*A Second Field Season on Mars**: The Merits of Returning to Gusev Crater for a Sample Caching Mission

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*Jim Rice, and Mark Salvatore

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ASU School of Earth & Space Exploration

A Second Field Season on Mars: The Merits of Returning to Gusev Crater for a Sample Caching Mission

DISCLAIMER

I would not promote Gusev for Mars 2020 if it were not a caching mission.

Scientifically, Why Gusev Crater?

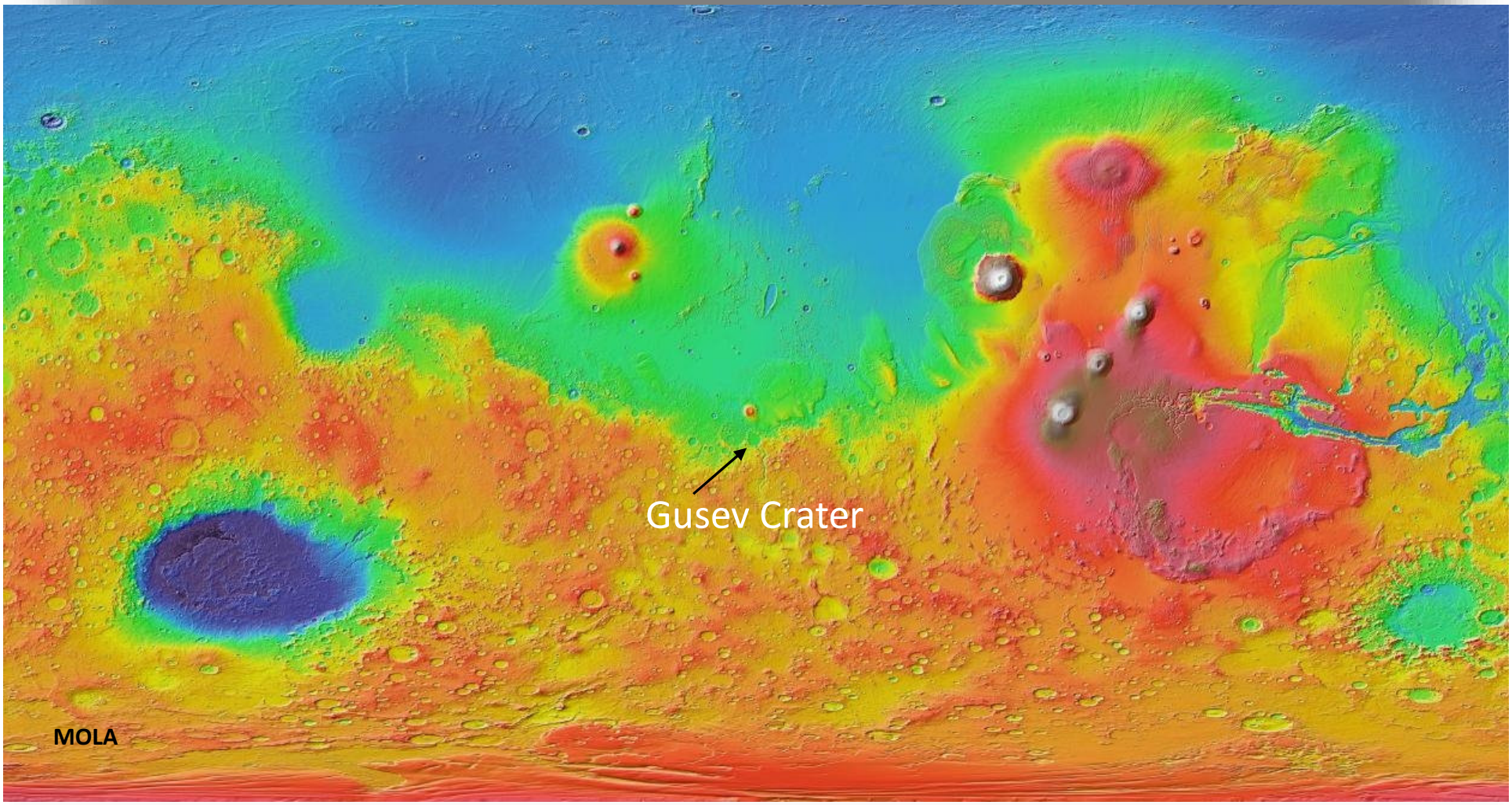
Threshold Geological Criteria:

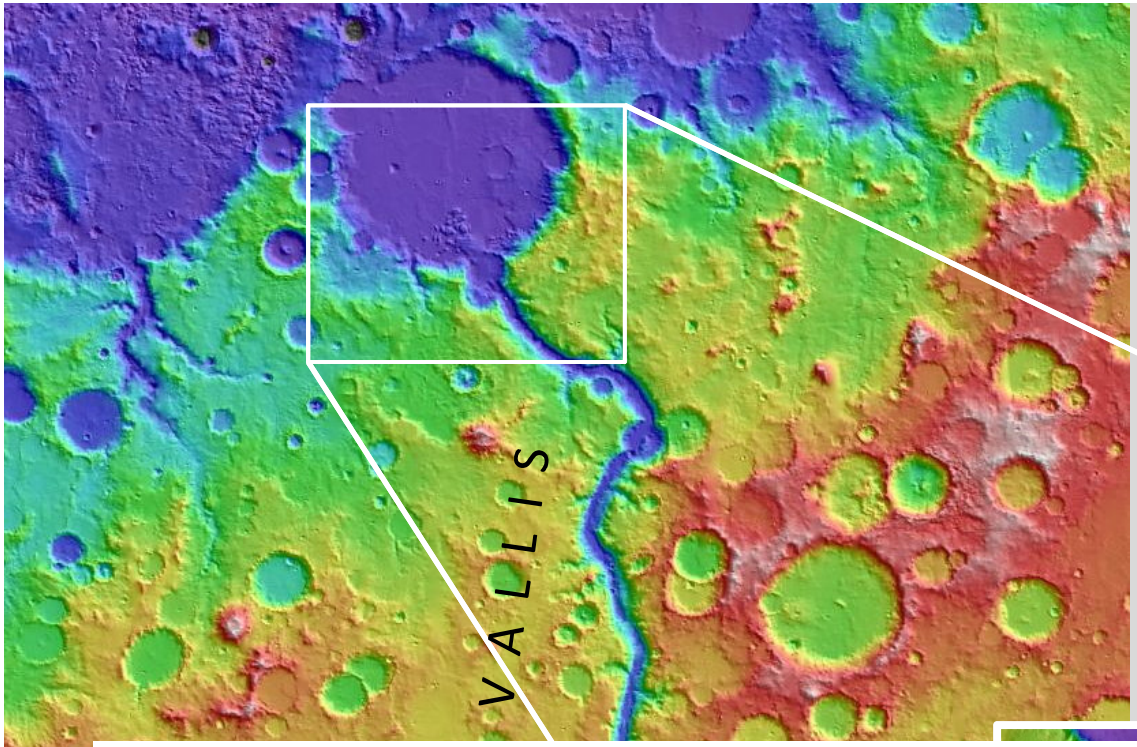
- ☑ 1. Presence of subaqueous sediments or hydrothermal sediments (equal 1st priority), OR
  hydrothermally altered rocks or low-T fluid-altered rocks (equal 2nd priority)
- ☑ 2. Presence of minerals indicative of aqueous processes (e.g., phyllosilicates, carbonates, sulfates, etc.) in outcrop
- ☑ 3. Noachian/Early Hesperian age based on stratigraphic relations and/or crater counts
- ☑ 4. Access to unaltered igneous rocks as float
- ☑ 5. Not a Special Region

Potential Qualifying Geological Criteria:

- ☑ 1. Morphological criteria for standing bodies of water and/or fluvial activity (deltaic deposits, shorelines, etc.).
- ☑ 2. Assemblages of secondary minerals of any age.
- ☒ 3. Presence of former water ice, glacial activity or its deposits.
- ☑ 4. Igneous rocks of Noachian age, of known stratigraphic relation, better if including exhumed megabreccia.
- ☑ 5. Volcanic unit of Hesperian or Amazonian age well-defined by crater counts and well-identified by morphology and/or mineralogy.
- ? 6. Probability of samples of opportunity (ejecta breccia, mantle xenoliths, etc.).
- ? 7. Potential for resources for future human mission

Global Context

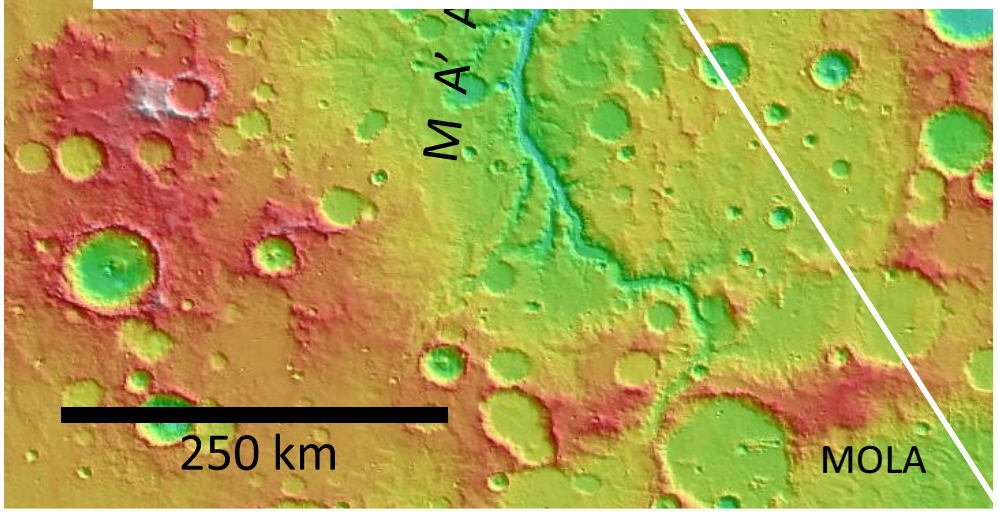


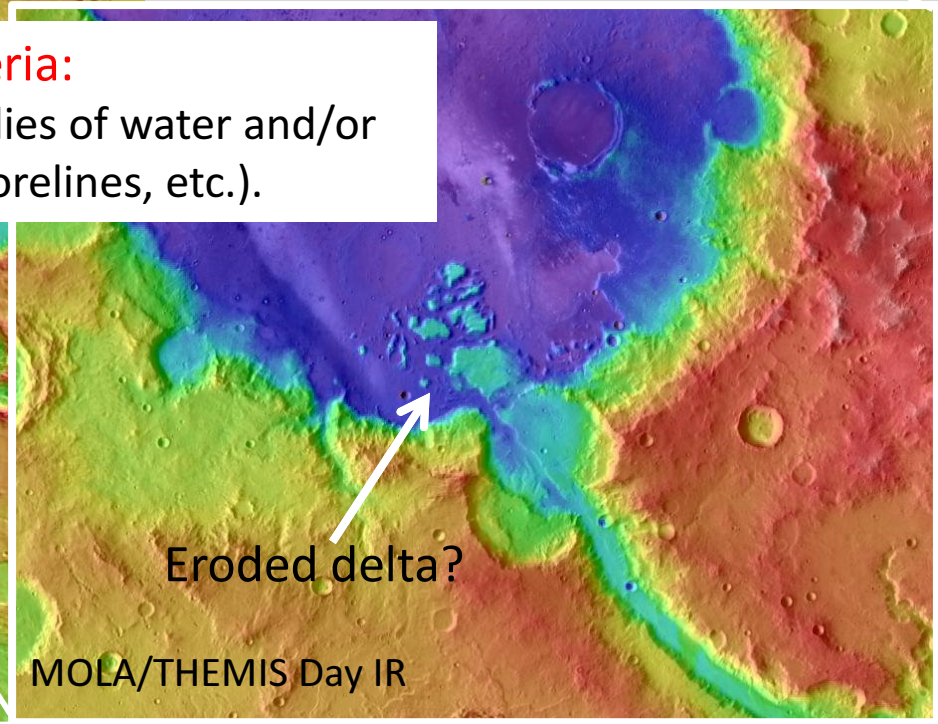


Gusev crater was chosen for the Mars Exploration Rover Spirit because of geomorphic features indicative of an ancient lake, i.e., a potentially habitable environment

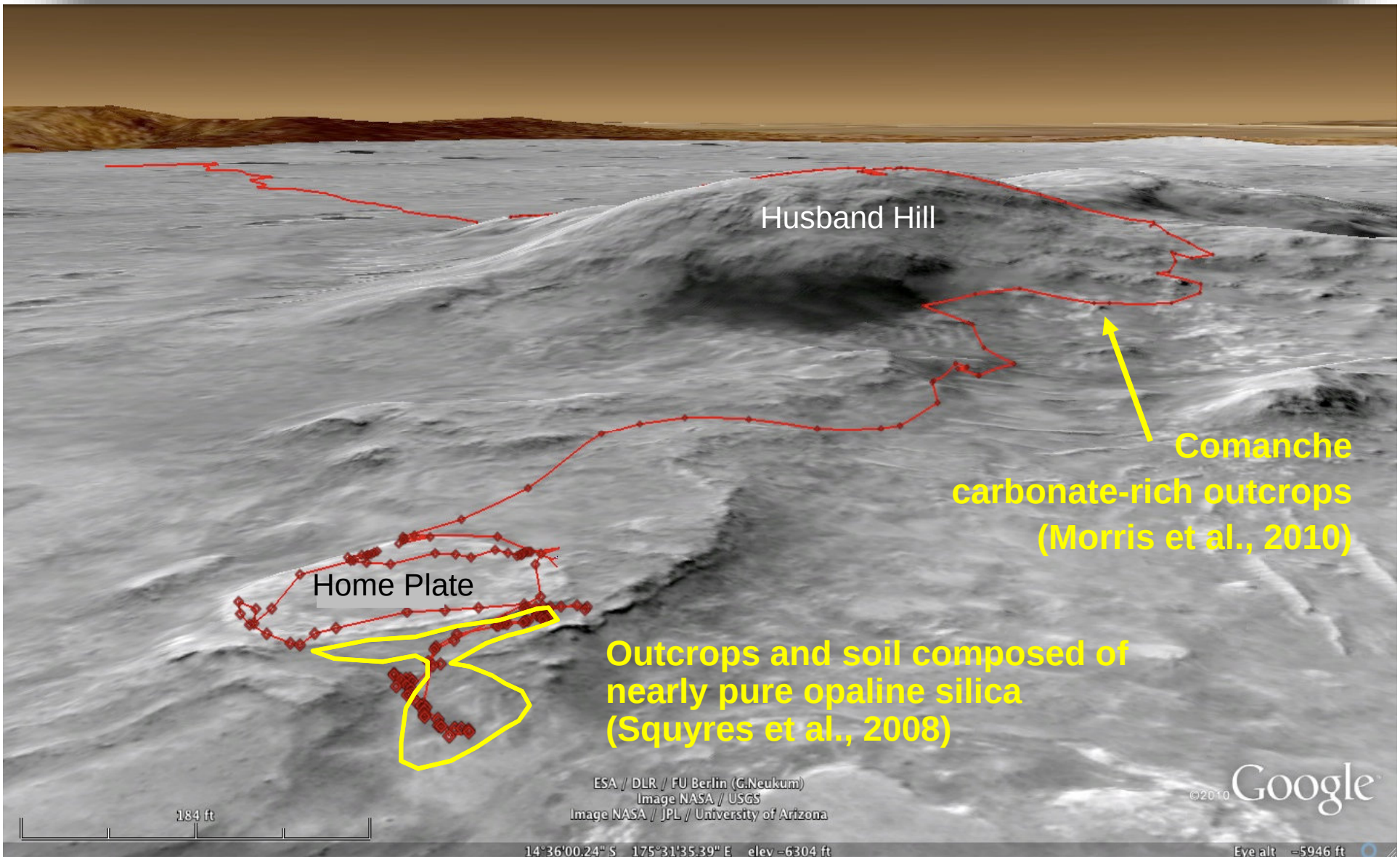
Potential Qualifying Geological Criteria:

☑ 1. Morphological criteria for standing bodies of water and/or fluvial activity (deltaic deposits, shorelines, etc.).

