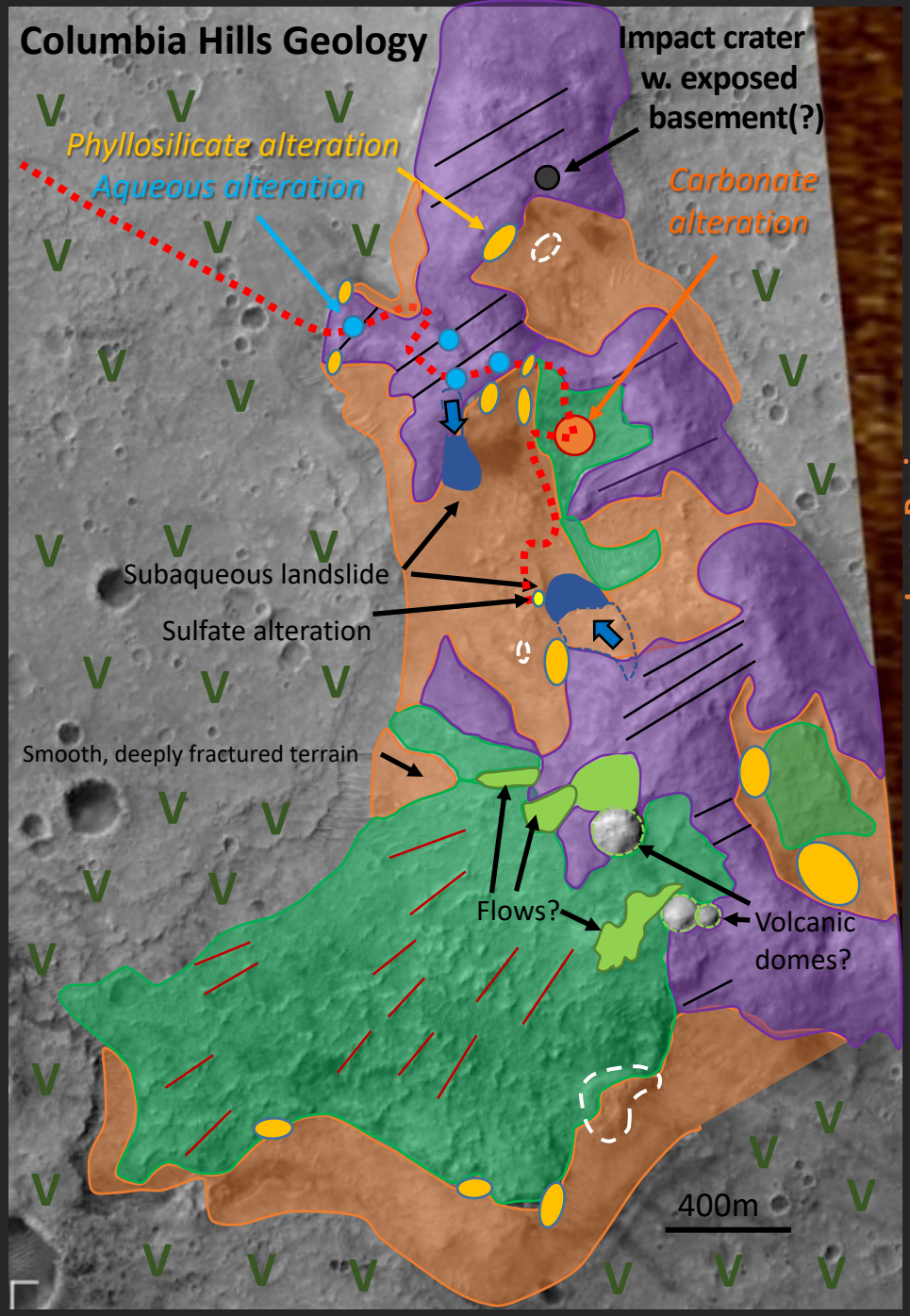
Columbia Hills *vs* Jezero-Midway + NE Syrtis



COLUMBIA HILLS



"So much more to explore"



Event stratigraphy of the Columbia Hills

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

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

Subaerial

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)*;

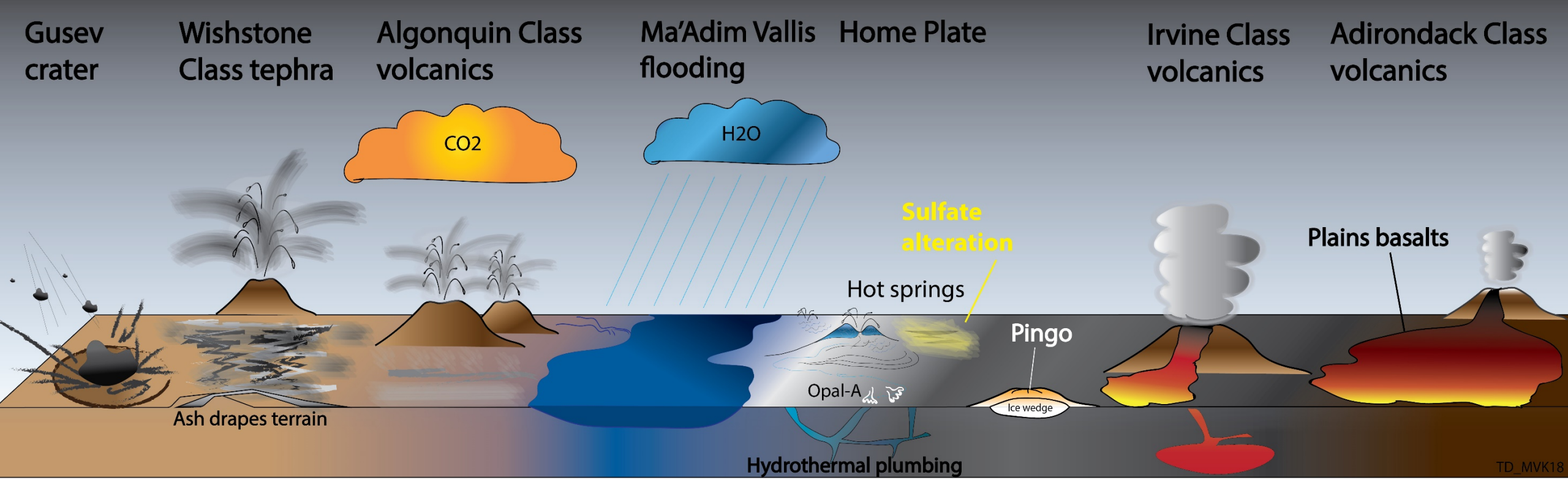
Uplift and erosion

aqueous and sulfate alteration (Watchtower Class)

