Mars 2020 Science Team Assessment of Columbia Hills

Mars 2020 4th Landing Site Workshop

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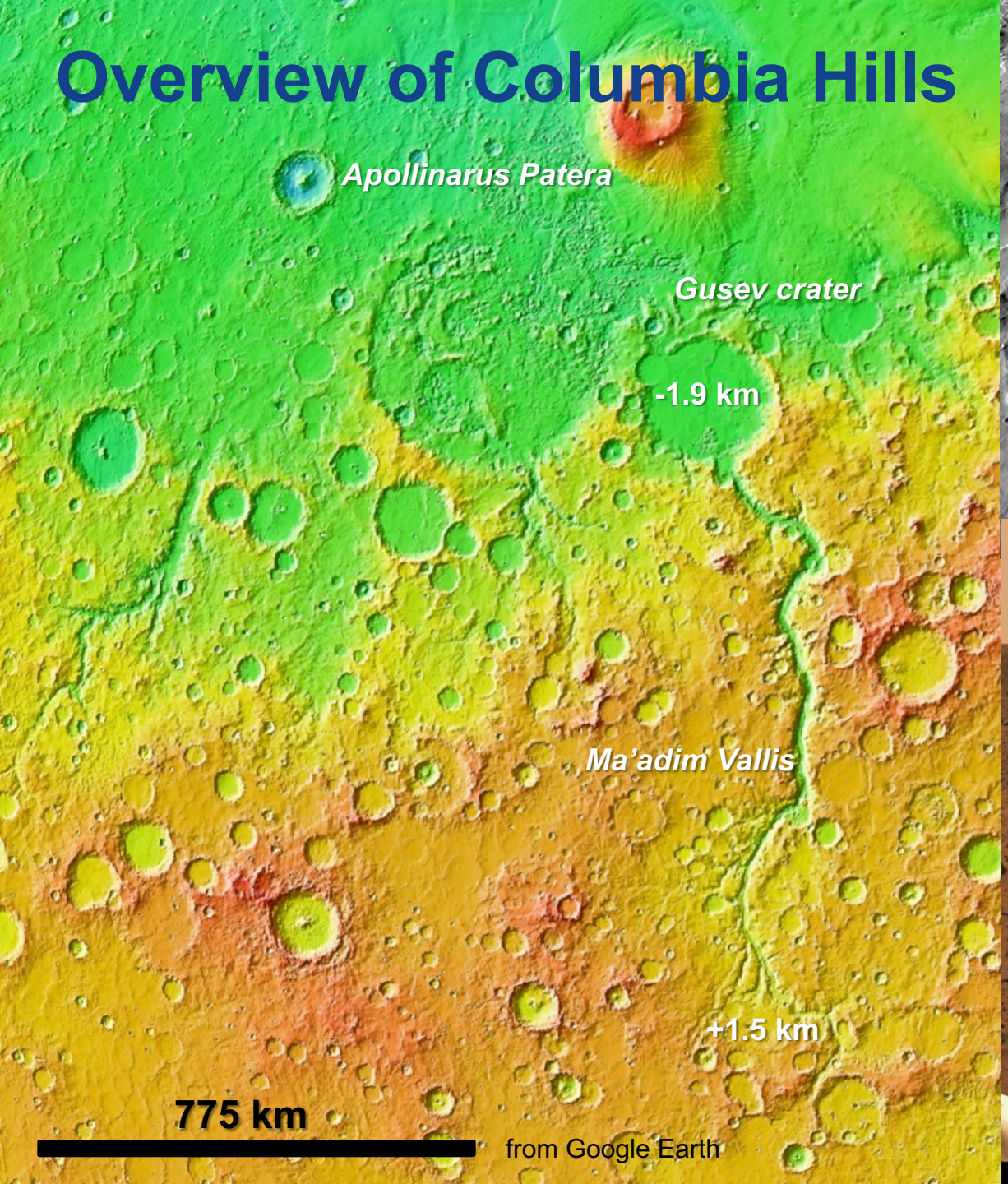
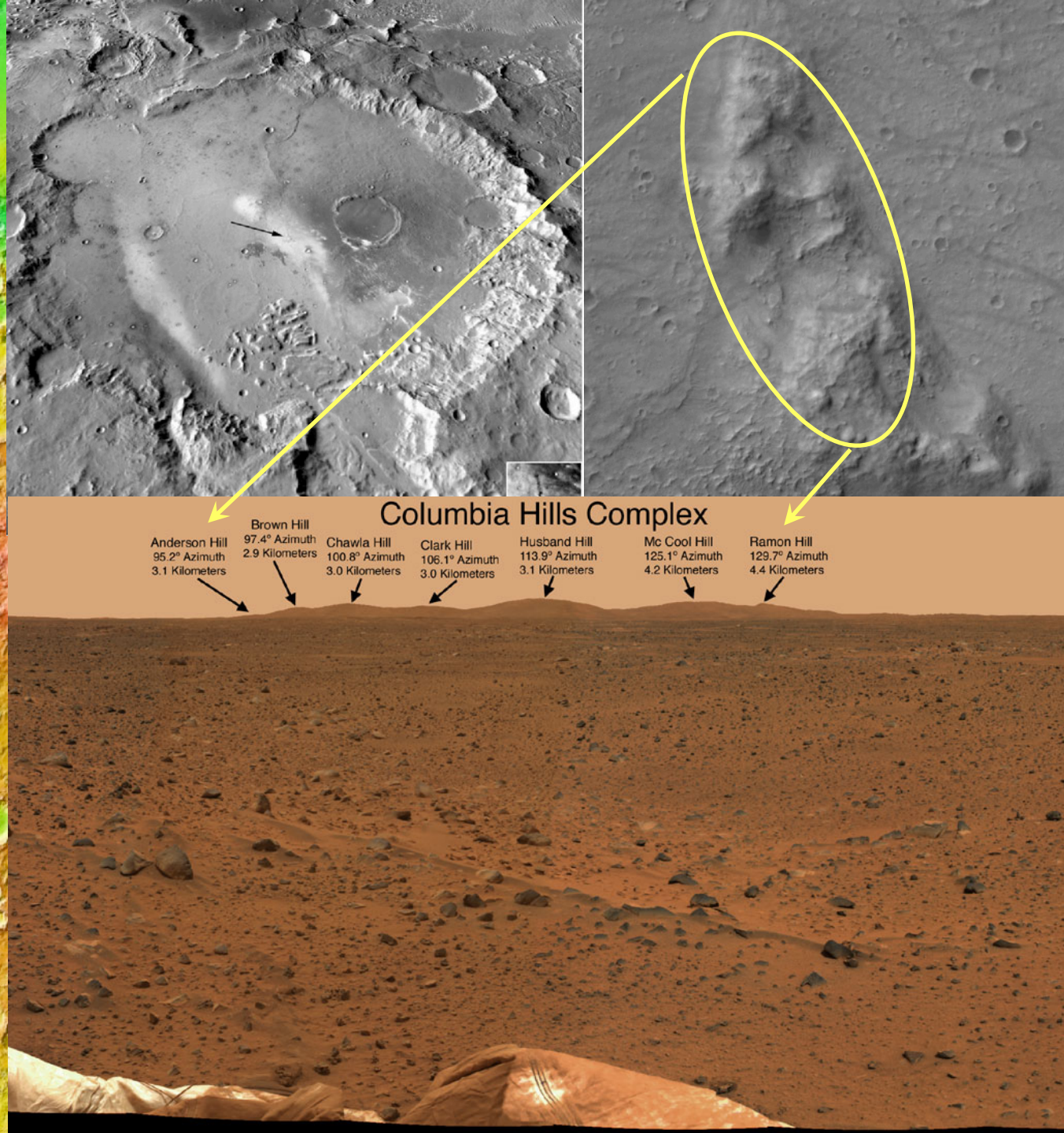
On behalf of the Mars 2020 Science Team Landing Site Working Group

October 16-18, 2018

Overview of Columbia Hills





Goal that provides enduring focus to the mission

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To explore and sample possible biosignatures in an ancient hydrothermal system, and to sample diverse volcanic rocks, alteration products, and sedimentary rocks from ancient Mars

Summary of in-situ mission objectives and strategies

- **Objective 1**: Provide additional geologic context for the opaline silica and carbonate-bearing rocks to assist in resolving uncertainties related to their origin, including:
  - Opaline silica: precipitated structures or leaching rinds?
  - Carbonates: lacustrine evaporites or hydrothermal alteration minerals?
- **Strategies**:
  - Mastcam-Z and SuperCam: determine the broader geographic distribution of opaline silica and carbonate-bearing outcrops, as well as their associated volcanic/volcaniclastic rocks and soils
  - PIXL/SuperCam: map mm- to sub mm-scale chemistry of sedimentary and volcaniclastic outcrops to determine petrologic relationships
  - SHERLOC and SuperCam: search for organics and determine mineralogy in the opaline silica outcrops, carbonate-bearing outcrops
  - RIMFAX to map subsurface geological structure of Columbia Hills and Home Plate, extend geological contacts beneath regolith cover
    - Map geographic extent of SiO_2 - and S-rich subsurface soils to determine their relationship to outcrop

Summary of in-situ mission objectives and strategies

- **Objective 2**: Provide additional geologic context for all the diverse lithologies of the Columbia Hills to constrain:
  - Depositional setting and processes
  - Relative age, stratigraphic relationships
  - Relevance to regional/global Martian geological history
  - Potential for habitability and biosignature preservation
- **Strategies**:
  - RIMFAX: map subsurface geological structure and regolith cover of Columbia Hills to test genetic models for outcrop origins (impact, volcaniclastic, sedimentary)
  - PIXL/SuperCam: map mm- to sub mm-scale chemistry of diverse lithologies to determine petrologic relationships and constrain origin
  - SHERLOC, Mastcam-Z, SuperCam: search for organics, determine mineralogy to assess environments of deposition and aqueous alteration

Summary of in-situ mission objectives and strategies

- **Objective 3**: Explore new terrains to determine the broader geologic context of the Columbia Hills and ascertain if other habitable environments are recorded by the accessible geology of Gusev crater.
- **Potential Strategies**:
  - Explore additional opaline silica outcrops near Home Plate (e.g., Pioneer Mound)
  - Explore von Braun butte and Goddard crater to assess their origins
  - Explore the “Promised Land” (extended mission)
  - Explore the “Italy” kipuka (extended mission)
  - Explore the Ma’adim Vallis proximal deposits (extended mission)

Notional Mission Scenario for Columbia Hills

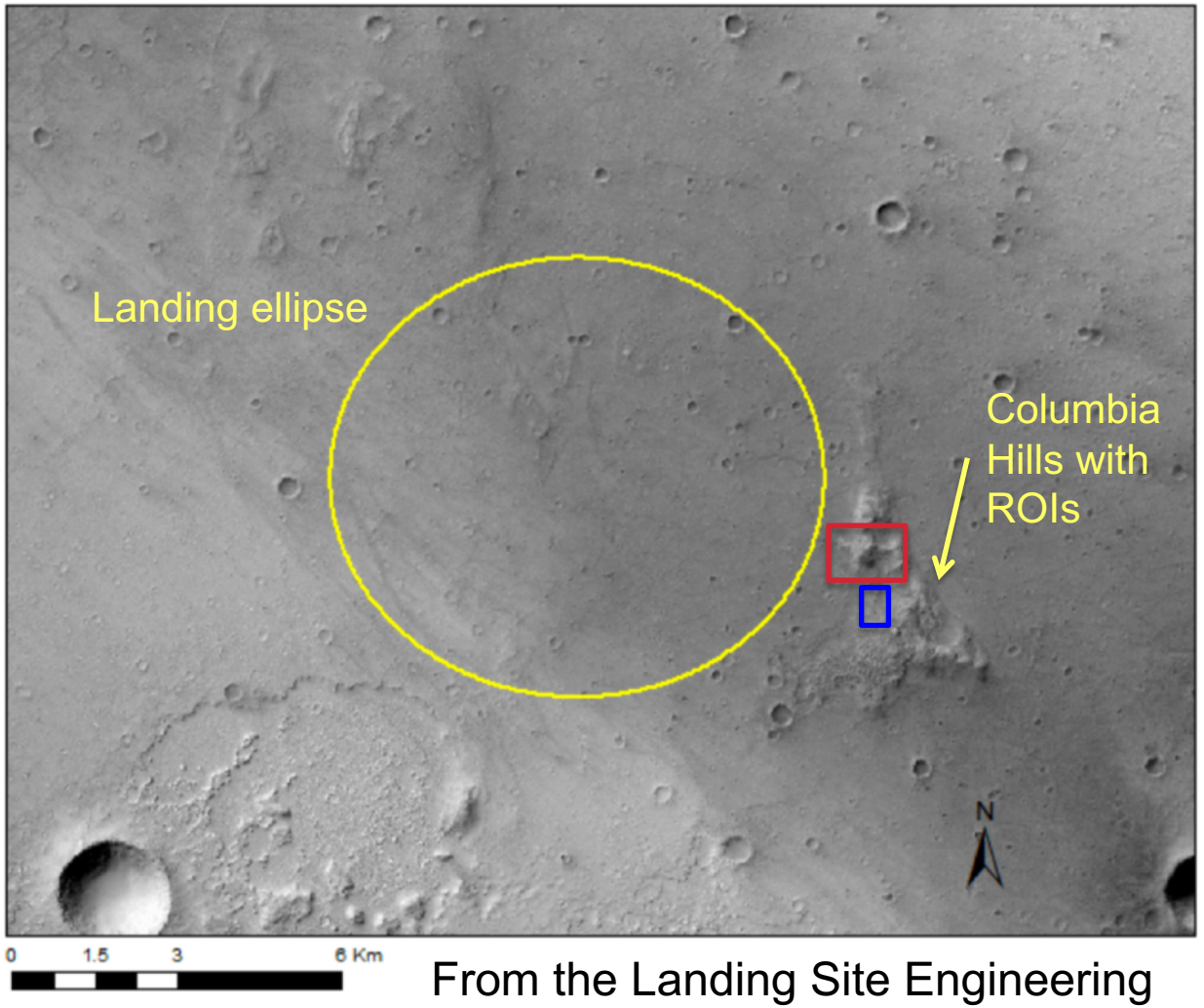
The mission scenario that follows is purely notional. We fully acknowledge that operations on the ground will be informed by what we learn on the surface. The notional scenario we present has been created to allow inter-site comparison based on our current understanding of the landing site.

“If you don't know where you are going, you'll end up someplace else.”

— Yogi Berra

Notional Mission Scenario for Columbia Hills

- Land at Gusev crater
- Sample Hesperian-aged Adirondack-class basalts on the plains (Waypoint 1)
- Focused drive to the Columbia Hills (~5 km from center of ellipse)
- Walkabout at Home Plate (ROI 1 - Campaign 1) to locate and sample opaline silica targets, S- and SiO_2-rich soils, volcaniclastics
- Walkabout of von Braun butte and Goddard crater (ROI 1 - Campaign 2)
- Drive to ROI 2 via McCool Hills landslide deposit and candidate carbonate-bearing rocks at Allegheny Ridge
- Reconnoiter and sample Comanche carbonate-bearing ultramafic rock (ROI 2 – Campaign 1)
- Drive to and sample basaltic soil (Waypoint 2)
- Choose between ROI 2 – Campaign 2 options: West Spur to acquire suites of unaltered and altered rocks OR return to Allegheny Ridge to acquire further carbonate samples



From the Landing Site Engineering Assessment Preview

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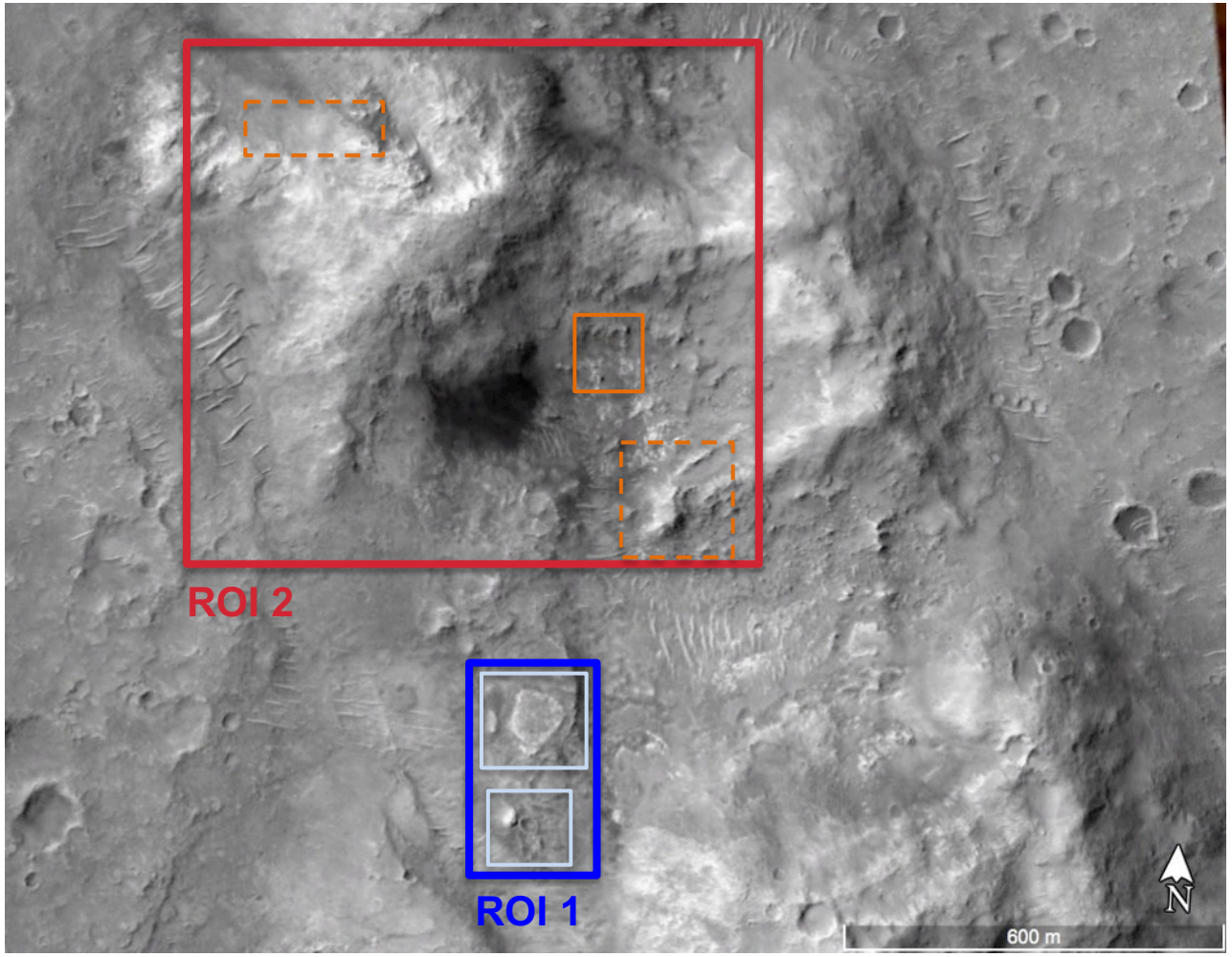