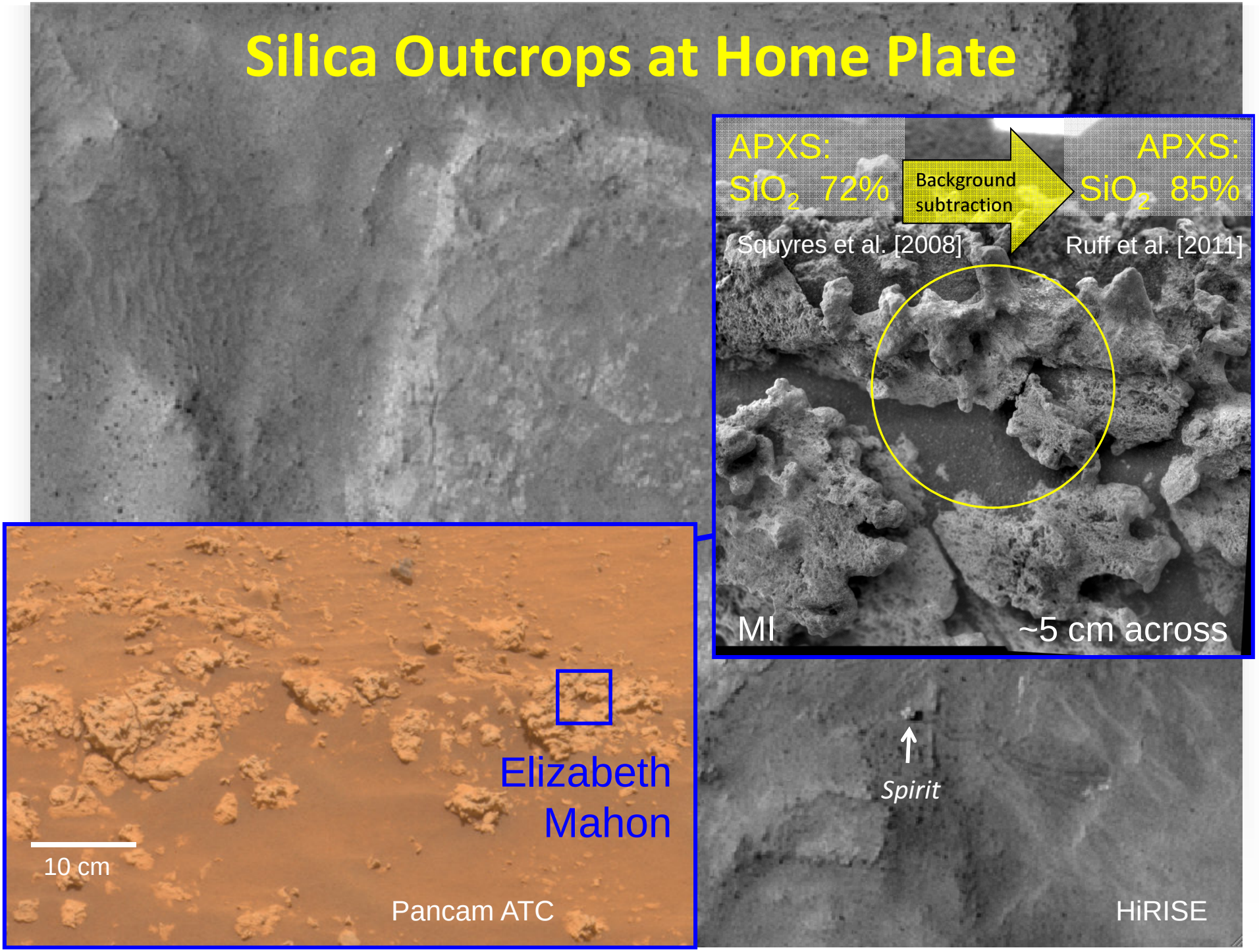




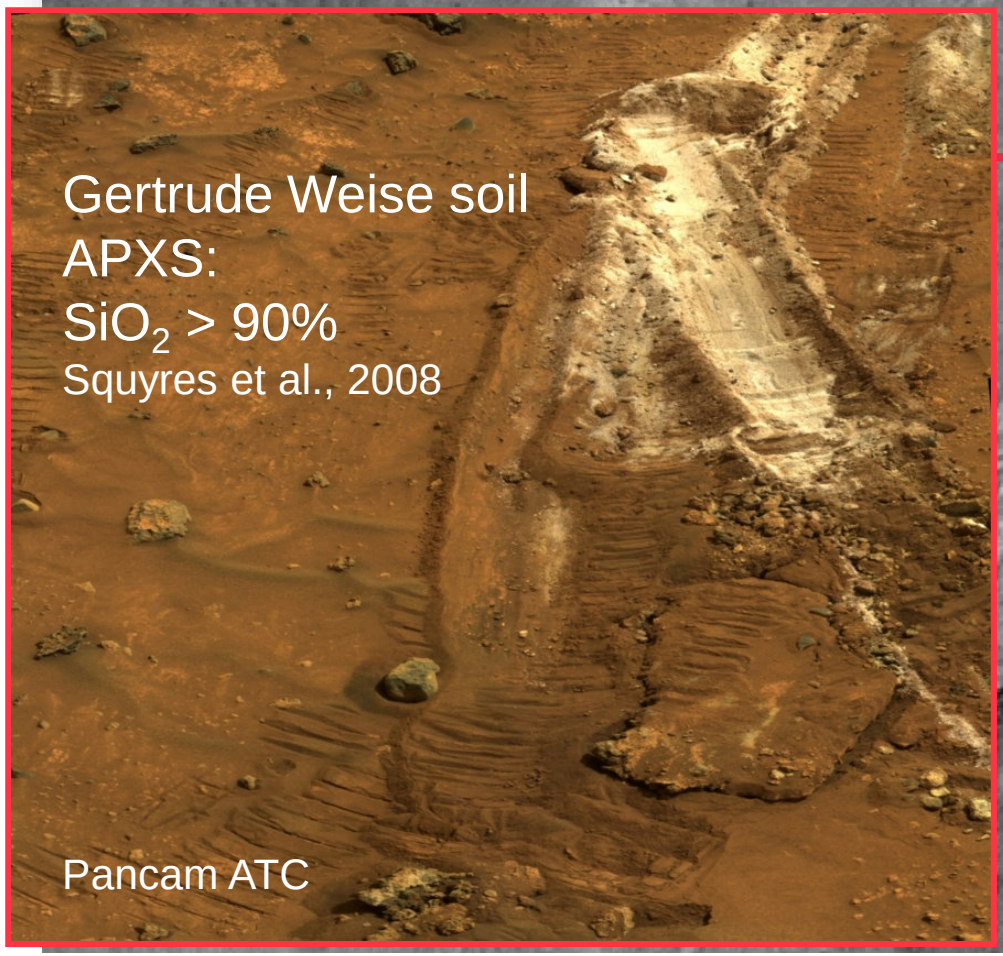
Key Water-related Discoveries in Gusev

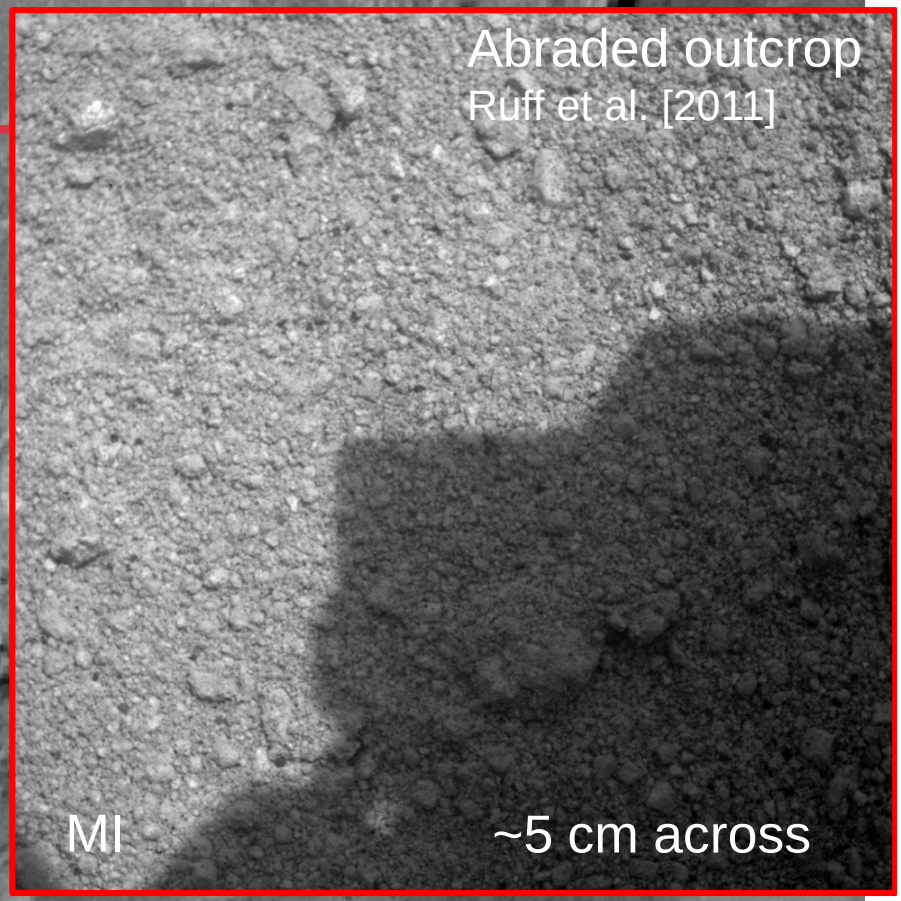


Silica Outcrops at Home Plate

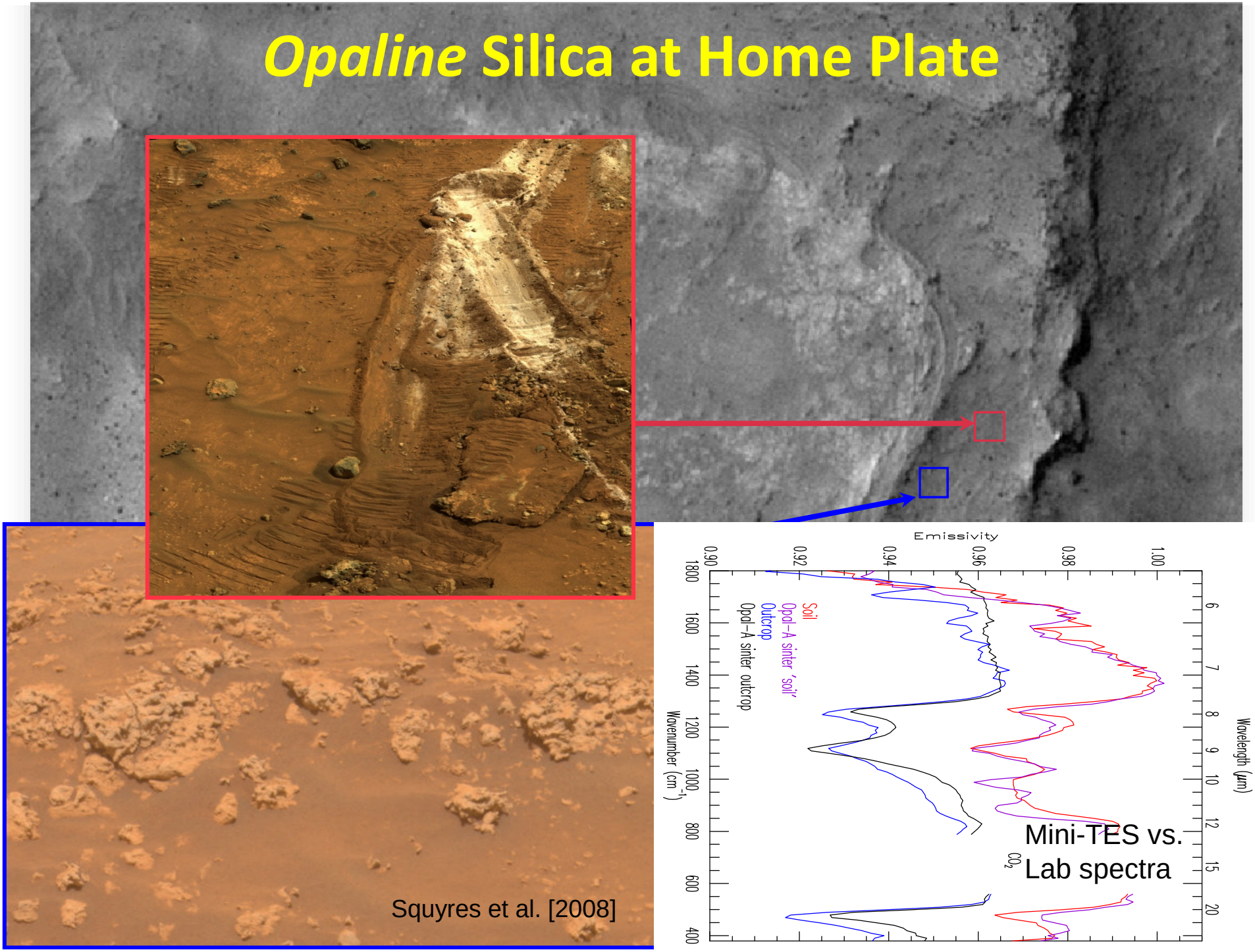


Silica Soil at Home Plate





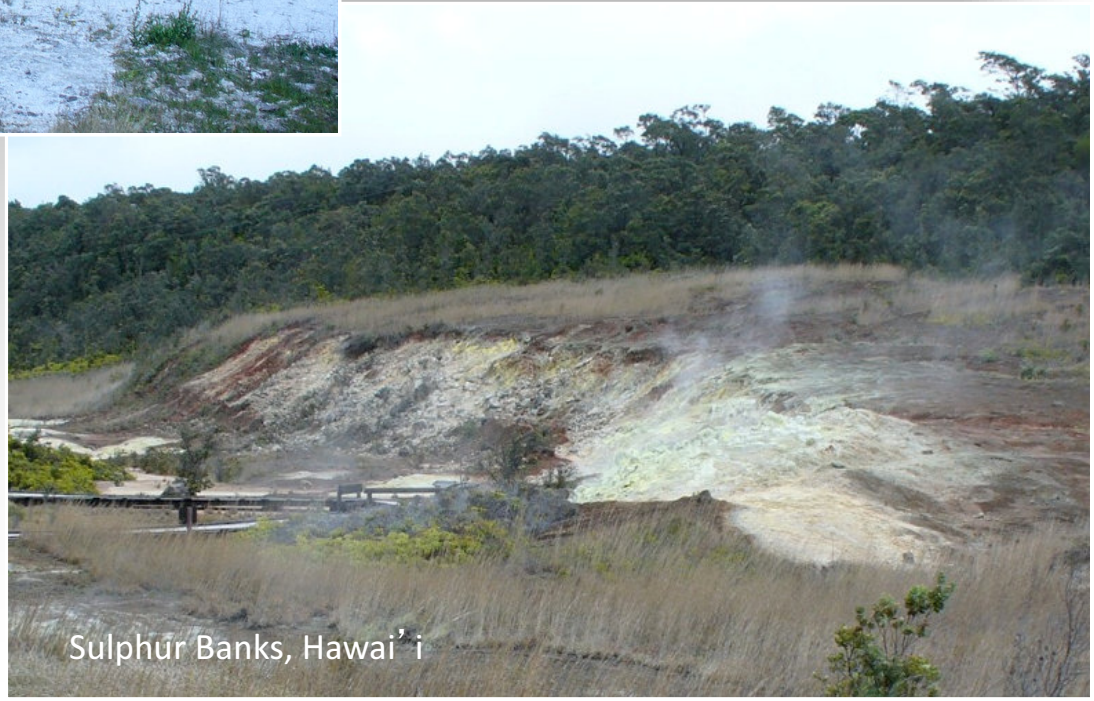
Opaline Silica at Home Plate

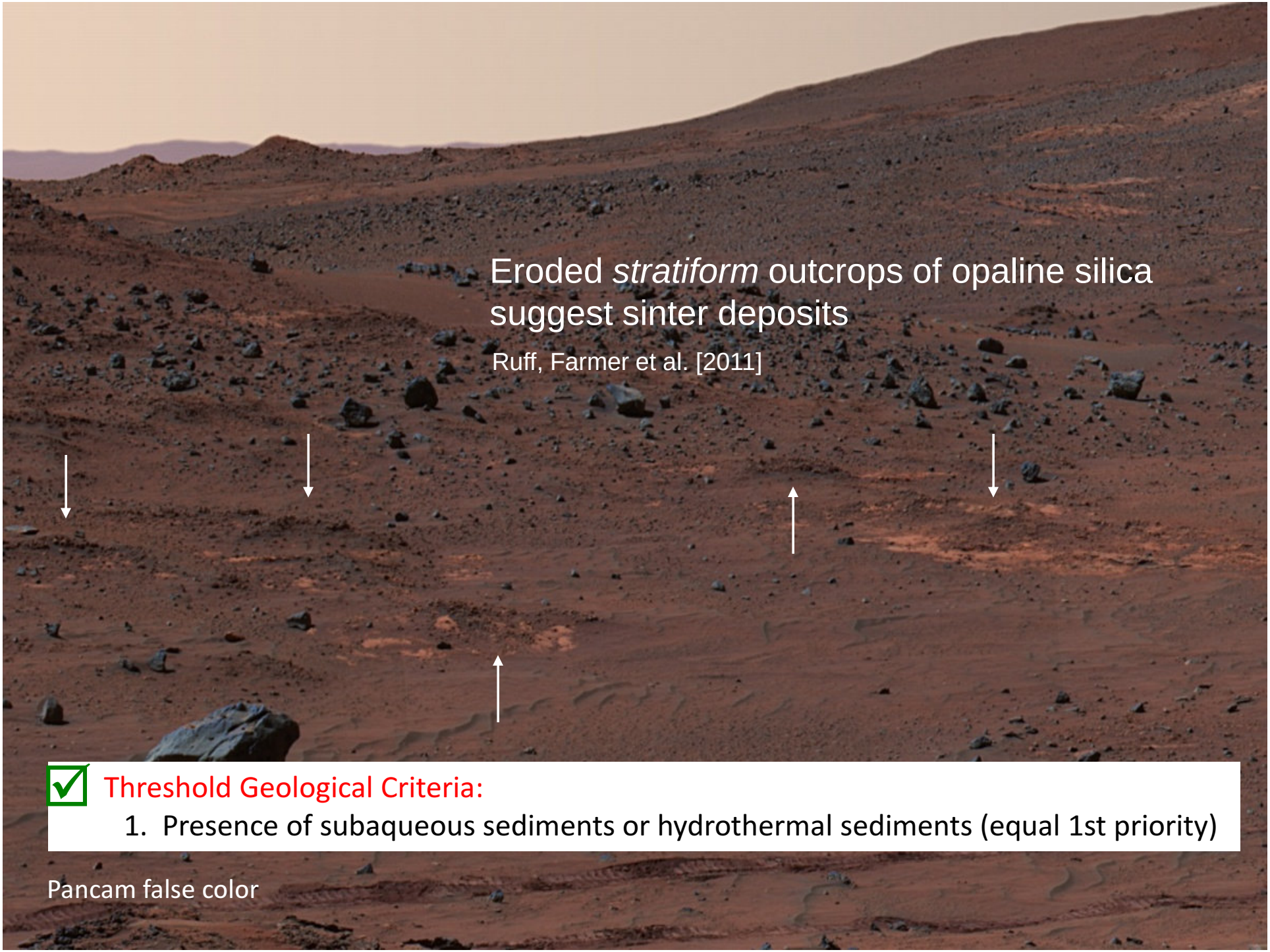


Candidate Origins

Hot spring sinter: opaline silica outcrops are primary precipitates from silica-rich liquid producing *stratiform* deposits

