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Mars 2020 Science Team Assessment of Jezero crater

Mars 2020 4th Landing Site Workshop

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

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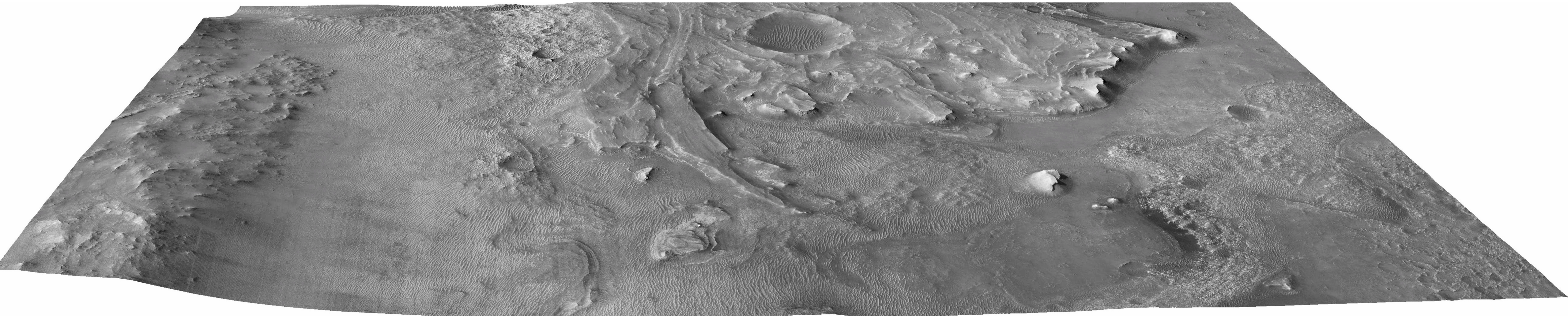
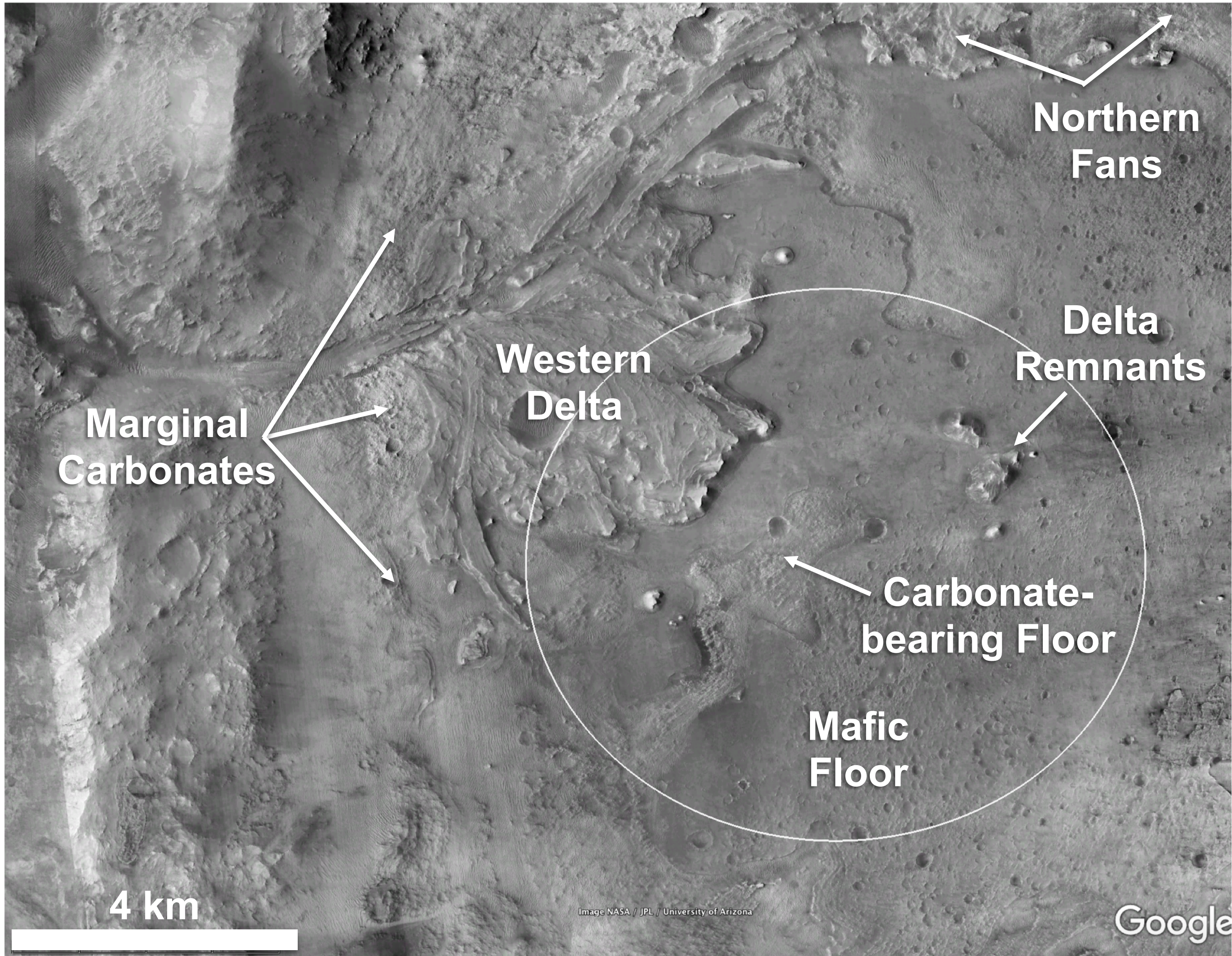


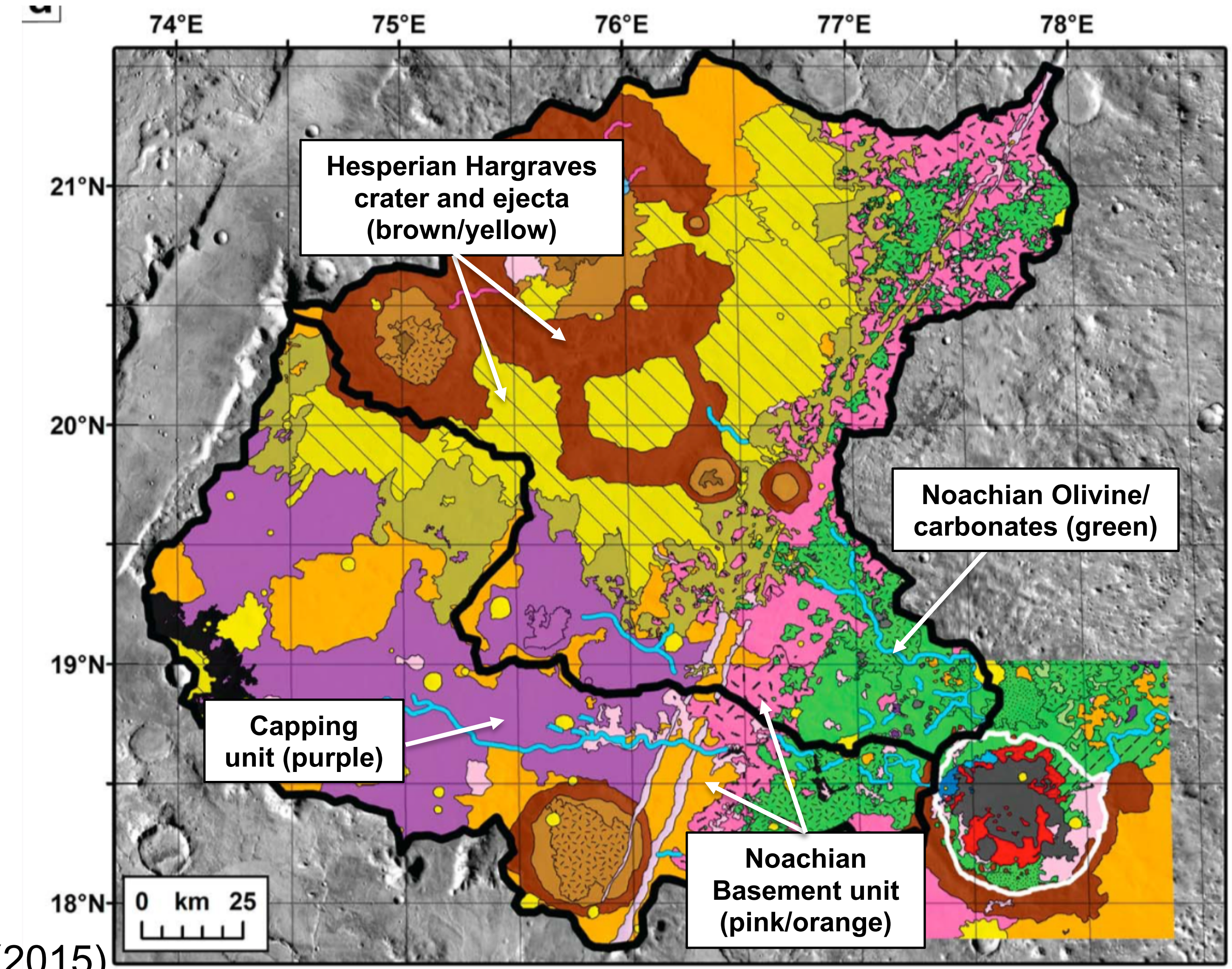
Overview of Jezero crater

- Jezero is a Noachian crater that once contained a paleolake and delta(s), fed by large regional watersheds
- Carbonates in a variety of depositional settings contrast with Hesperian sites like Meridiani and Gale
- Distal delta-lacustrine 'bottomset' beds (mudstones?) and near-shore carbonates both have high biosignature preservation potential