Possible basement in floor of impact crater

Aqueous alteration

Geological history of Columbia Hills, Gusev Crater

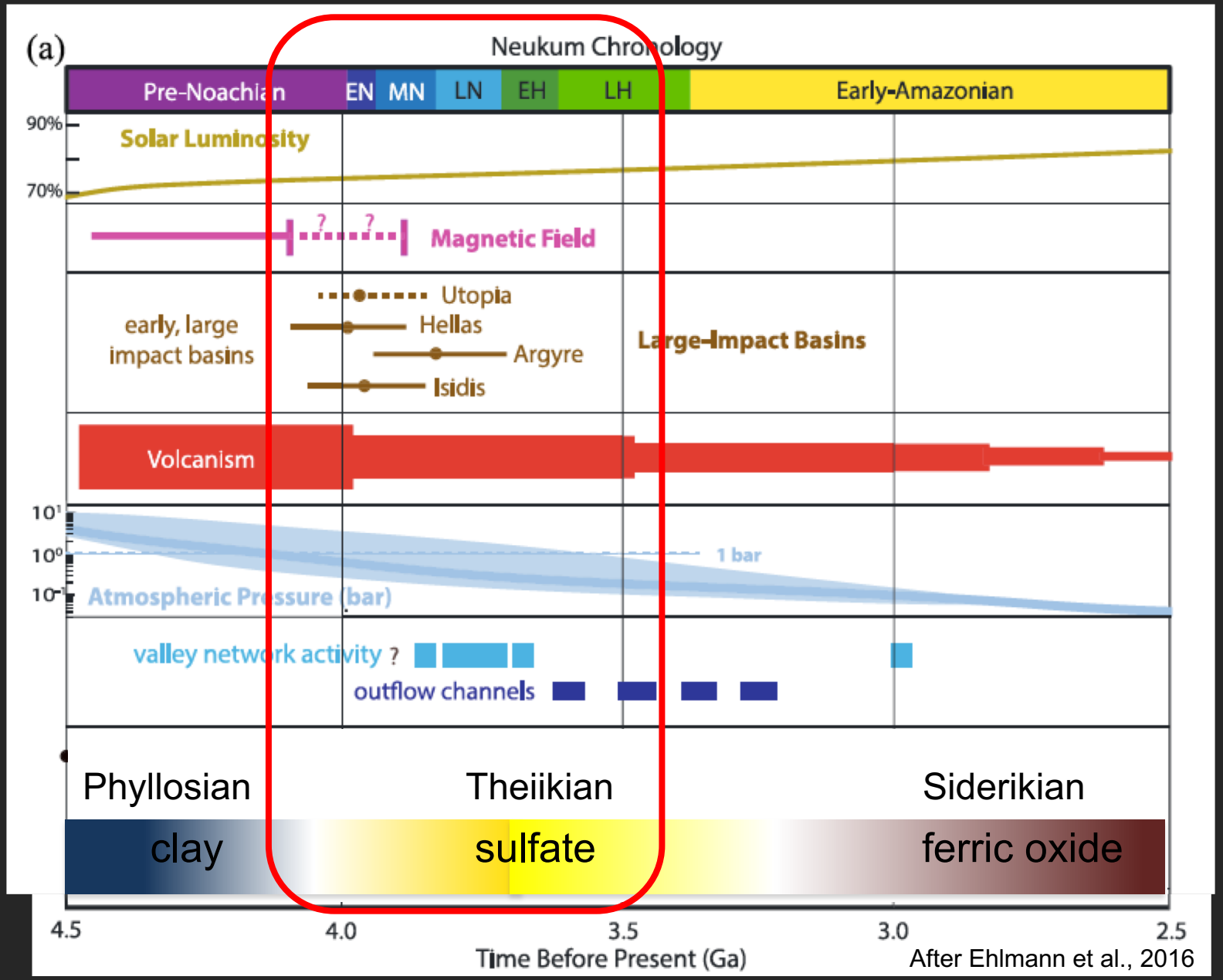


~4 Ga
Early Noachian

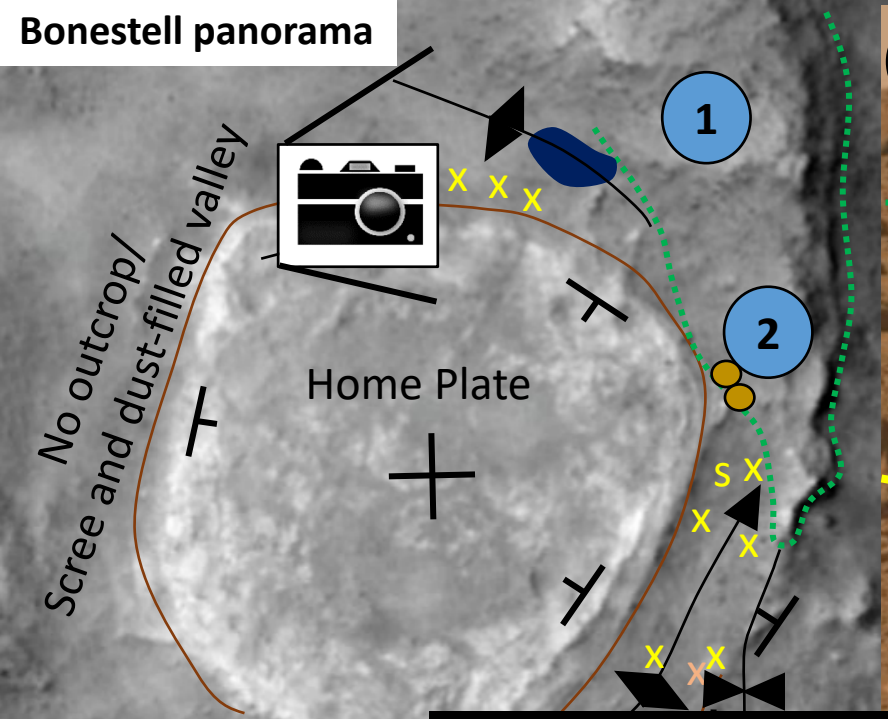