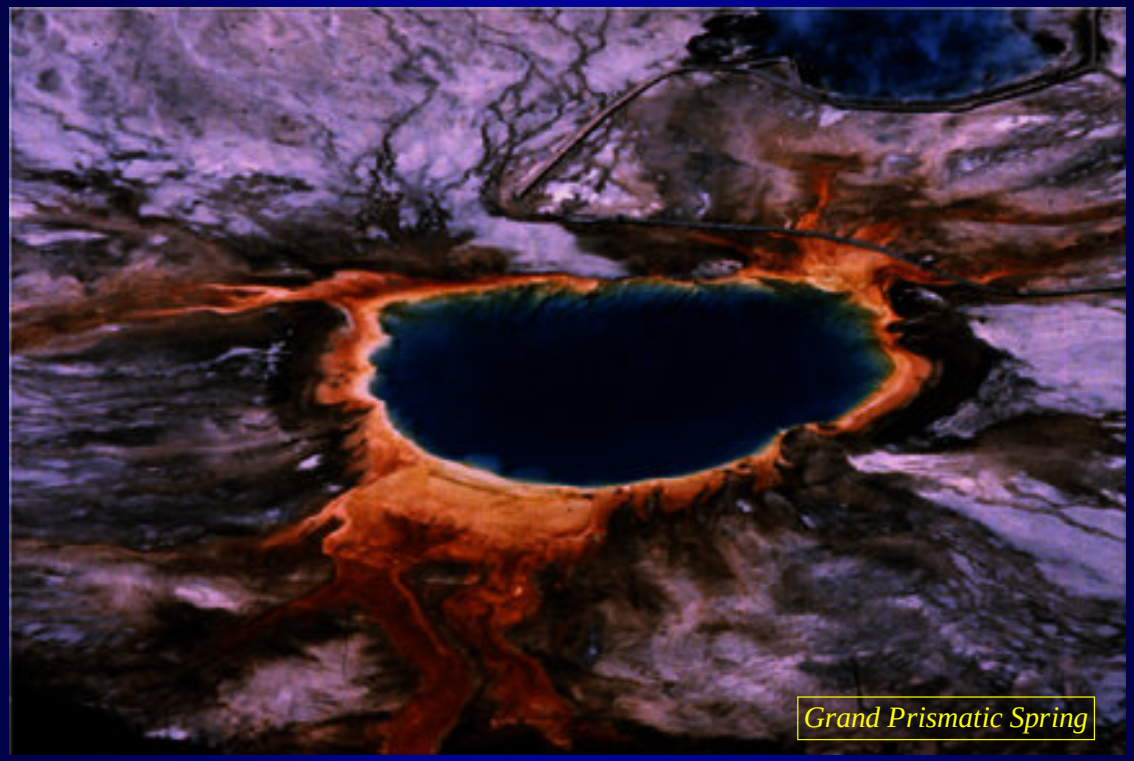
Fumarolic silica residue: opaline silica outcrops are country rock altered by acid-sulfate steam condensates producing *non-stratal* alteration




Eroded *stratiform* outcrops of opaline silica suggest sinter deposits
Ruff, Farmer et al. [2011]
Threshold Geological Criteria:
1. Presence of subaqueous sediments or hydrothermal sediments (equal 1st priority)
Pancam false color

Hydrothermal Systems and Life

Hydrothermal Springs: Natural Laboratories for studying microbial fossilization.

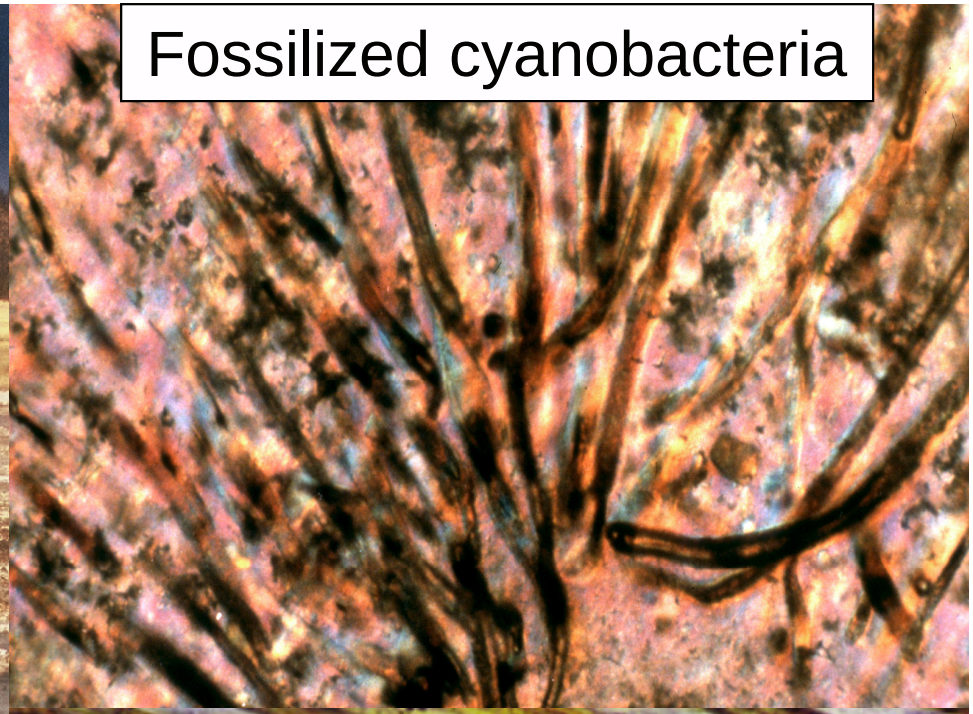


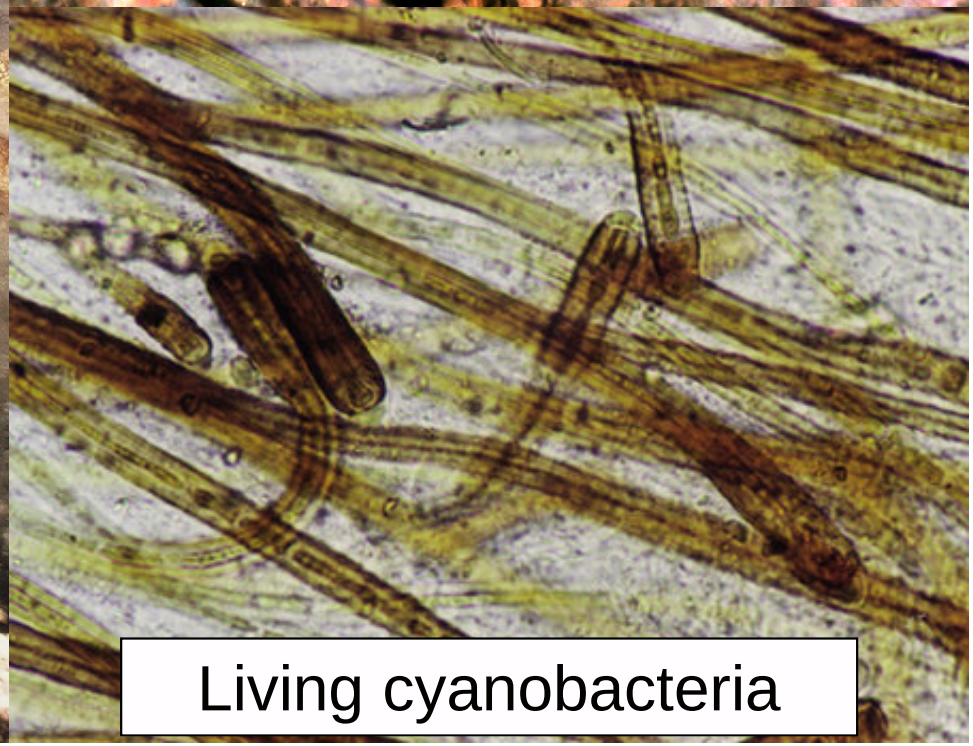
Grand Prismatic Spring

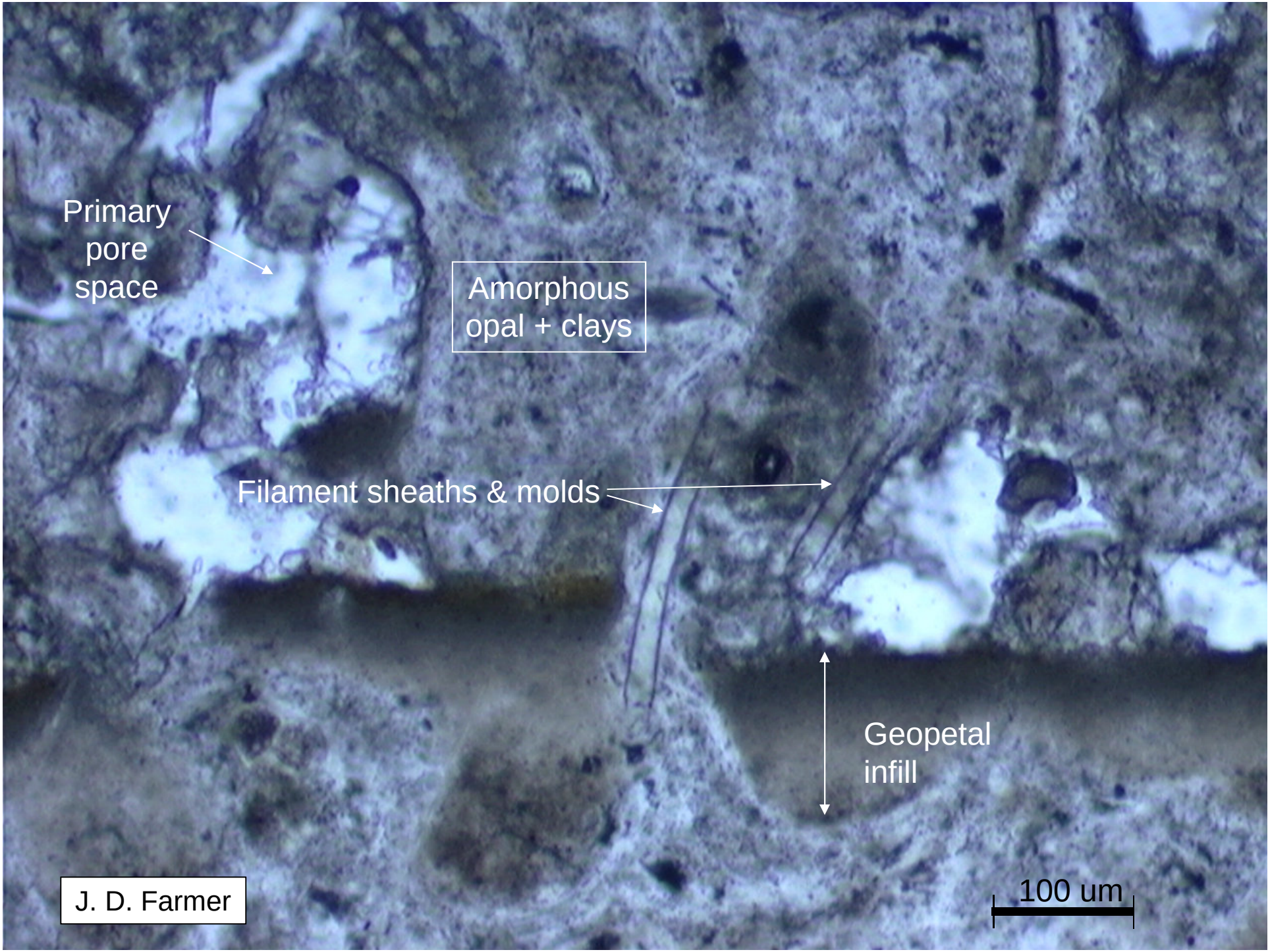
- Hydrothermal environments exhibit high rates of biological productivity that often coexist with pervasive mineral precipitation.
- Such conditions favor microbial fossilization.
- The deposits of hydrothermal systems preserve a wide variety of fossil biosignatures.