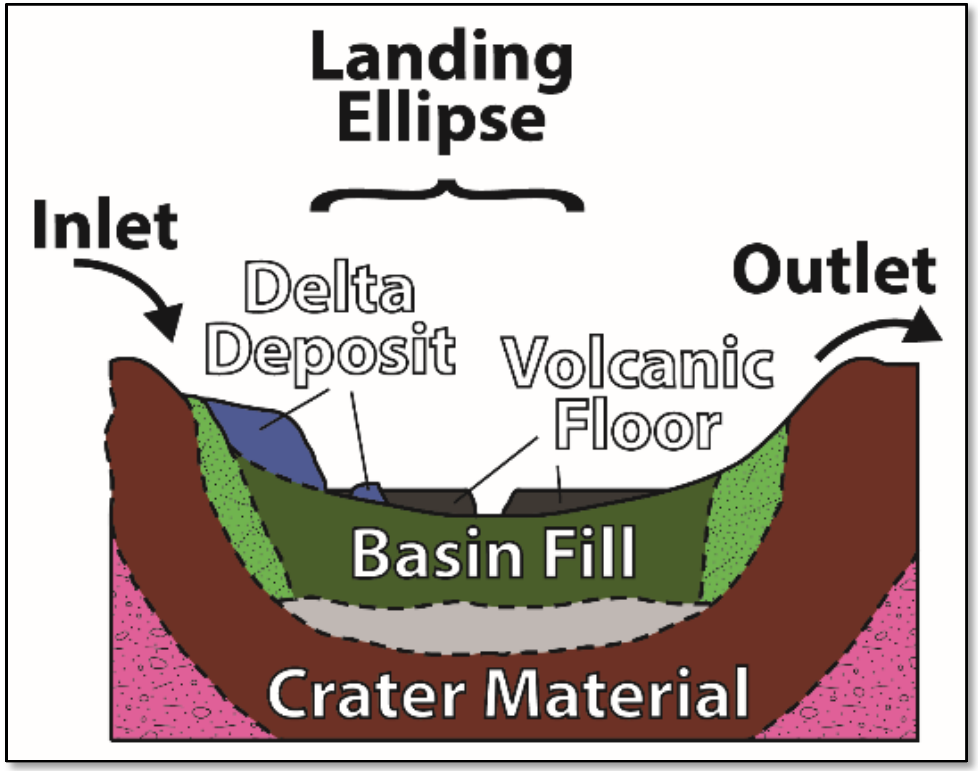
Overview of Jezero crater

- Jezero is located on the inner ring of the Isidis Basin, and impacted into basement materials interpreted to be Isidis ejecta
- The Jezero impact likely pre-dates the regional olivine/carbonate unit, placing the impact in the Noachian
- Both of these regional units contribute to the two large watersheds that fed the Jezero paleolake



Goudge et al. (2015)

Science questions for igneous and impact units in Jezero crater

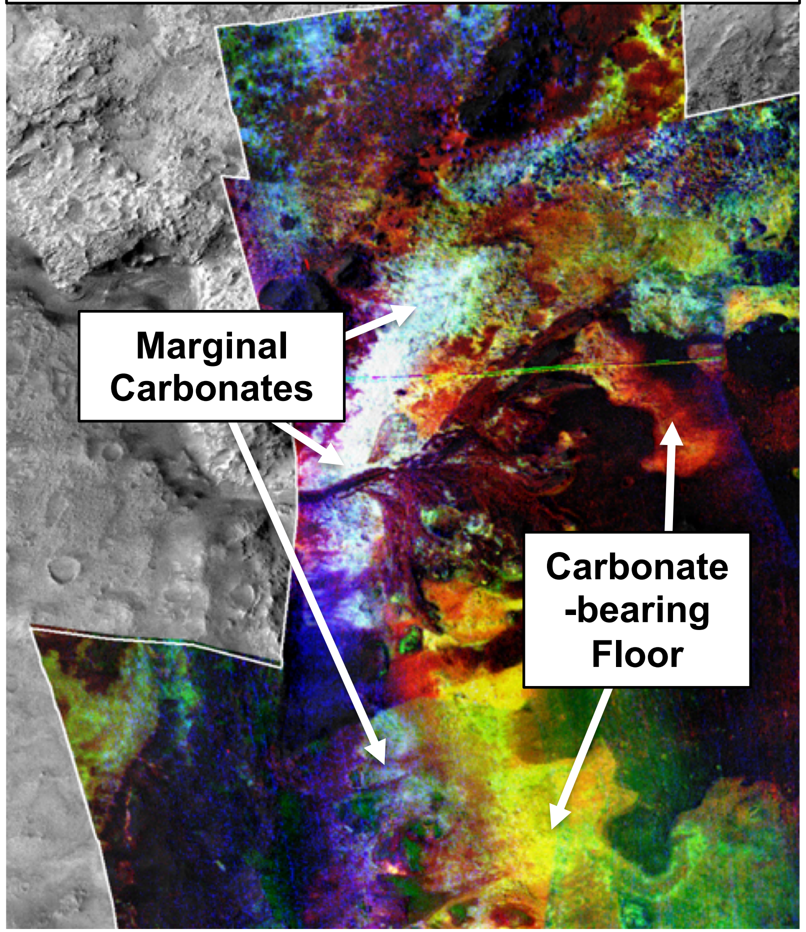


Goudge et al. (2015)

- **Mafic Floor:**
  - ☐ Igneous or sedimentary? Superposed or interstratified with the delta?
  - ☐ What can the petrologic properties of the unit tell us about martian volcanism?
  - ☐ What is the unit's age and burial history?
- **Crater rim and basement unit:**
  - ☐ What is the origin and alteration history of the regional Noachian crust?
  - ☐ Did Jezero generate an impact hydrothermal system, and do precipitates from that system preserve biosignatures?

Science questions for carbonate units in Jezero crater

CRISM diversity within carbonate units
Blue/white = strong carbonates, Green = strong hydration, Red/yellow = strong olivine



Horgan et al., submitted

- **Marginal Carbonates and Carbonate-bearing Floor**
  - What is the relationship between the carbonates in Jezero and those on the surrounding plains?
  - Do the Marginal Carbonates contain near-shore precipitates, and do they preserve potential biosignatures?
  - Was the olivine/carbonate-bearing floor transported via fluvial/aeolian processes or emplaced along with the regional unit, and how did the carbonate form?
  - Do the carbonate deposits contain a record of Noachian atmospheric composition and escape?

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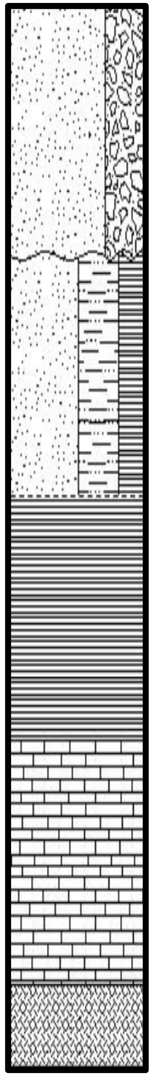
Science questions for Jezero basin infill



Inverted Channels

Point Bar unit

Lower delta strata

Distal delta-lacustrine strata 'bottomsets'

Ol-carbonate-bearing Floor unit

- **Delta-lacustrine stratigraphy**
  - ☐ Were the lake and delta surface habitable environments, and do their sediments contain biosignatures & organics?
  - ☐ What does the Jezero stratigraphy tell us about early Mars valley network hydrology and erosion?
  - ☐ What does the chemistry of the sediments tell us about early Mars chemical weathering processes?
  - ☐ What can we learn about ancient subsurface water flow and habitability from diagenesis of the sediments?

Goal that provides enduring focus to the mission

To explore the history of water and chemistry in an ancient crater lake basin and associated river-delta environments to probe early Martian climates and search for life

Summary of in-situ mission strategies and objectives

- **HABITABILITY** - Determine if fine-grained lower delta strata, delta top, and carbonate-bearing units were habitable environments. Determine if serpentinization occurred in carbonate units.
- **BIOSIGNATURE PRESERVATION** – Search for organics derived from lacustrine environments in delta bottomsets, as well as morphological biosignatures in marginal carbonate units.
- **RELATIVE CHRONOLOGY** - Determine the relative age-relationships of the Mafic Floor, Carbonate-bearing Floor, and delta stratigraphy using stratigraphic observations
- **IGNEOUS HISTORY** - Determine igneous geochemistry of Mafic Floor unit (if volcanic flow or ash) or provenance/diagenesis if cemented sandstone
- **CARBONATES** - Characterize the texture, mineralogy and chemistry of carbonate-bearing Light-toned Floor and Marginal Carbonates, and regional olivine/carbonate unit
- **LAKE EVOLUTION** – Analyze delta succession and marginal deposits to determine open/closed basin history, number and duration of major lacustrine sequences, geochemical evolution of the lake
- **NOACHIAN CLIMATE** – weathering history of detrital and sub-aerial deltaic sediments, stratigraphic record of valley network activity, chemistry of surface waters, surface hydrology
- **CHEMISTRY & HISTORY OF SUBSURFACE WATER** – diagenesis of sedimentary rocks, chemistry of fracture-fills, alteration of olivine/carbonate-bearing units

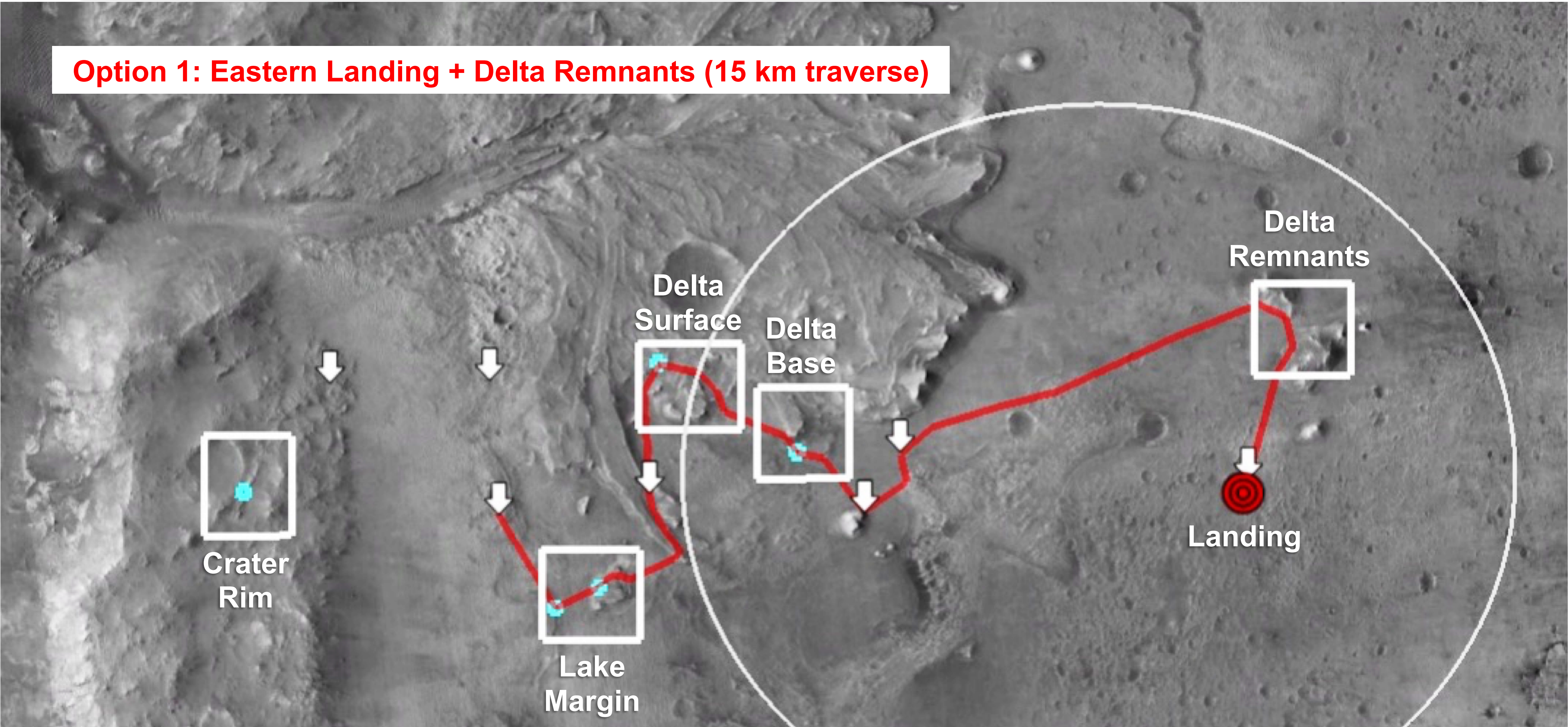
Notional Mission Scenario for Jezero Crater

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.