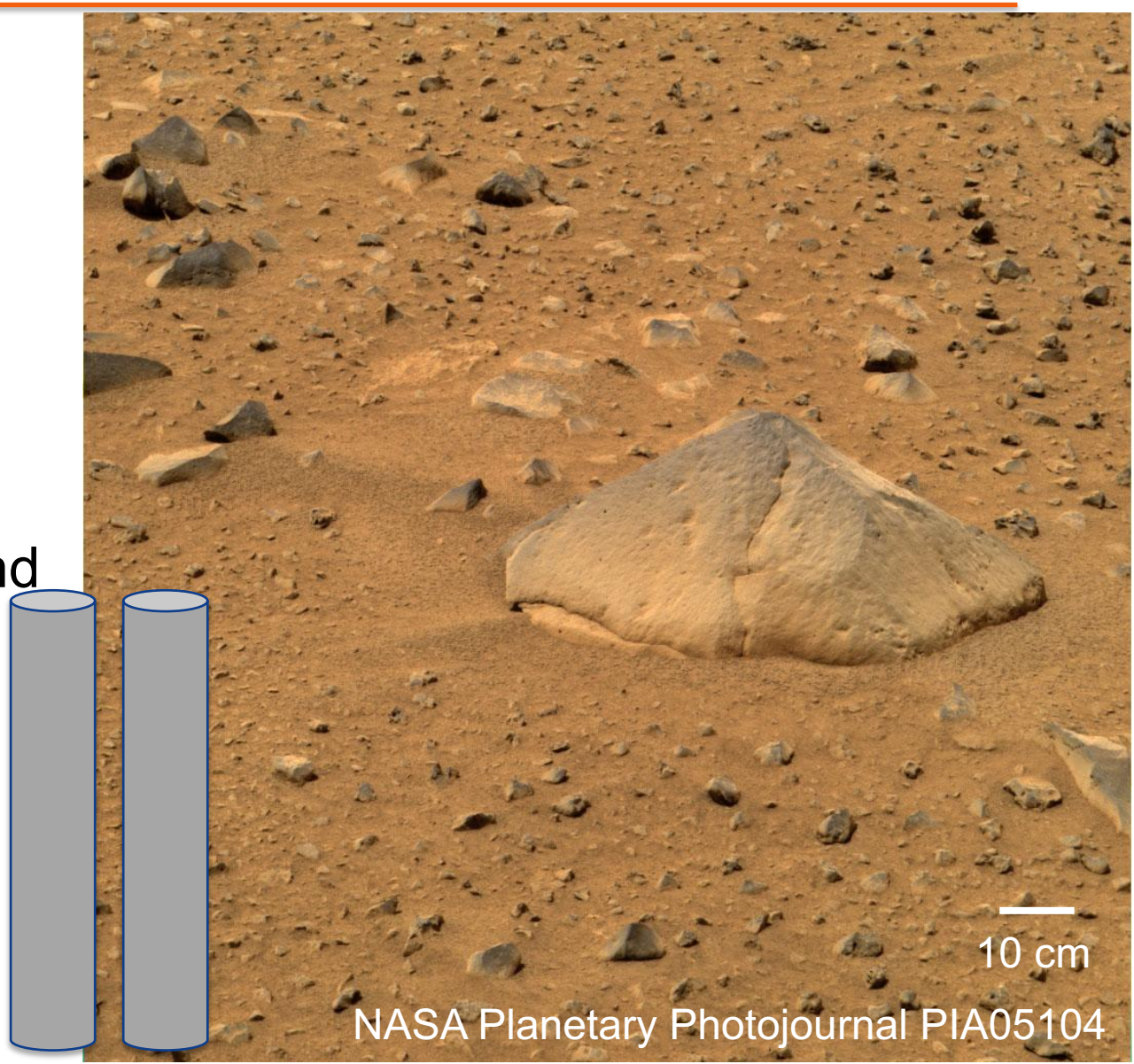
600 m

Waypoint 1 – Adirondack class basalt

- Provide a quantitative anchor point for dating Martian surfaces
- Two samples
  - Option 1: Both from the same rock (replicate analyses)
  - Option 2: From different rocks (lateral variability)
- Use Navcam, Mastcam-Z, SuperCam and PIXL to locate pristine Adirondack-class basalt samples

Samples 1 and 2

Two samples for reproducibility or variability



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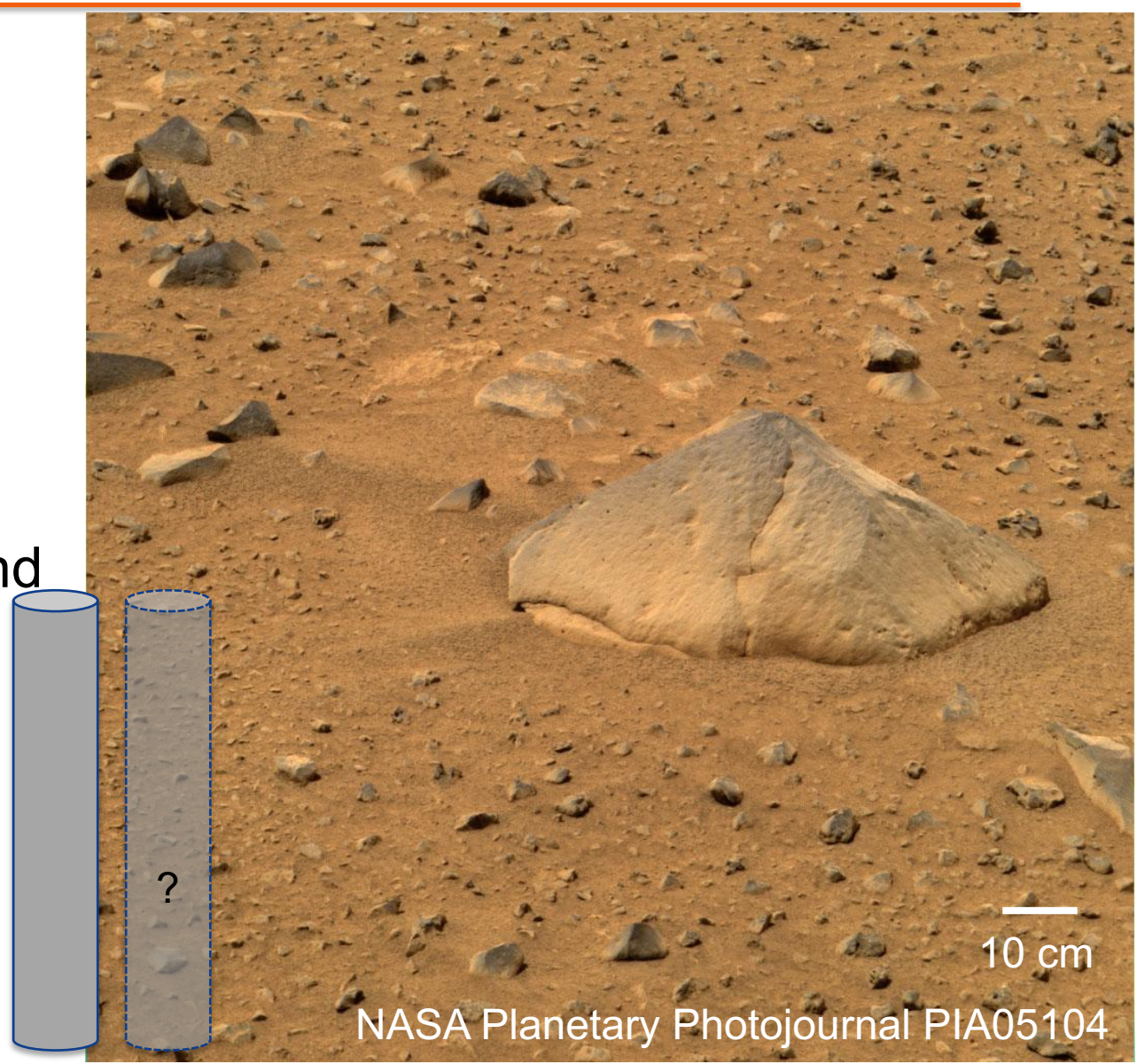
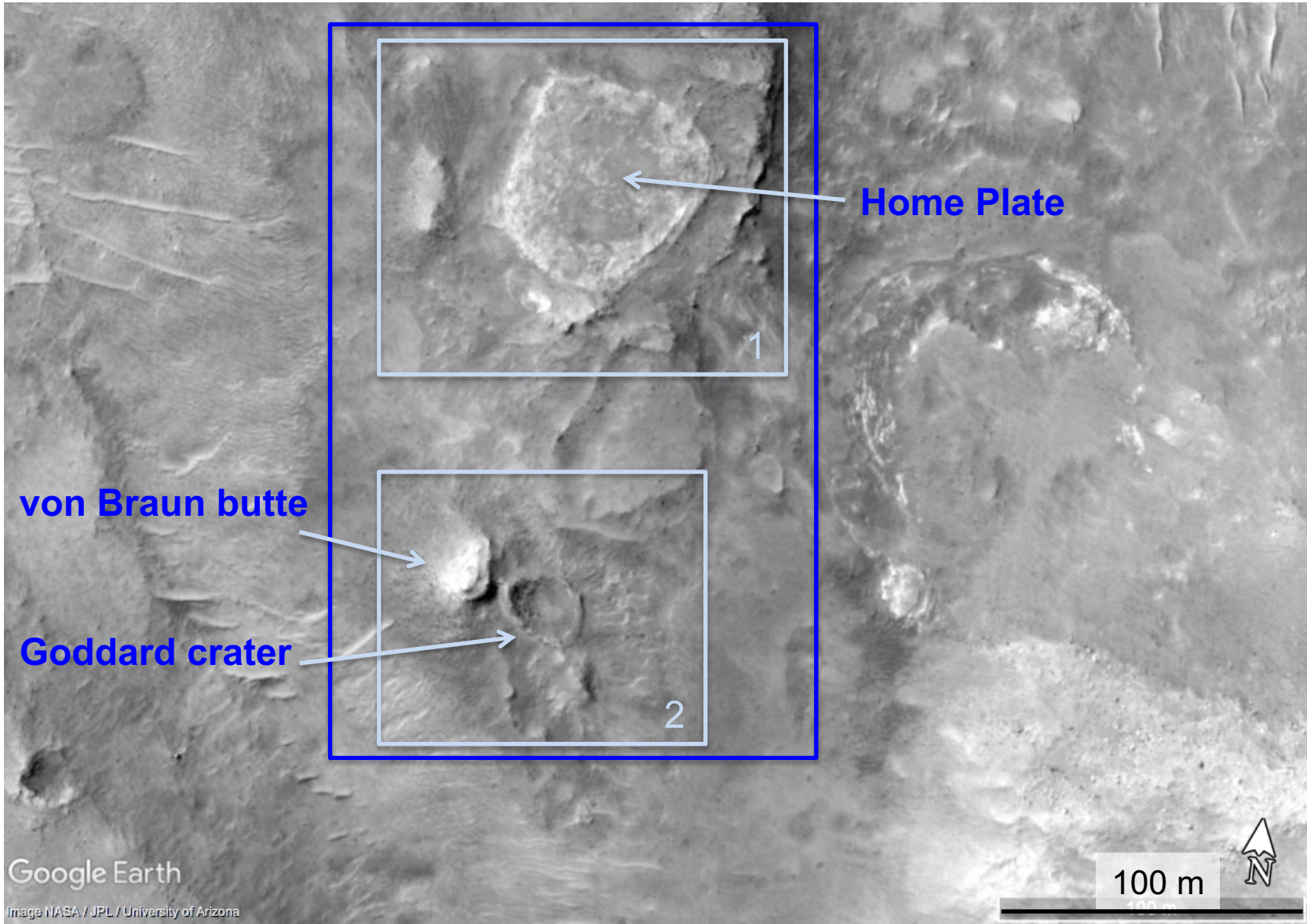
Sample 1

Dateable sample from a cratered surface



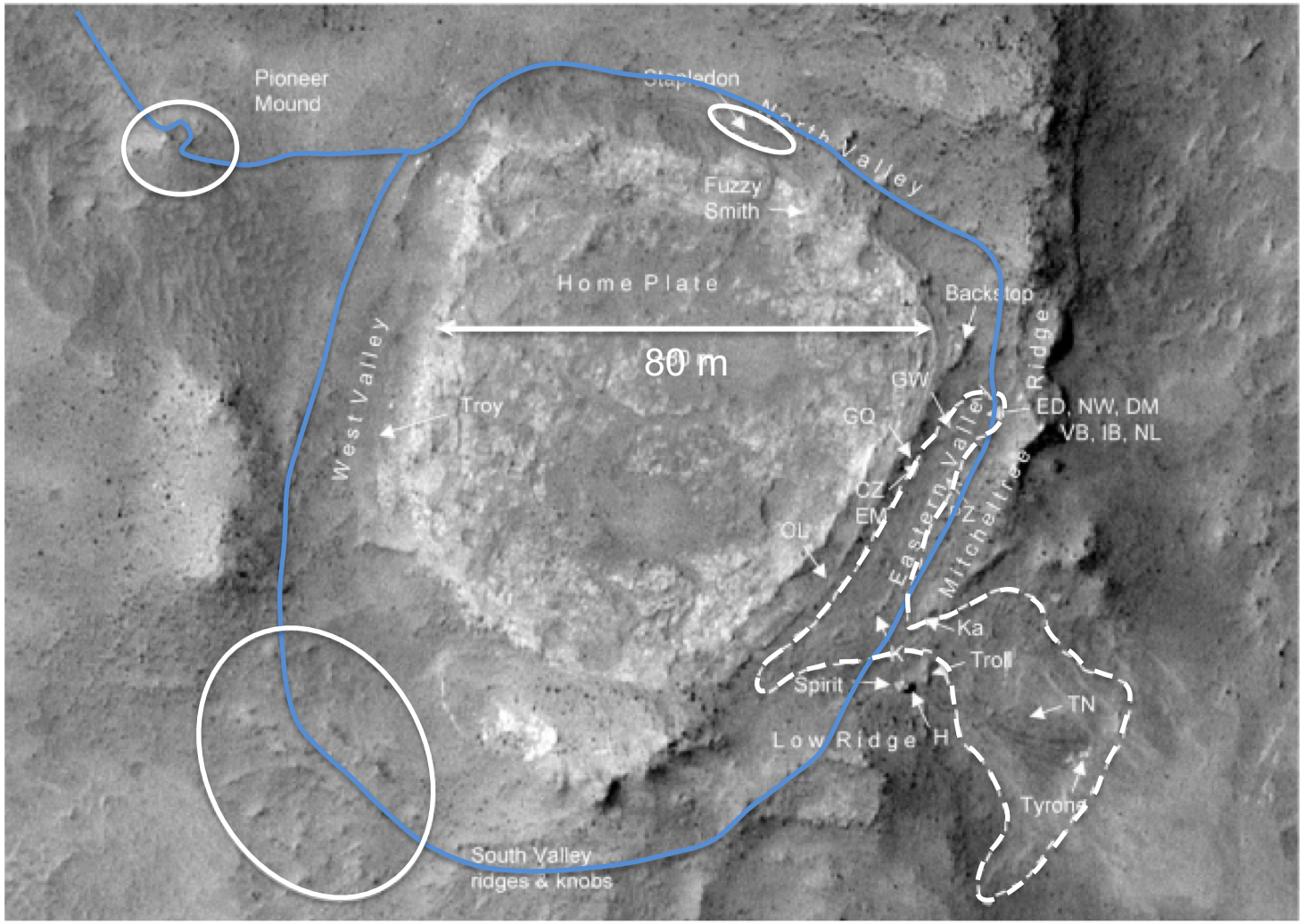
ROI 1 Overview

- **Highest priority:** investigation and sampling of opaline silica outcrops
- Other samples of interest: Barnhill class volcaniclastics, SiO_2-rich and S-rich soils
- Reconnaissance of Goddard crater and von Braun butte – possible sample acquisition



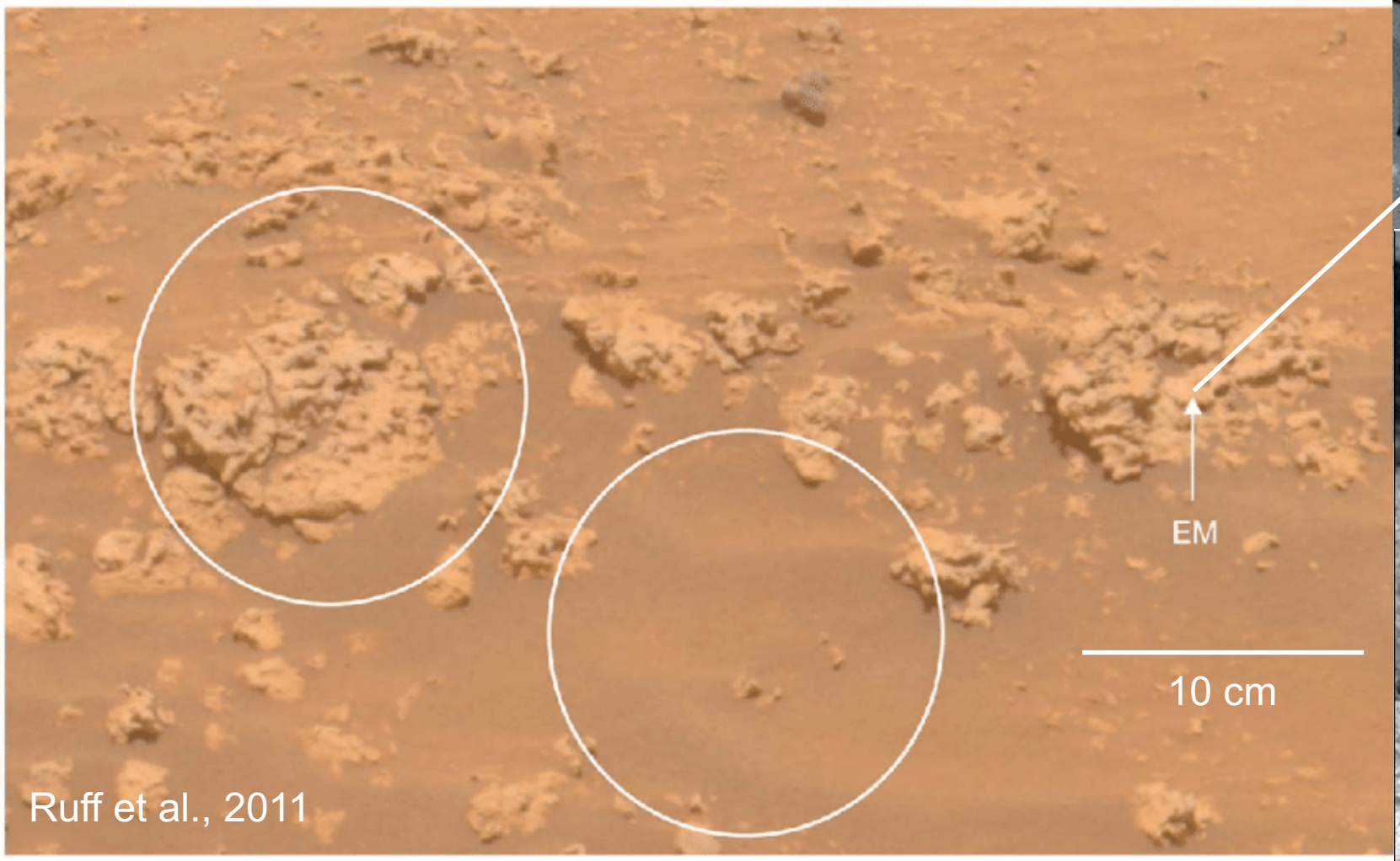
ROI 1 – Campaign 1 – Home Plate walkabout