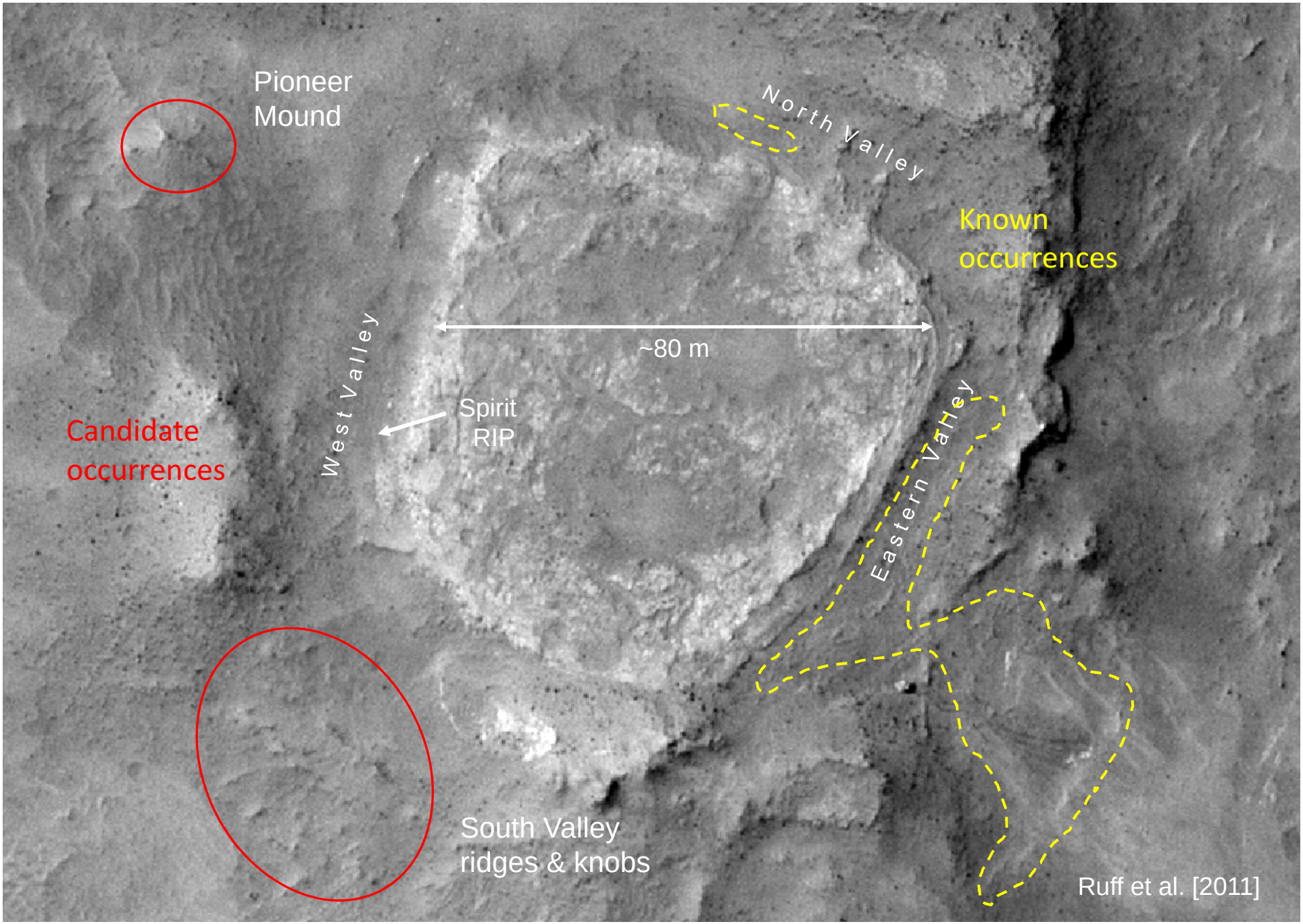
J. D. Farmer

Life at High Temperatures
Borcher's Spring, Yellowstone

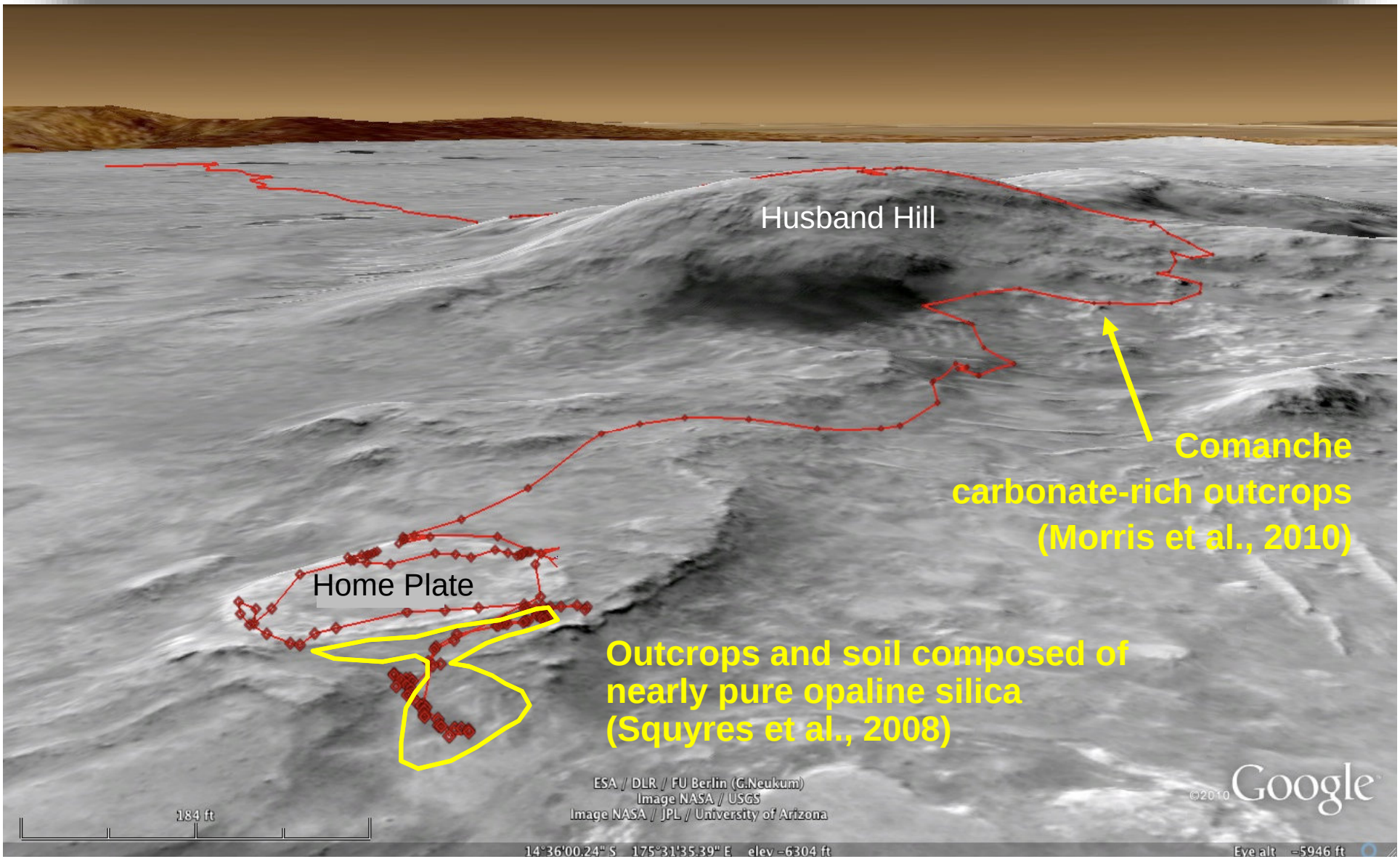

Fossilized cyanobacteria


Living cyanobacteria


Primary pore space
Amorphous opal + clays
Filament sheaths & molds
Geopetal infill
J. D. Farmer
100 um


Pioneer
Mound
North Valley
Known
occurrences
~80 m
West Valley
Spirit
RIP
Candidate
occurrences
Eastern Valley
South Valley
ridges & knobs
Ruff et al. [2011]

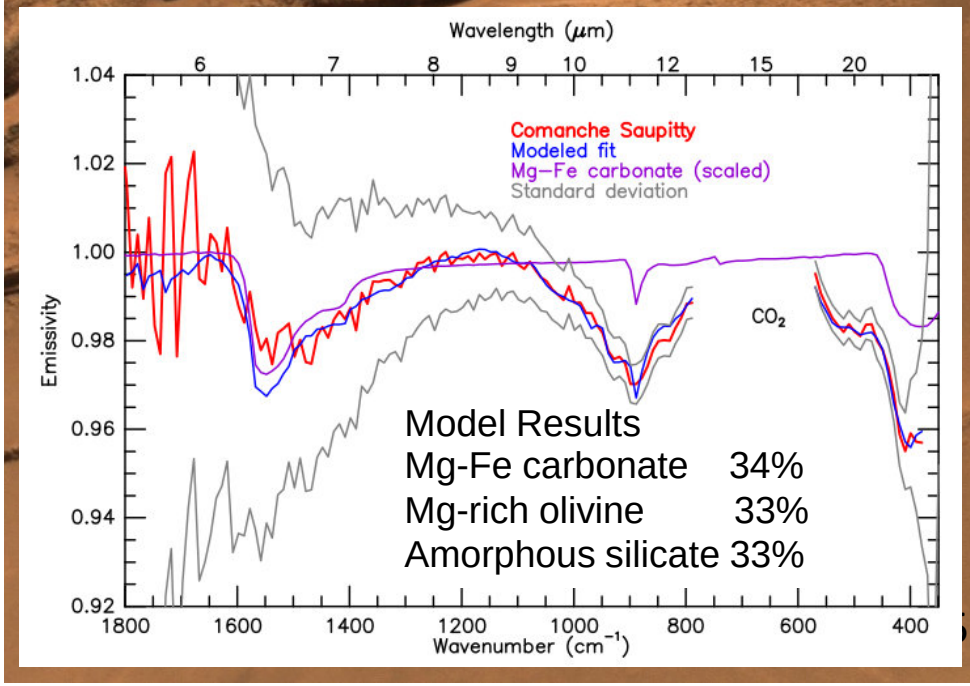
Key Water-related Discoveries in Gusev



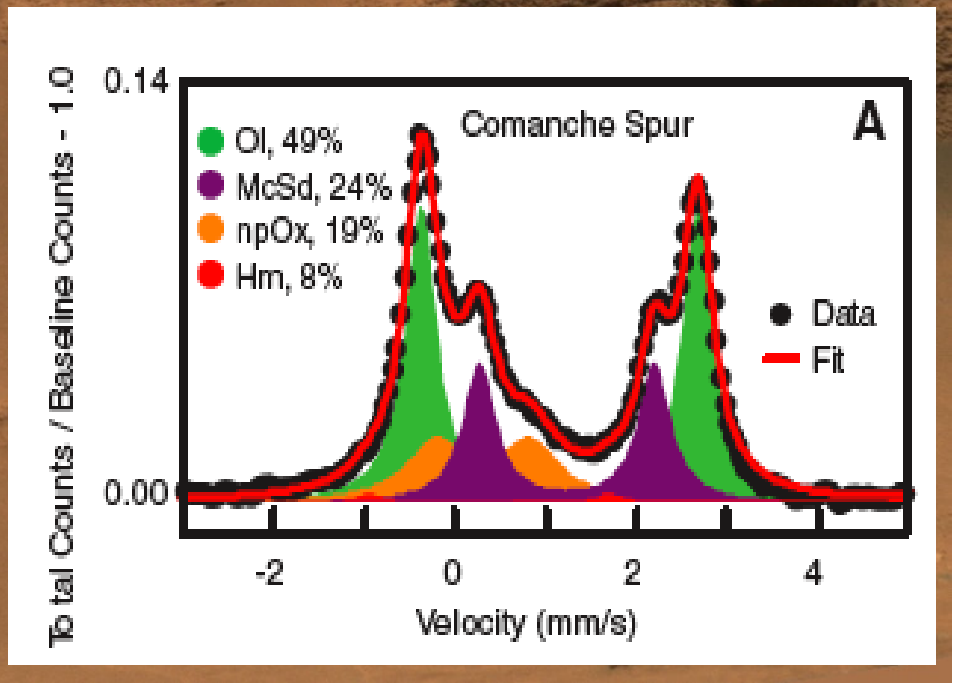
Comanche Outcrops

- Comanche is 16-34 wt% Mg-Fe carbonate, ~40 wt% Mg-rich olivine (Fo_{72}), and the remainder as an amorphous silicate (Morris et al., 2010)

Mini-TES (bulk mineralogy)



Mössbauer (Fe mineralogy)



Comanche Outcrops

APXS (elemental chemistry)

Table 1. Chemical composition of Comanche Spur Palomino whole rock, with light elements as CO_2 and calculated components olivine, carbonate, and residue.

	Whole rock* (wt %)	Component†		
		Olivine‡ (wt %)	Carbonate§ (wt %)	Residue (wt %)
SiO_2	36.1 ± 0.4	37.8	–	62.1
TiO_2	0.22 ± 0.06	–	–	0.66
Al_2O_3	2.56 ± 0.08	–	–	7.68
Cr_2O_3	0.63 ± 0.03	–	–	1.88
Fe_2O_3	4.84 ± 0.03	–	–	14.5
FeO	15.4 ± 0.1	25.6	19.2	–
MnO	0.37 ± 0.01	–	1.43	–
MgO	21.6 ± 0.2	36.4	26.2	–
CaO	1.69 ± 0.02	–	6.55	–
Na_2O	1.0 ± 0.2	–	–	3.0
K_2O	0.03 ± 0.05	–	–	0.1
P_2O_5	0.39 ± 0.07	–	–	1.16
SO_3	2.36 ± 0.04	–	–	7.08
Cl	0.53 ± 0.01	–	–	1.61
CO_2	12 ± 5	–	46.4	–
Chemistry total	99.8	99.8	99.8	99.8
Component total	99.8	40.9	25.7	33.2

*APXS data from (*21*) recalculated to 12 wt % CO_2. †All Ca and all Mn calculated as carbonate. ‡Equivalent to $(Mg_{0.72}Fe_{0.28})SiO_4$. §Equivalent to $(Mg_{0.62}Fe_{0.25}Ca_{0.11}Mn_{0.02})CO_3$.

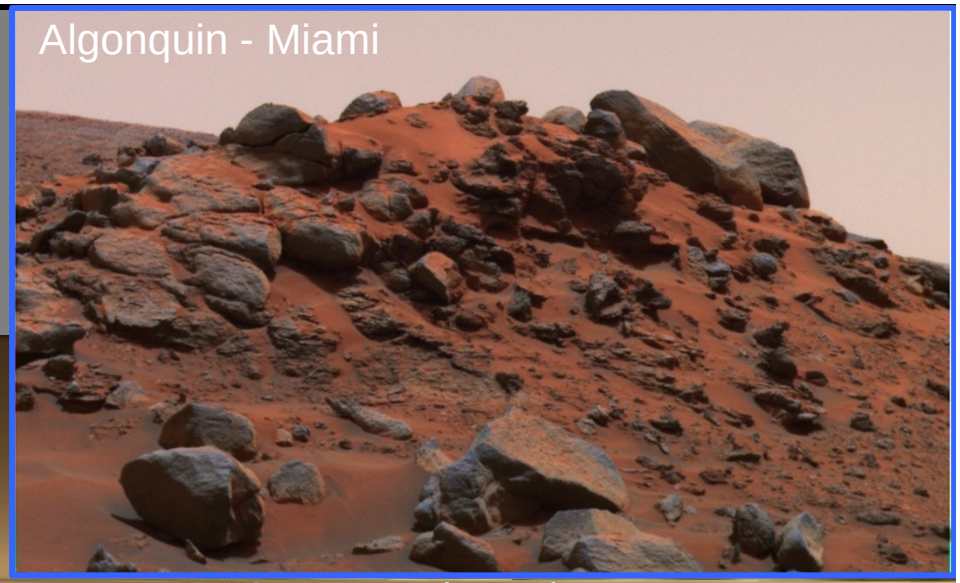
Morris et al. (2010)

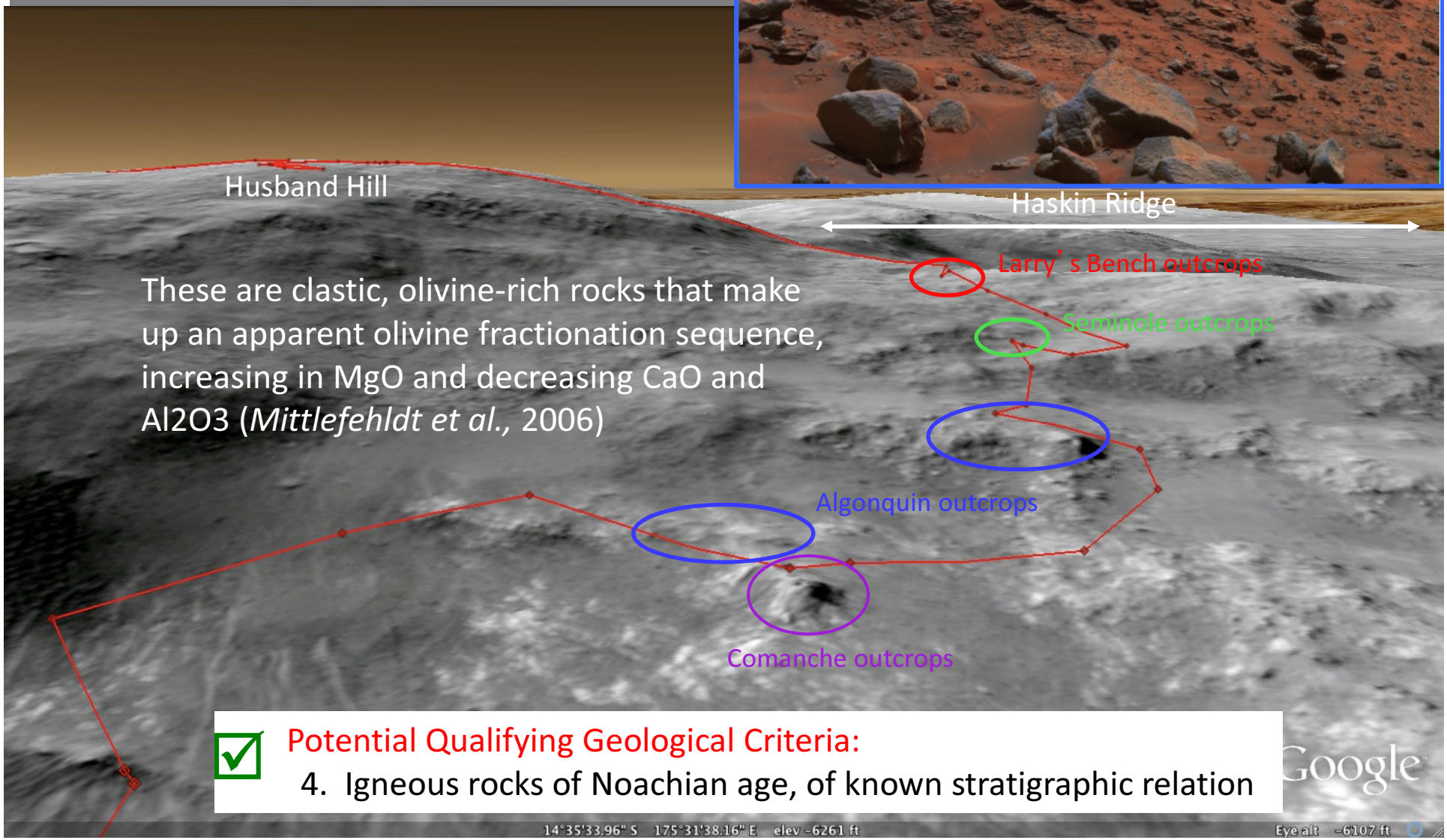
Comanche Outcrops

- Hypothesis 1: Carbonate enrichment inferred to result from volcanic hydrothermal activity via dissolution of pre-existing carbonate rocks followed by transport and precipitation into the Comanche outcrops (Morris et al., [2010])
- Hypothesis 2: Carbonate enrichment resulted from water-limited leaching of formerly widespread Algonquin-like tephra deposits by surface ephemeral waters, followed by transport and evaporative precipitation of the fluids into Comanche outcrops (Ruff, Niles, Alfano, and Clarke [2014], *Geology*)