”In preparing for battle I have always found that plans are useless but planning is indispensable.”

-Dwight D. Eisenhower

Notional Mission Scenario for Jezero crater



Notional Mission Scenario for Jezero crater

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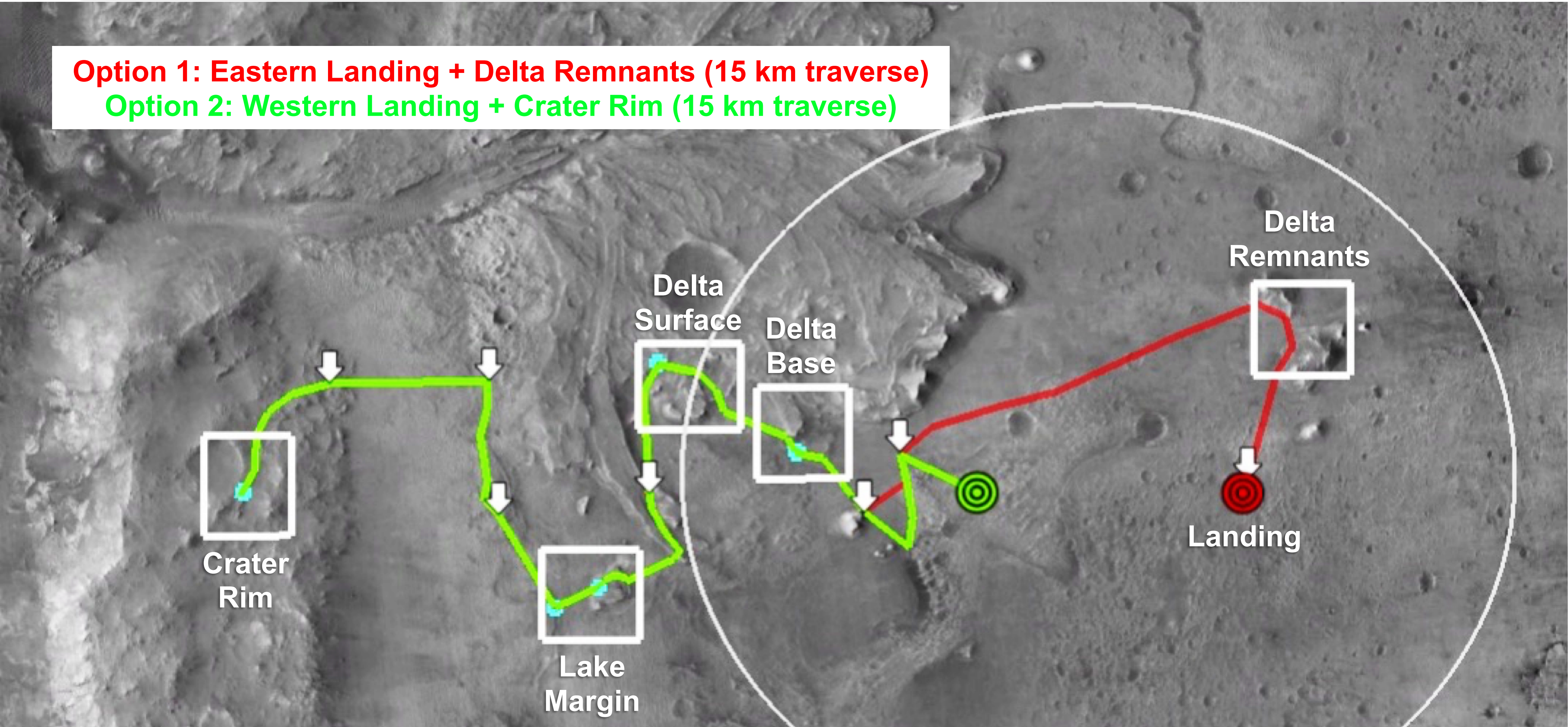

Notional Mission Scenario for Jezero crater

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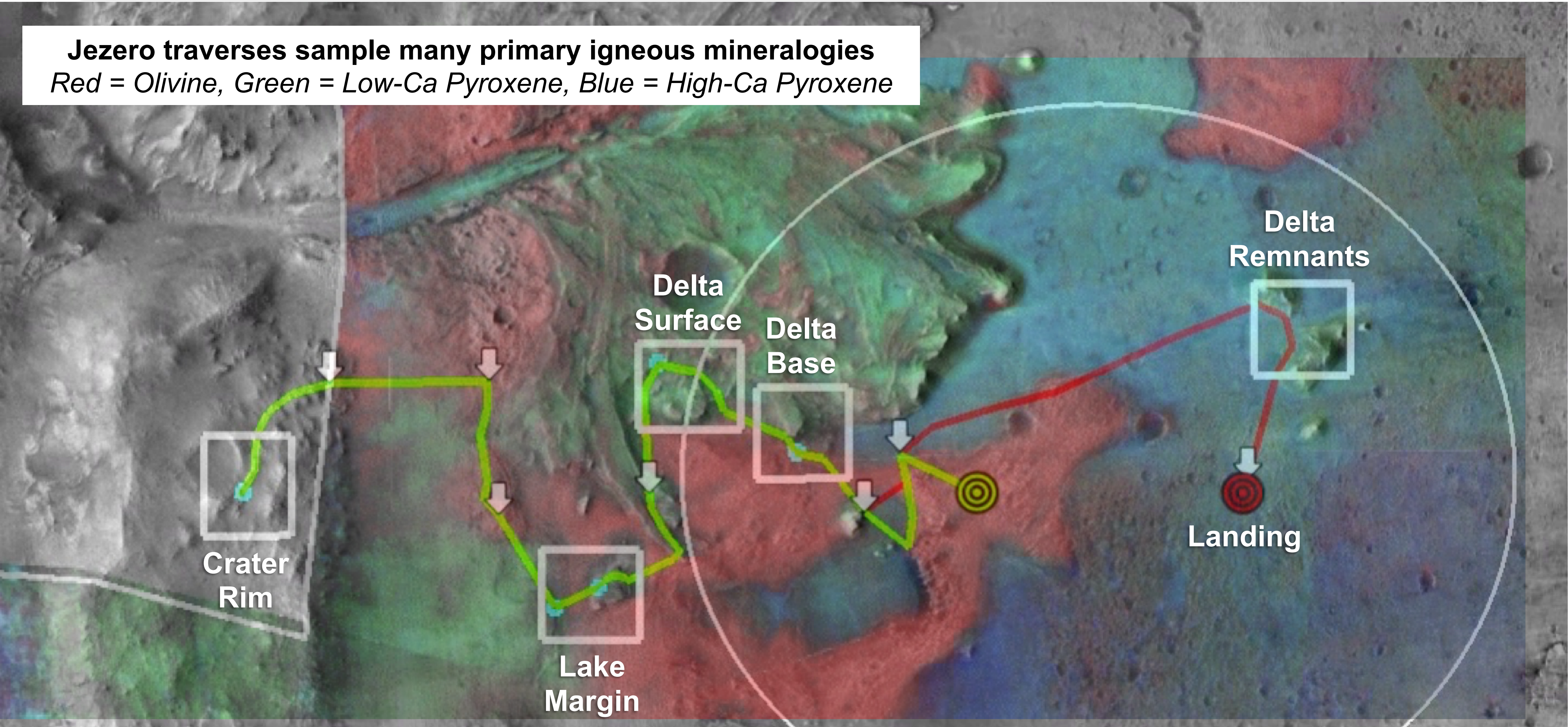
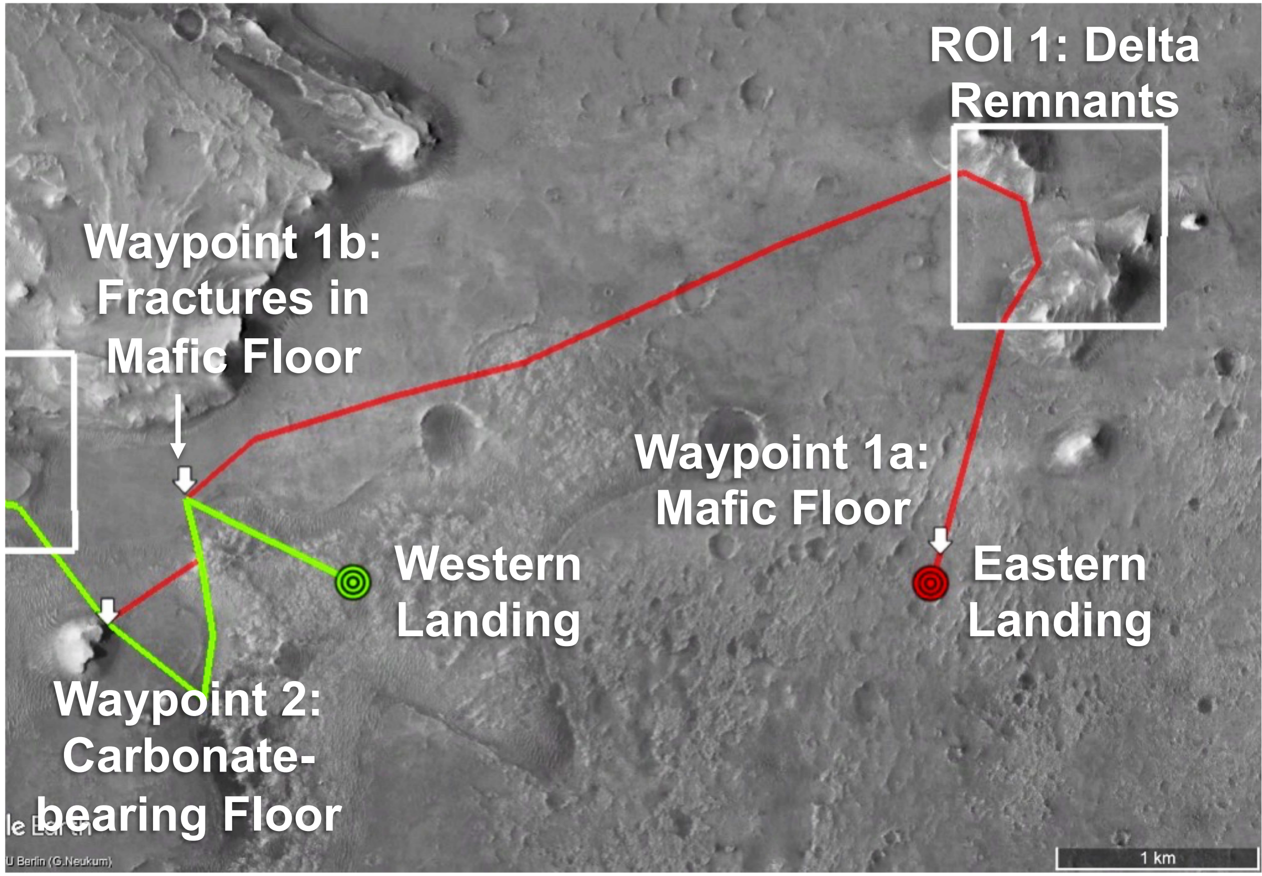
Jezero traverses sample many primary igneous mineralogies
Red = Olivine, Green = Low-Ca Pyroxene, Blue = High-Ca Pyroxene