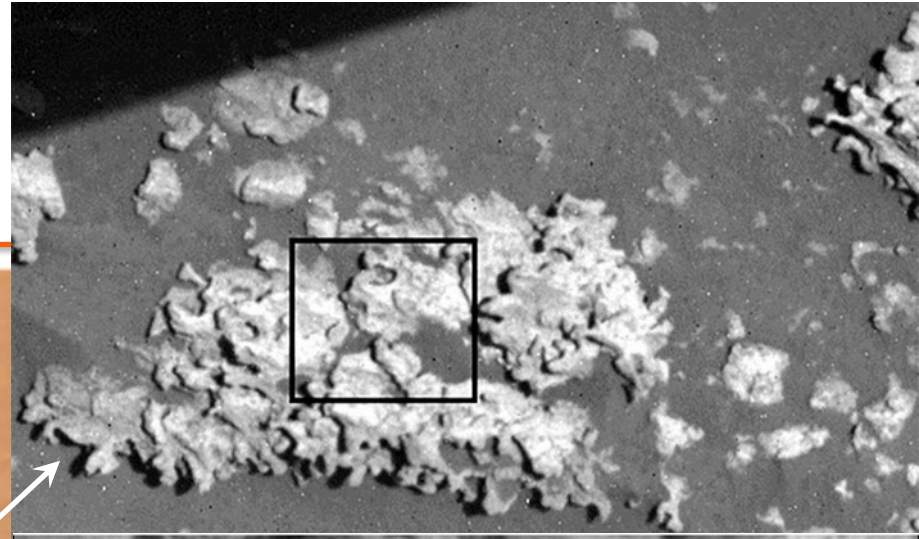
- Use Mastcam-Z and SuperCam to remap (e.g., look for old occurrences, seek new ones) opaline silica outcrops around Home Plate given nine years of aeolian changes
- Use Mastcam-Z and SuperCam to explore other candidate opaline silica outcrops: Stapledon, Pioneer Mound, South Valley ridges (white ovals)
- Use PIXL and SHERLOC to map fine-scale chemistry and organics within opaline silica outcrops
- Use Mastcam-Z and SuperCam to locate SiO_2-rich (Gertrude Weise-type) and S-rich (Paso Robles-type) soils for sampling
- Acquire a Barnhill-class volcaniclastic sample from Home Plate

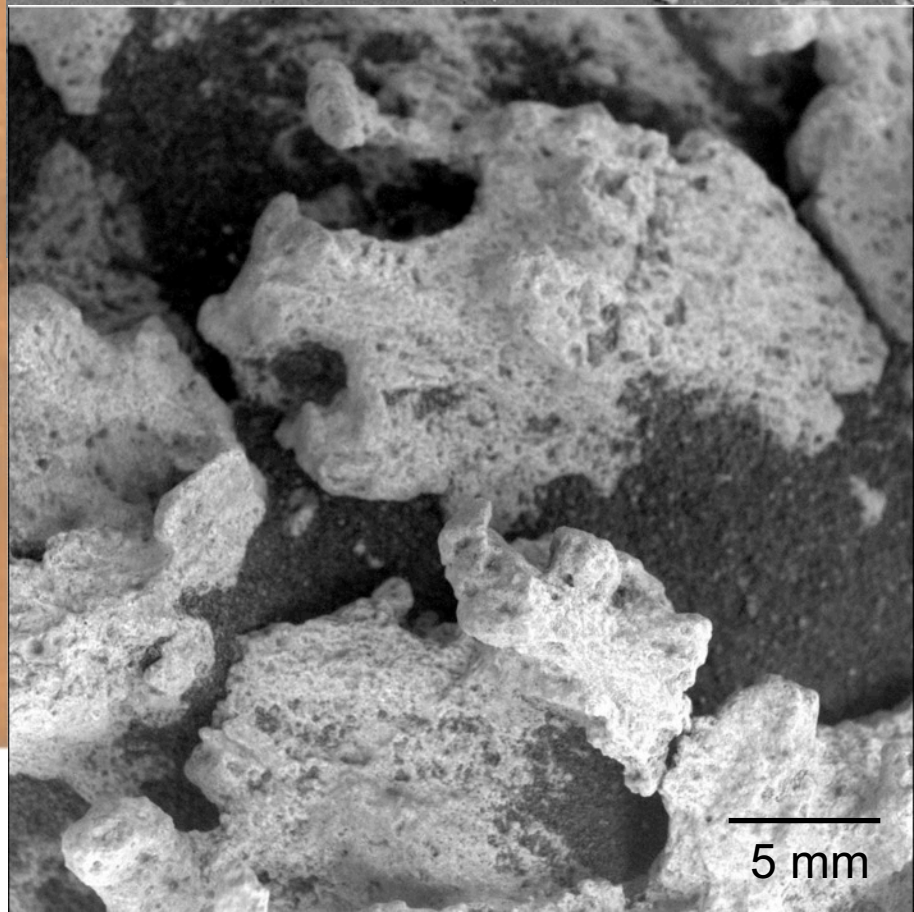


Adapted from Ruff et al., 2011

Opaline silica outcrops



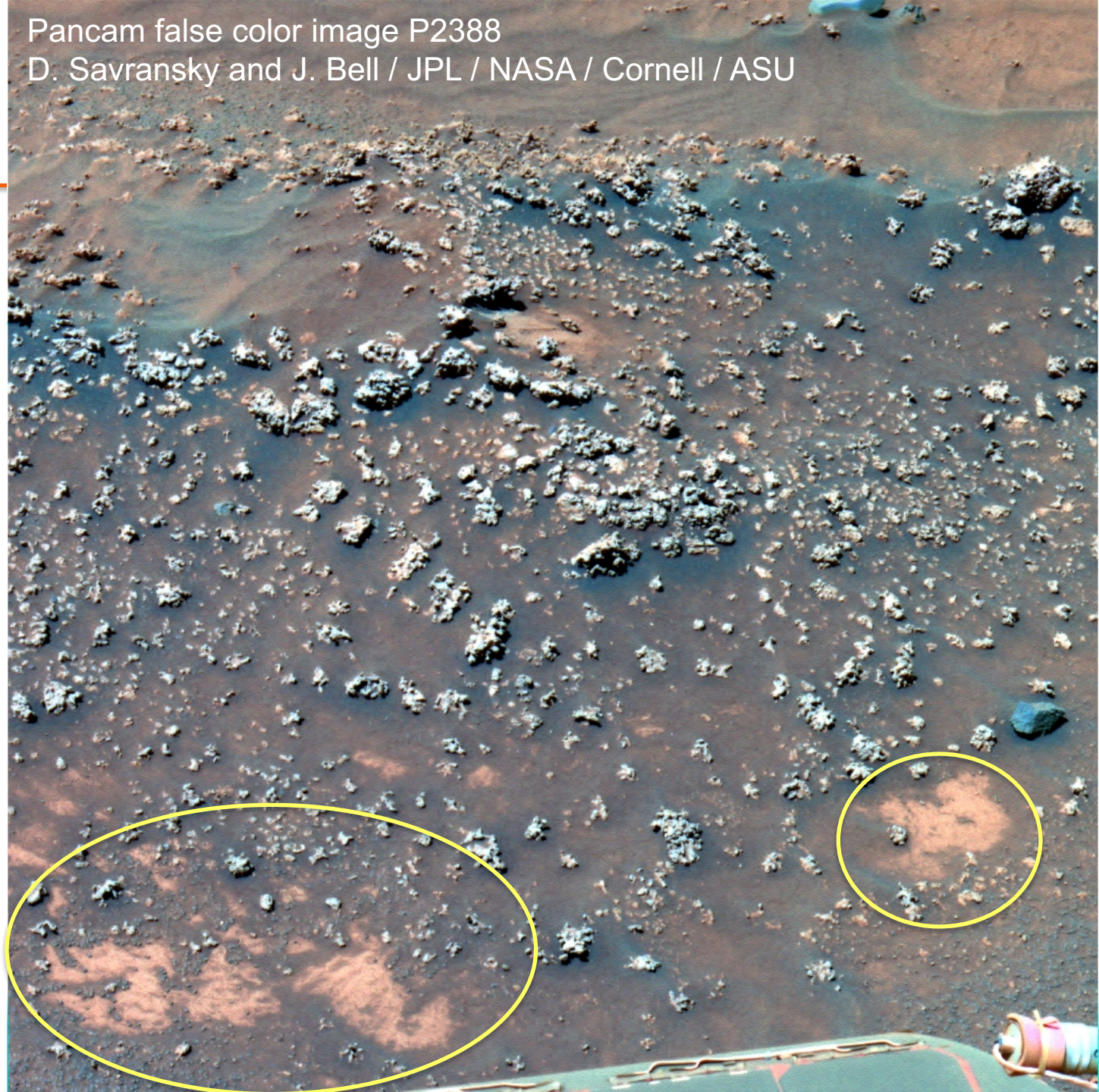




Home Plate Walkabout: characterize regional geometries of silica outcrops to help test formation hypotheses (precipitation vs. leaching)

Halley subclass

- Buff-colored, platy outcrops stratigraphically below the opaline silica outcrops (Ruff et al., 2011)
- Hematite-rich, Zn-rich, Ca-sulfate-bearing, strong hydration signature (Ming et al., 2008; Ruff et al, 2011)
- In-situ chemistry, mineralogy and texture observations bear on silica formation mechanism (leaching vs. precipitation)
- Acquire sample given its altered nature and relationships to silica outcrops and Home Plate



ROI 1 – Campaign 1 – Home Plate walkabout

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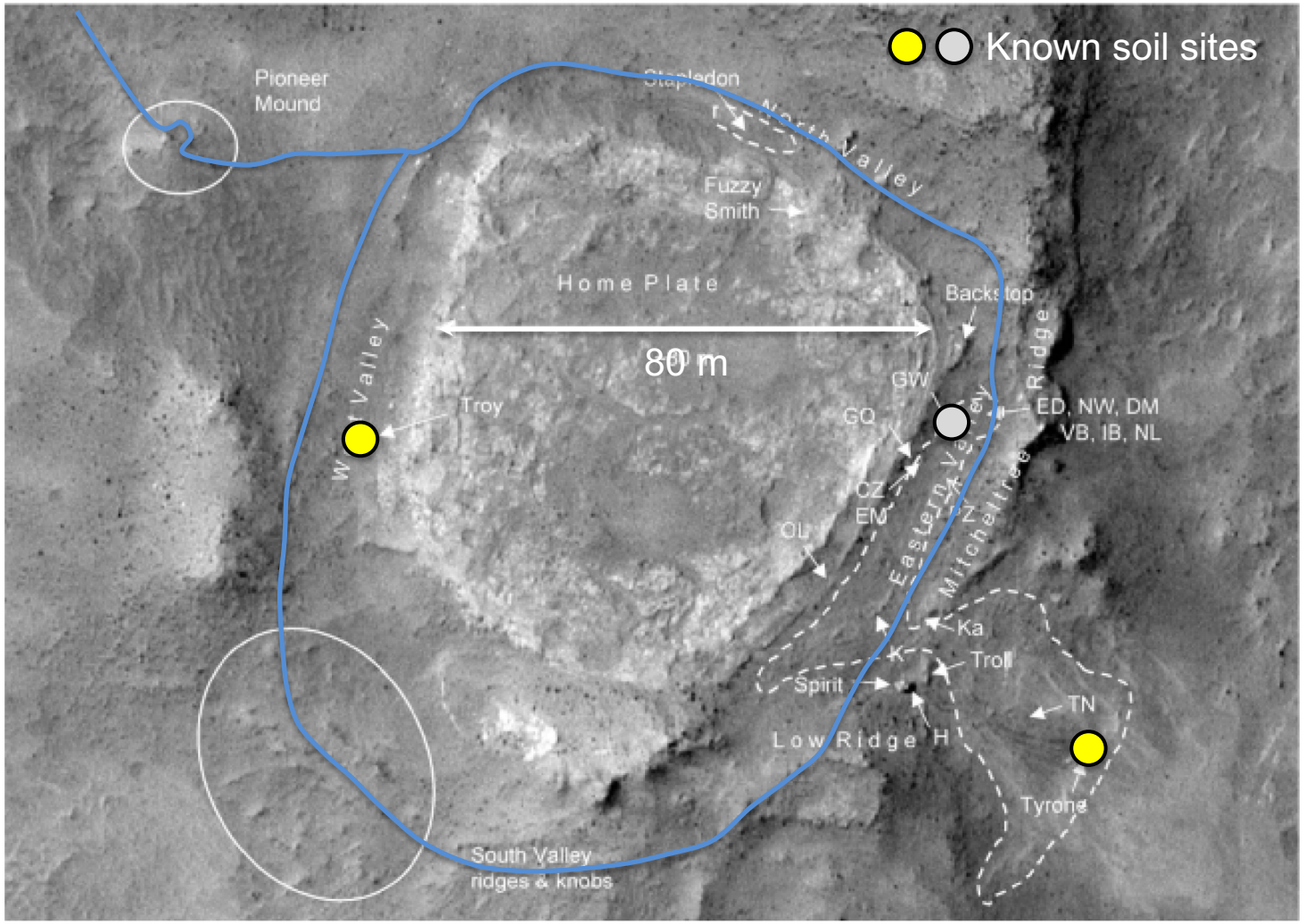
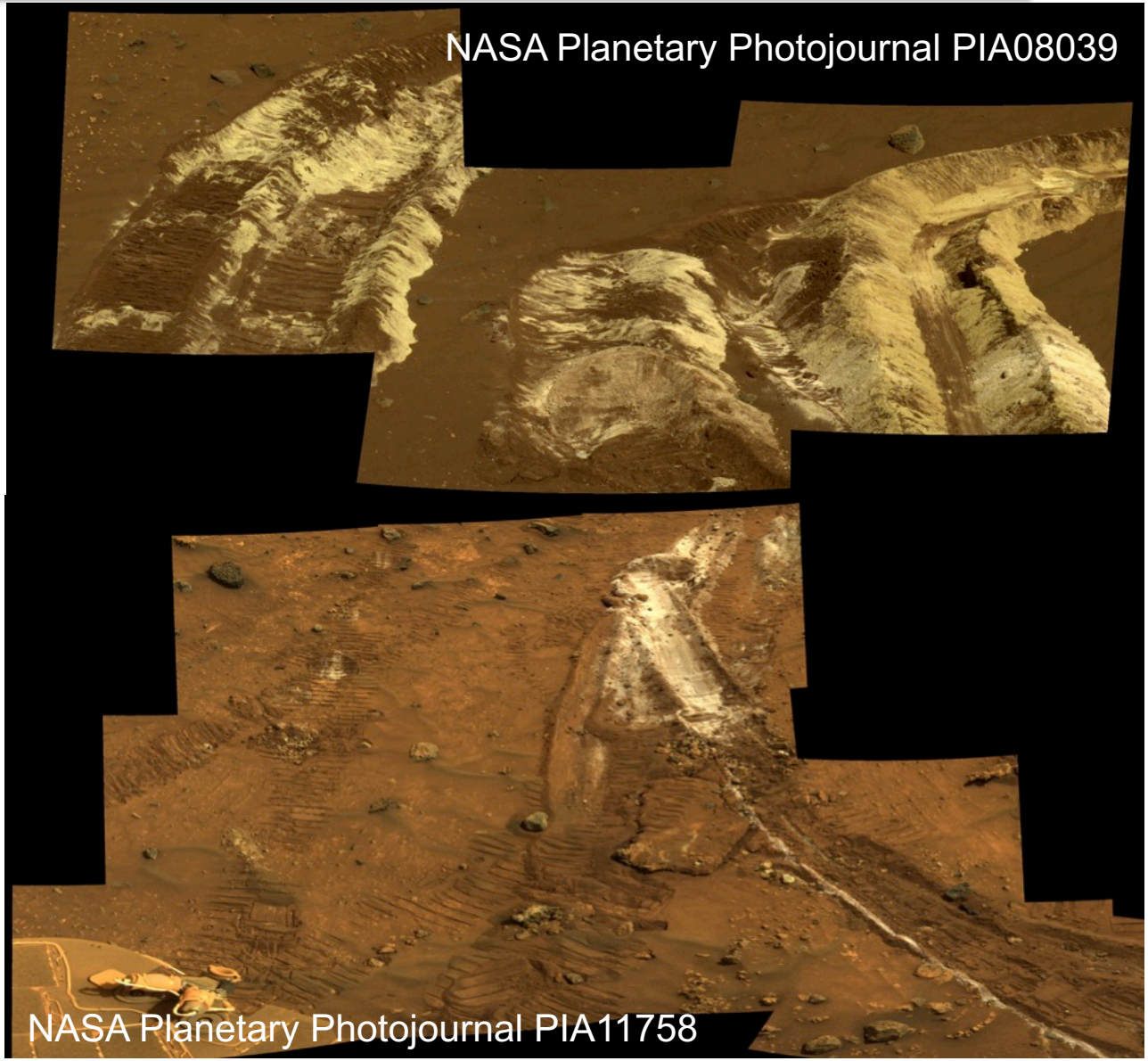
- Use Mastcam-Z and SuperCam to locate SiO_2-rich (Gertrude Weise-type) and S-rich (Paso Robles-type) soils for sampling
- Acquire a Barnhill-class volcaniclastic sample from Home Plate



Soils

- Multiple examples of S-rich soils observed by Spirit both around Home Plate and across Columbia Hills
  - Multiple sampling sites to choose from
- Use mobility system to create trenches of fresh material
- Use Mastcam-Z and SuperCam to locate and remotely characterize soil chemistry, mineralogy, hydration and sorting
- Use PIXL and SHERLOC to determine soil chemistry and mineralogy, WATSON for grain size/sorting
- RIMFAX to probe layering in soils