Pancam approximate true color; scene width ~5 m

Relationship to Olivine-rich Algonquin Outcrops





These are clastic, olivine-rich rocks that make up an apparent olivine fractionation sequence, increasing in MgO and decreasing CaO and Al2O3 (*Mittlefehldt et al.*, 2006)

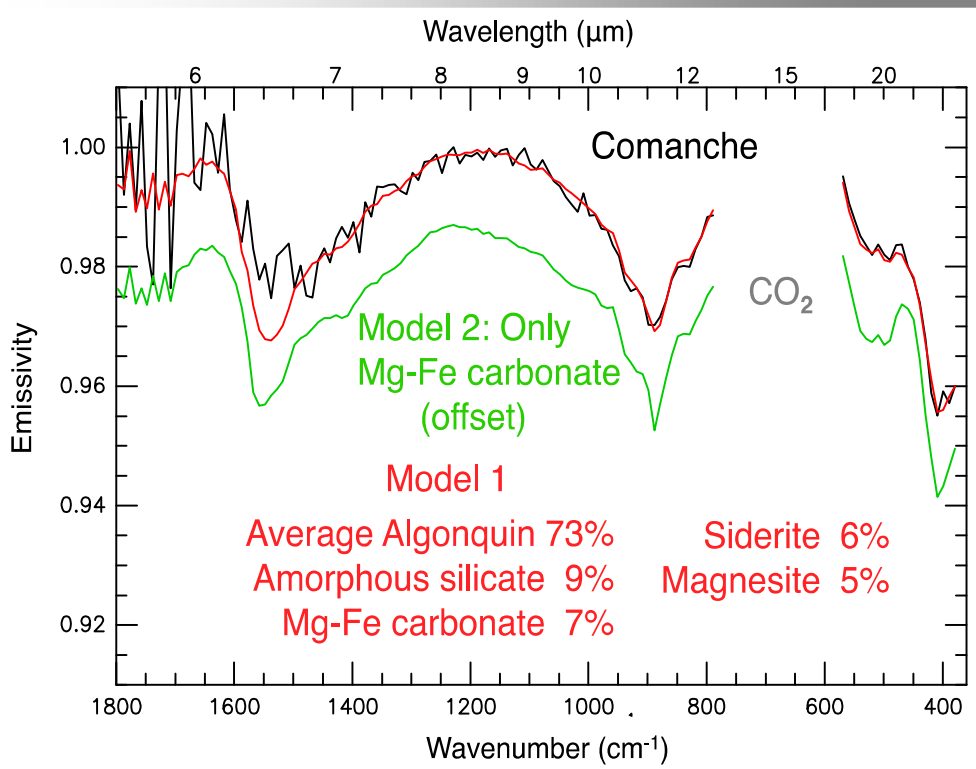
☑ Potential Qualifying Geological Criteria:

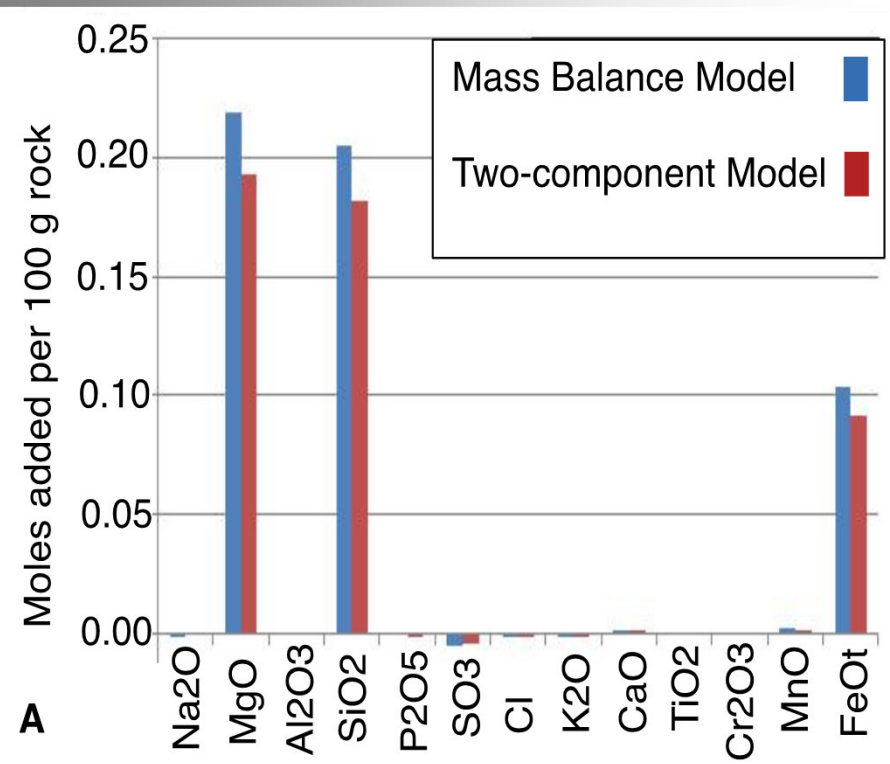
4. Igneous rocks of Noachian age, of known stratigraphic relation

Relationship to Olivine-rich Algonquin Outcrops (2)

- Spectral and chemical models indicate Comanche alteration was an addition to Algonquin-like host rock rather than depletion or isochemical replacement of primary phases

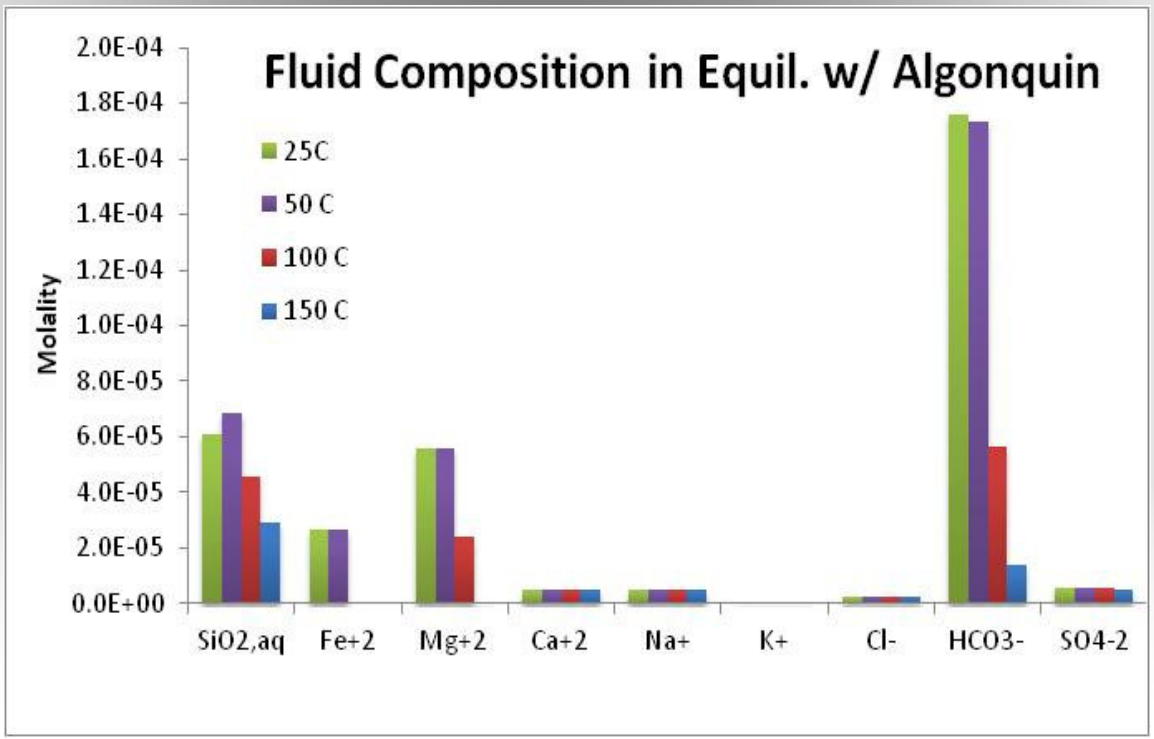
Ruff et al., 2014, *Geology*



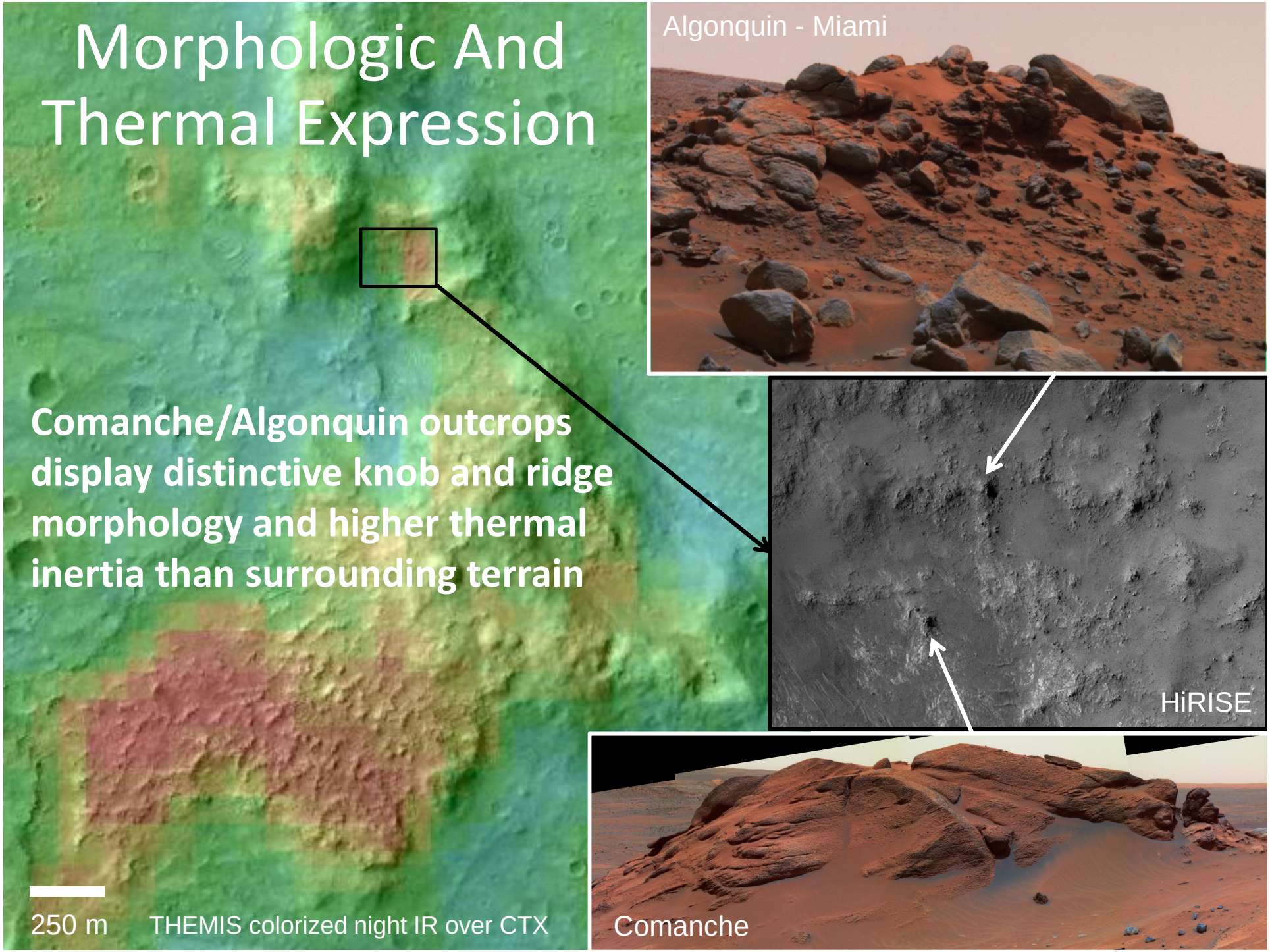


Relationship to Olivine-rich Algonquin Outcrops (3)

- A key result is that the chemistry of the added phases strongly resembles that of fluids in equilibrium with Algonquin-like rocks; could explain minimal Ca-carbonate
- Low temperature fluids are required to generate abundant Fe^{2+} under modeled conditions; weakens case for hydrothermal fluids



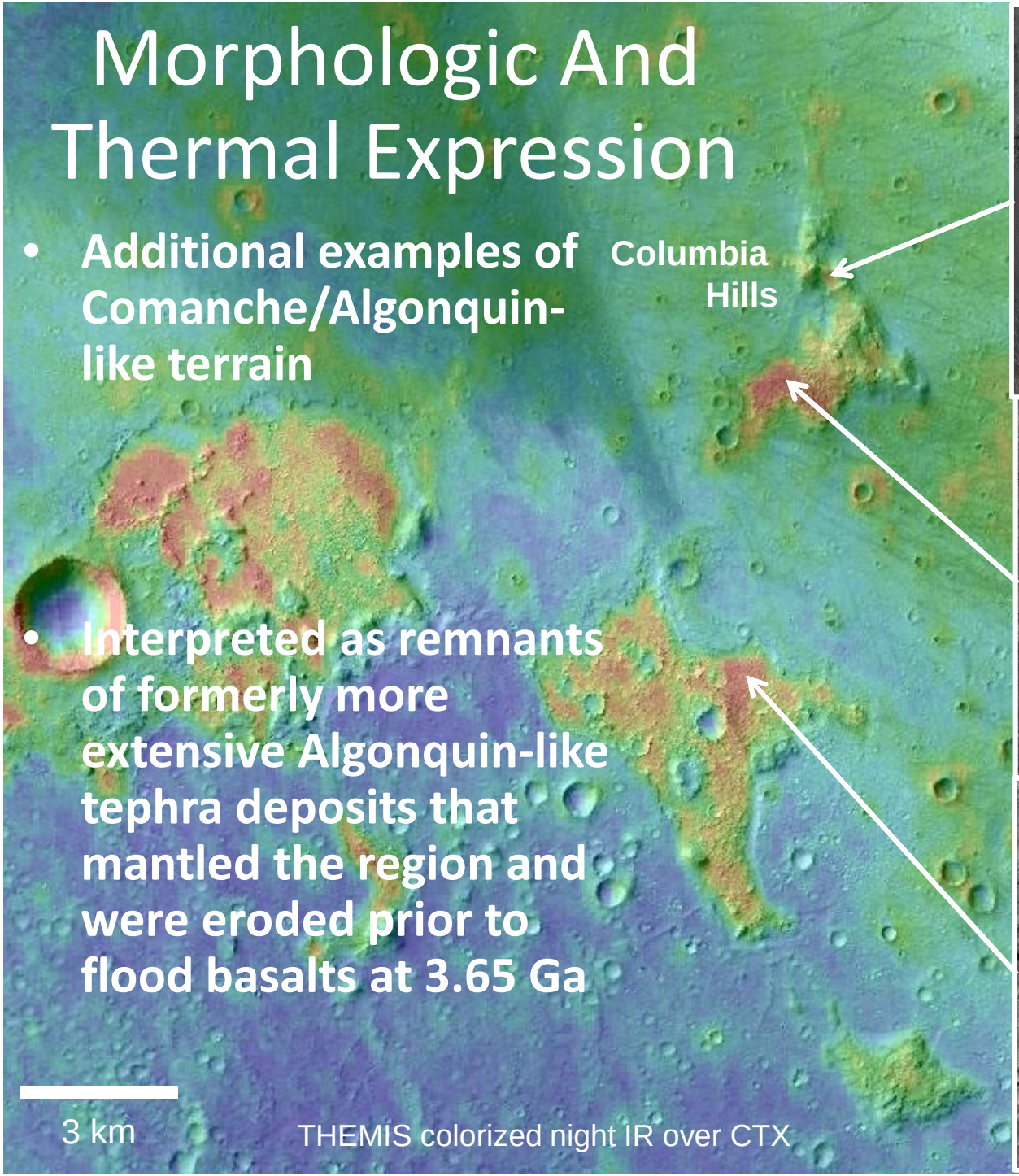
Morphologic And Thermal Expression



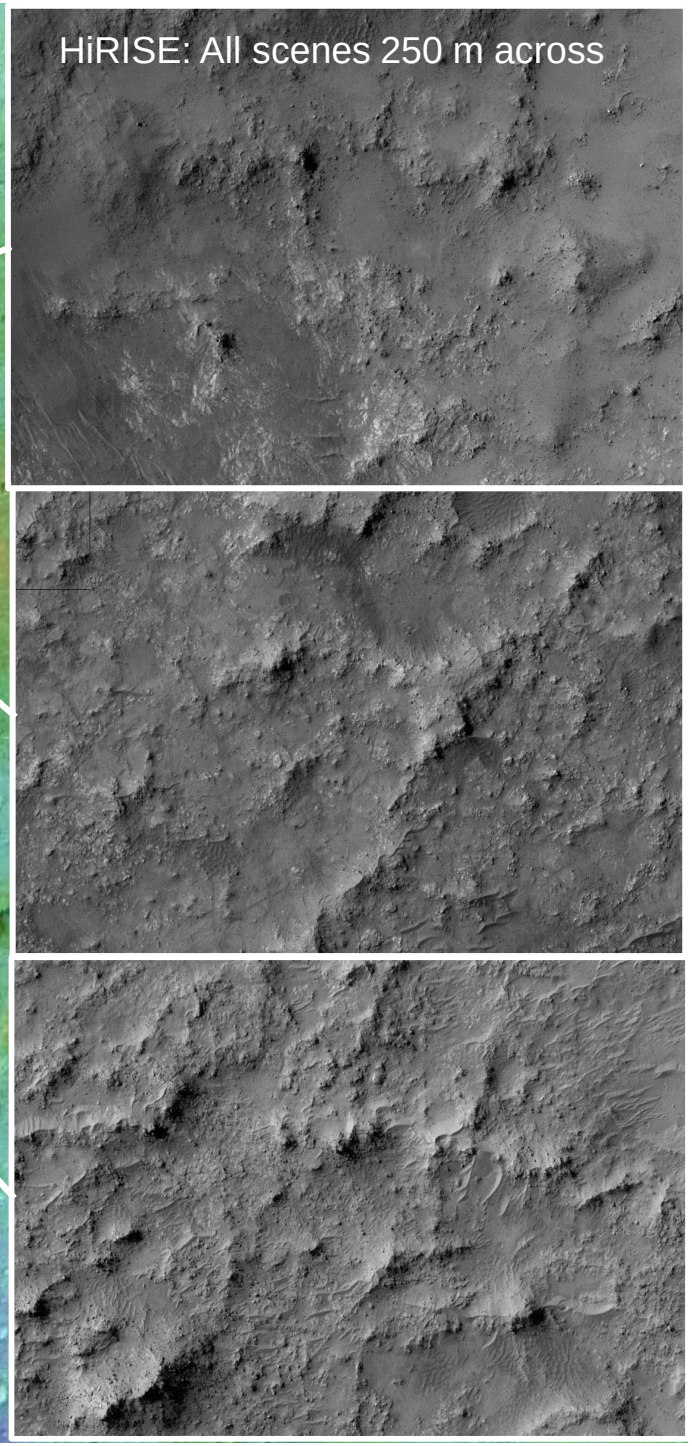
Comanche/Algonquin outcrops display distinctive knob and ridge morphology and higher thermal inertia than surrounding terrain