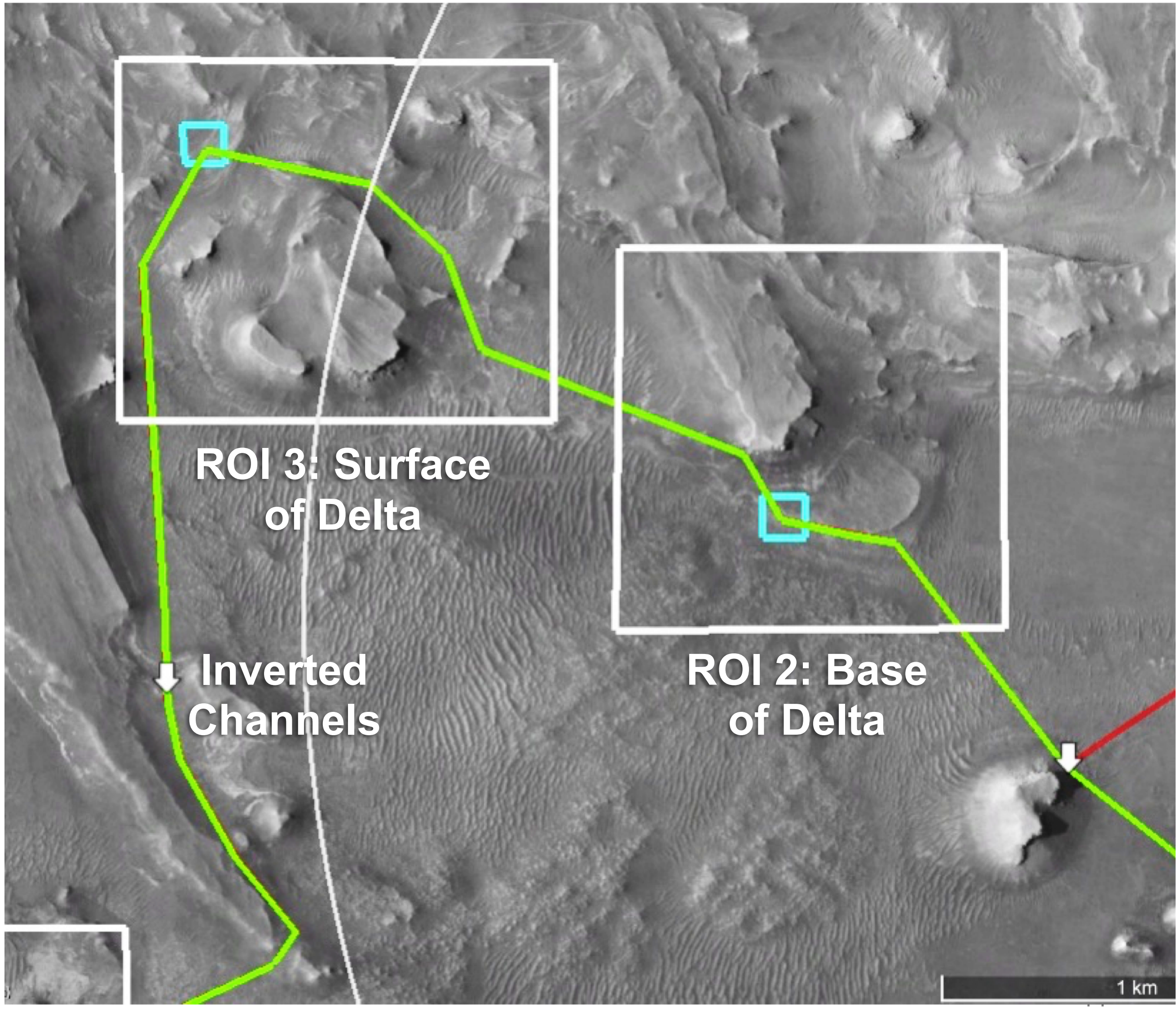
Notional Mission Scenario for Jezero crater

- Land at Jezero crater
- **Waypoint 1a:** Characterize **mafic floor unit** (volcanic flow, ash, or cemented sandstone). Sample.
- **ROI 1:** Drive to nearest **delta-lacustrine remnant** (unless Western delta is nearer). Characterize sedimentary facies, palaeoenvironment, and chemistry. Sample.
- Drive toward southeastern margin of delta
- **Waypoint 1b:** Investigate and sample filled fractures in **mafic floor**
- **Waypoint 2:** Investigate and sample **carbonate-bearing floor**, contact with mafic floor, and relationship to distal delta remnants.



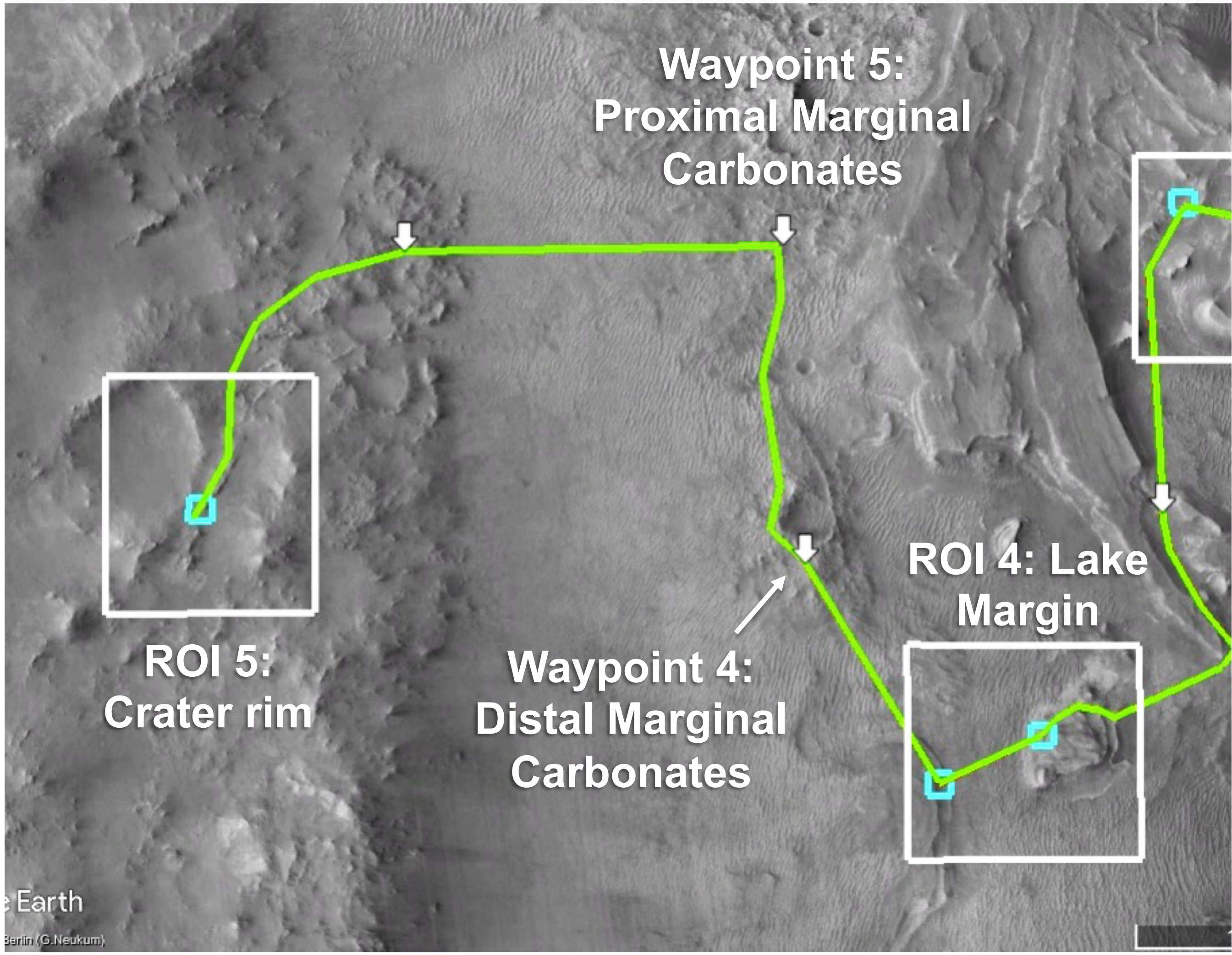
Notional Mission Scenario for Jezero crater

- **ROI 2** – Investigate and sample **base of delta**
  - Campaign: Lowermost delta stratigraphy, contact with carbonate-bearing floor and olivine/carbonate delta facies.
- **ROI 3** – Investigate and sample **delta top palaeoenvironment**
  - Campaign: Characterize olivine/ carbonate/silica-bearing point bar deposits and relationship to overlying LCP/clay-bearing channel deposits
- Drive to to southern extent of delta
- **Waypoint 3:** Characterize and sample LCP/clay-bearing **inverted channel facies**



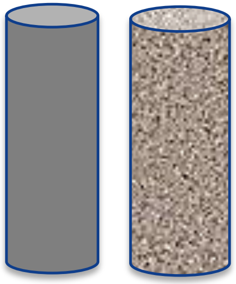
Notional Mission Scenario for Jezero crater

- **ROI 4** – Investigate and sample **lake margin** environments
  - Campaign 1: Well-exposed delta-lacustrine sequence, far SW extent of delta
  - Campaign 2: Lateral facies transition to finely stratified horizontal marginal strata (lake margin strata?)
- Turn north to traverse Marginal Carbonates
- **Waypoints 4/5:** Determine if **Marginal Carbonate** unit is a lacustrine precipitate and search for biosignatures. Sample.
- **ROI 5 –** Determine whether crater rim preserves hydrothermal environments. Sample.