~3.8 Ga
Warm/wet period

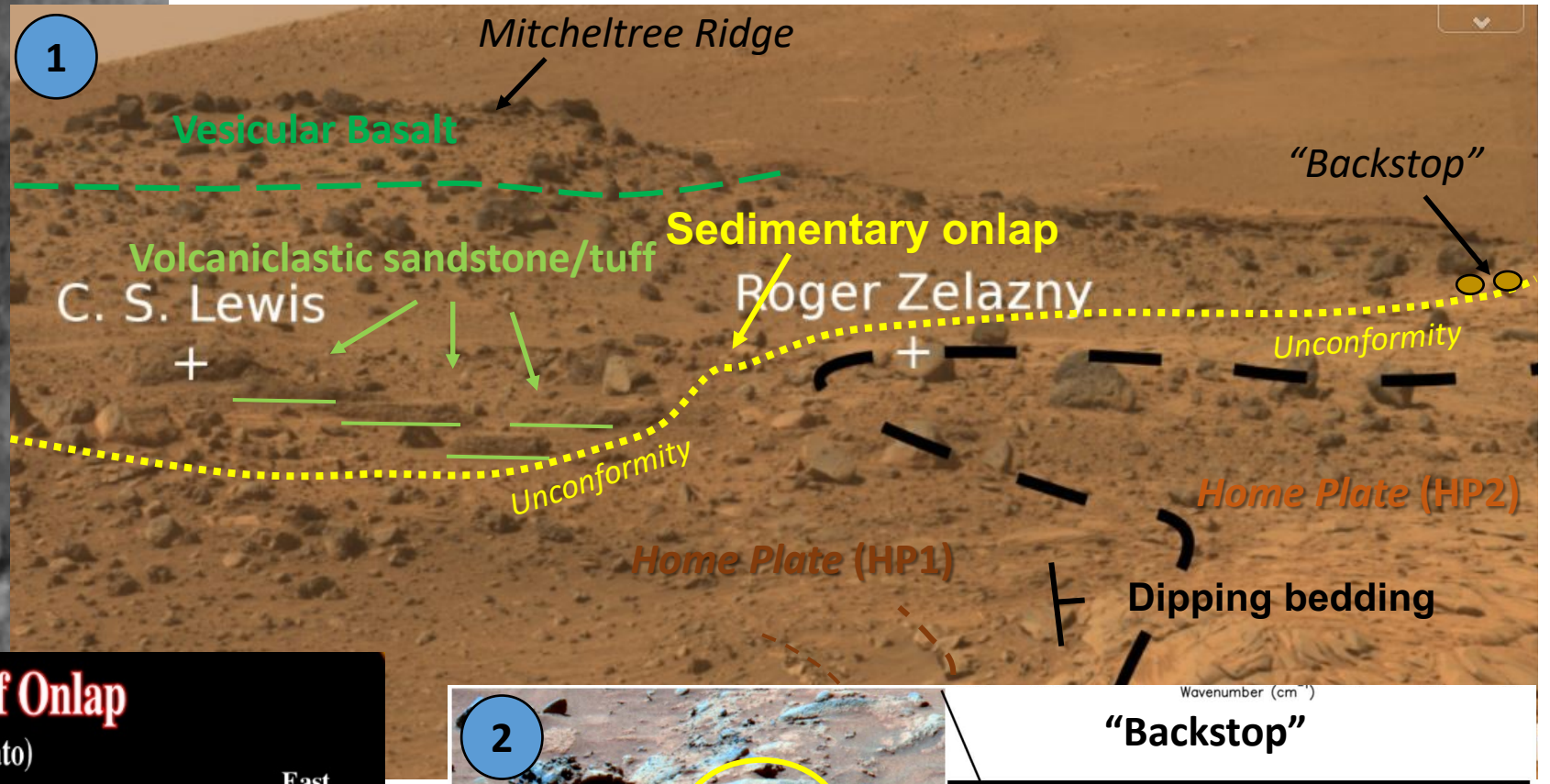
~3.6 - 3.5 Ga
Late Hesperian

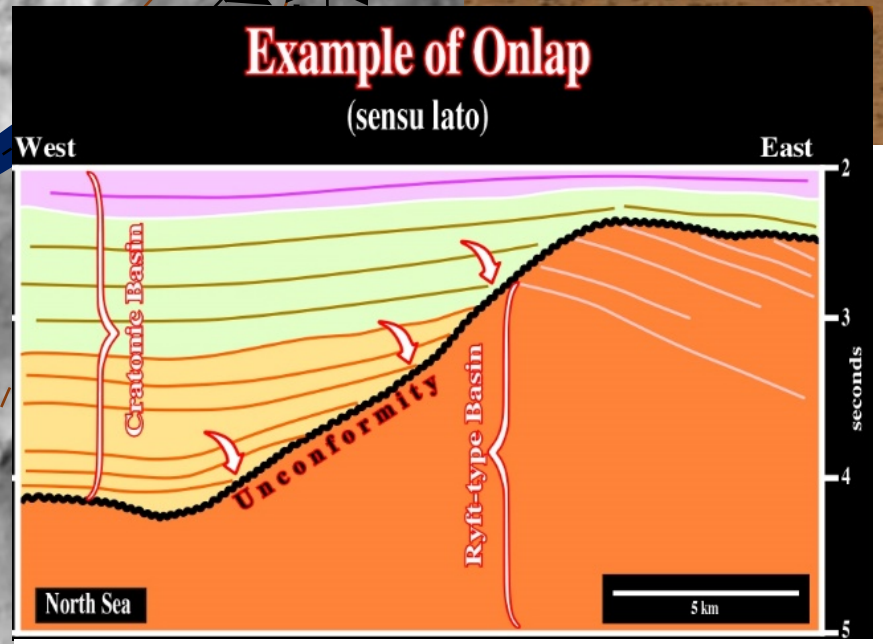
Tara's diagram



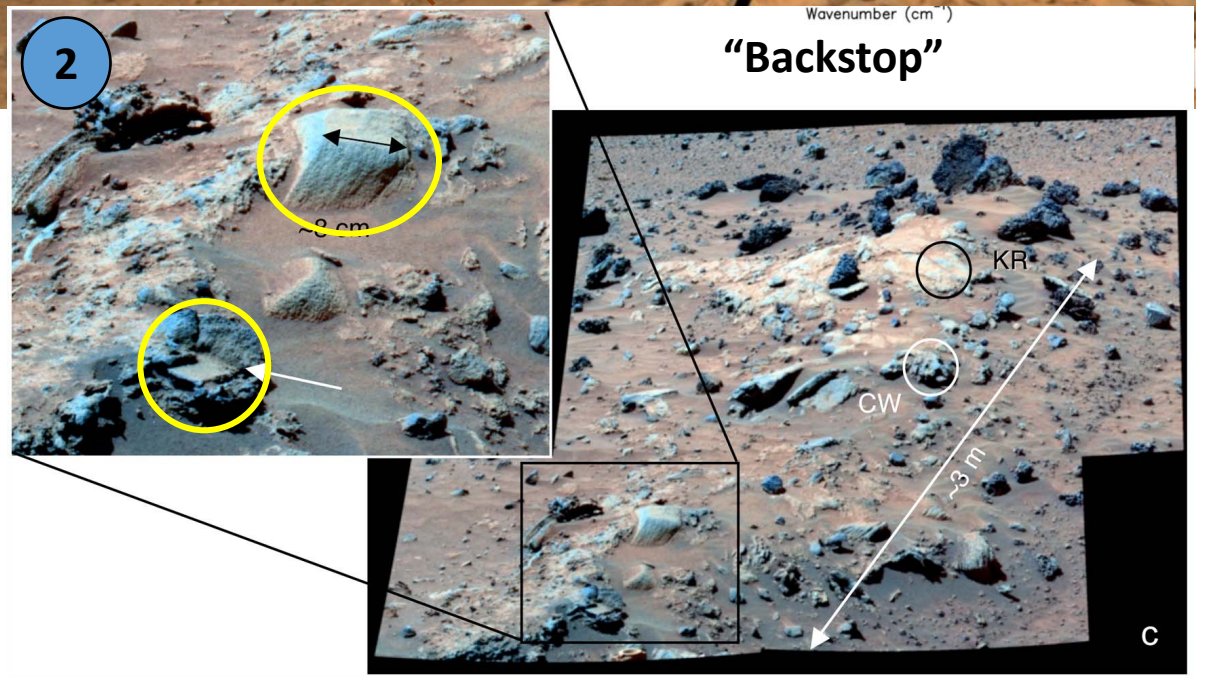