Morphologic And Thermal Expression

- **Additional examples of Comanche/Algonquin-like terrain**
- **Interpreted as remnants of formerly more extensive Algonquin-like tephra deposits that mantled the region and were eroded prior to flood basalts at 3.65 Ga**



THEMIS colorized night IR over CTX



Hypothesis: Given the likelihood of water flows from Ma'adim Vallis, we suggest a scenario in which flooding led to water-limited leaching of formerly widespread Algonquin-like tephra deposits followed by transport and evaporative precipitation of the fluids into the Comanche rock. (Ruff et al., 2014)

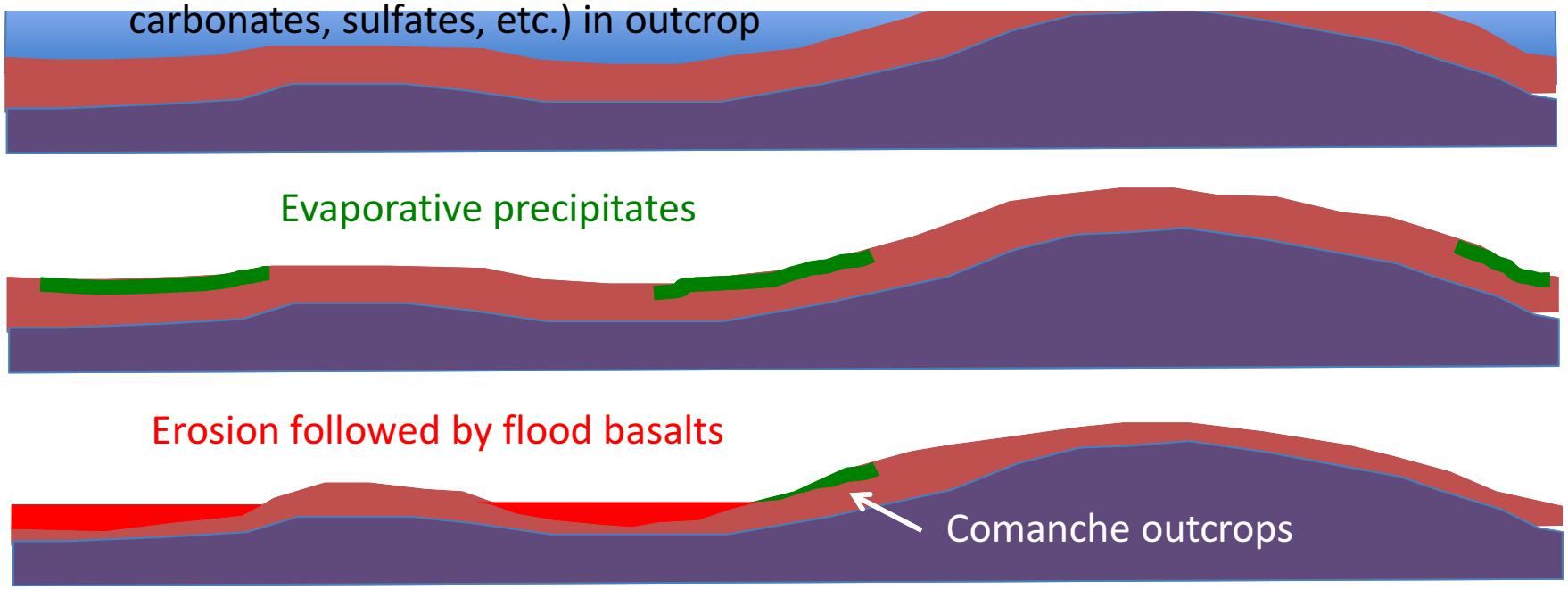
Threshold Geological Criteria:

☑ 1. Presence of subaqueous sediments or hydrothermal sediments (equal 1st priority),

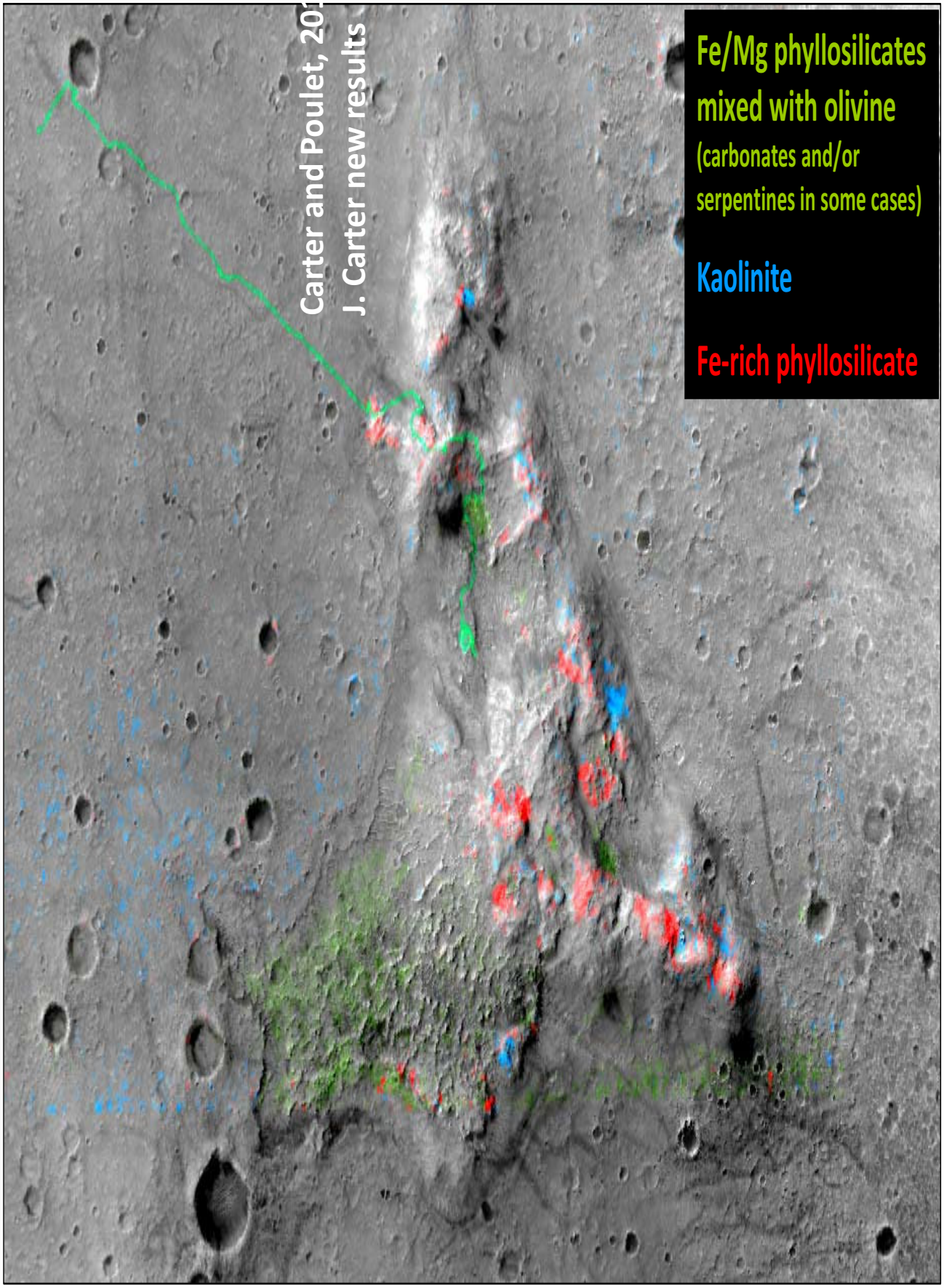
OR

☑ hydrothermally altered rocks or low-T fluid-altered rocks (equal 2nd priority)

2. Presence of minerals indicative of aqueous processes (e.g., phyllosilicates, carbonates, sulfates, etc.) in outcrop



Re-analysis of the Columbia Hills using CRISM : results



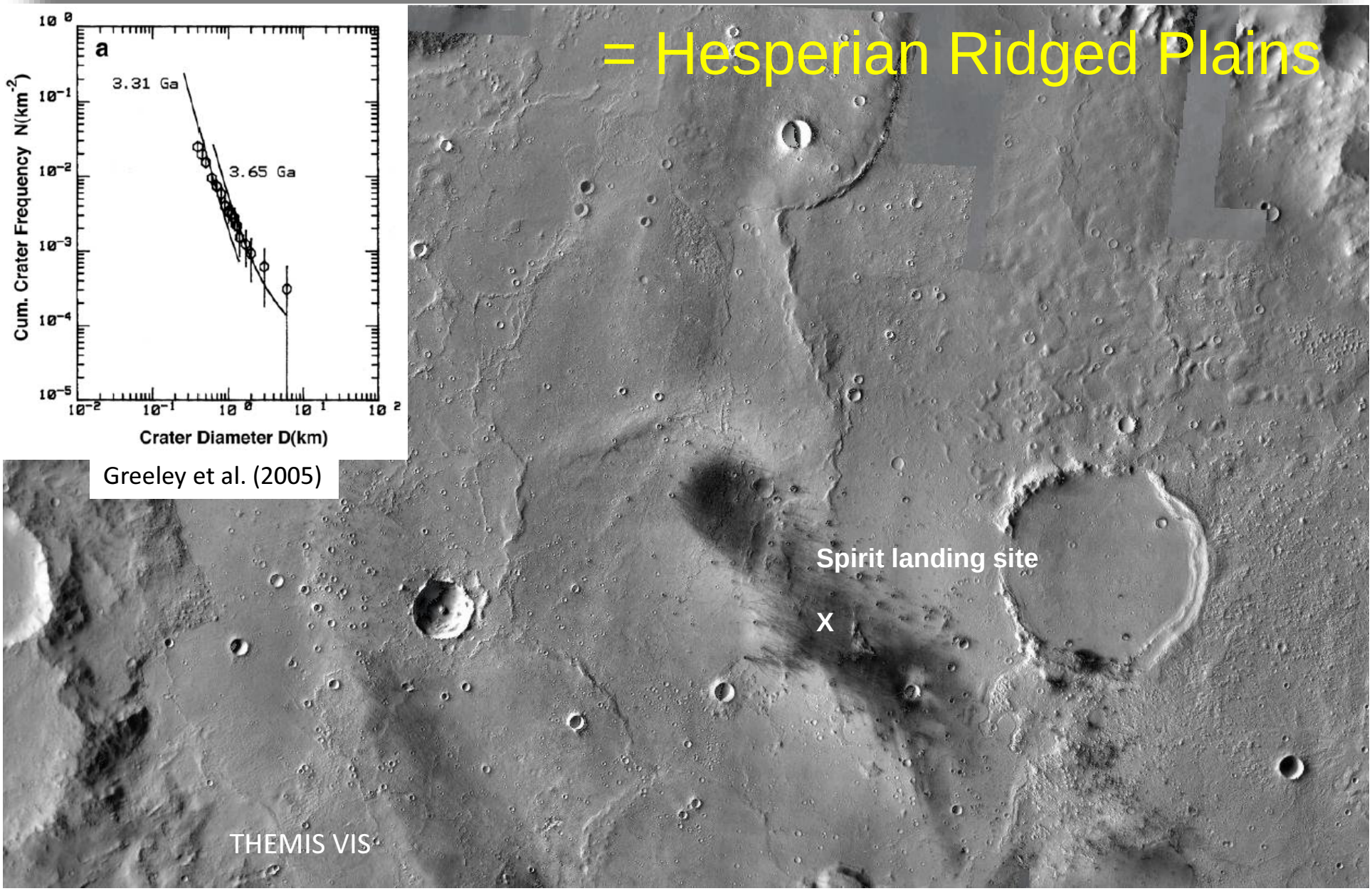
Re-analysis of the Columbia Hills using CRISM : results

Potential Qualifying Geological Criteria:

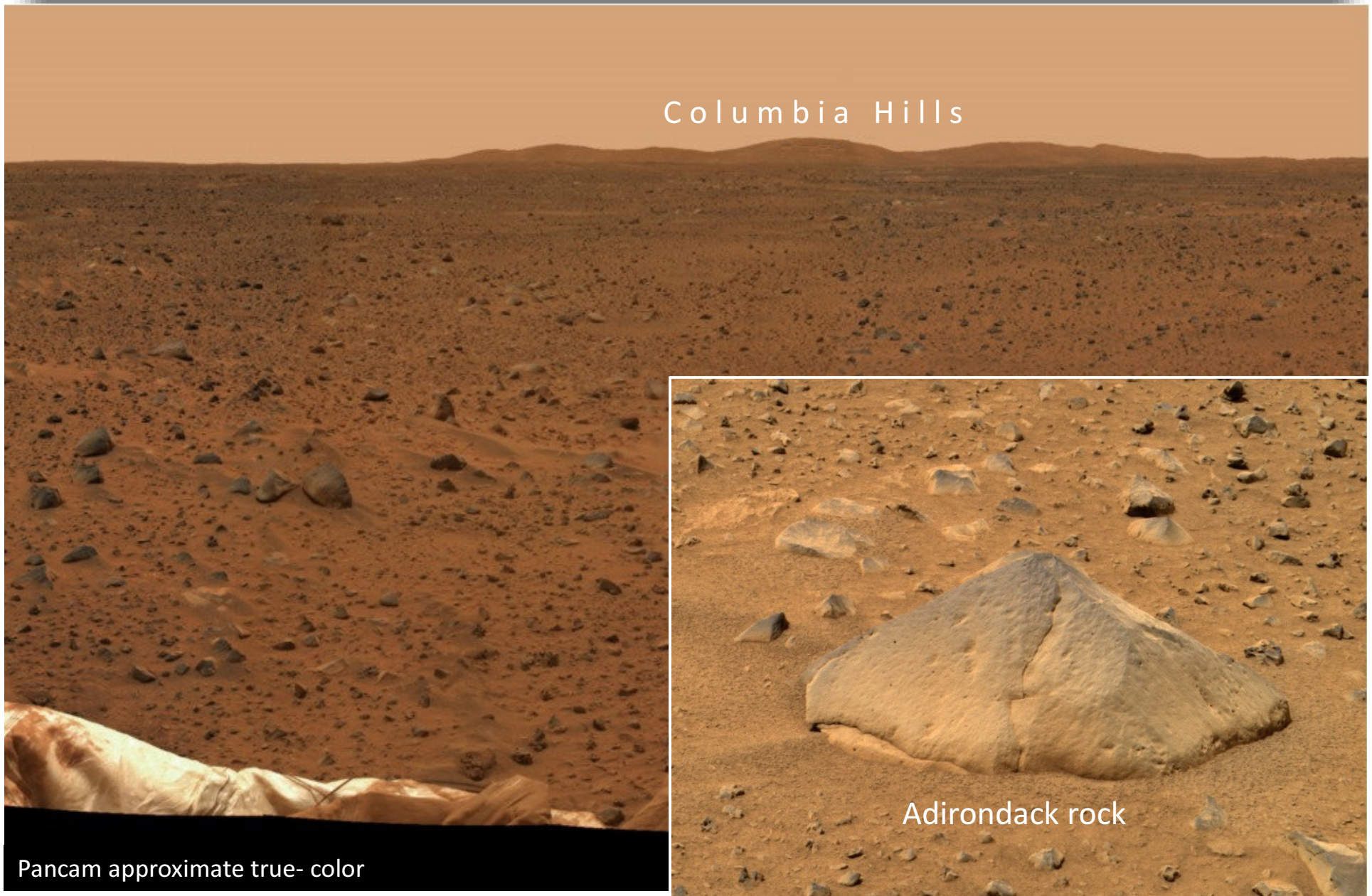
✓ 2. Assemblages of secondary minerals of any age.