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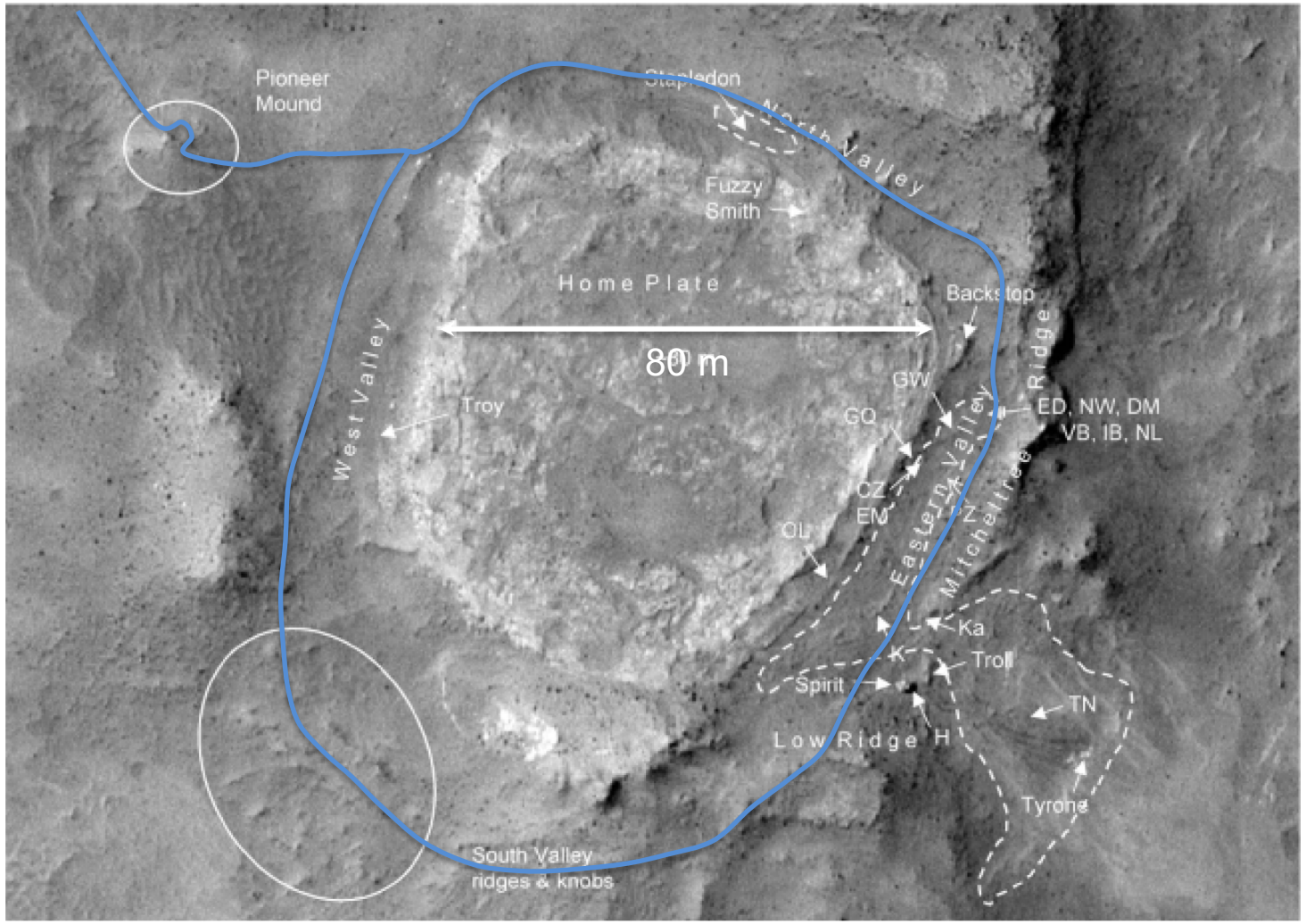


Home Plate

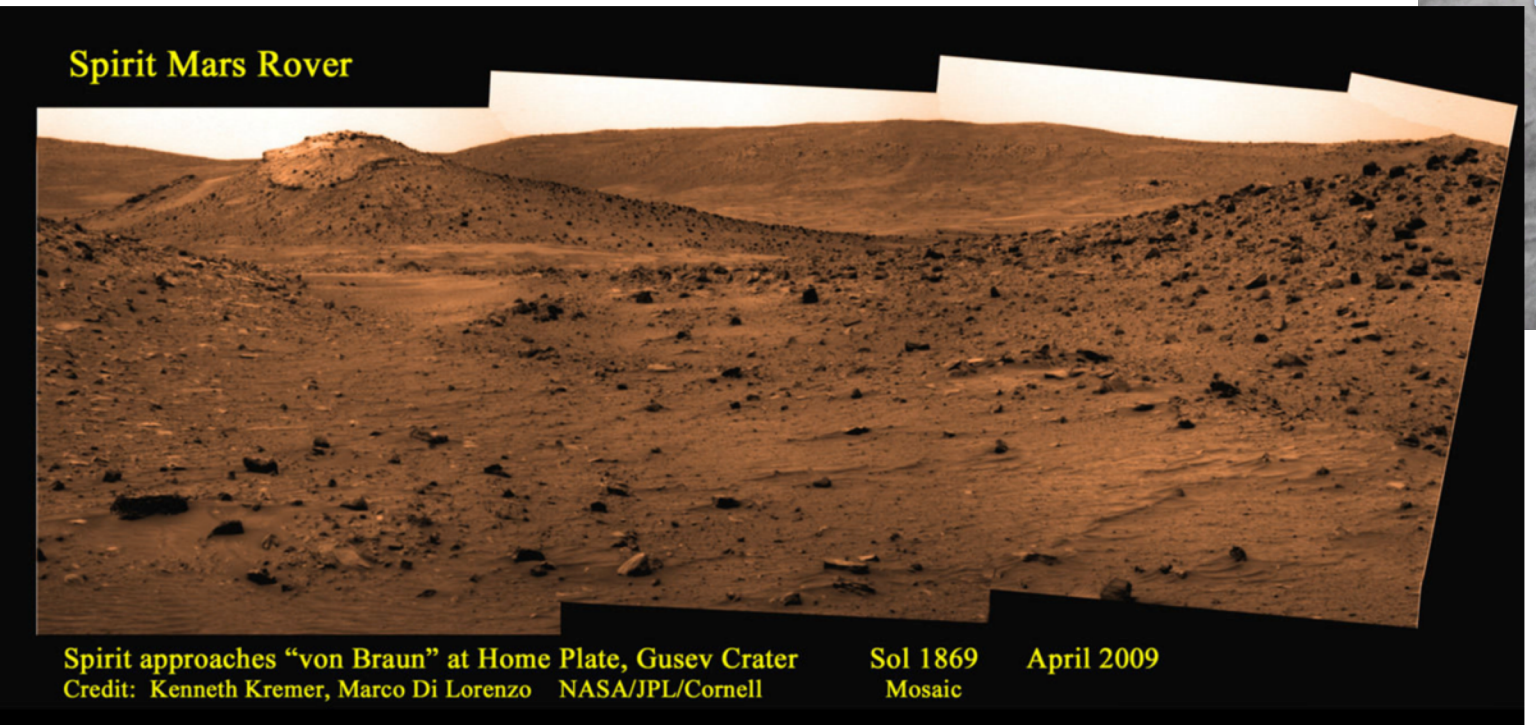
10 cm

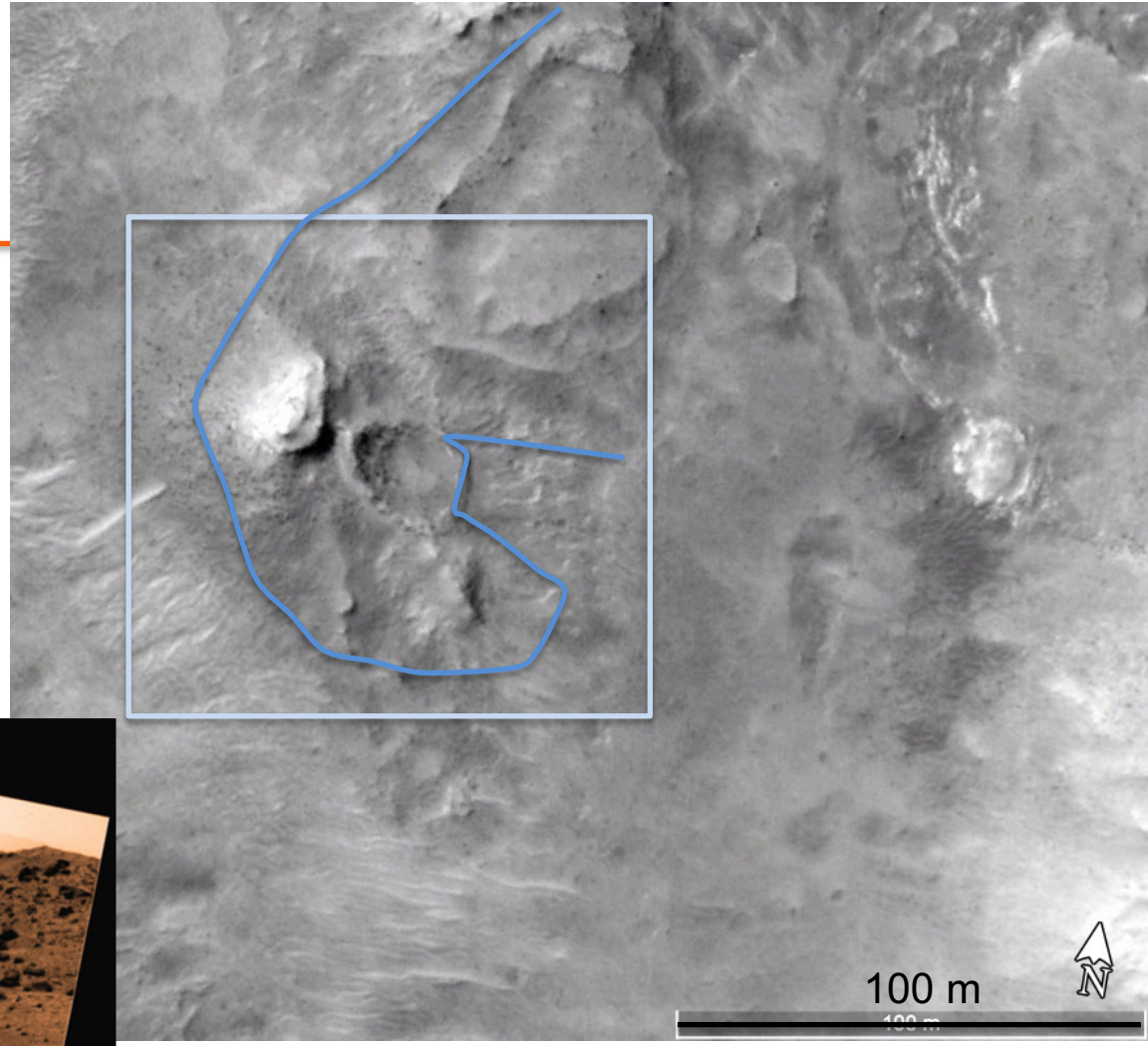
10 cm

- Sample volcaniclastic sediment to compare chemistry and volatile content to other Columbia Hills igneous lithologies, investigate eruption conditions
- Sampling options: coarsely bedded lower unit (pyroclastic), thinly bedded upper unit (reworked pyroclastic?), or both

ROI 1 – Campaign 2 – Goddard-von Braun walkabout

- Use Mastcam-Z and SuperCam to characterize structures and lithologies present within both features
- Use PIXL, SHERLOC, WATSON to probe chemical, mineralogical and textural evidence for the origin and alteration of the lithologies (explosive volcanism? hydrothermal alteration?)

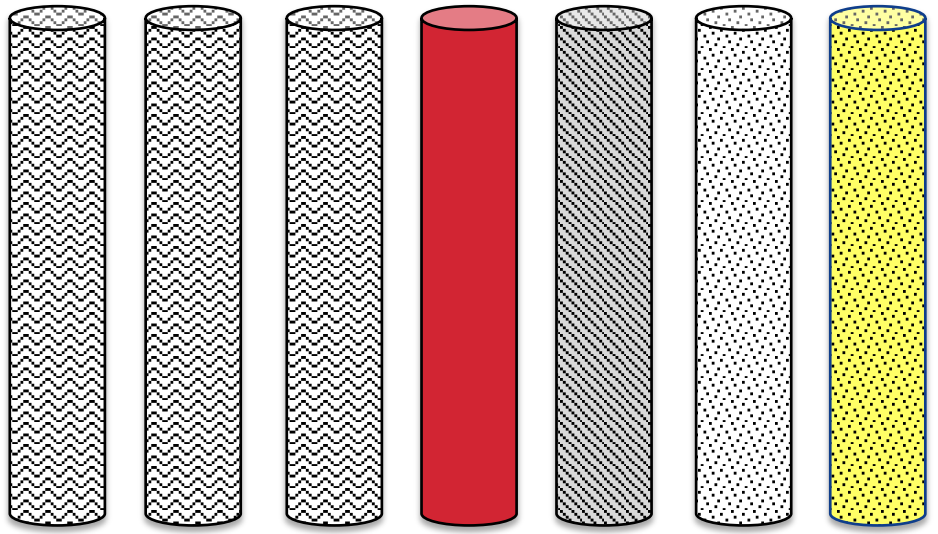


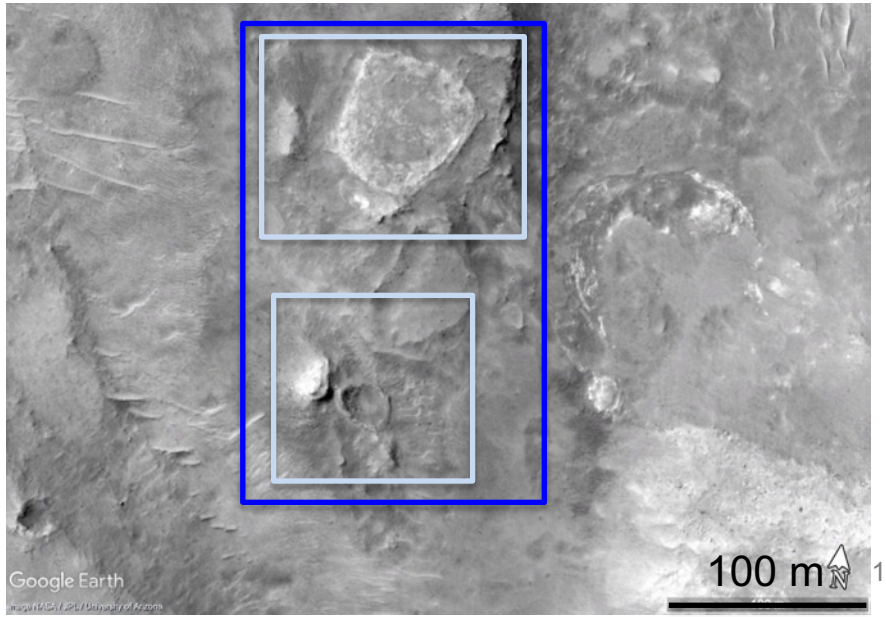


- Use RIMFAX to probe subsurface structure
- Use collective observations to determine if/how the features relate to the formation/alteration of Home Plate, and/or lithologies within Columbia Hills overall

ROI 1 Sampling Strategy

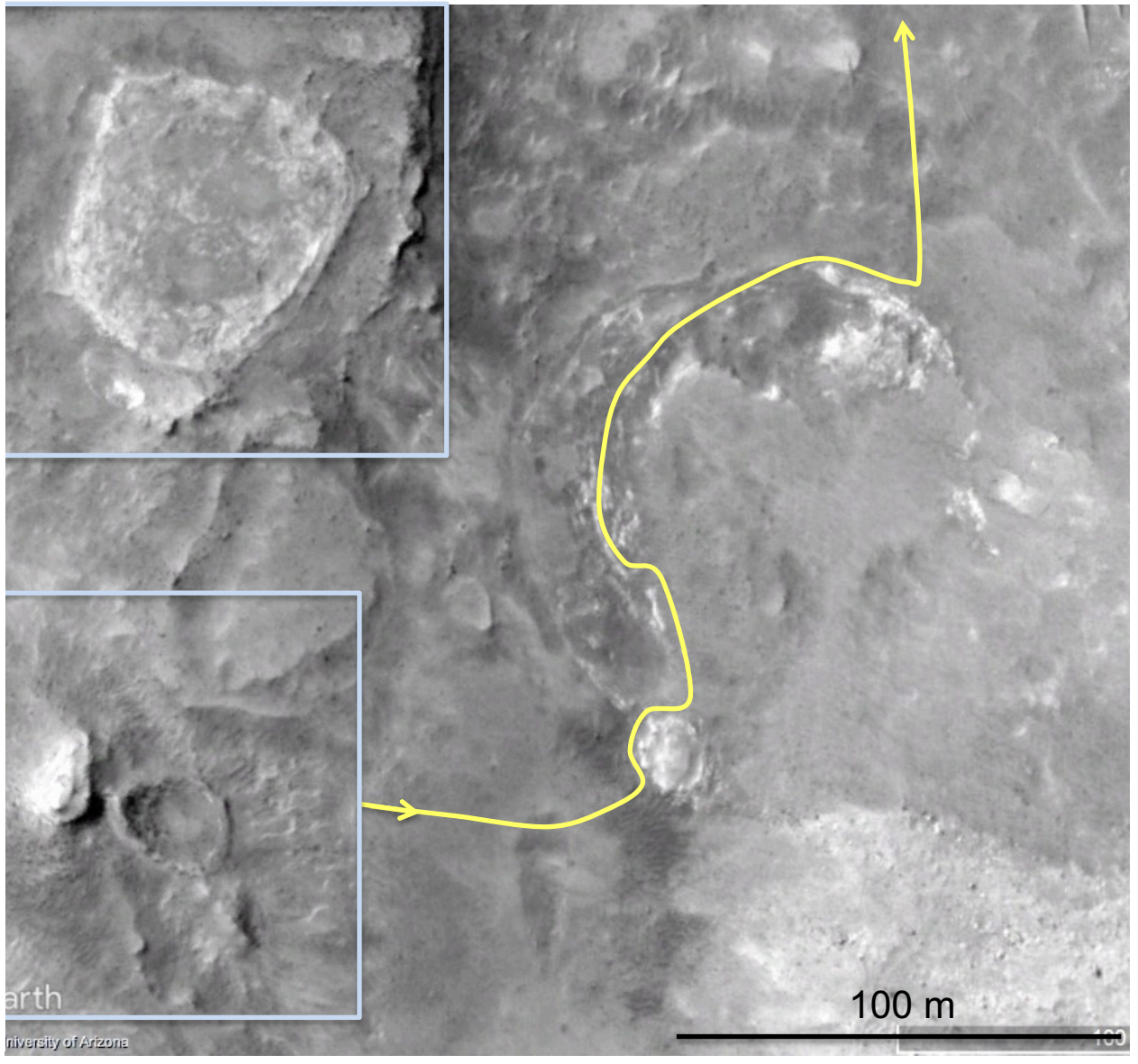
- Samples 3-5: Opaline silica deposits
  - Acquire multiple examples to overcome variability (e.g., preservation, exposure, alteration)
  - Time can be invested in finding the most promising and drillable sites
- Sample 6: Halley subclass outcrop
  - Stratigraphically below silica, altered lithology
- Sample 7: Barnhill-class volcaniclastics
  - Volcaniclastic sediment
- Samples 8 and 9: SiO_2-rich and S-rich soils
  - Part of a soil sample suite representing compositional endmembers
- Additional Samples
  - Examples from von Braun butte and/or Goddard crater?