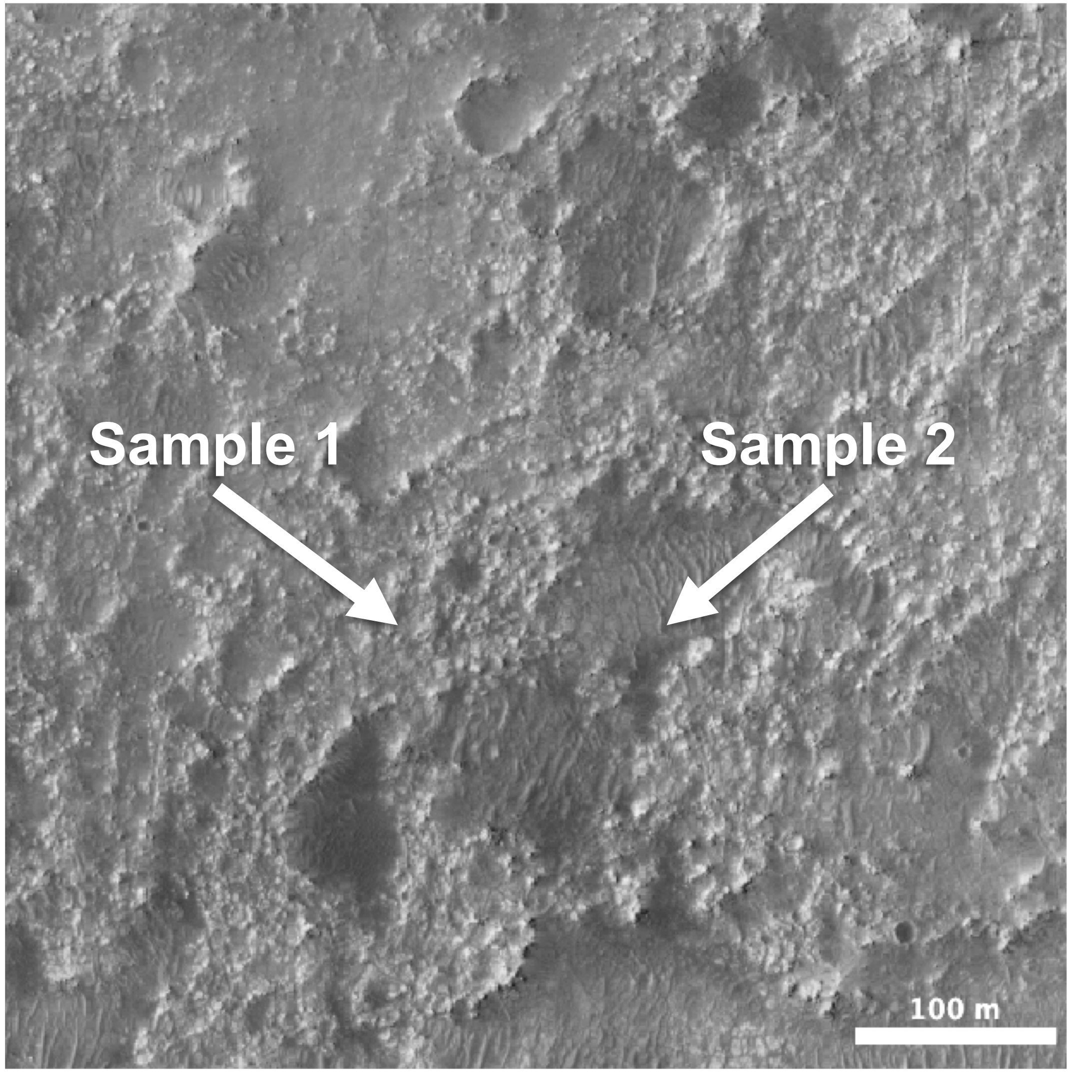


Waypoint 1a – Mafic Floor unit

- Sample closest location after landing
- Constrain composition and depositional origin of Mafic Floor unit (a. volcanic flow, b. ash or c. cemented sandstone)
- If igneous, determine mineralogy, chronology & igneous petrogenesis
- If sedimentary, establish provenance, grain mineralogy & ages, diagenesis
- Use Mastcam-Z, SuperCam, PIXL, SHERLOC, RIMFAX



Samples 1 + 2:
Typical Mafic Floor
+ Regolith

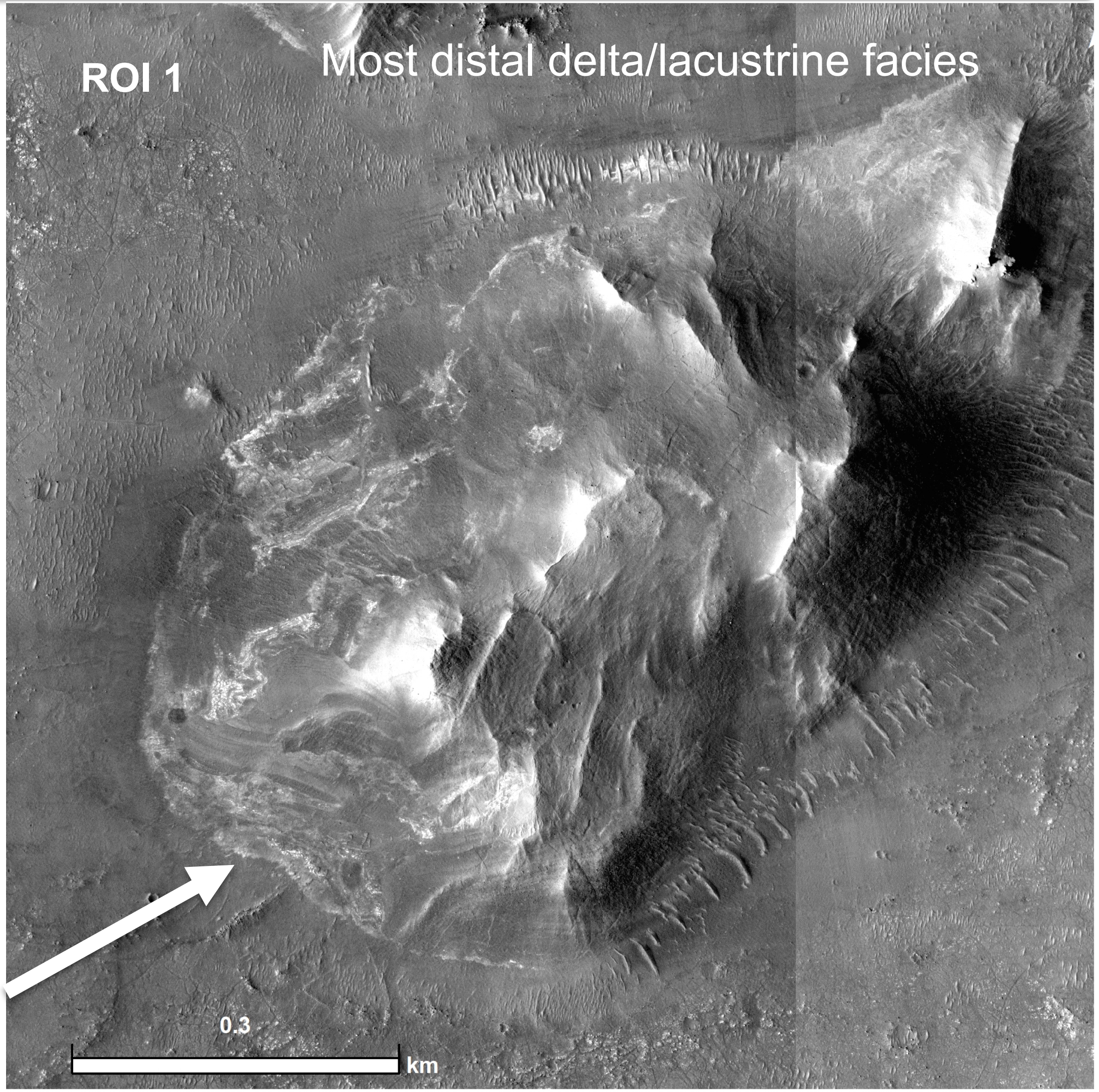


ROI 1 Overview – Delta-lacustrine remnants

(only if near landing site otherwise skip and drive to main Western delta)

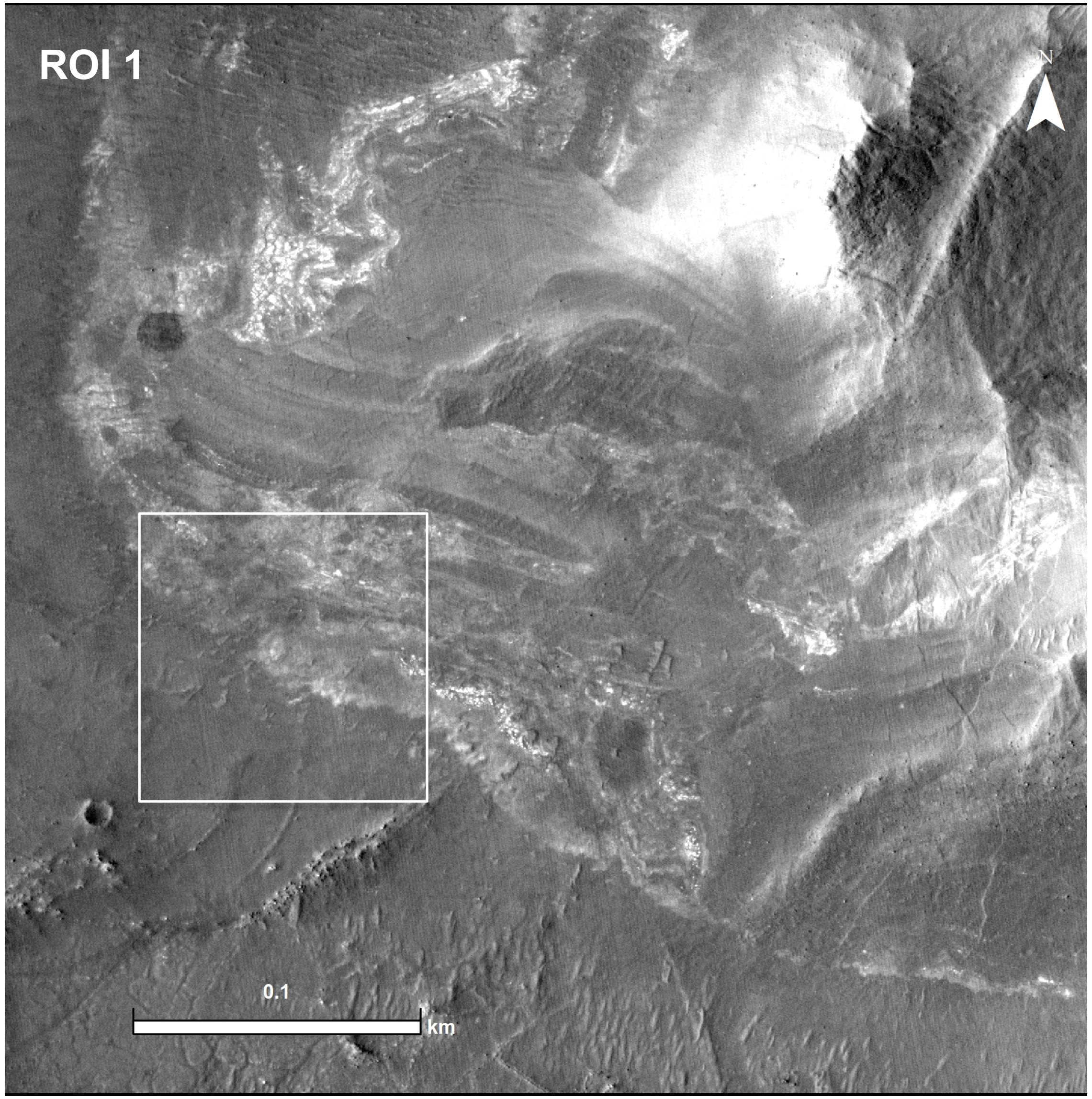
- Objective: Characterize fine-grained lacustrine – distal deltaic strata
- Search for facies indicative of water depth variations (shallow or deep water, subaerial exposure), interstratified ash beds, chemical sedimentary layers (evaporites)
- Difficult to characterize internal stratigraphy from orbital data – *no extended campaign.*
- Characterize contact with Mafic Floor – superposition or inter-stratification relationship?
  - Important target for placing Mafic Floor in delta stratigraphy