3.65 Ga Wrinkle-ridged Plains of Gusev

Greeley et al. (2005)

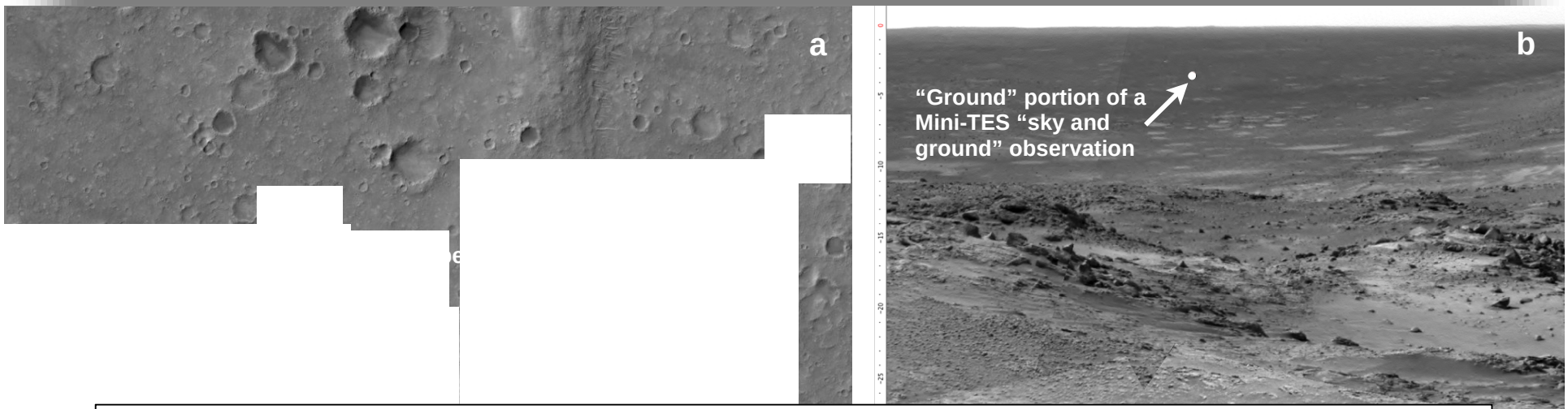


Hesperian Ridged Plains = Adirondack Class



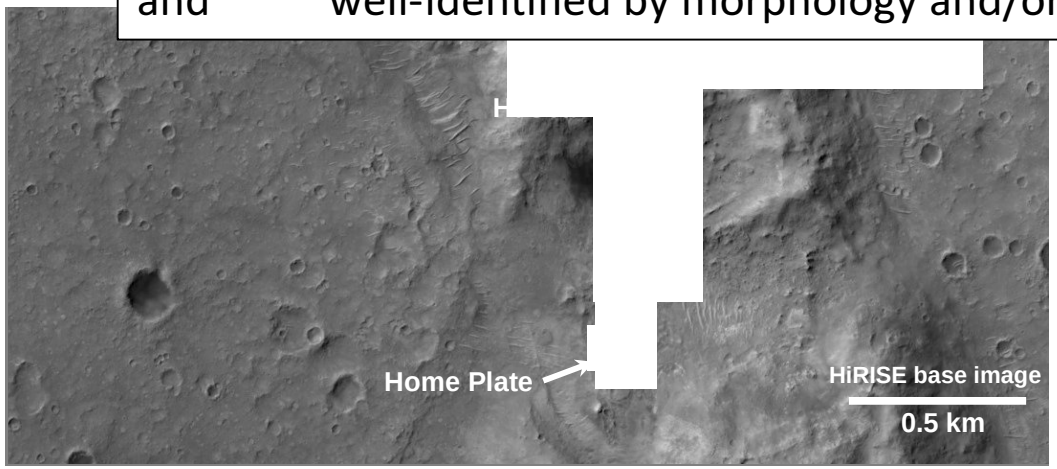
Pancam approximate true- color

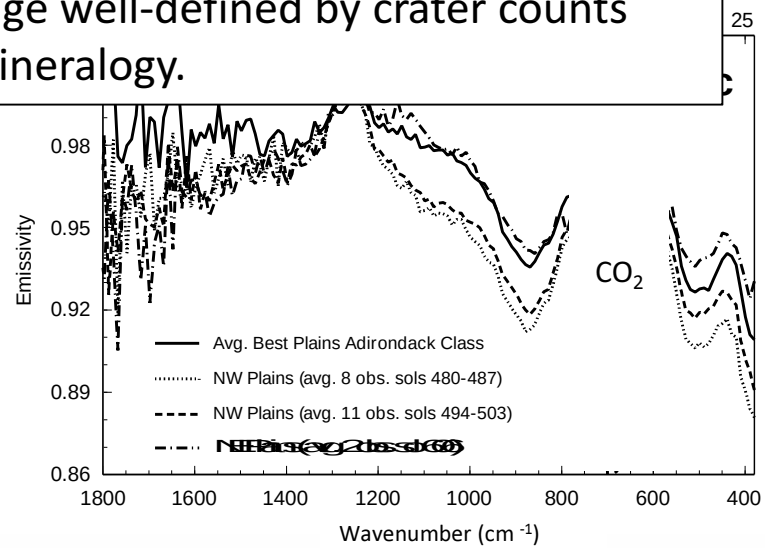
Wide Distribution of Adirondack Basalt on the Plains



Potential Qualifying Geological Criteria:

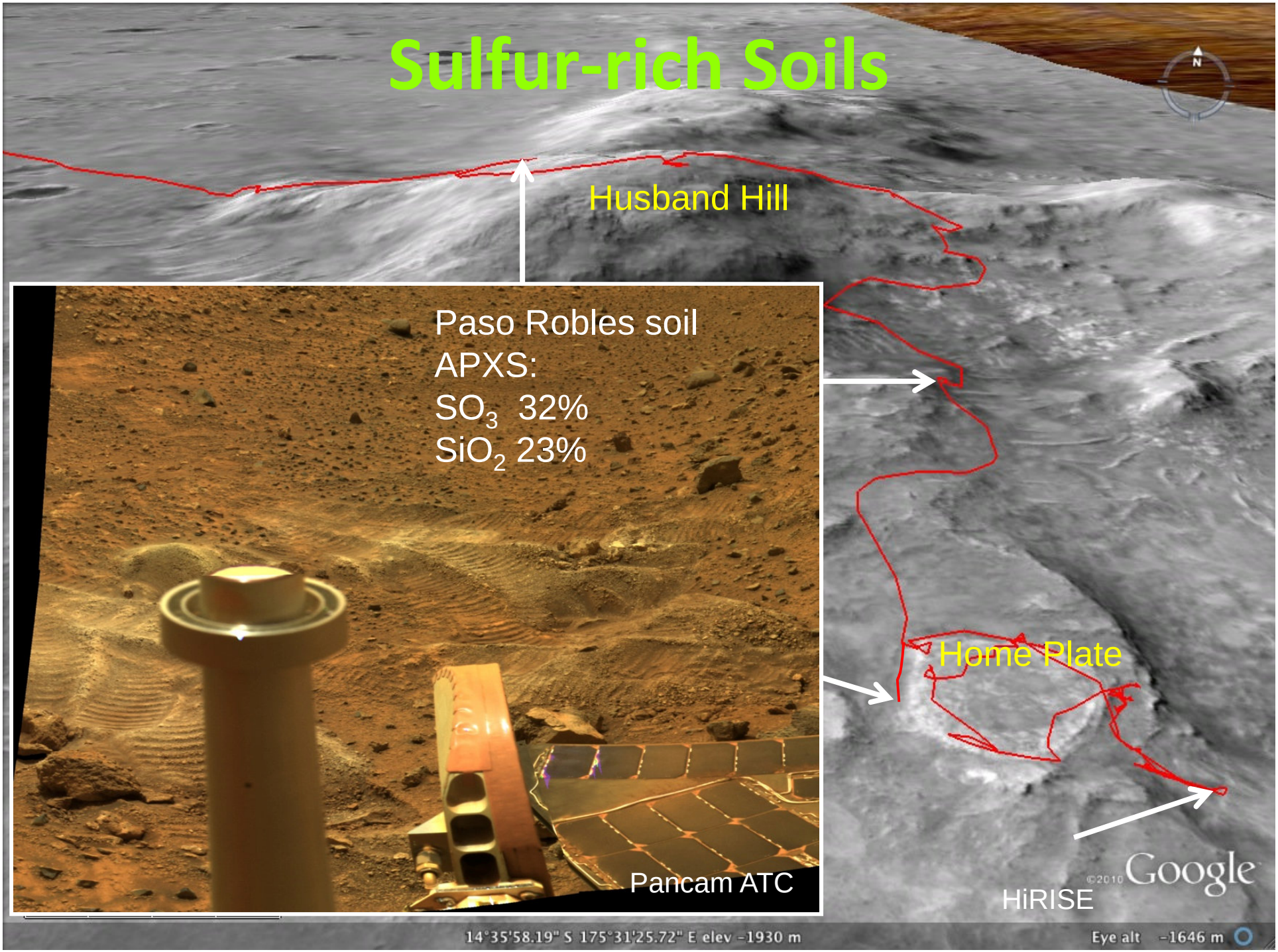
5. Volcanic unit of Hesperian or Amazonian age well-defined by crater counts and well-identified by morphology and/or mineralogy.



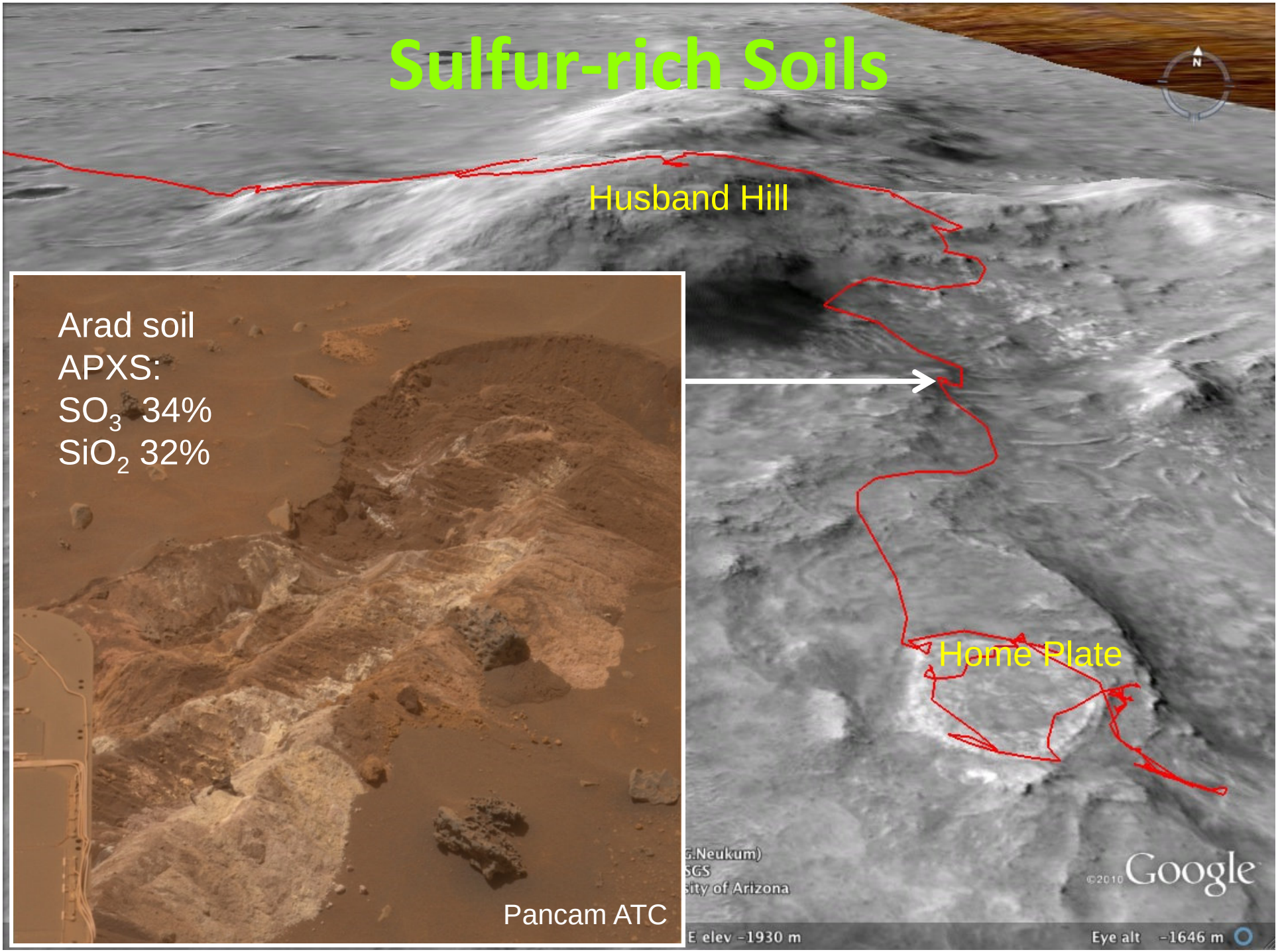


Hamilton and Ruff [2012]