Bonestell panorama



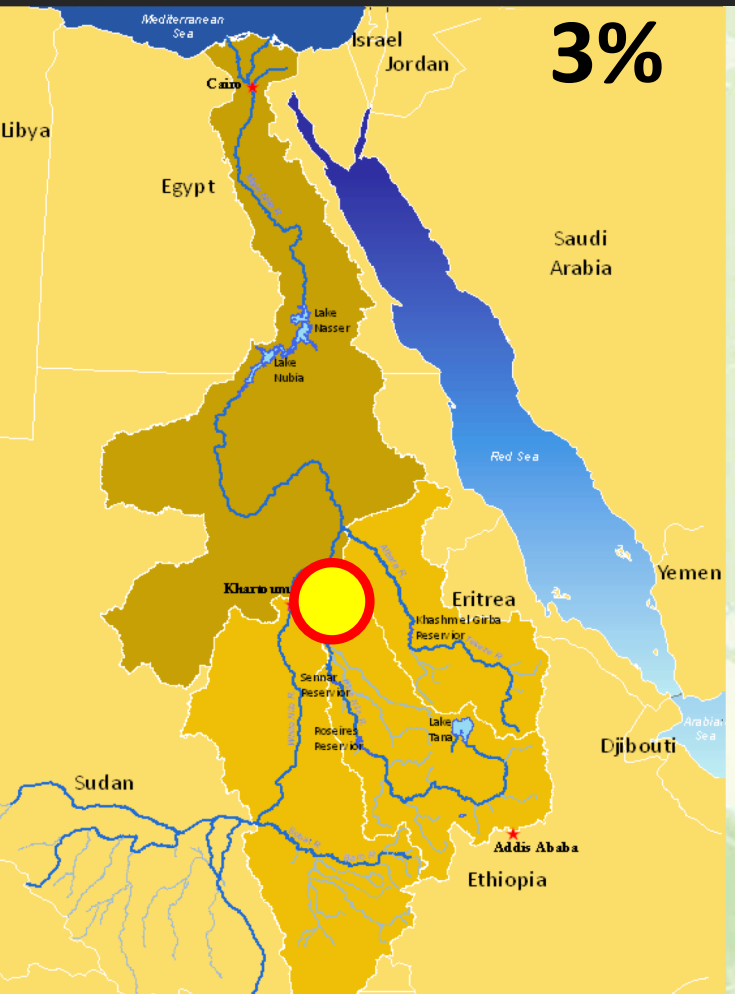


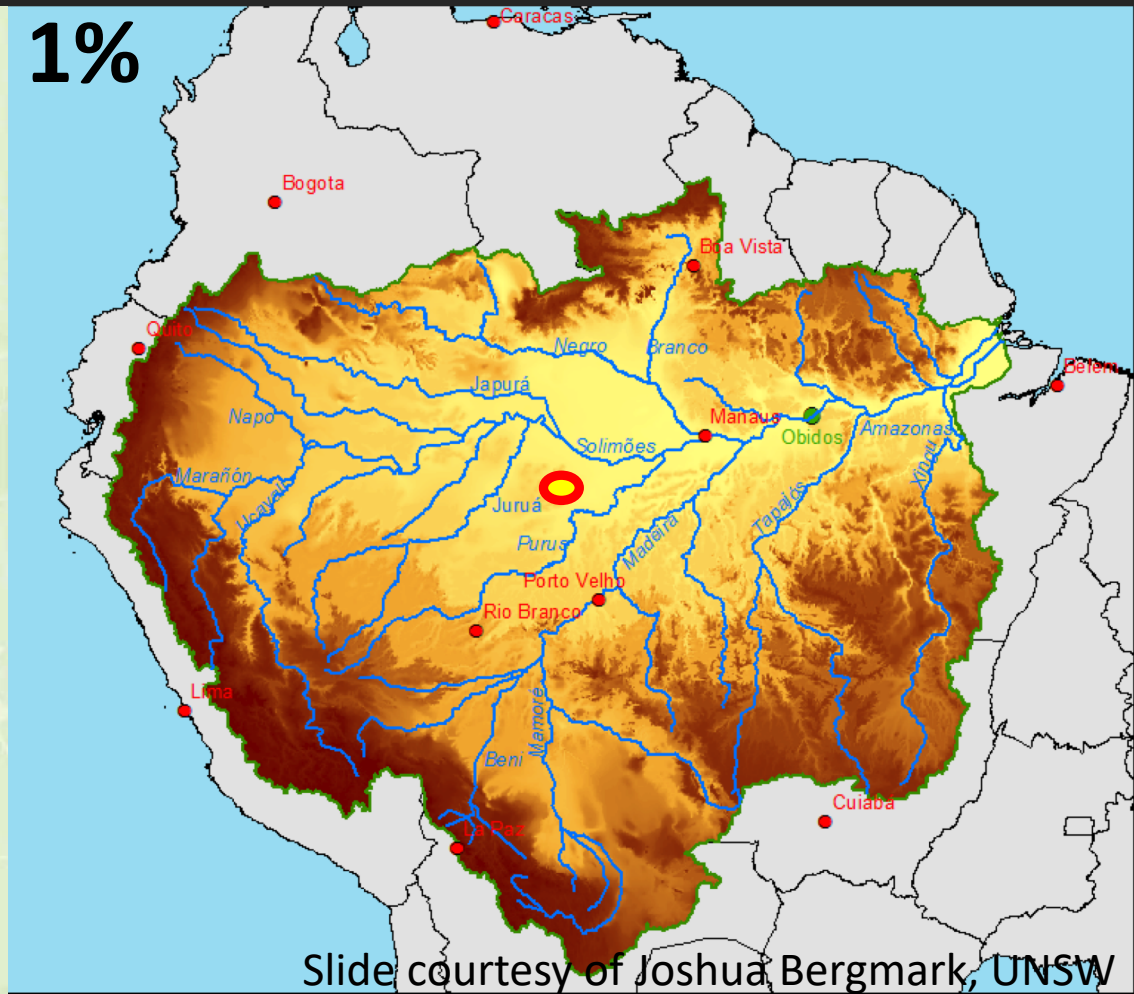


http://homepage.ufp.pt/biblioteca/Seismic/Pages/Page19.htm



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