ROI 1 to ROI 2 – McCool Hill landslide

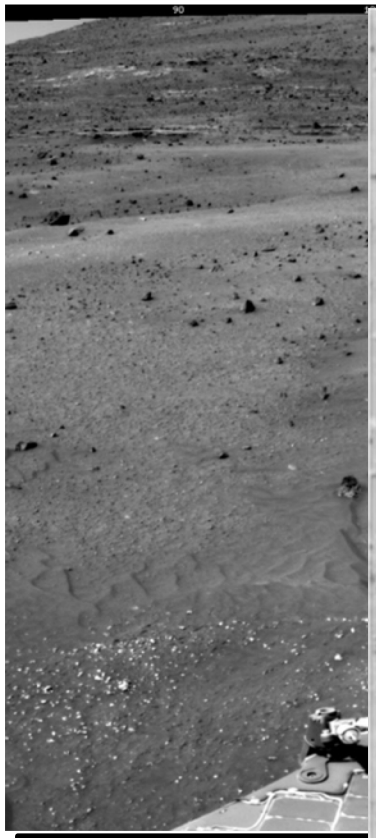
- Deposit not examined in detail by Spirit
- Use full instrument suite to characterize the landslide and materials buried by it
  - Mastcam-Z for bedding orientations, internal structure
  - SuperCam to survey chemistries
  - Opportunistic contact science with PIXL, SHERLOC and WATSON for chemistry, mineralogy and texture
  - Connect chemistry and structure to known outcrops to build context?
- RIMFAX to probe subsurface structure



ROI 1 to ROI 2 – McCool Hill landslide

Sol 873: Pancam super-resolution

ROI 1 to ROI 2 – McCool Hill landslide

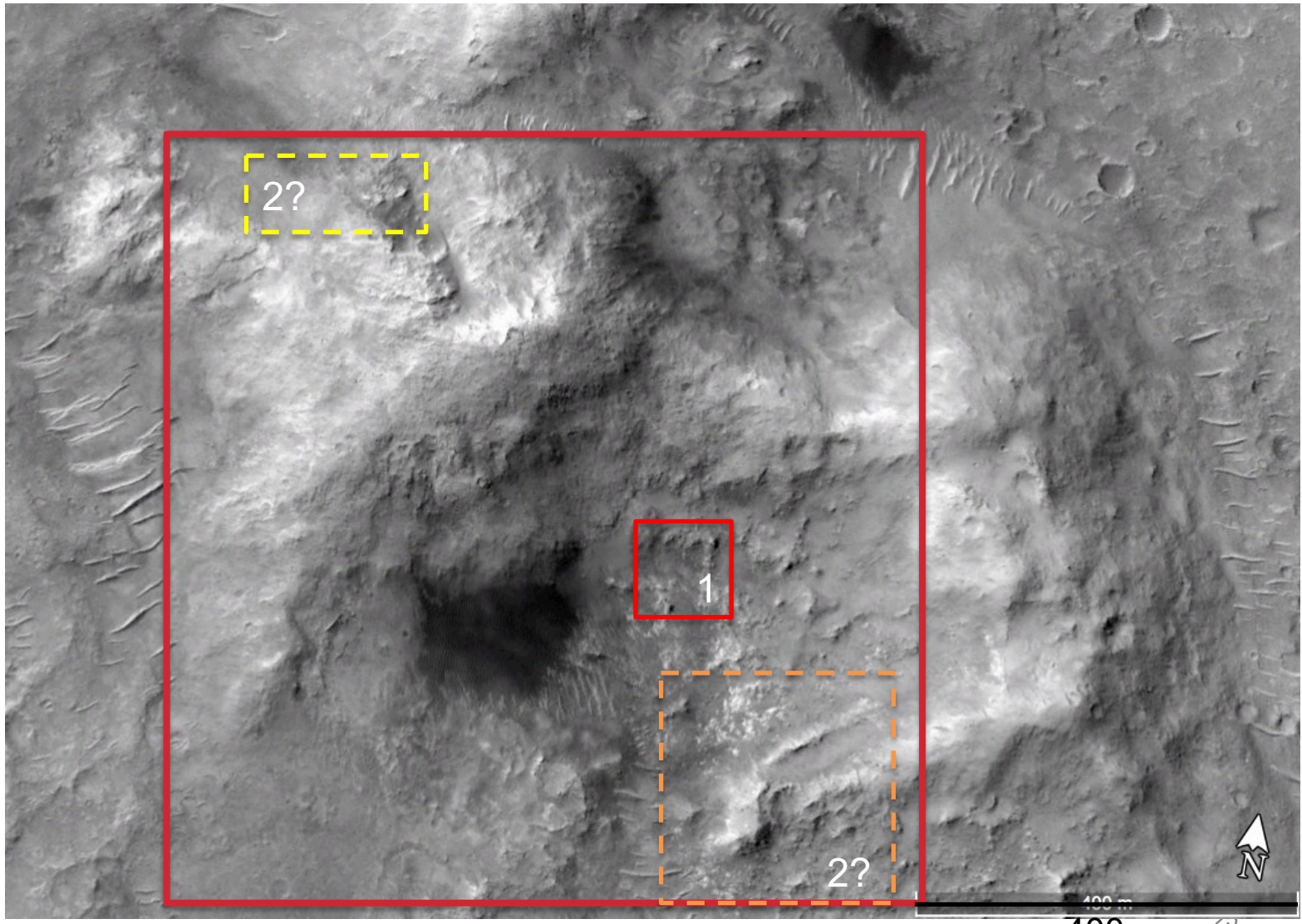


Navcam view looking ~so

Sol 813: Pancam super-resolution

ROI 2 Overview

- Reconnoiter and sample Comanche ultramafic-carbonate assemblage + Algonquin ultramafic lithology (ROI 2 – Campaign 1)
- “Choose Your Own Adventure” for Campaign 2:
  - Traverse to and across West Spur to acquire suites of unaltered and altered lithologies (yellow)
  - Return to just-surveyed candidate carbonate-bearing rocks at Allegheny Ridge (orange)



ROI 2 – Candidate Carbonate Outcrop "Walkthrough"

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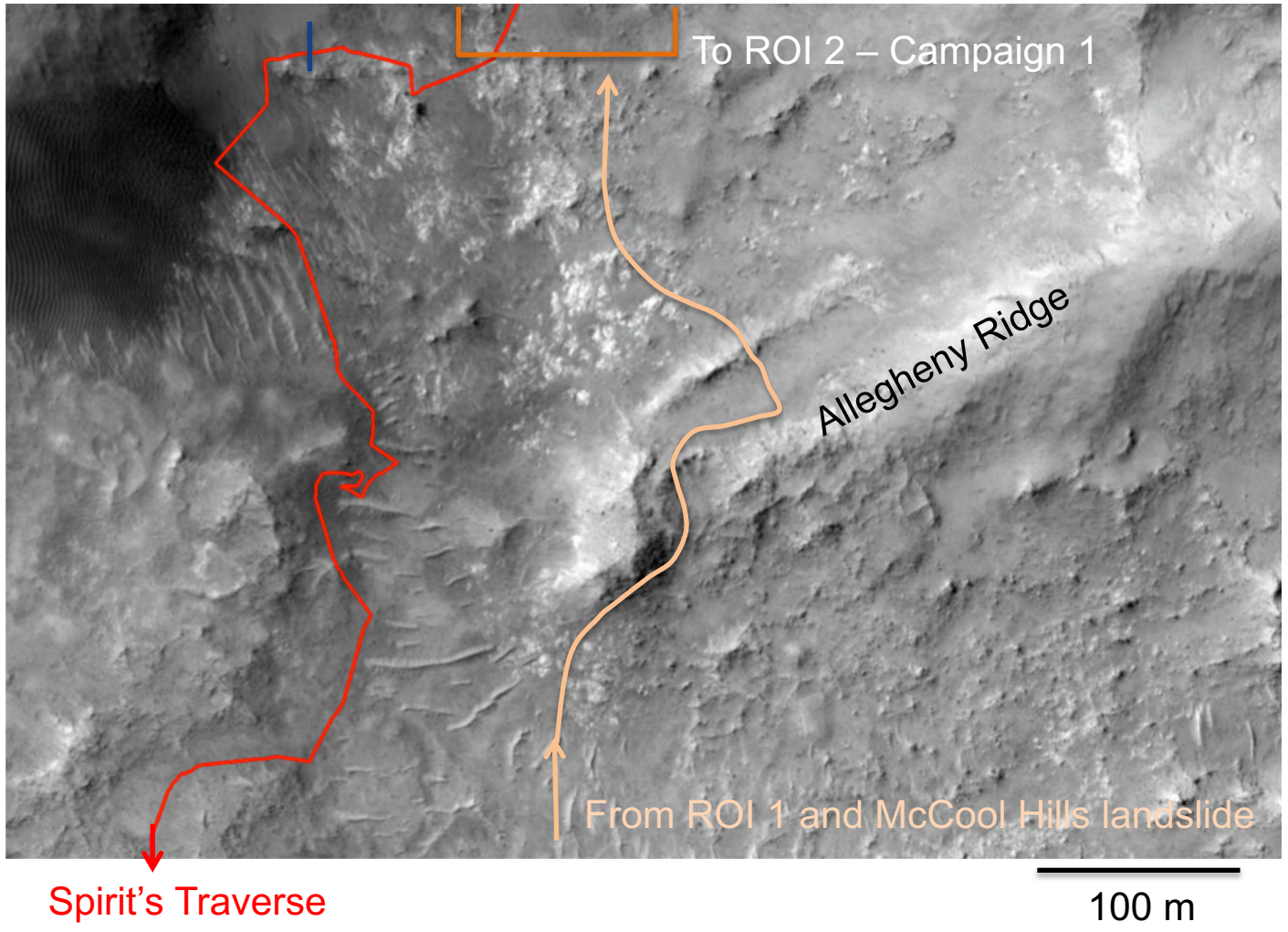
- Explore context of rocks similar to Comanche and Algonquin classes (as viewed in HiRISE) at a location not examined in detail by Spirit
- Mastcam-Z and SuperCam along traverse to identify lithologies present
- Opportunistic contact science with PIXL and SHERLOC to characterize lithologies
- RIMFAX to probe and help resolve subsurface structure of Columbia Hills



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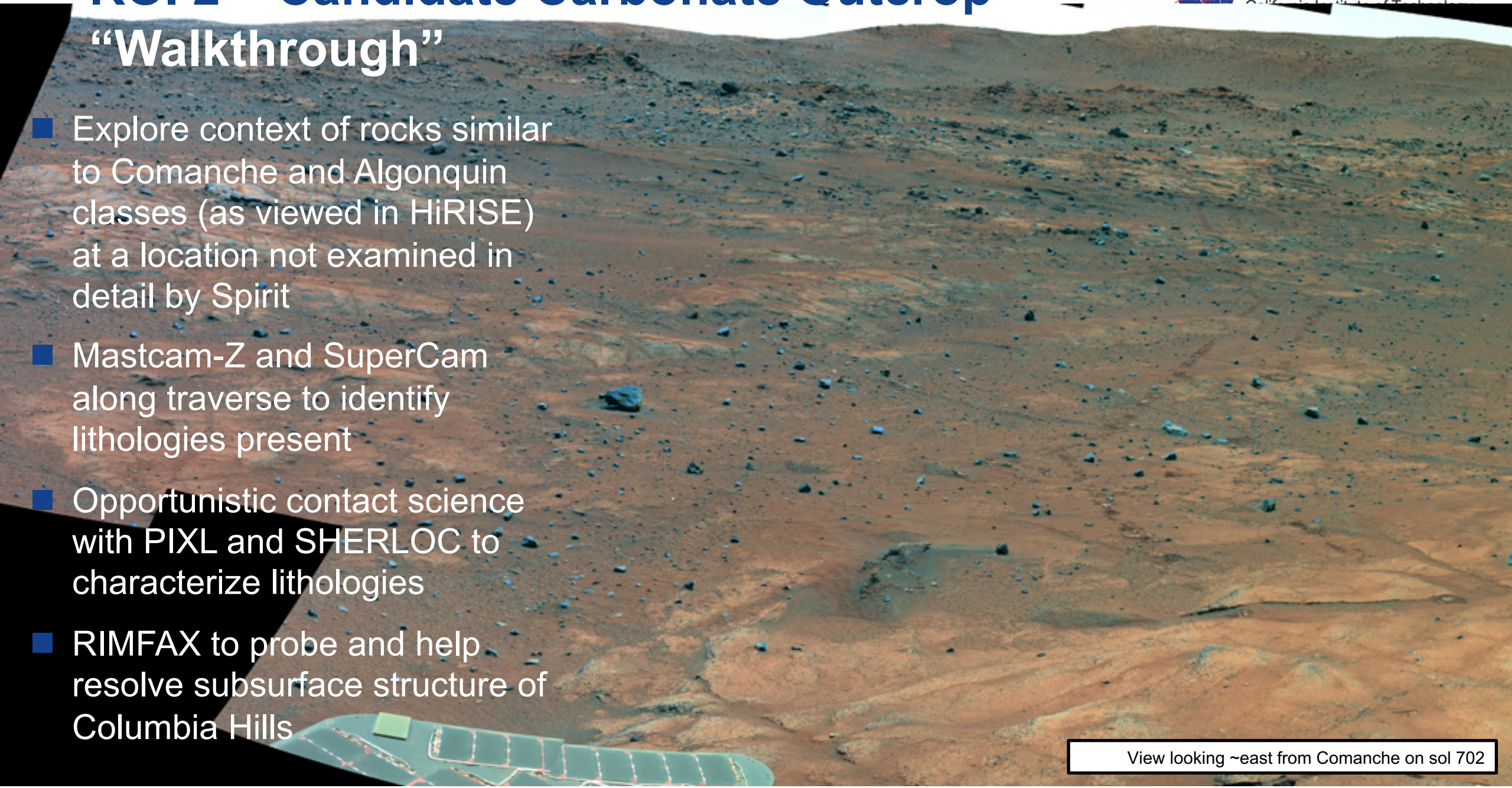
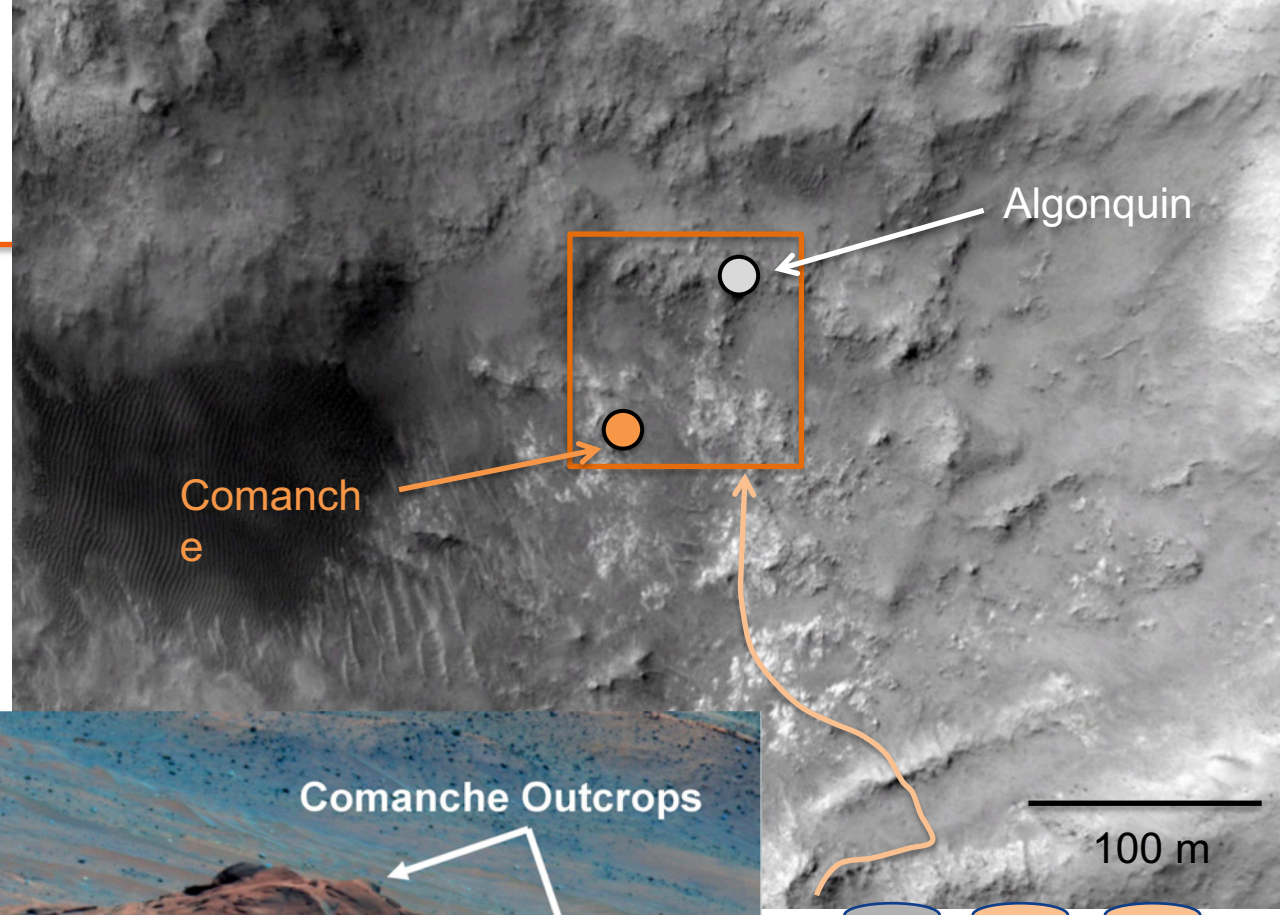
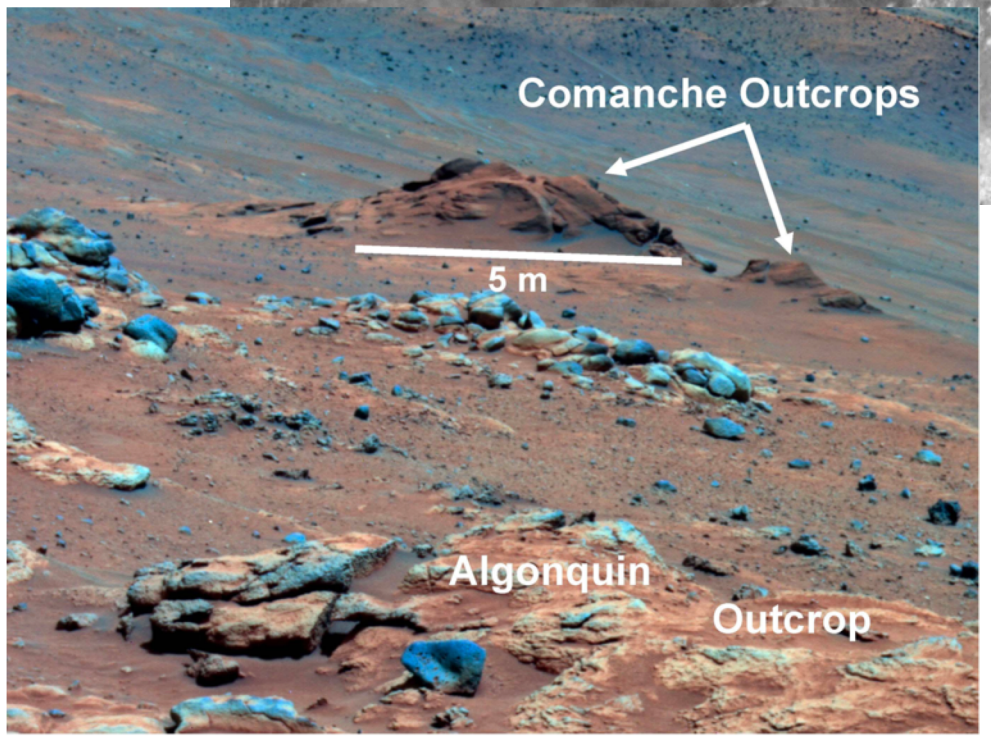