Contact



ROI 1 Details – Distal delta/lacustrine remnants

- Use Mastcam-Z and SuperCam to characterize sedimentary structures, facies and architecture
- Use WATSON to characterize grain size
- Use SuperCam, PIXL and SHERLOC to characterize chemistry in fine-grained deposits
- Use SHERLOC/SuperCam to search for organics
- Use Mastcam-Z and RIMFAX to characterize relationship of remnants with Mafic Floor unit

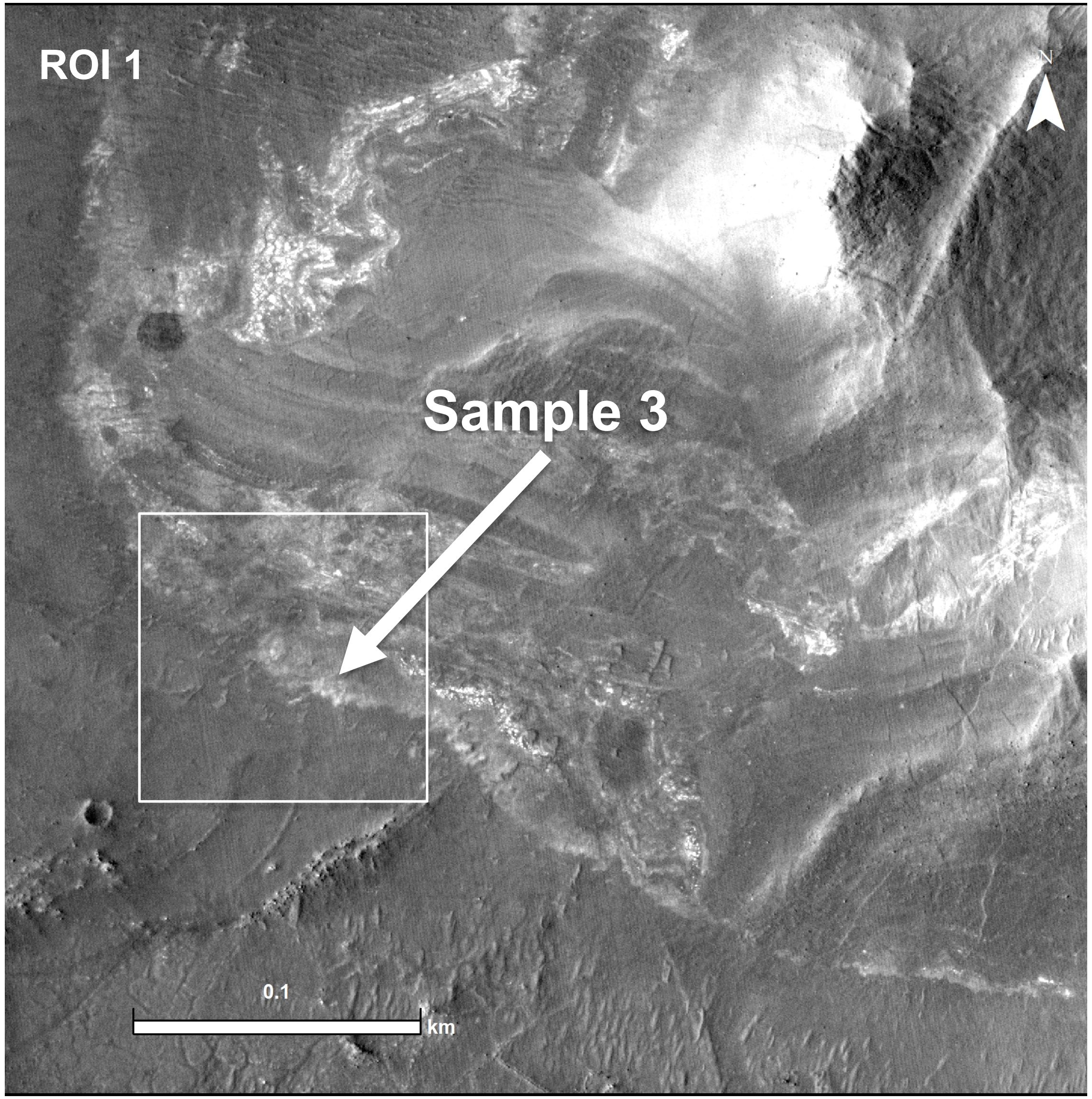


ROI 1 Sampling Strategy – Delta remnants

- 1 sample if compelling
  - Acquire 1 sample of fine-grained lacustrine to distal delta deposits
  - These probably have been irradiated for some time so may not be great for organic preservation

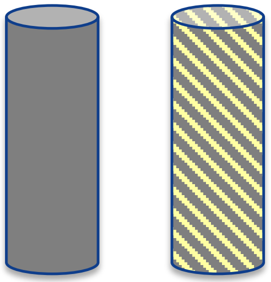
Sample 3

Basinal lacustrine facies – but probably long surface exposure

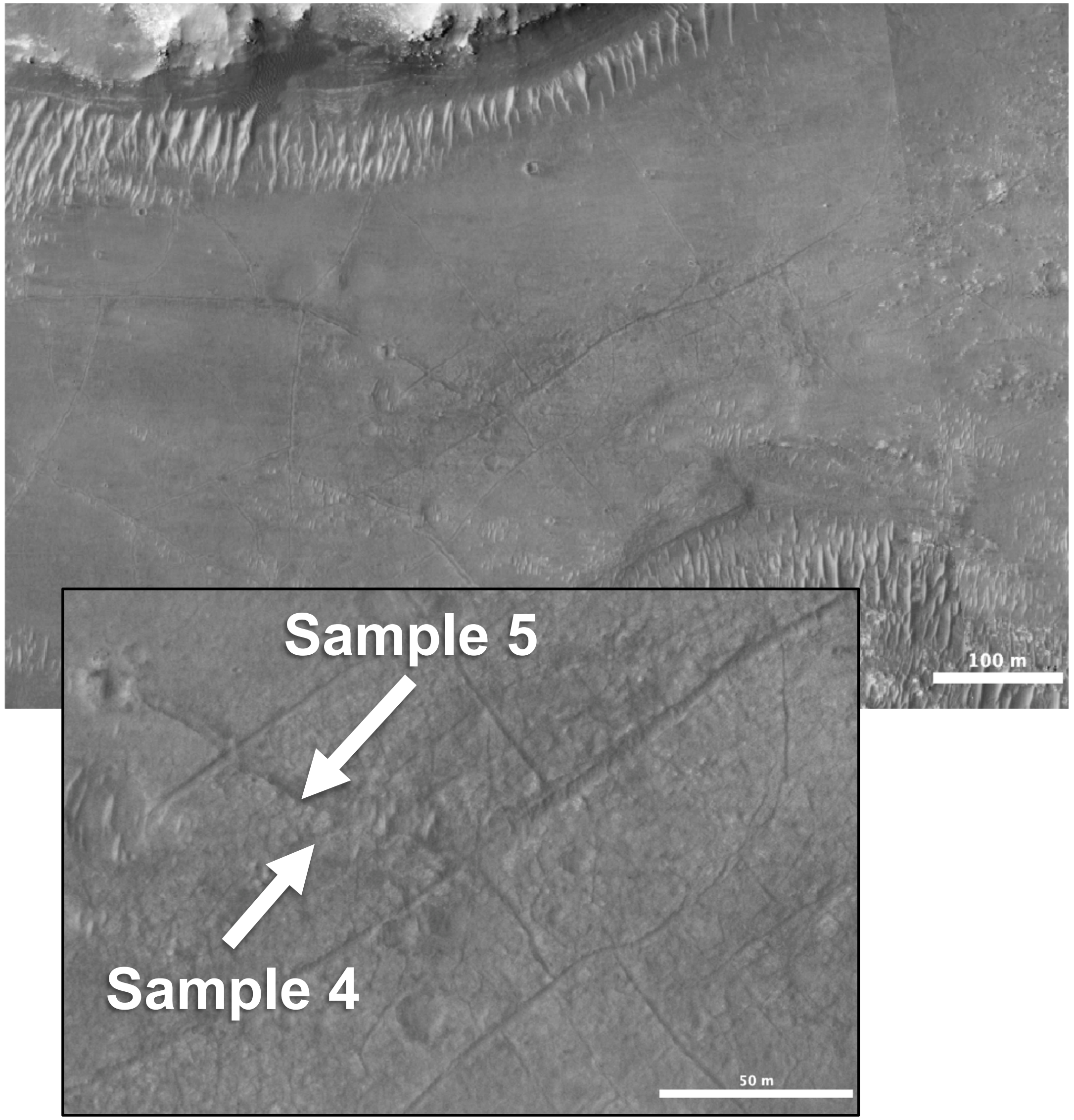


Waypoint 1b – Fractures in Mafic Floor unit

- Area with relatively low sediment cover, clear surface texture, and large fracture network
- Characterize and sample a pair of unaltered mafic floor and any fracture fill material to investigate emplacement and alteration history
- Fracture-fill texture from Mastcam-Z, SuperCam, WATSON; Chemistry and mineralogy of fracture fill with PIXL, SuperCam, and SHERLOC
- RIMFAX to constrain subsurface geometry of fractures