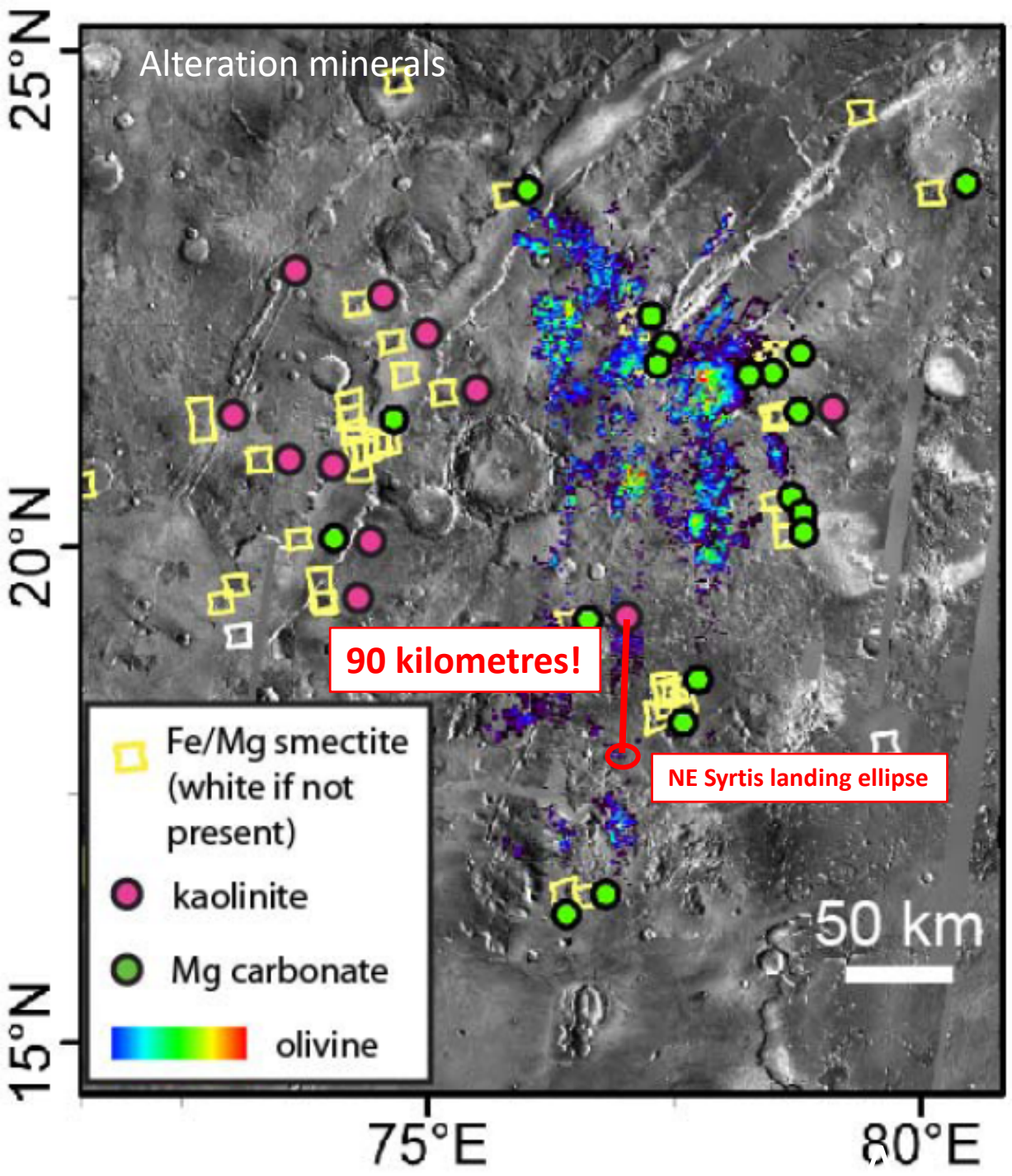


Slide courtesy of Joshua Bergmark, UNSW

NE Syrtis Major – land of many mesas

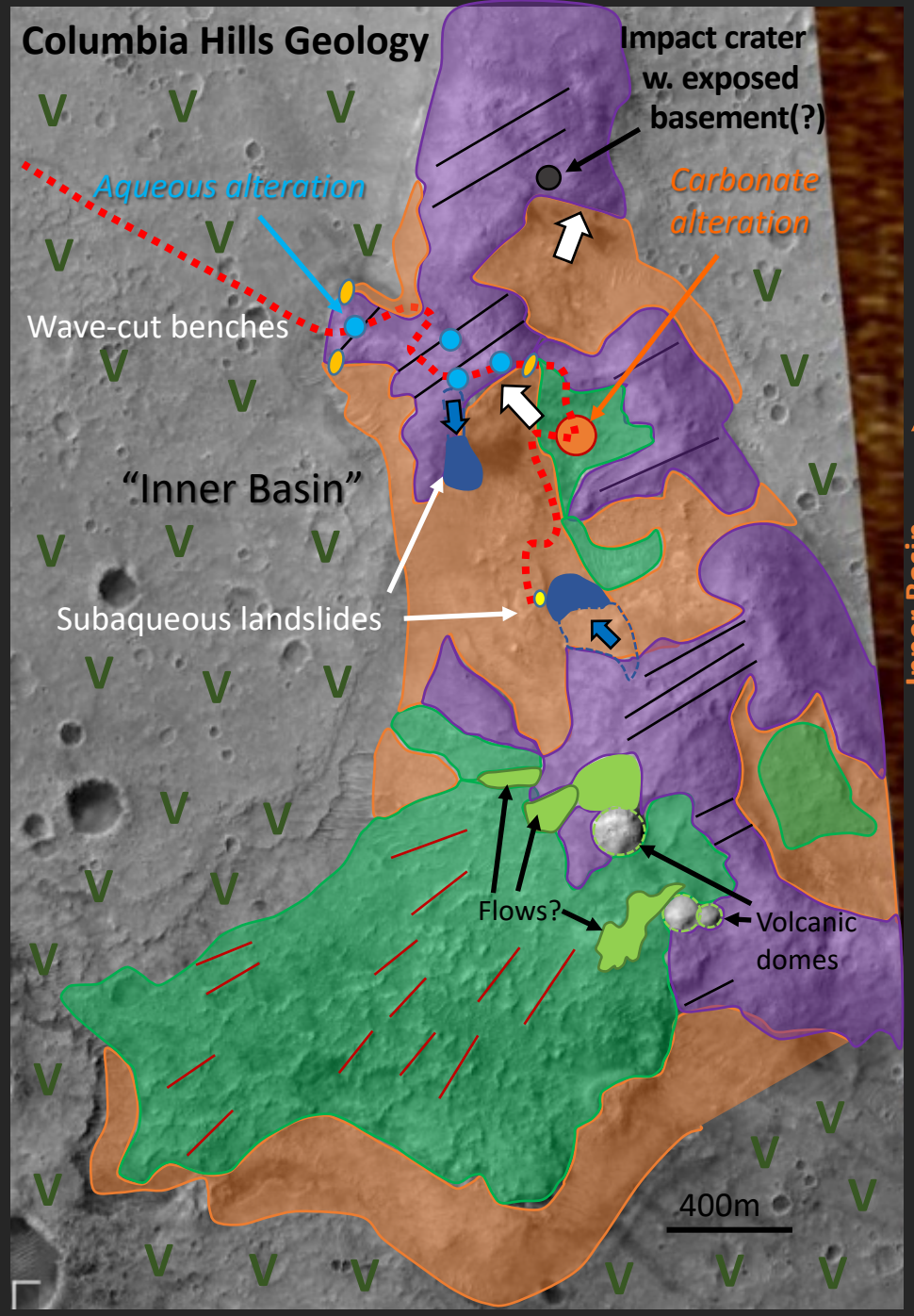
Capping Mafic Rock