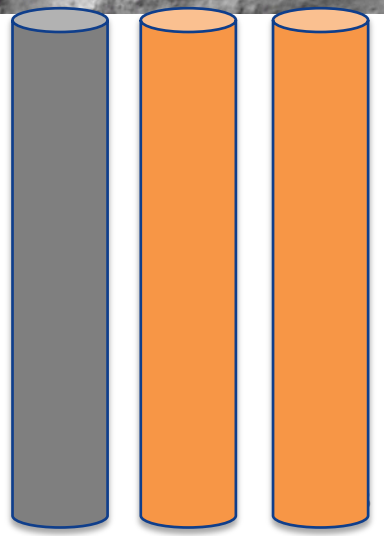
View looking ~east from Comanche on sol 702

ROI 2 – Campaign 1 – Algonquin/Comanche

- Mastcam-Z and SuperCam surveys for additional carbonate occurrences, new characterization of original occurrence
- Detailed chemistry, mineralogy and organics surveys with PIXL and SHERLOC – insight into origin
- Grain-scale texture from WATSON
- RIMFAX to probe and help resolve subsurface structure of Columbia Hills
- Acquire ultramafic Algonquin sample and Comanche ultramafic-carbonate assemblage





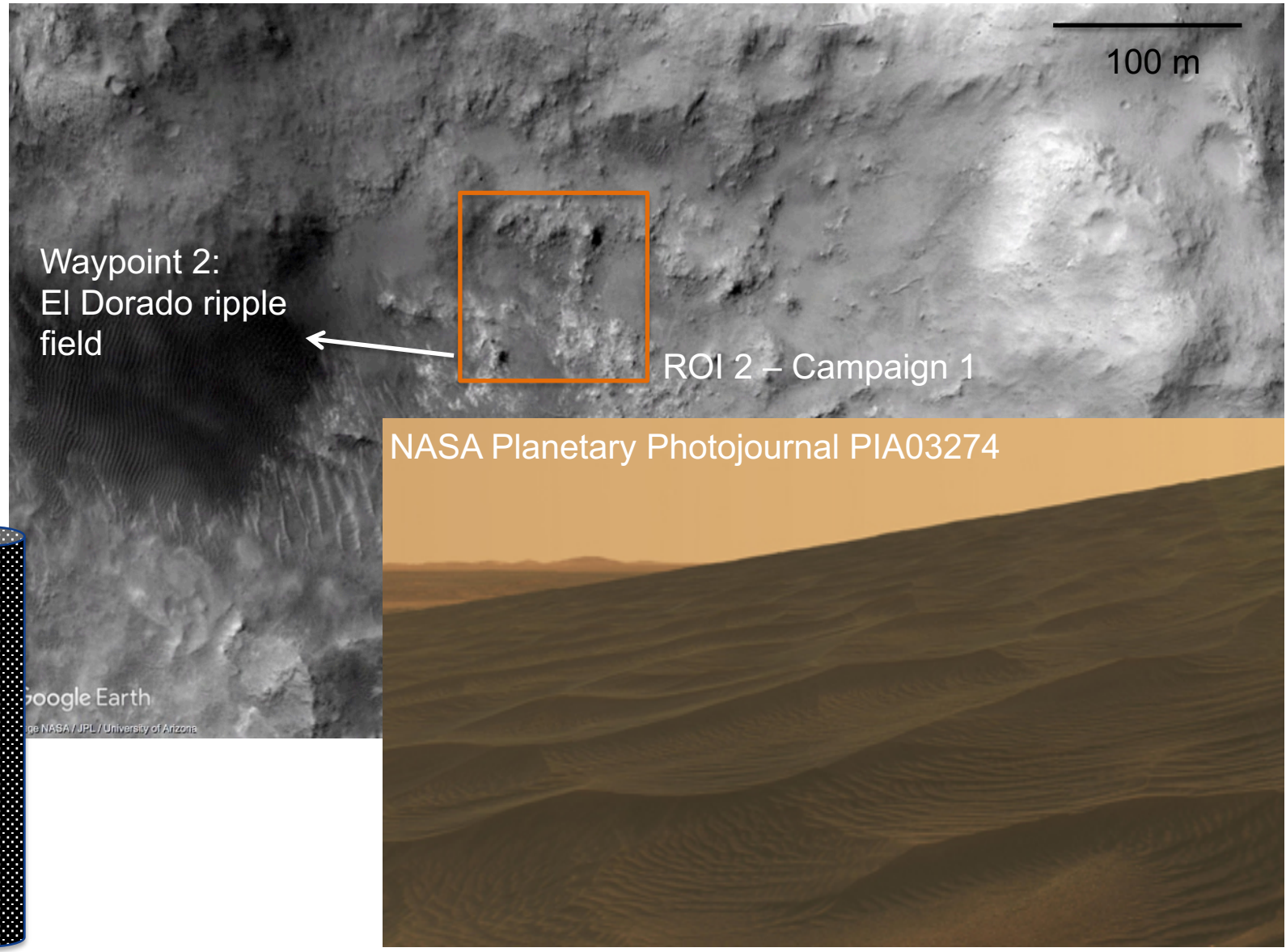


Waypoint 2 – Basaltic Soil

- Part of a soil sample suite representing compositional endmembers
- Compare mineralogy to basaltic soils studied elsewhere (e.g., Bagnold dunes, Gale crater)
- Acquire at El Dorado ripple field

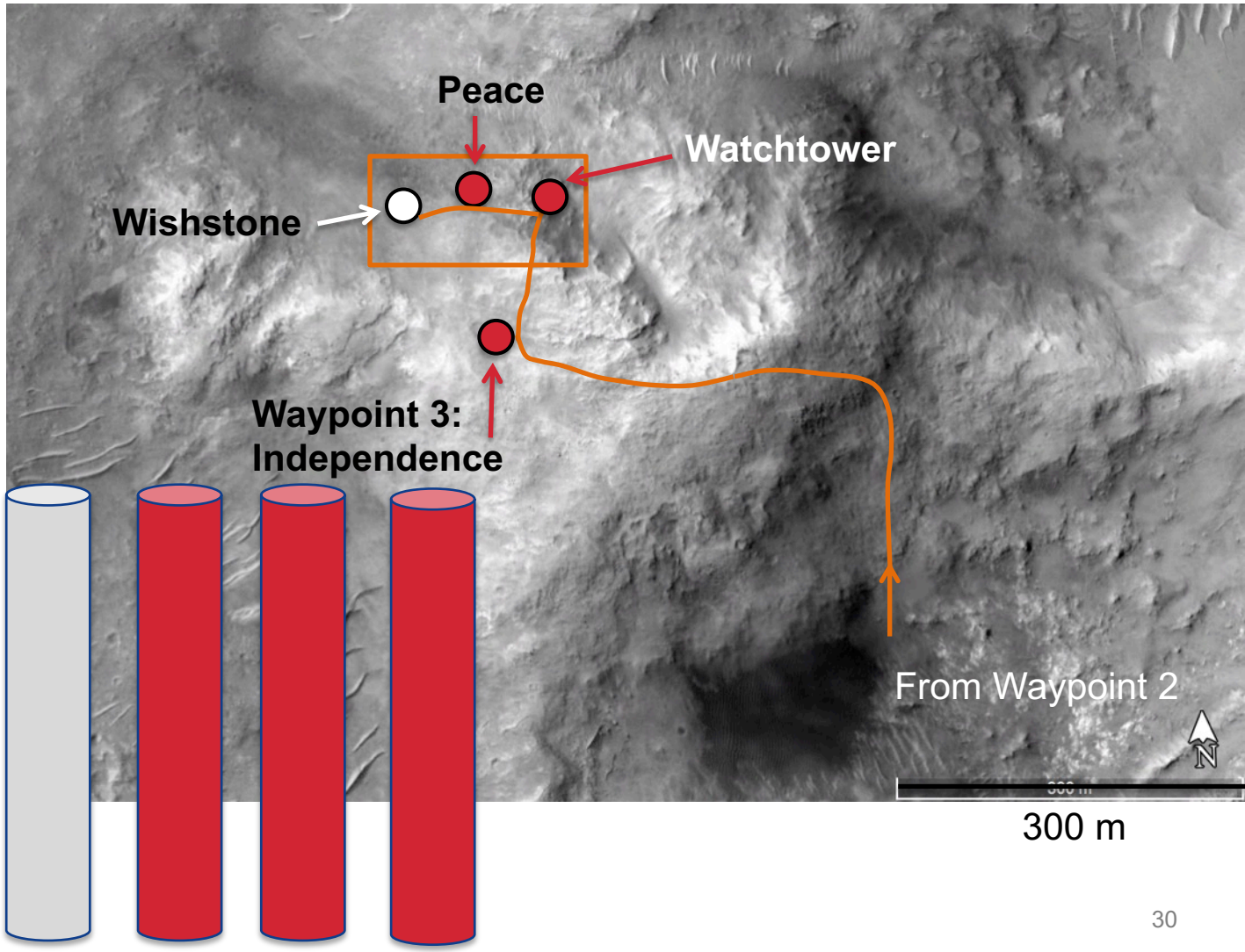
Sample 13

Acquire a relatively unaltered basaltic soil (e.g., Laguna class)



ROI 2 – Campaign 2 – West Spur Option

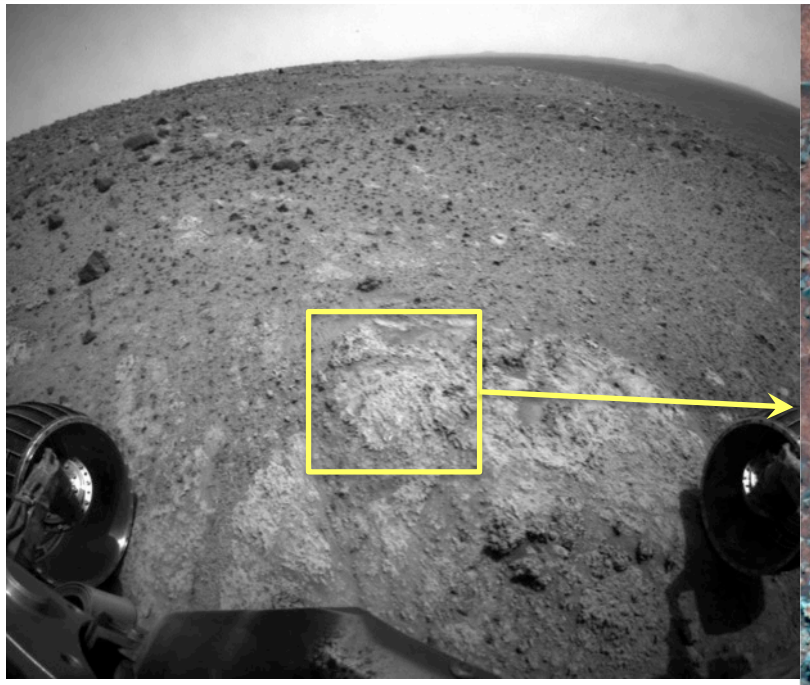
- **Waypoint 3 enroute:** Independence-class rocks (low Fe and Mg, high Al/Si, clay-bearing? [Clark et al., 2007])
- **Within campaign:** Wishstone-Watchtower pair and Peace-class
- SuperCam survey along traverse to locate new occurrences of classes and/or identify new classes
- PIXL and SHERLOC for new insight into chemistry and mineralogy of classes
- Mastcam-Z for new stereo observations of bedding geometries
- RIMFAX to probe and help resolve subsurface structure of Columbia Hills



ROI 2 – Campaign 2 – West Spur Option

- **Waypoint 3: Independence class**

- MER interpretation: aluminous, Fe-poor, clay (smectite?)-bearing outcrop (Clark et al., 2007)

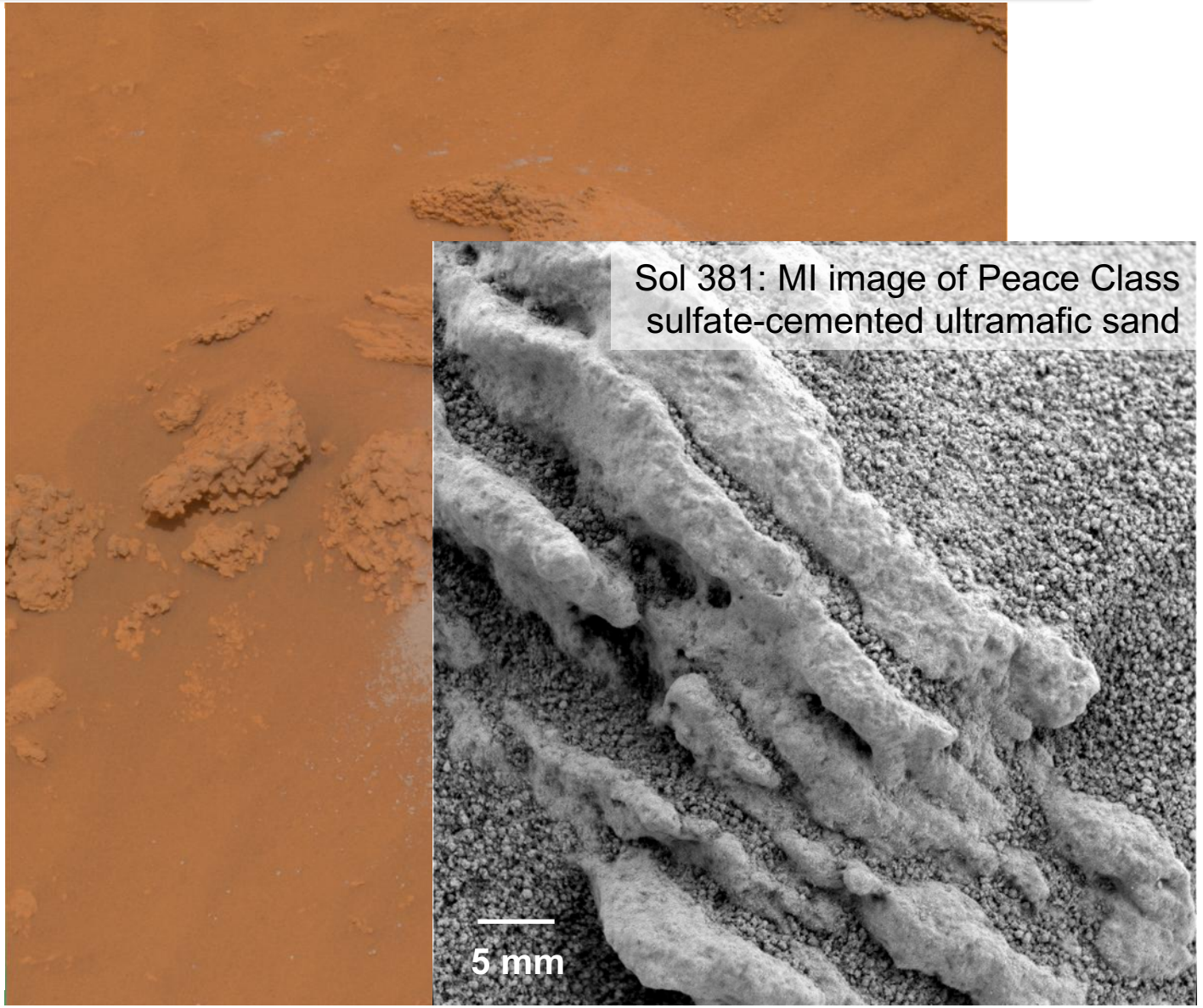


- Resolve chemical signature of clay vs. lack of spectral evidence for clay
  - SuperCam and Mastcam Z to survey outcrop chemistry and mineralogy
  - PIXL and SHERLOC for grain scale view of mineral assemblages and alteration relationships