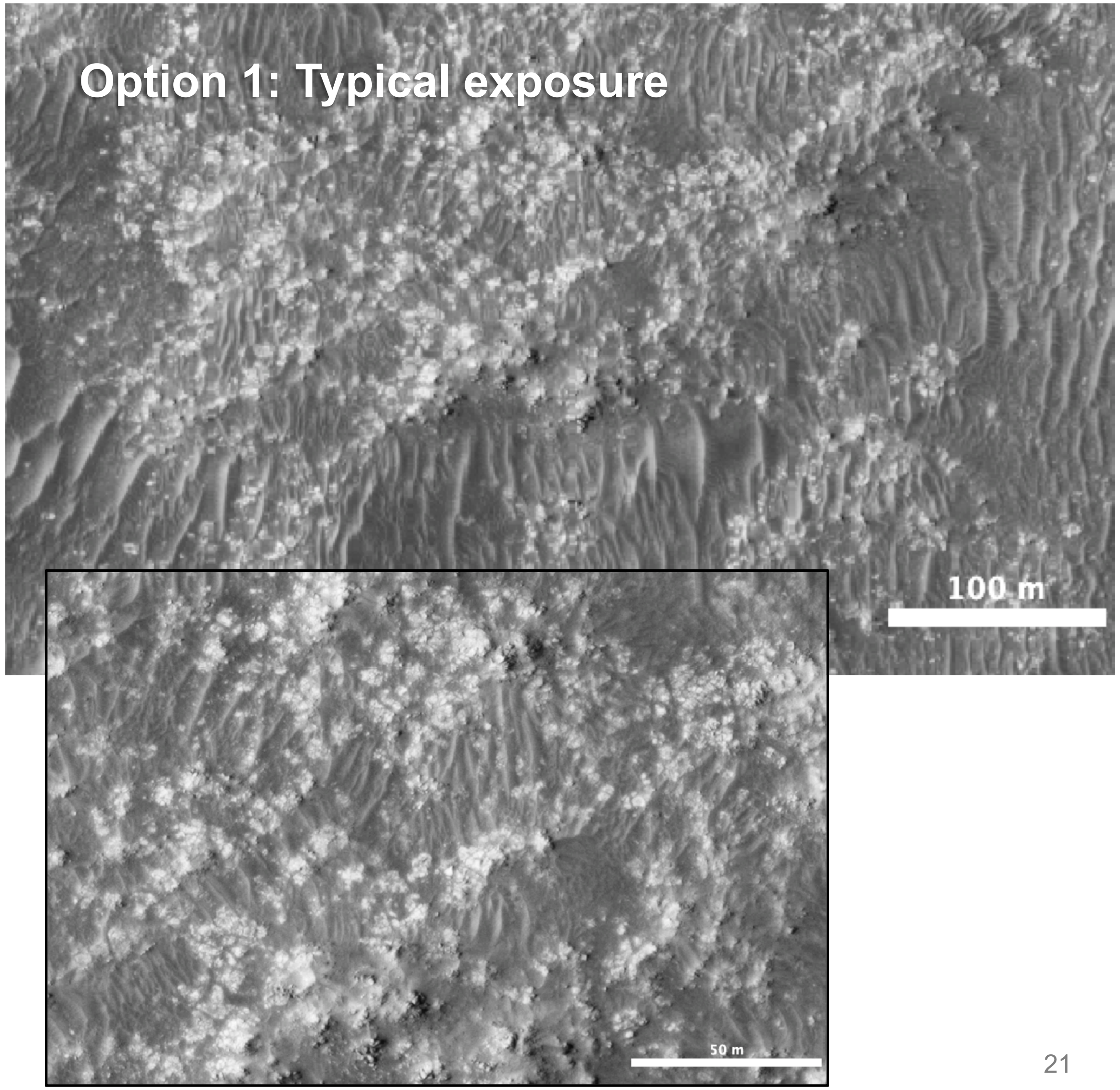


Samples 4/5: Unaltered/altered Mafic Floor



Waypoint 2 – Carbonate-bearing Floor unit

- Determine origin and alteration history of carbonate-bearing floor unit (tephra, aeolian, lacustrine?)
- Investigate at first encounter with good exposure of light-toned pockmarked texture, sample either here or at later contacts with overlying Mafic Floor or delta
- Mastcam-Z/SHERLOC/SuperCam for physical and compositional properties
- PIXL, SHERLOC to map microscale chemistry, mineralogy, and texture
- SuperCam/SHERLOC to search for organics
- RIMFAX to determine subsurface structure



Waypoint 2 – Carbonate-bearing Floor unit (other options)

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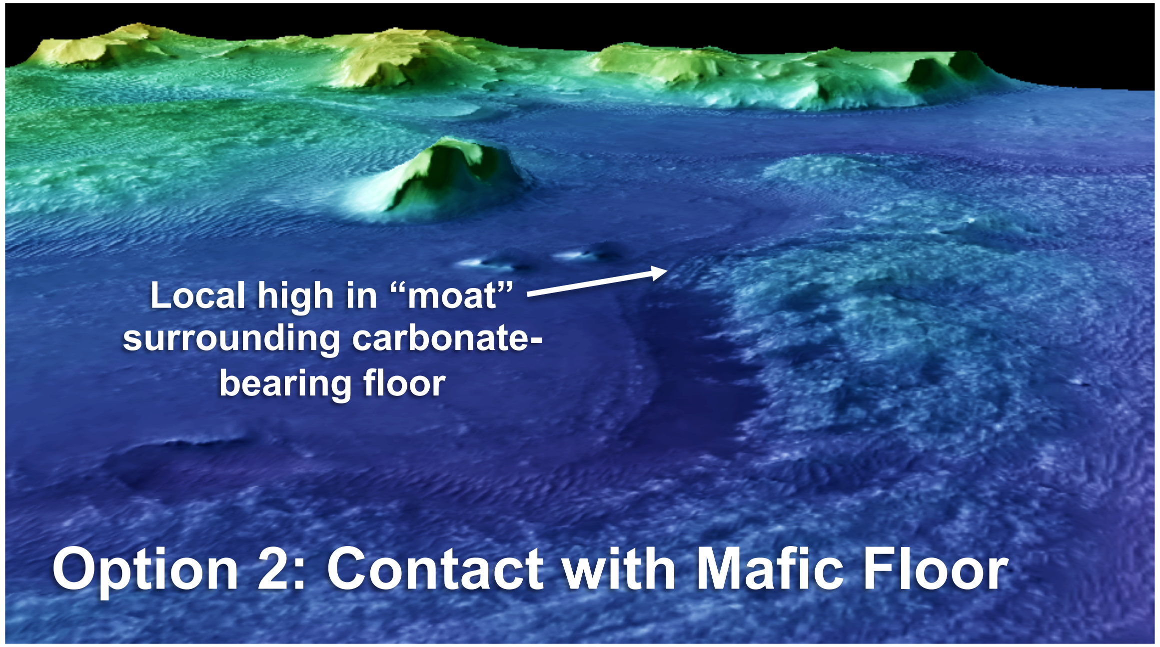
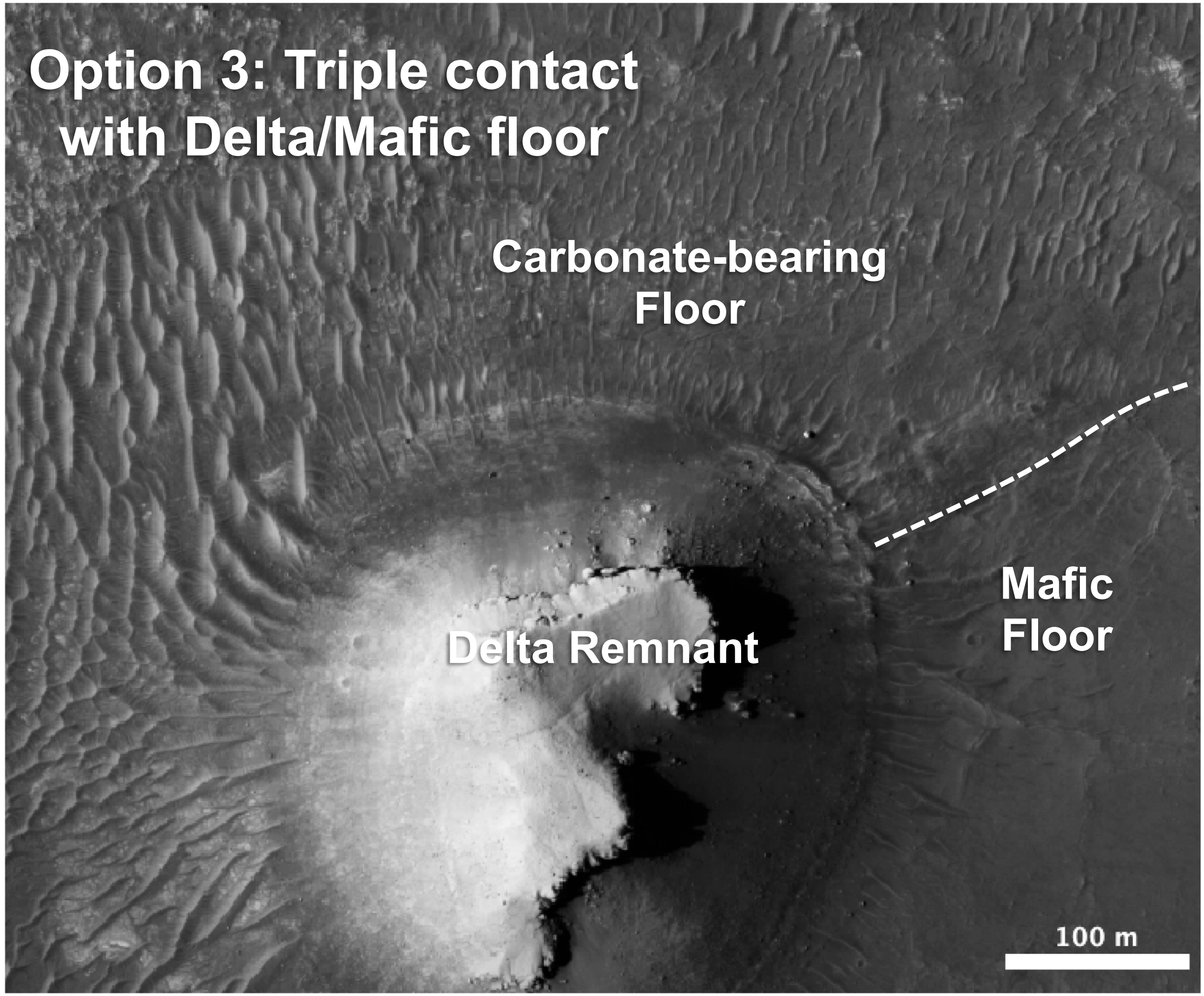
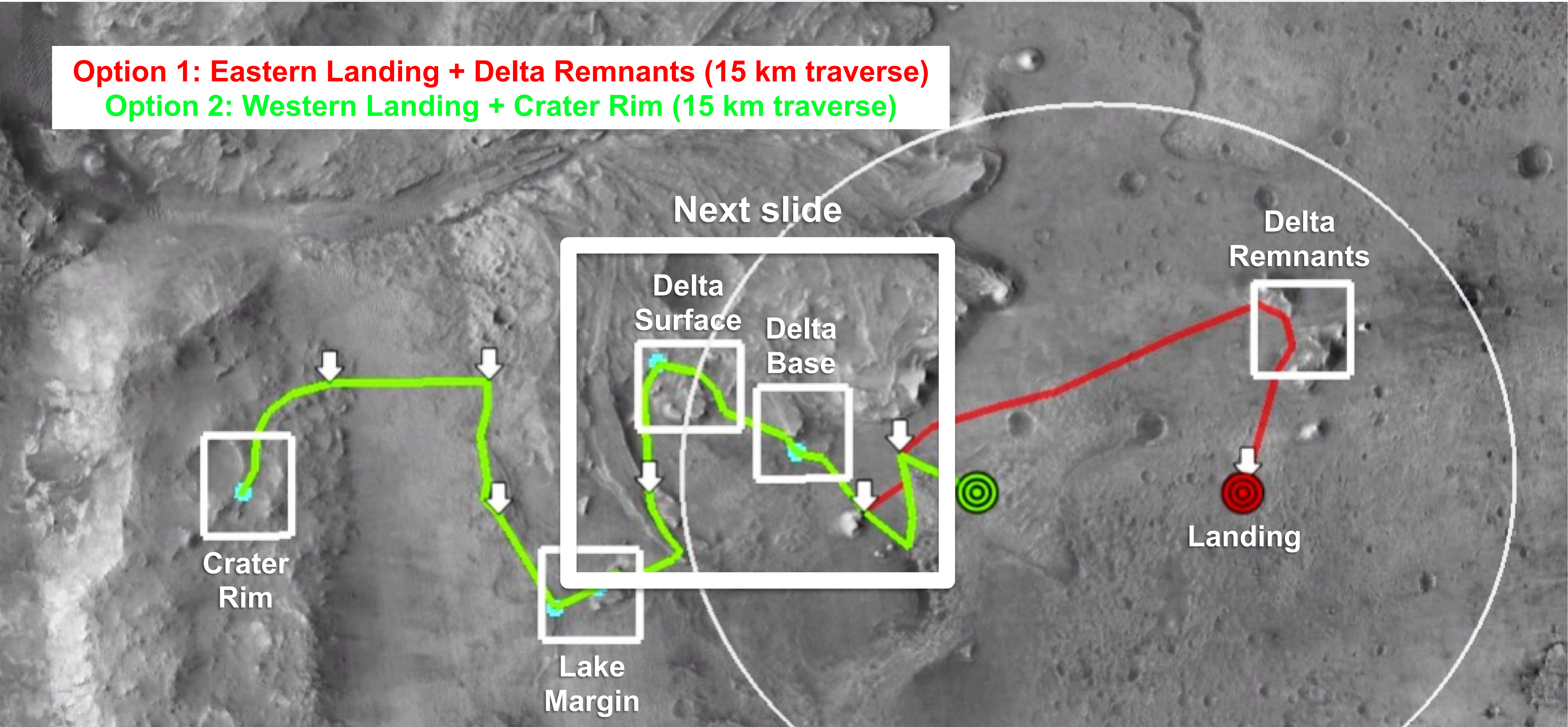