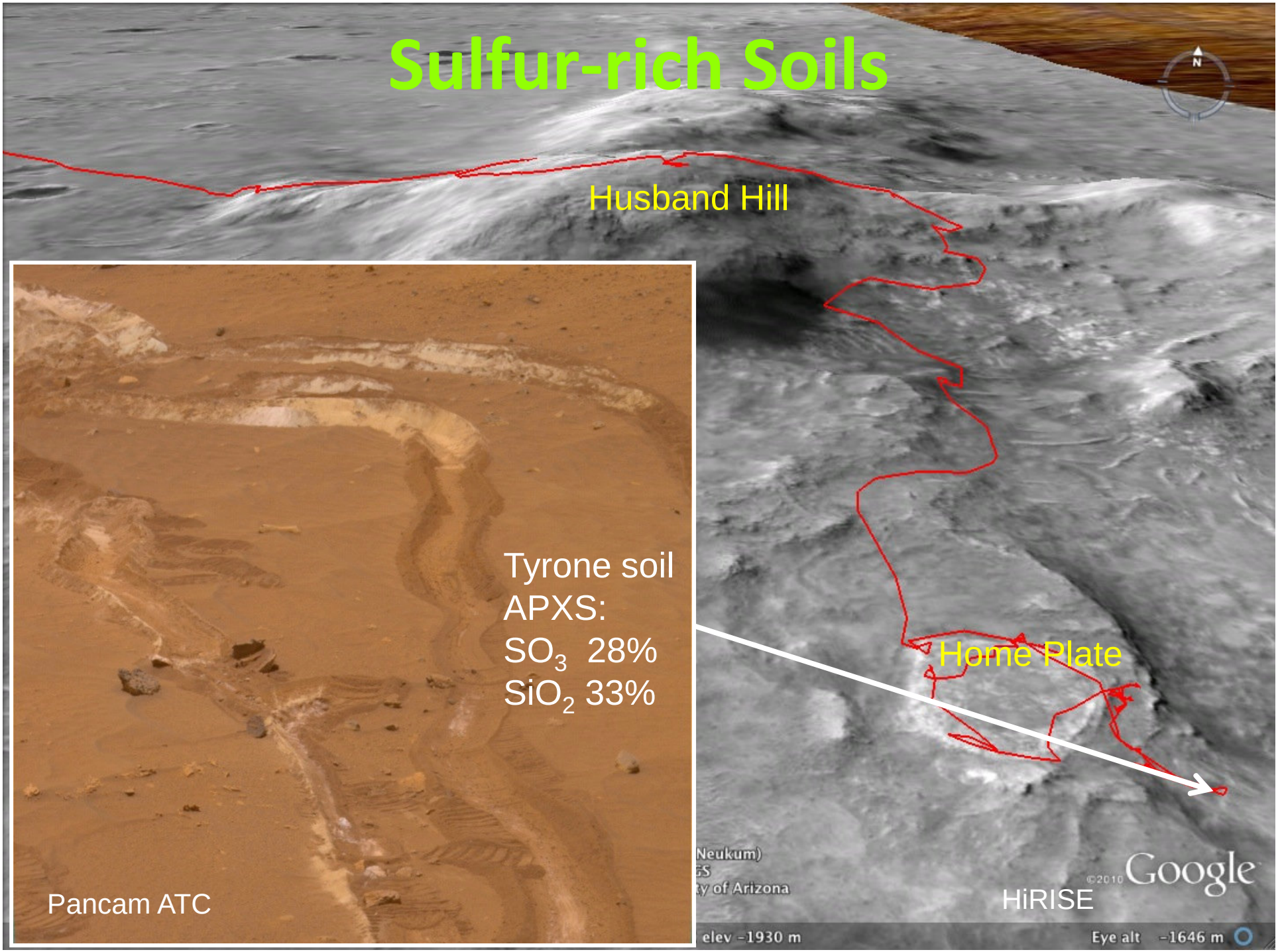
Sulfur-rich Soils



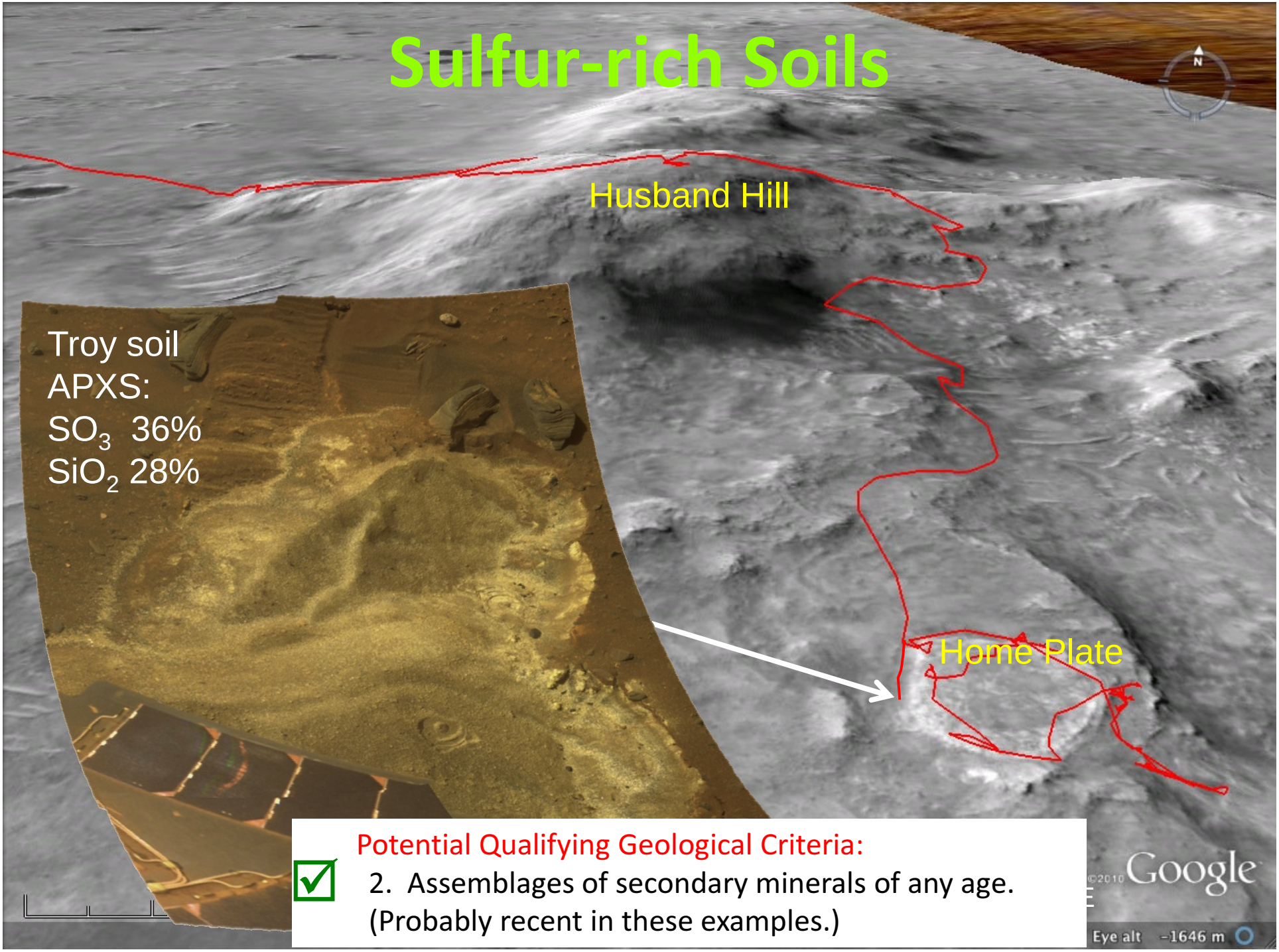
Sulfur-rich Soils



Sulfur-rich Soils



Sulfur-rich Soils



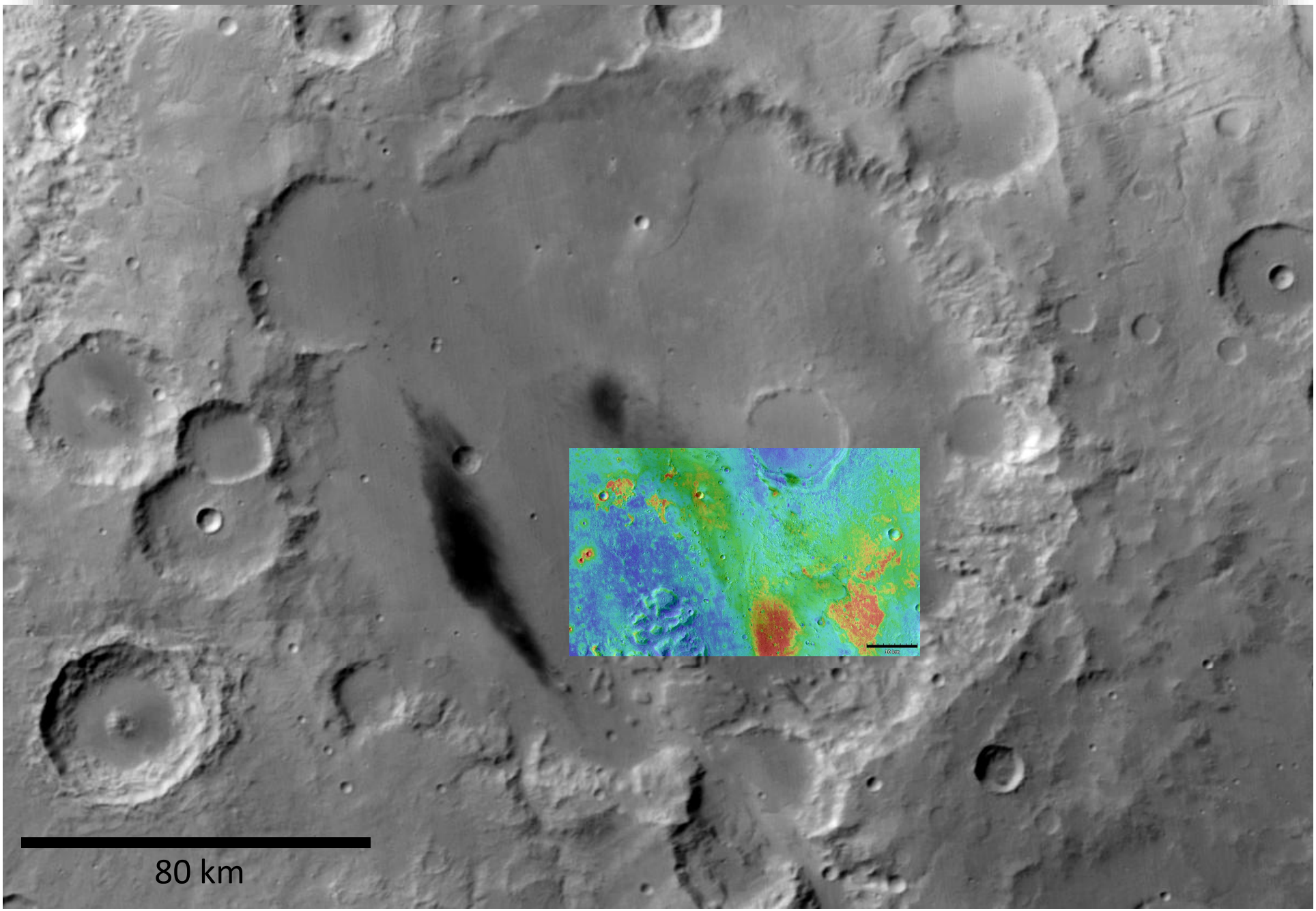
Potential Qualifying Geological Criteria:

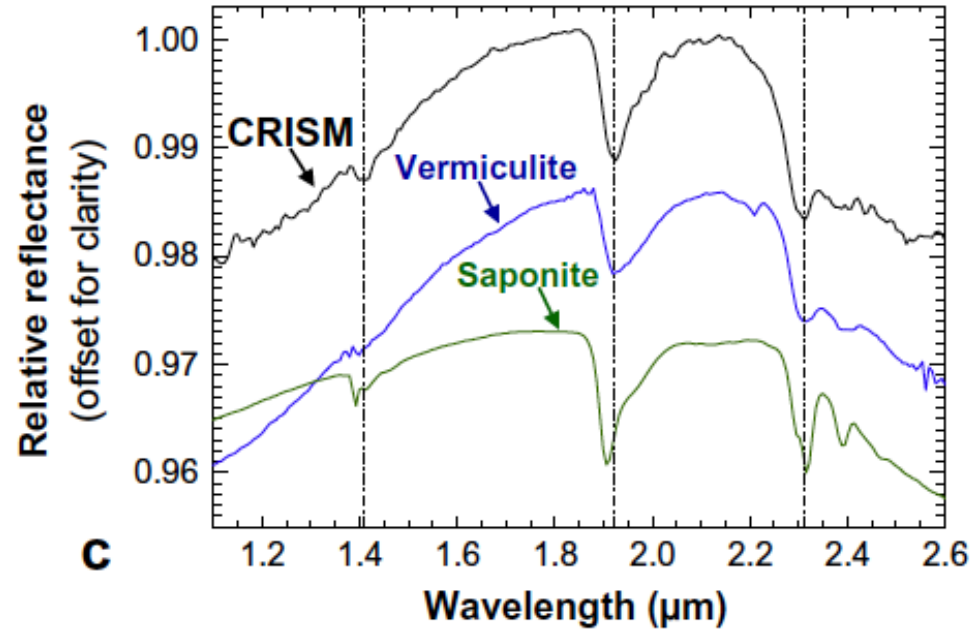
☑ 2. Assemblages of secondary minerals of any age. (Probably recent in these examples.)

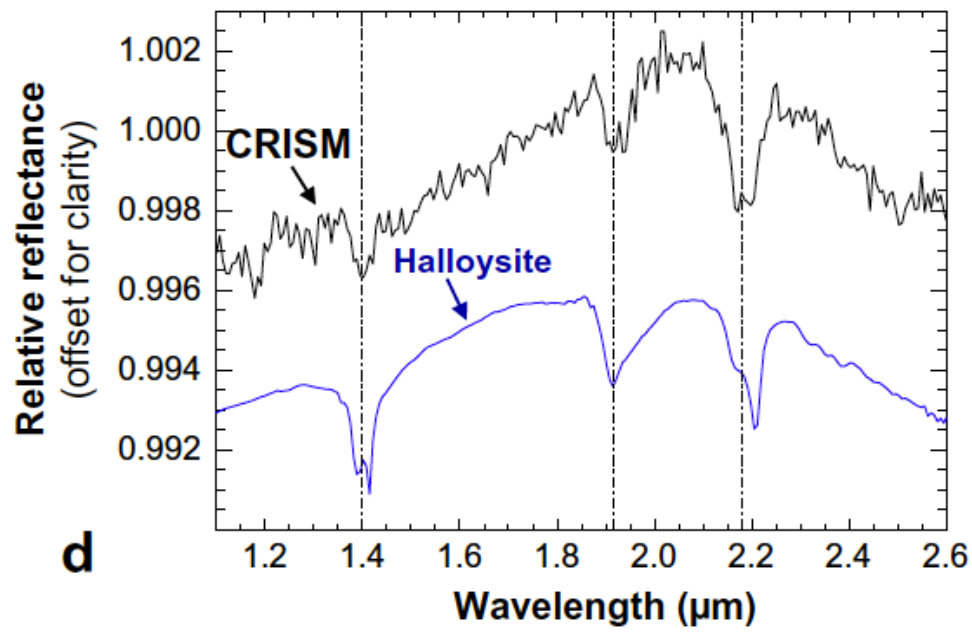
Conclusions

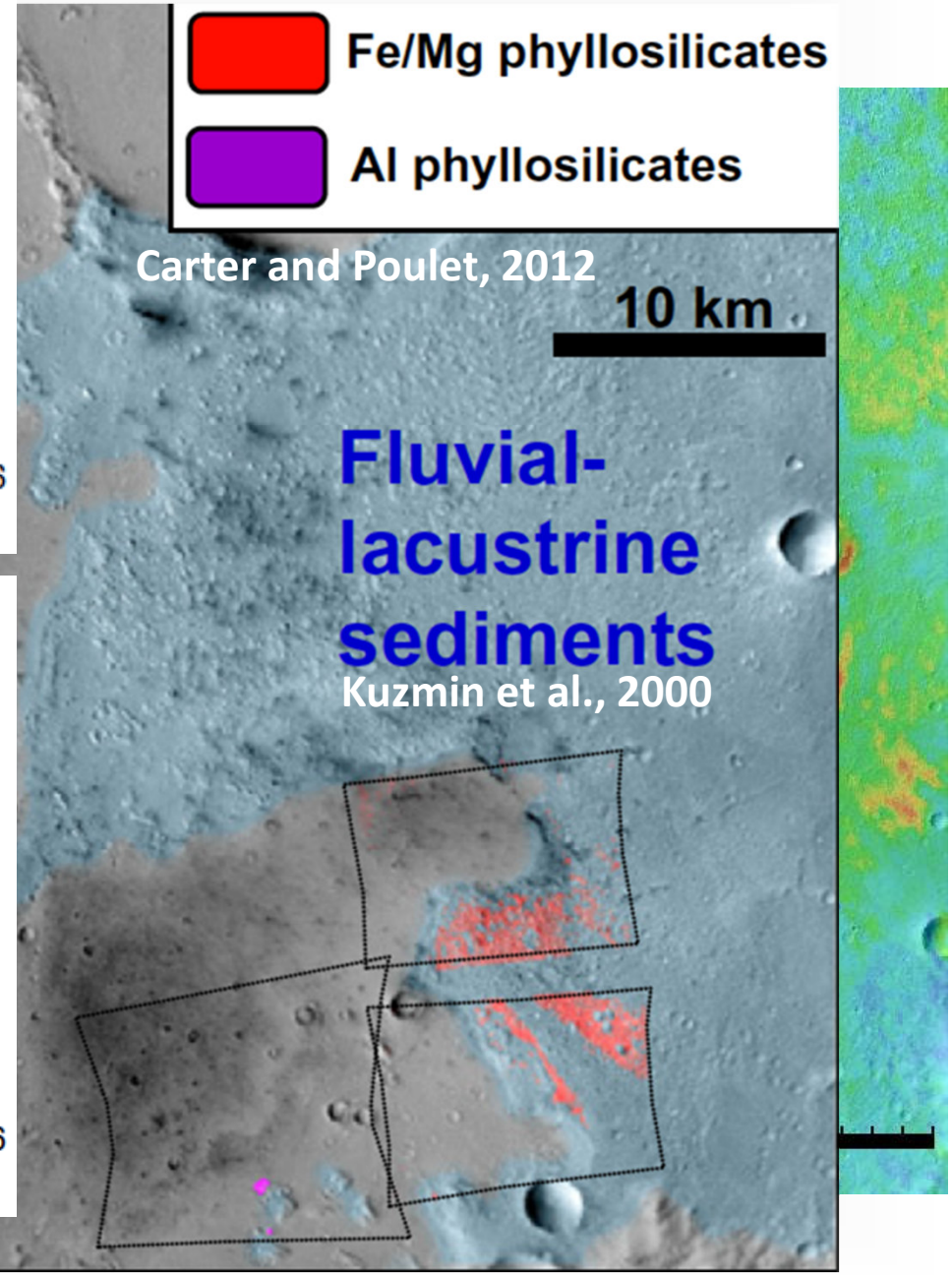
- Gusev crater displays a rich history of aqueous, hydrothermal, volcanic, and erosional processes
- It checks all the boxes for Threshold Geological Criteria and most of the Qualifying Criteria, already validated in situ
- Testable hypotheses and new questions can be investigated in conjunction with sampling across a *compact* and *accessible* landing site
- Which samples to cache can be debated *years in advance*

Back Up


80 km


1.00
0.99
0.98
0.97
0.96
Relative reflectance
(offset for clarity)
CRISM
Vermiculite
Saponite
c
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
Wavelength (μm)


1.002
1.000
0.998
0.996
0.994
0.992
Relative reflectance
(offset for clarity)
CRISM
Halloysite
d
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
Wavelength (μm)


Fe/Mg phyllosilicates
Al phyllosilicates
Carter and Poulet, 2012
10 km
Fluvial-lacustrine sediments
Kuzmin et al., 2000