Olivine–Carbonate Formation
LCP-bearing Mounds
Clay-rich basement

2 km



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

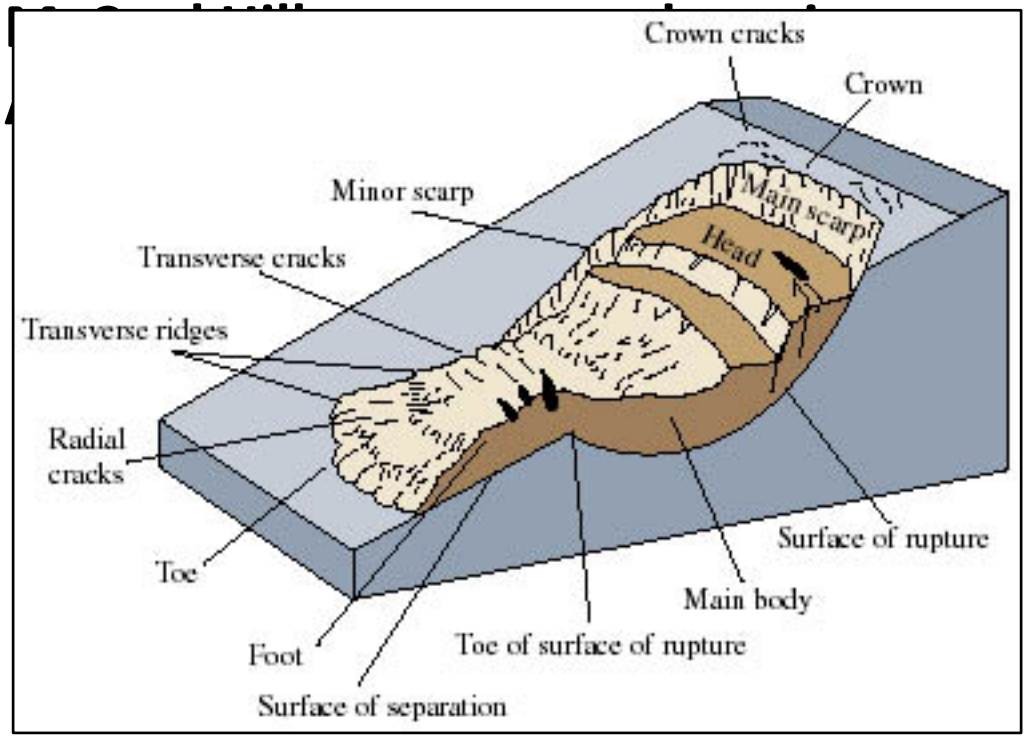
aqueous and sulfate alteration (Watchtower Class)