Clark et al., 2007

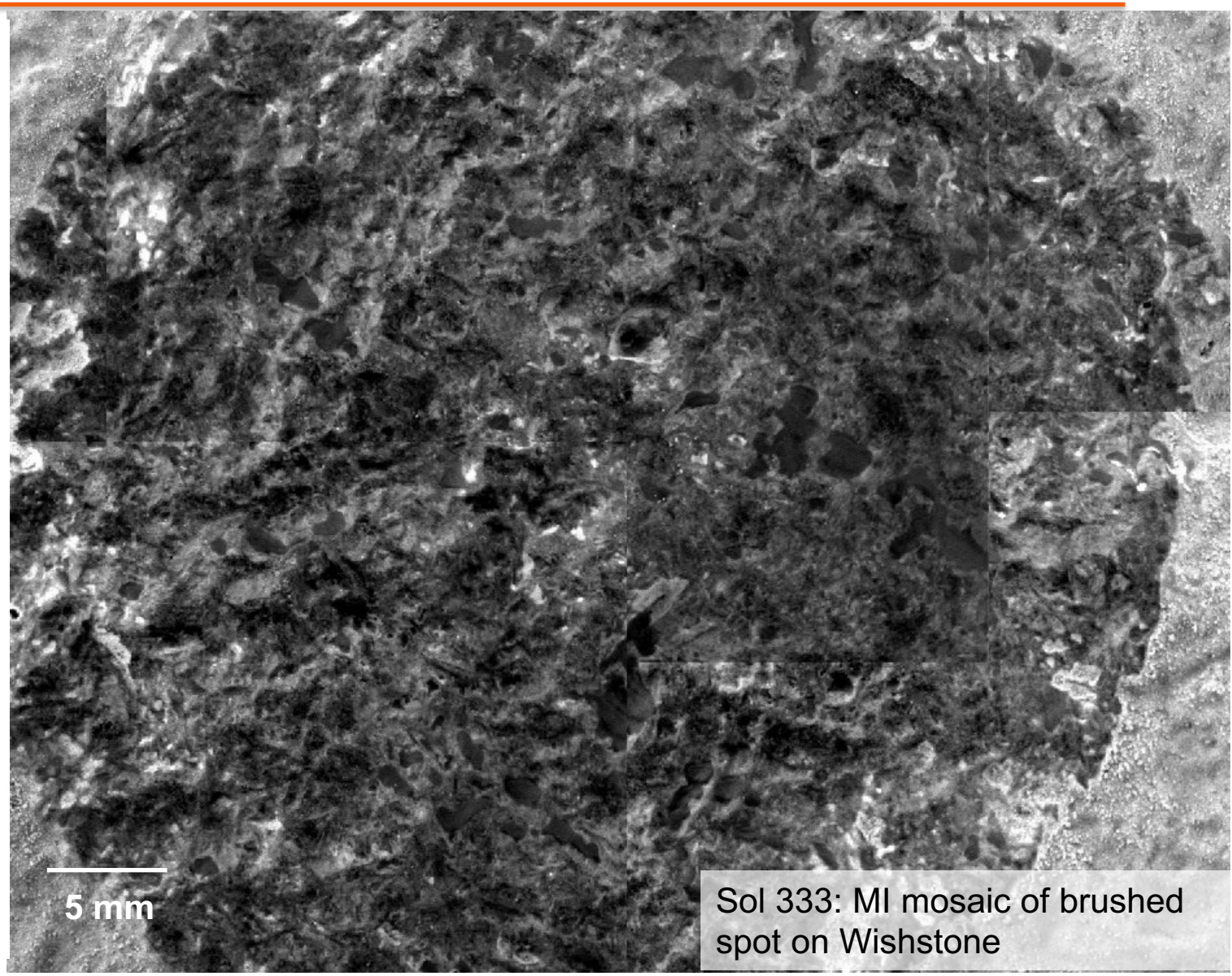
ROI 2 – Campaign 2 – West Spur Option

- **Peace class** (Squyres et al., 2006)
- MER interpretation: Magnetite-rich basaltic sandstone cemented by Mg and Ca-sulfate salts. Sand was deposited by wind or water, and briefly wetted by liquid water that evaporated, forming sulfate cement
- Mastcam Z for bedding geometry
- SuperCam for variability in outcrop chemistry
- PIXL and SHERLOC to separate matrix grain chemistry/mineralogy and cement chemistry/mineralogy, link matrix grains to other known lithologies



ROI 2 – Campaign 2 – West Spur Option

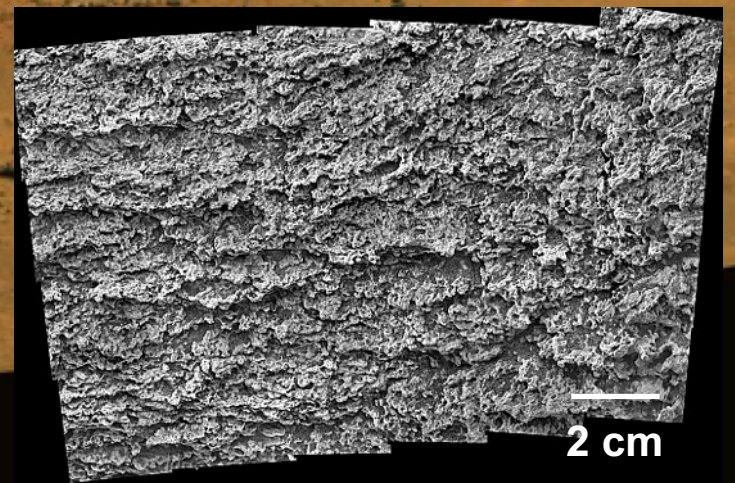
- **Wishstone class** (Squyres et al., 2006)
- MER interpretation: Moderately altered pyroclastic deposit (tephrite?)
- Mastcam Z and SuperCam to seek other examples of the class
- PIXL and SHERLOC to constrain origin of high P, Ti chemistry, grain scale maps resolve chemistry and mineralogy within the clastic texture



Sol 333: MI mosaic of brushed spot on Wishstone

ROI 2 – Campaign 2 – West Spur Option

- **Watchtower class** (Squyres et al., 2006)
- MER interpretation: Probable ejecta formed by impact(s) into Wishstone class material + an Fe-Mg-rich material. Mineralogical variability indicative of low water/rock ratio alteration post-deposition?
- Mastcam Z and SuperCam to link mineralogical variability to chemical variability
- PIXL, SHERLOC and WATSON to investigate source of mineralogical and textural variability at the grain scale
- Combined chemistry/mineralogy data to resolve endmembers contributing to the class

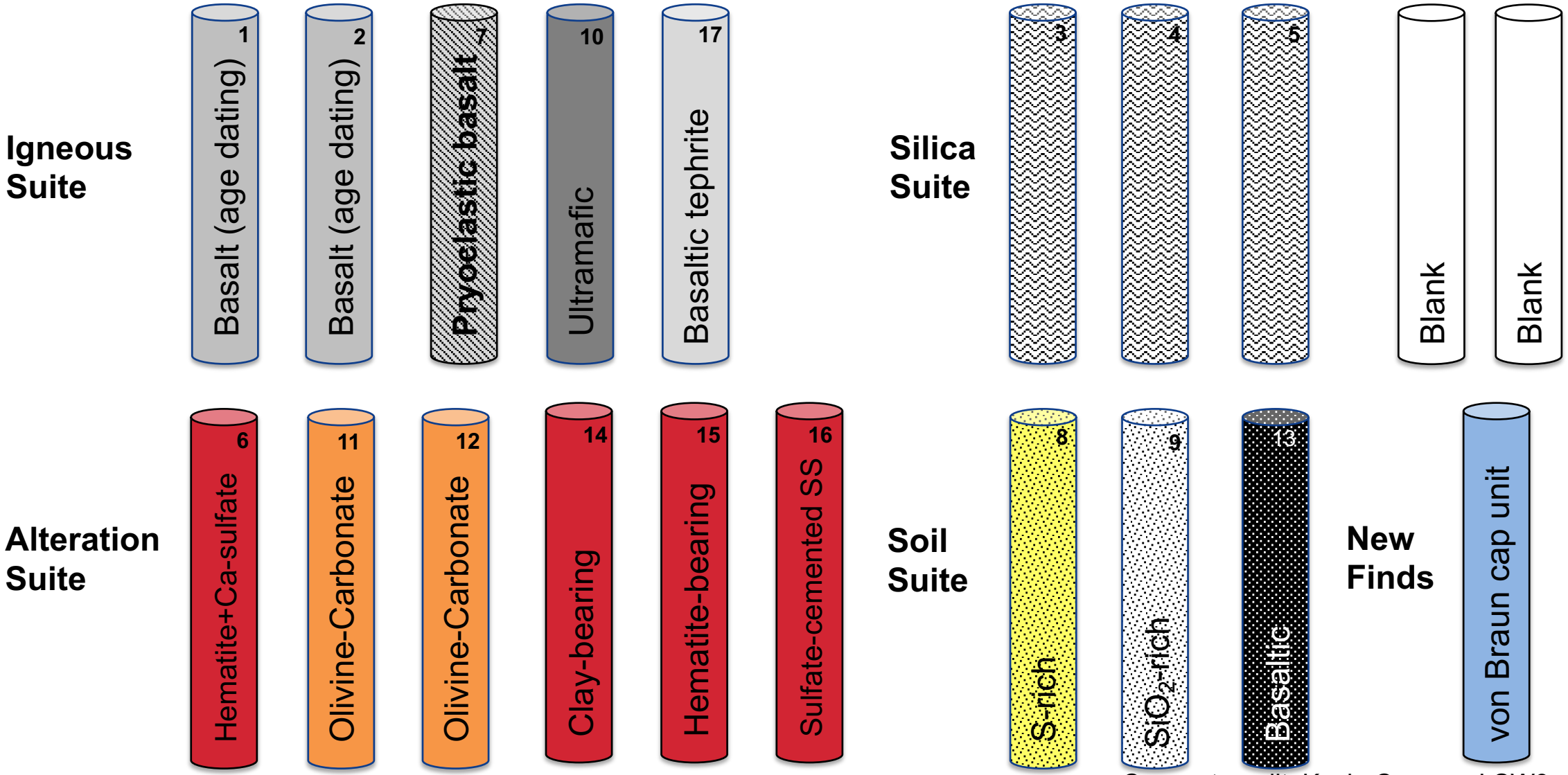


Sol 333 Microscopic Imager mosaic of Watchtower class

ROI 2 Sampling Strategy – Option 1

- Samples 10-12: Algonquin-Comanche suite
  - Algonquin-class ultramafic rock contributes to an igneous rock sample suite
  - Algonquin-Comanche pair helps constrain carbonate formation conditions (hydrothermal? lacustrine?) (Morris et al., 2010; Ruff et al., 2011)
- Sample 13: Basaltic soil
  - Completes suite of soil chemistries/mineralogies
- Samples 14-16: Lithologies representing different alteration chemistries/mineralogies
  - Independence: low Fe, clay? (Clark et al., 2007)
  - Watchtower: very high $Fe^{3+}/Fe_{(total)}$, elevated P, Ti (Ming et al., 2008)
  - Peace: sulfate-cemented ultramafic sandstone (Squyres et al., 2006)
- Sample 17: Relatively unaltered igneous lithologies (McSween et al., 2008)
  - Wishstone: strongly alkalic tephrite, P-rich – paired with Watchtower sample
  - Contributes to an igneous rock sample suite

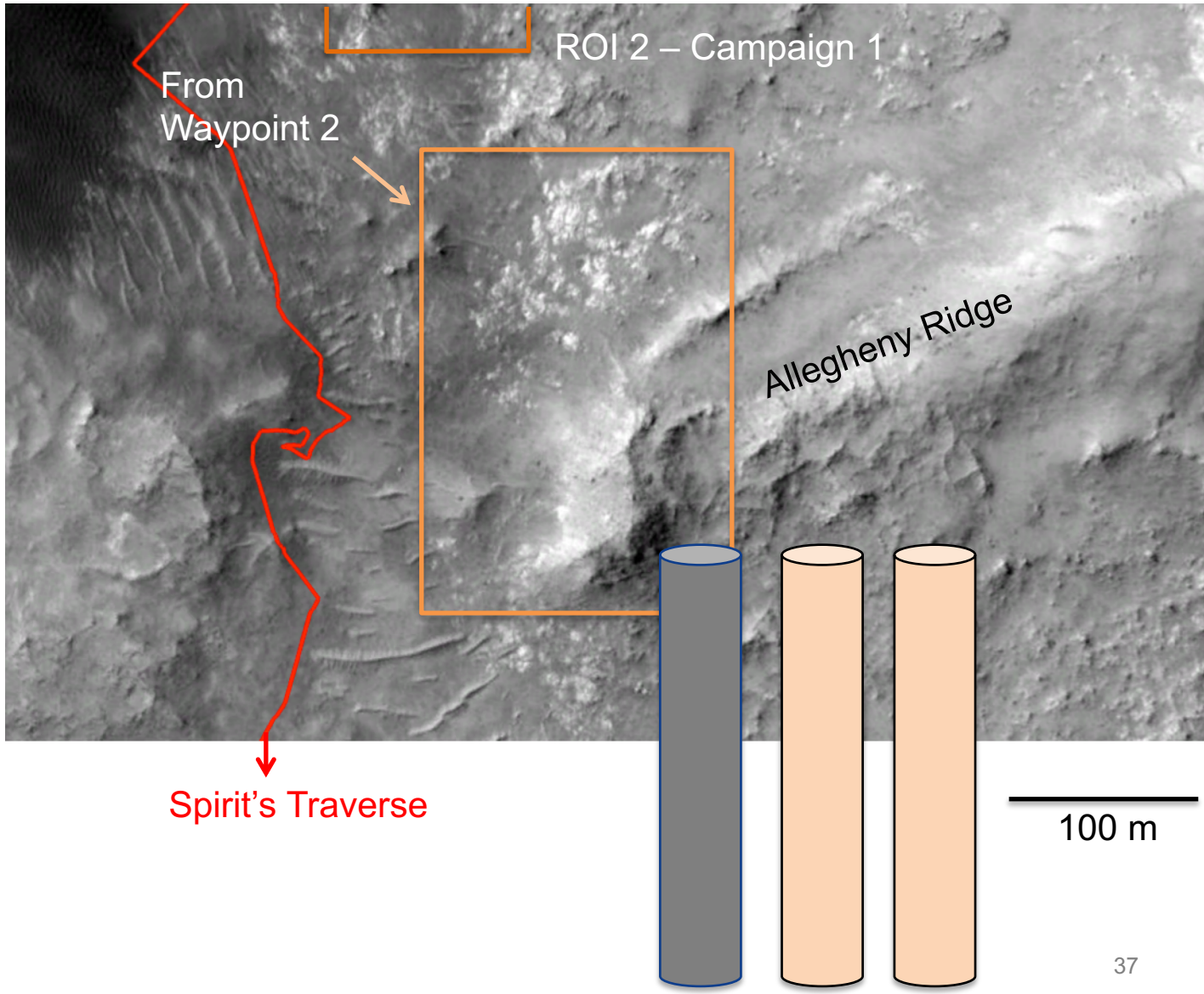
Summary: Baseline Sample Cache (option 1)



Concept credit: Kevin Cannon, LSW3, slide 38

ROI 2 – Campaign 2 – Allegheny Ridge Option

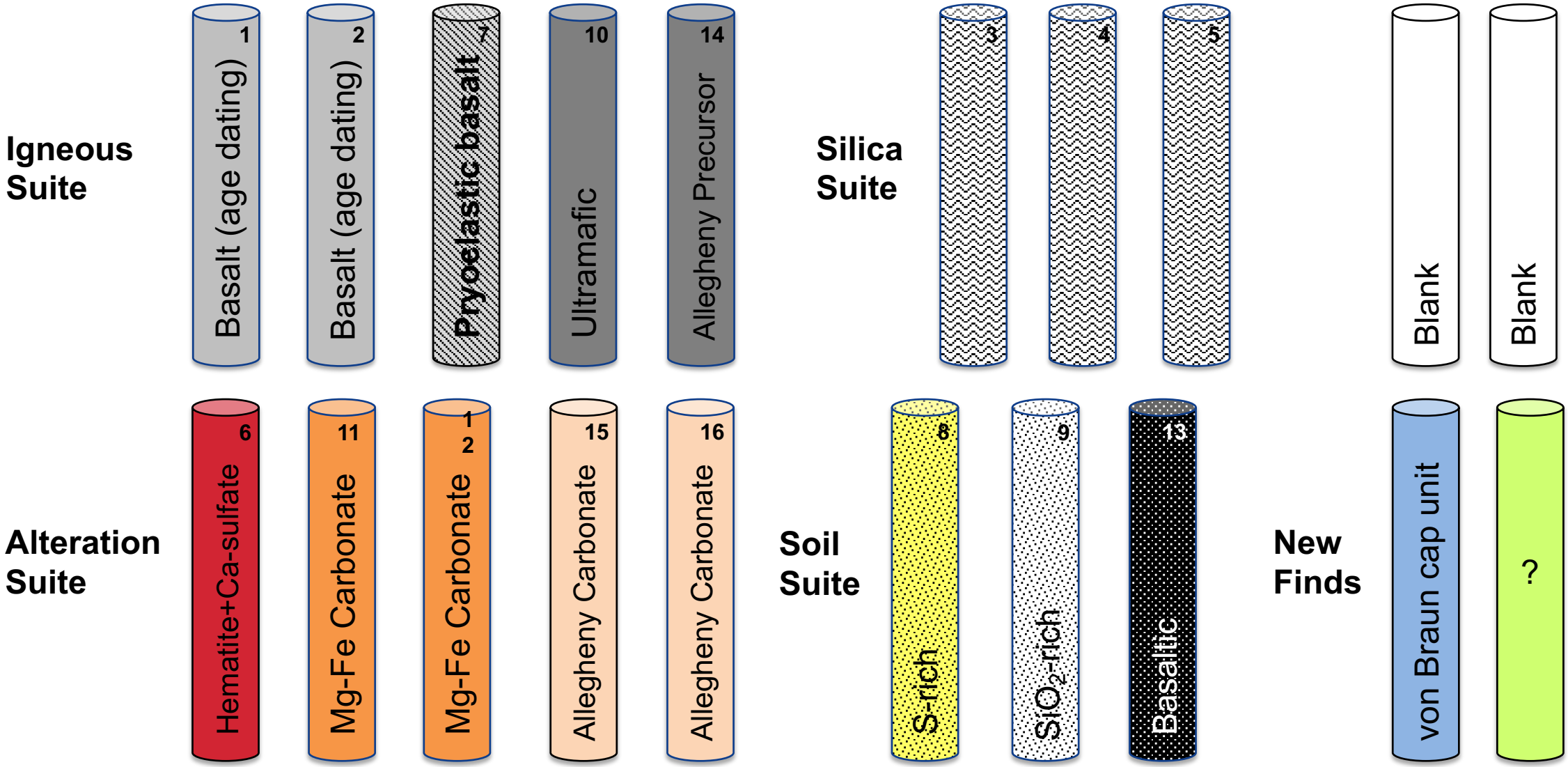
- Return to Allegheny Ridge informed by observations acquired during traverse from ROI 1 to ROI 2
- Detailed PIXL, SHERLOC and WATSON at sites of interest for further insight into chemistry, mineralogy, organics and texture
- SuperCam and Mastcam-Z to locate new occurrences of classes and/or identify new classes
- Mastcam-Z for new stereo observations of bedding geometries
- RIMFAX to further probe subsurface structure of Columbia Hills
- Select sample acquisition sites



ROI 2 Sampling Strategy – Option 2

- Samples 10-12: Algonquin-Comanche suite
  - Algonquin-class ultramafic rock contributes to an igneous rock sample suite
  - Algonquin-Comanche pair helps constrain carbonate formation conditions (hydrothermal? lacustrine?) (Morris et al., 2010; Ruff et al., 2011)
- Sample 13: Basaltic soil
  - Completes suite of soil chemistries/mineralogies
- Samples 14-16: Allegheny Ridge samples
  - If lithologies are related to Algonquin-Comanche suite, acquire one unaltered (or precursor) sample and two carbonate-bearing samples
  - If lithologies differ from those found previously by Spirit and/or by Mars 2020, acquire three (or more) samples that represent the diversity within the campaign area