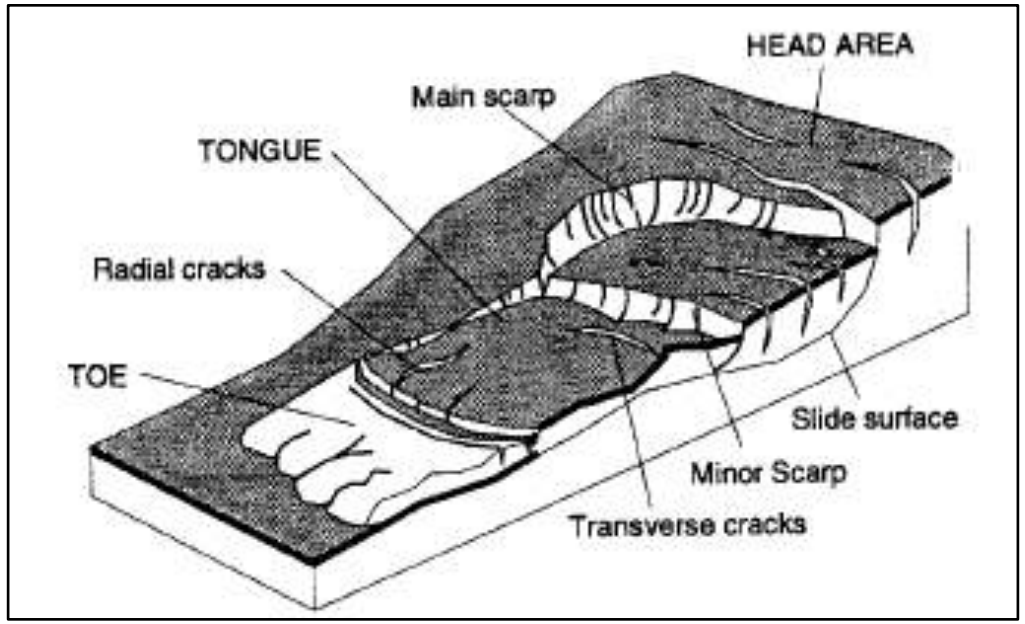
Wishstone Class: Hawaiite tephra with NE-SW bedding strike:

(and associated other classes);

Uplift and erosion

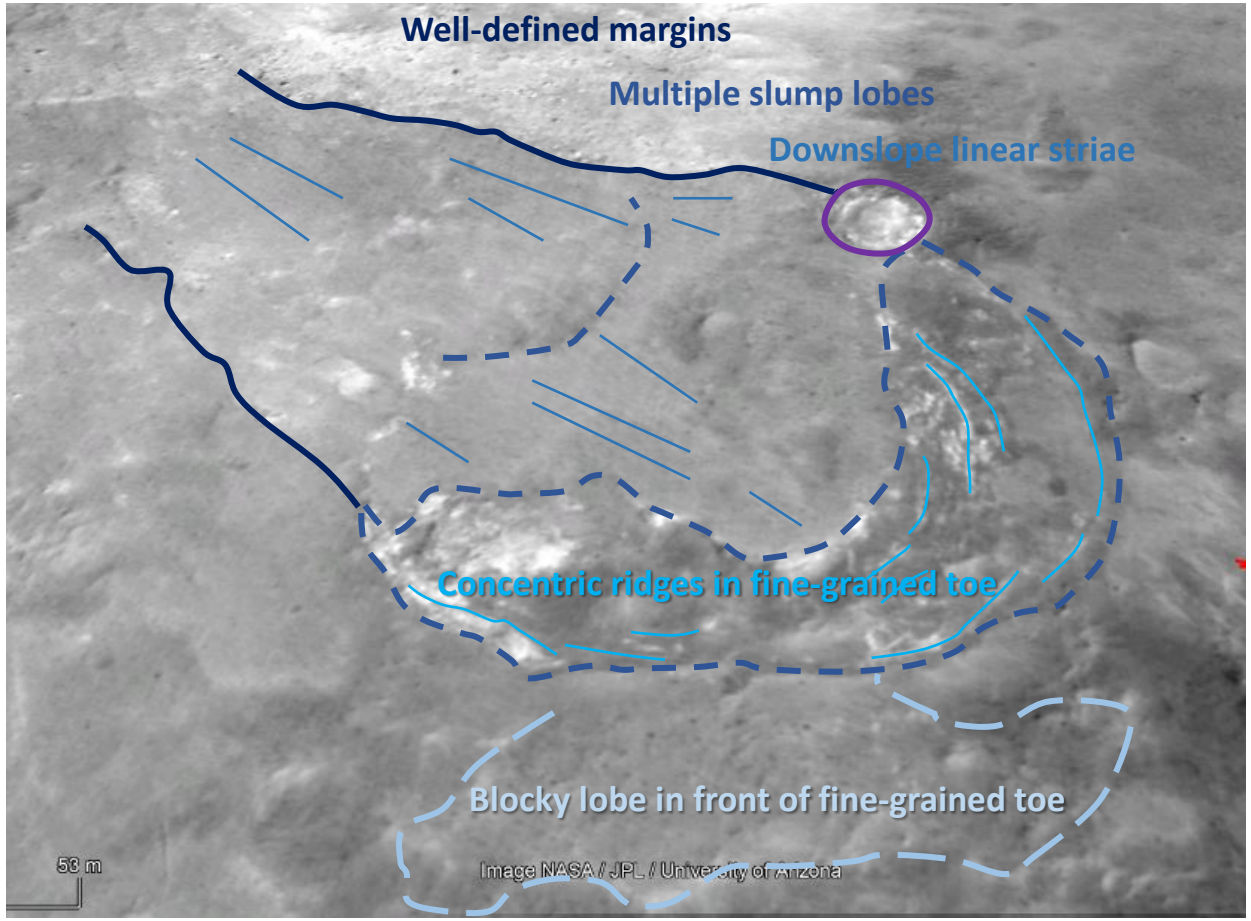
Possible basement in floor of impact crater



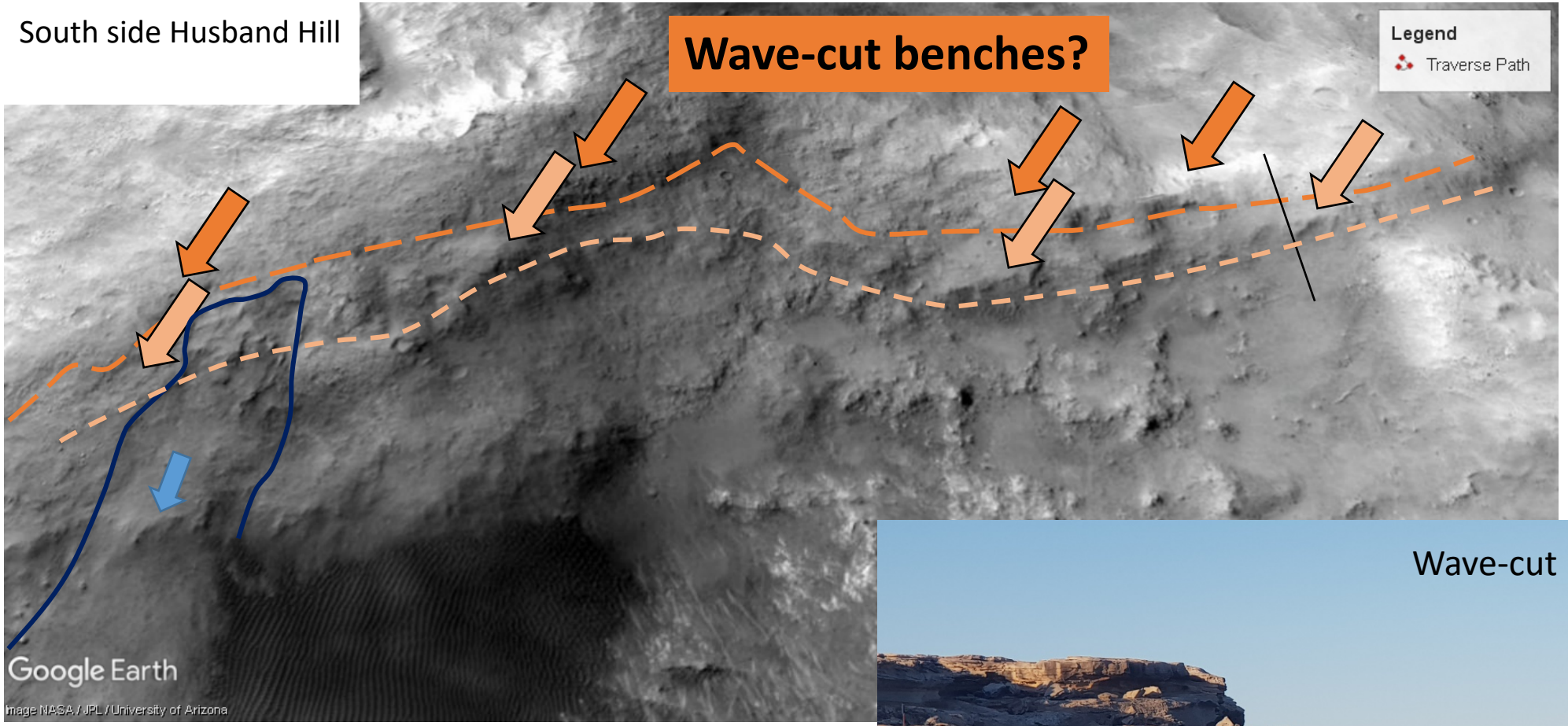


Terrestrial mass waste deposits have distinctly different features:

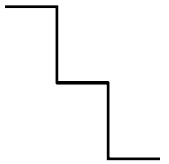
- Radial cracks
- Scarps
- Transverse cracks
- Toe lobes



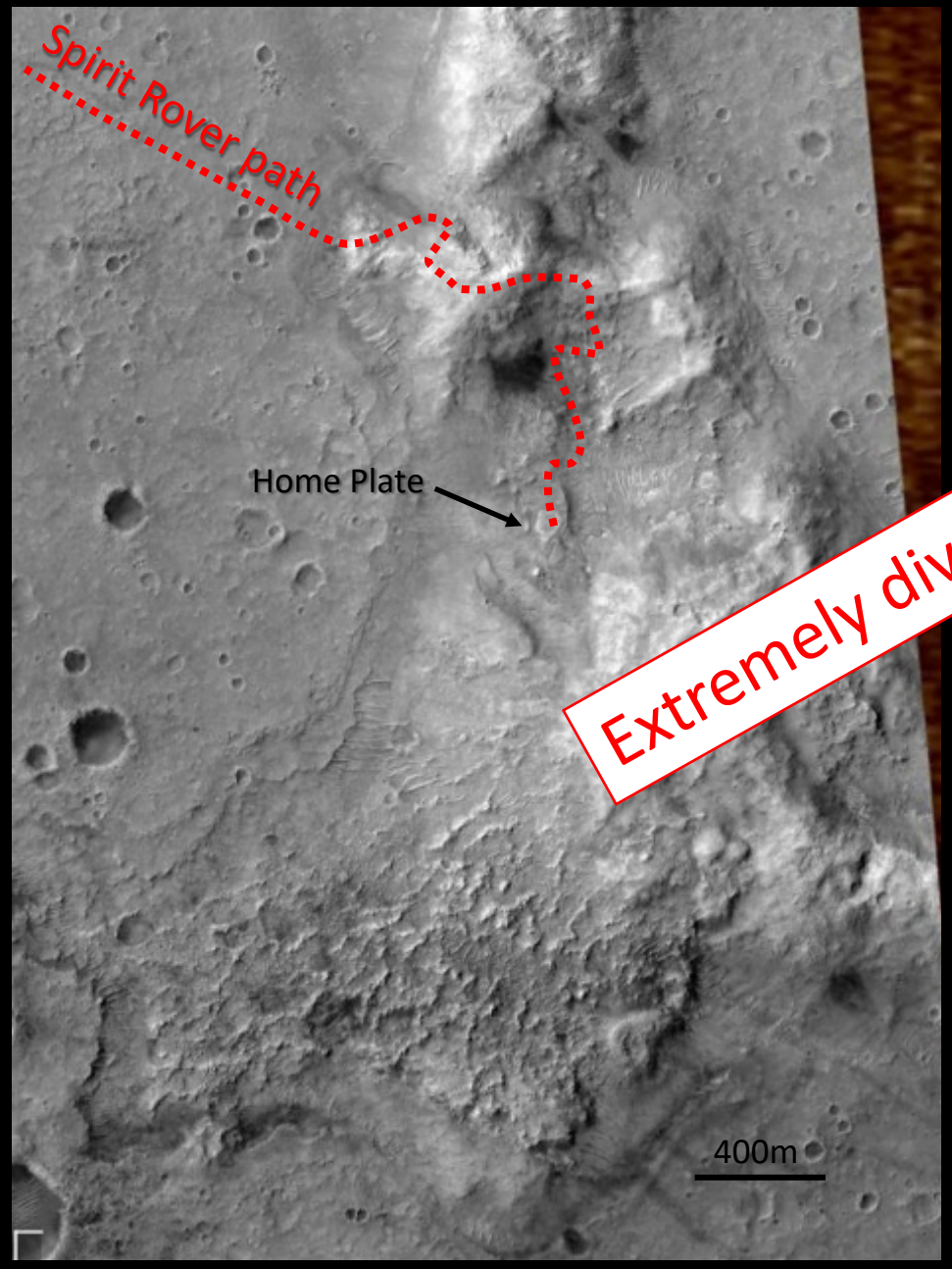
South side Husband Hill



Cross-section



Columbia Hills, Gusev Crater



Extremely diverse terrain