Baseline Mission Sample Cache – Option 2



Concept credit: Kevin Cannon, LSW3, slide 38

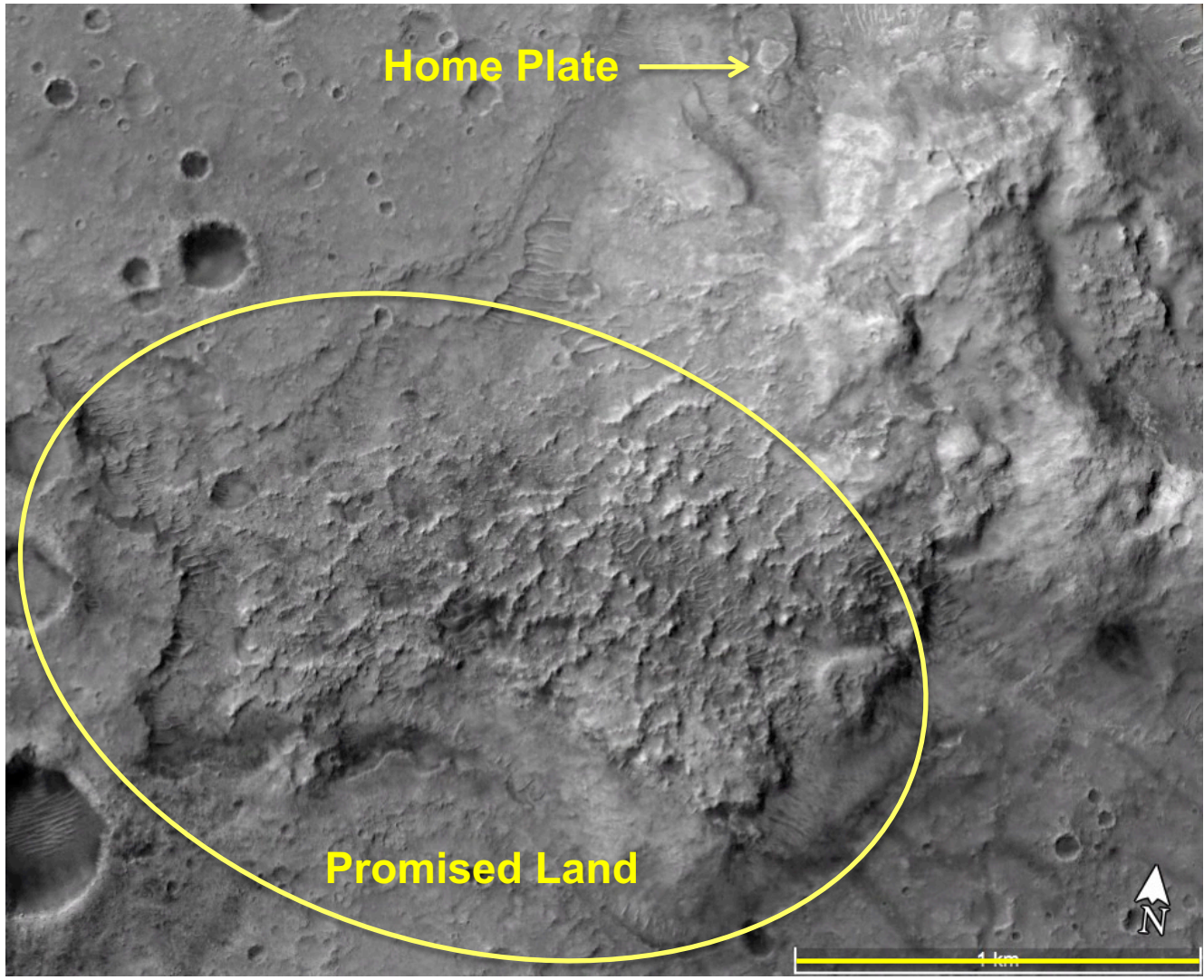
Summary of returned sample science mission strategies and objectives

Jet Propulsion Laboratory
California Institute of Technology

- **Biosignatures:** Determine if the opaline silica structures at Home Plate are biologically mediated, and contain evidence for past Martian life
- **Ancient Aqueous Conditions and Habitability:** Utilize the altered rock classes to determine the conditions (e.g., Eh, pH, water/rock ratio, fluid chemistries) and timing of their formation.
  - Utilize the microcrystalline structure, bound water, and potentially trapped fluids and gases in inclusions within the opaline silica samples to assess the history/temperature/chemistry of water in an ancient hydrothermal system (some analyses may only be possible if silica is a precipitate)
  - Utilize the Comanche-type carbonate-olivine assemblages to investigate the aqueous geochemistry of the carbonate formation environment and the implications for the history of surface water and habitability.
- **Geochronology:** Determine the age of the volcanic floor of Gusev crater using multiple geochronometers and feed forward into relative age dating of surfaces on Mars. Determine the age of carbonates.
- **Carbon Cycle:** Determine carbon isotopic ratios (^{13}C, clumped isotopes) in carbonate samples to assess the evolution of the carbon cycle.
- **Hydrologic Cycle:** Determine how the formation of hydrated opaline silica, sulfate soils and clay minerals recorded or influenced the Martian hydrologic cycle (e.g., ^{18}O, D/H, synchrotron analysis of structure).
- **Igneous History:** Through petrology, trace element analysis, and isotopic geochemistry relate Gusev igneous lithologies (ultramafic, mafic, alkalic) to one another and to the Martian meteorites, and gain insight into the formation and differentiation history of Mars from *in-place* samples
- **Magnetic Field:** Determine if any primary igneous lithologies preserve a magnetic field (SQUiD micro-magnetic analyses).

Extended Mission Exploration

- West Spur (see slides 30-37)
- The “Promised Land”
  - High thermal inertia, “etched terrain” (Milam et al., 2003)
  - Fe-Mg clay spectral signatures from orbit (Carter and Poulet, 2012)
  - Within 2 km from ROIs
- “Italy” kipuka
  - High thermal inertia, “etched terrain” (Milam et al., 2003)
  - Another window through the Hesperian floor cover – lacustrine deposits?
  - <5 km from southern end of “Promised Land”



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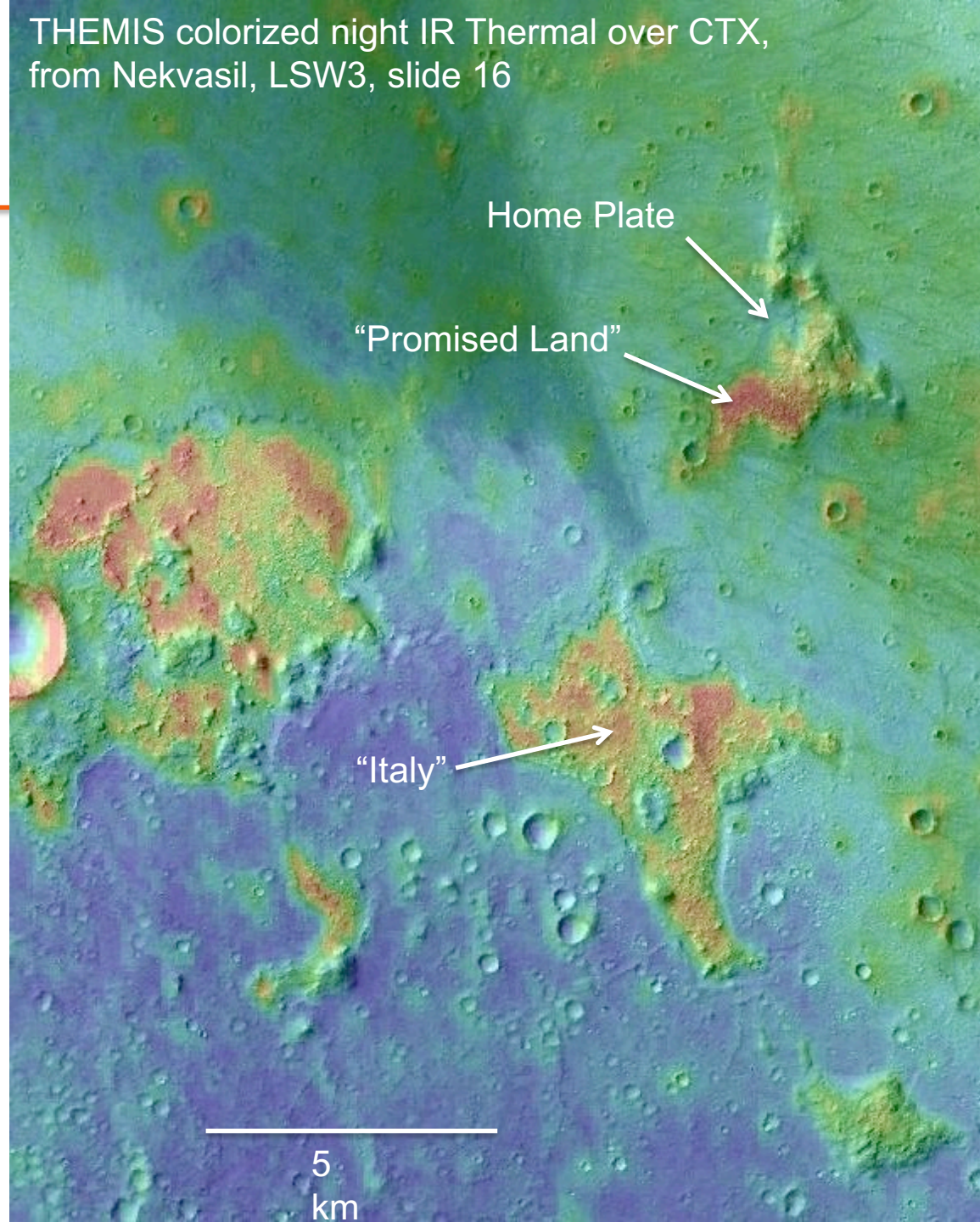
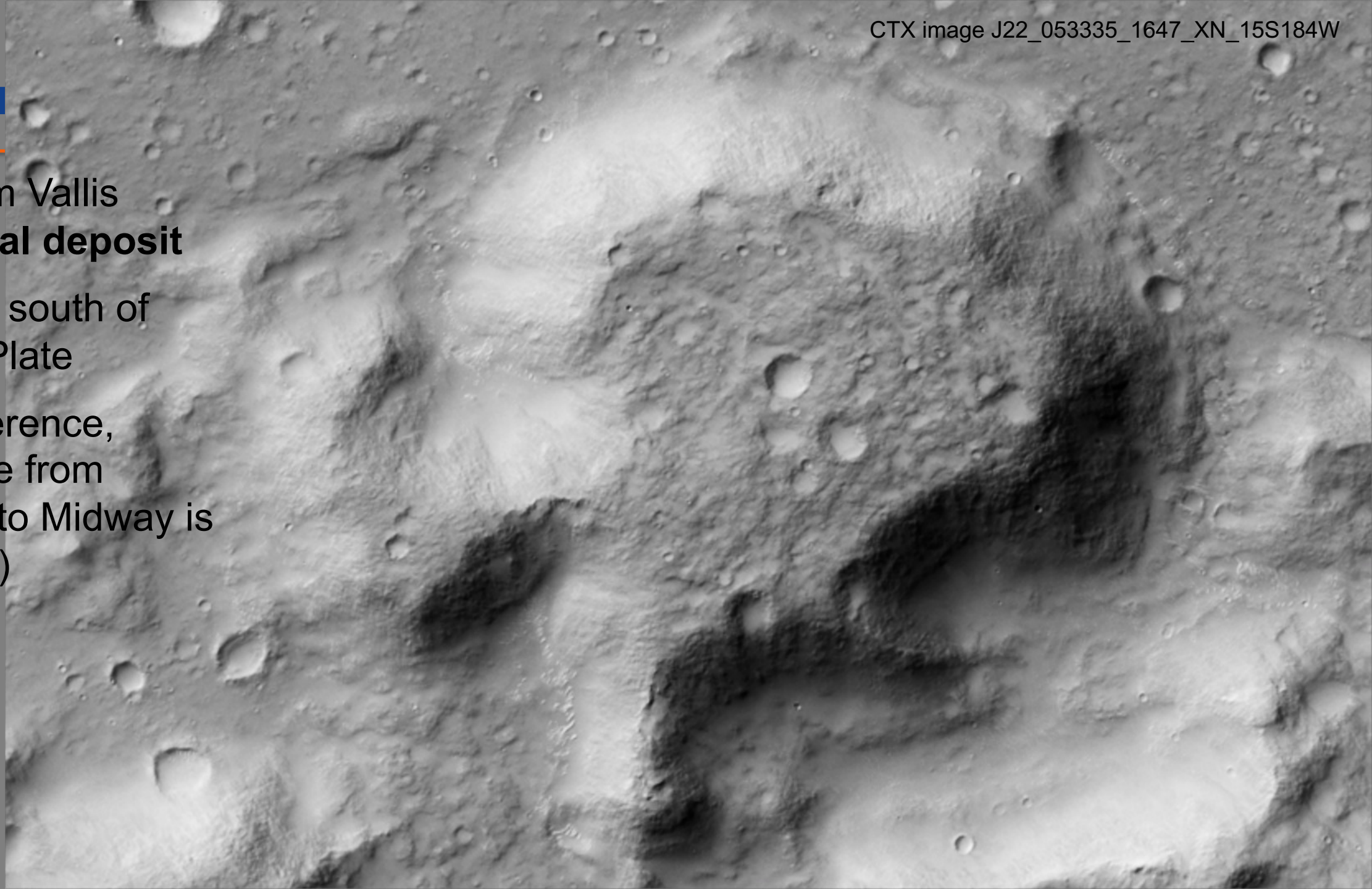


Exte

- Ma’adim Vallis **proximal deposit**
- ~23 km south of Home Plate
- (for reference, distance from Jezero to Midway is ~27 km)



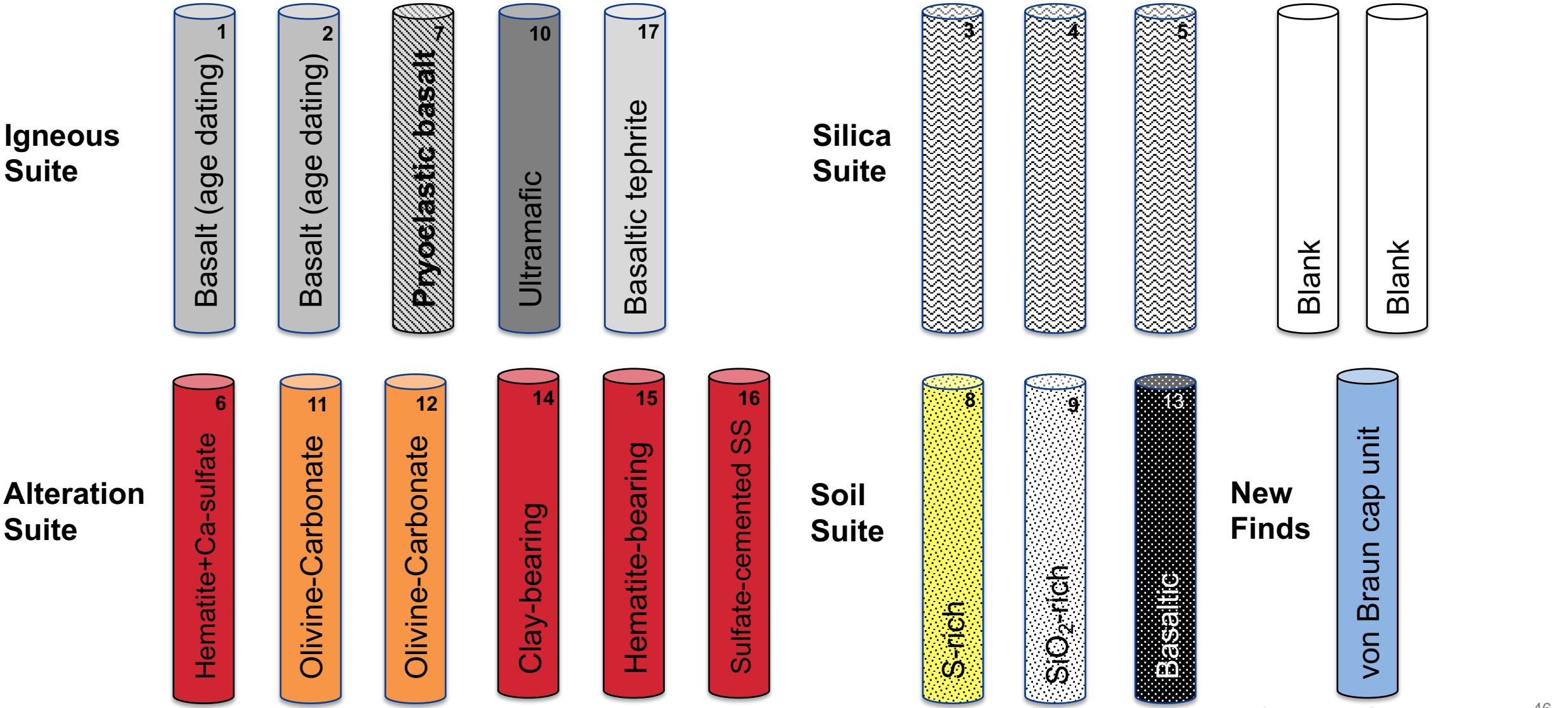
Benefits of a Mars 2020 mission unique to Columbia Hills

- In-situ identification of a potential biosignature
- A dateable surface and additional diverse and dateable igneous lithologies
- Evidence for habitable, volcanic-hosted, near-surface hydrothermal settings
- A diverse range of alteration chemistries and mineralogies in rocks and soils
- Existing knowledge of the overall geology and the compact, closely spaced ROIs enable efficient scientific exploration and execution of campaigns during the prime mission
  - No need to: test hypotheses about geologic setting that are based on orbital data; search for and identify sites of high-priority biosignature potential; halt or shorten drives to investigate exotics
  - More time to: refine existing models developed by the Spirit team using new observations by Mars 2020; explore the heterogeneity at each sampling site and thus increase our confidence in selecting the sample(s) of greatest interest and with the best geologic context
- Existing data from the Spirit mission could potentially enable strategic planning during the prime mission

Mars 2020 Science Team Concerns About Columbia Hills

- Opaline silica deposits
  - Multiple possible origins (biotic vs. abiotic, precipitation vs. leaching) may be difficult to resolve with M2020 instruments
  - Morphology will also make abrading and core sample acquisition challenging
- Likely dust/soil obscuration poses some challenges for “as-is” surface observations, long distance spectroscopy observations, and comparisons to orbital spectral data
- Limited outcrop exposure and extensive regolith cover both within Columbia Hills and around Home Plate makes advancements related to geologic context and stratigraphic/relative age relationships challenging during the prime mission
- As a site explored by a previous rover mission, Columbia Hills offers less potential to broaden our scientific knowledge of Mars than a new site

Columbia Hills Sample Cache – Option 1



Concept credit: Kevin Cannon, LSW3, slide 38