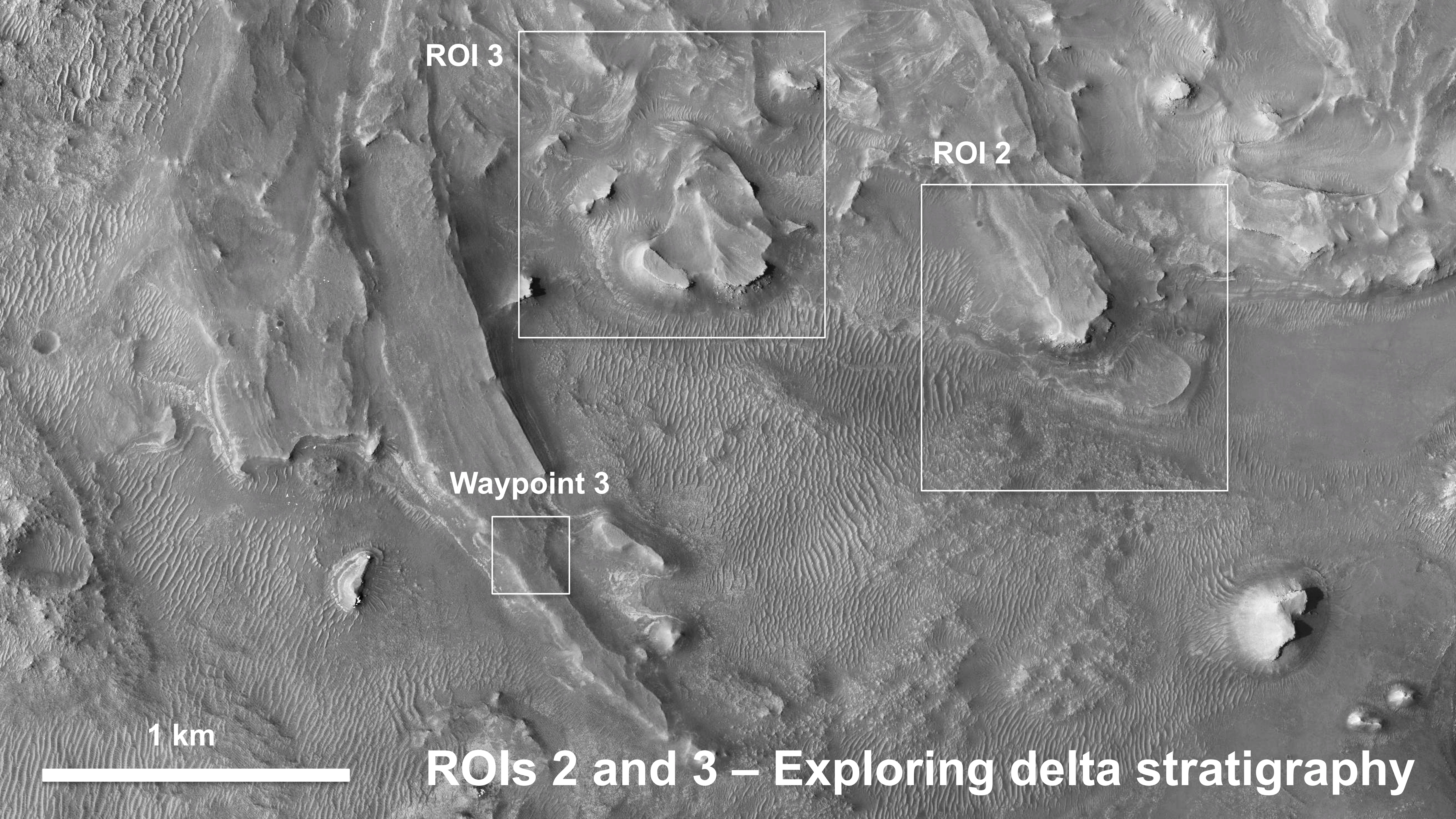
Sample 6: Carbonate-bearing Floor unit

Option to collect from first encounter or near contact with mafic floor for less irradiation



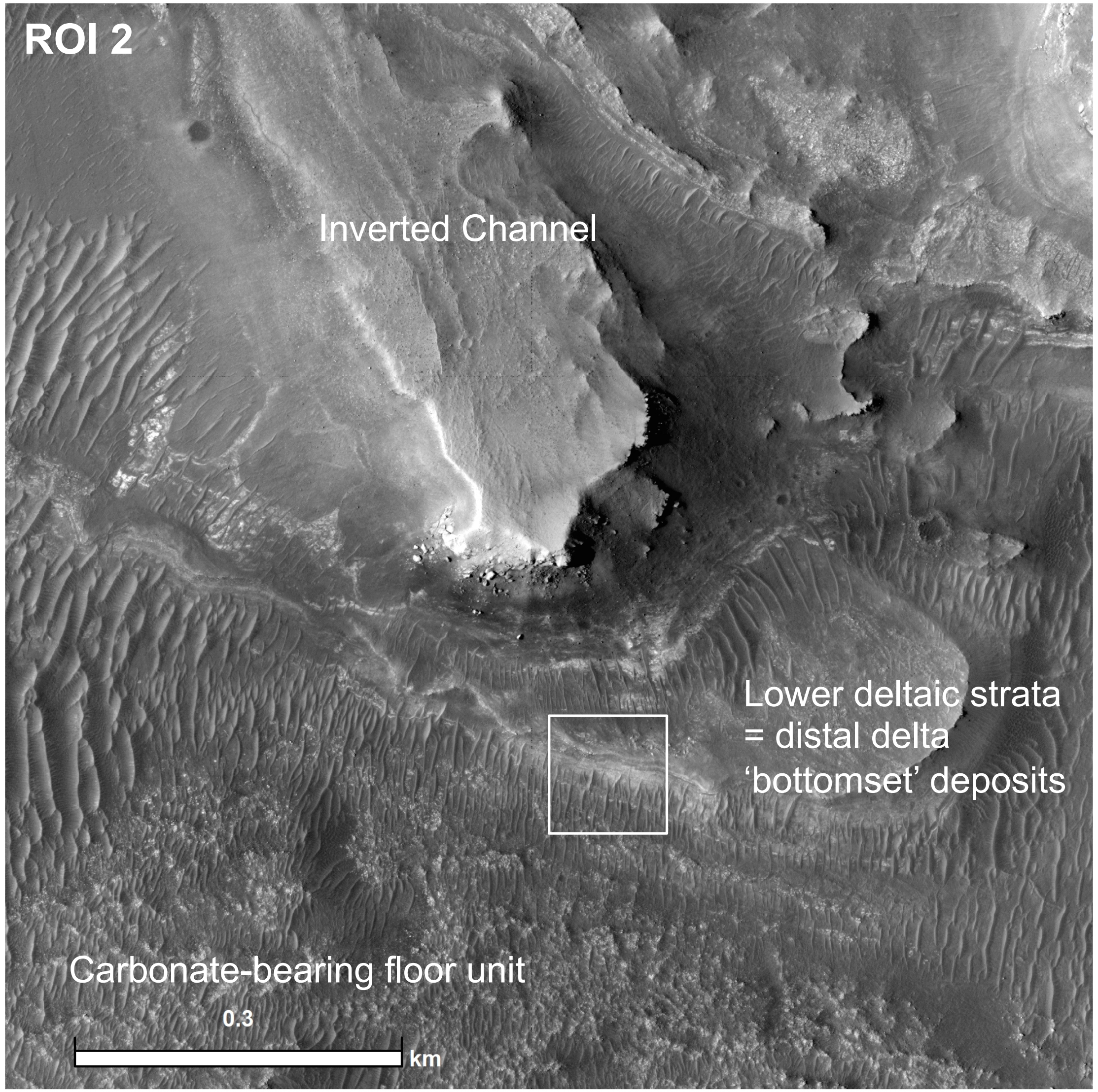
Notional Mission Scenario for Jezero crater



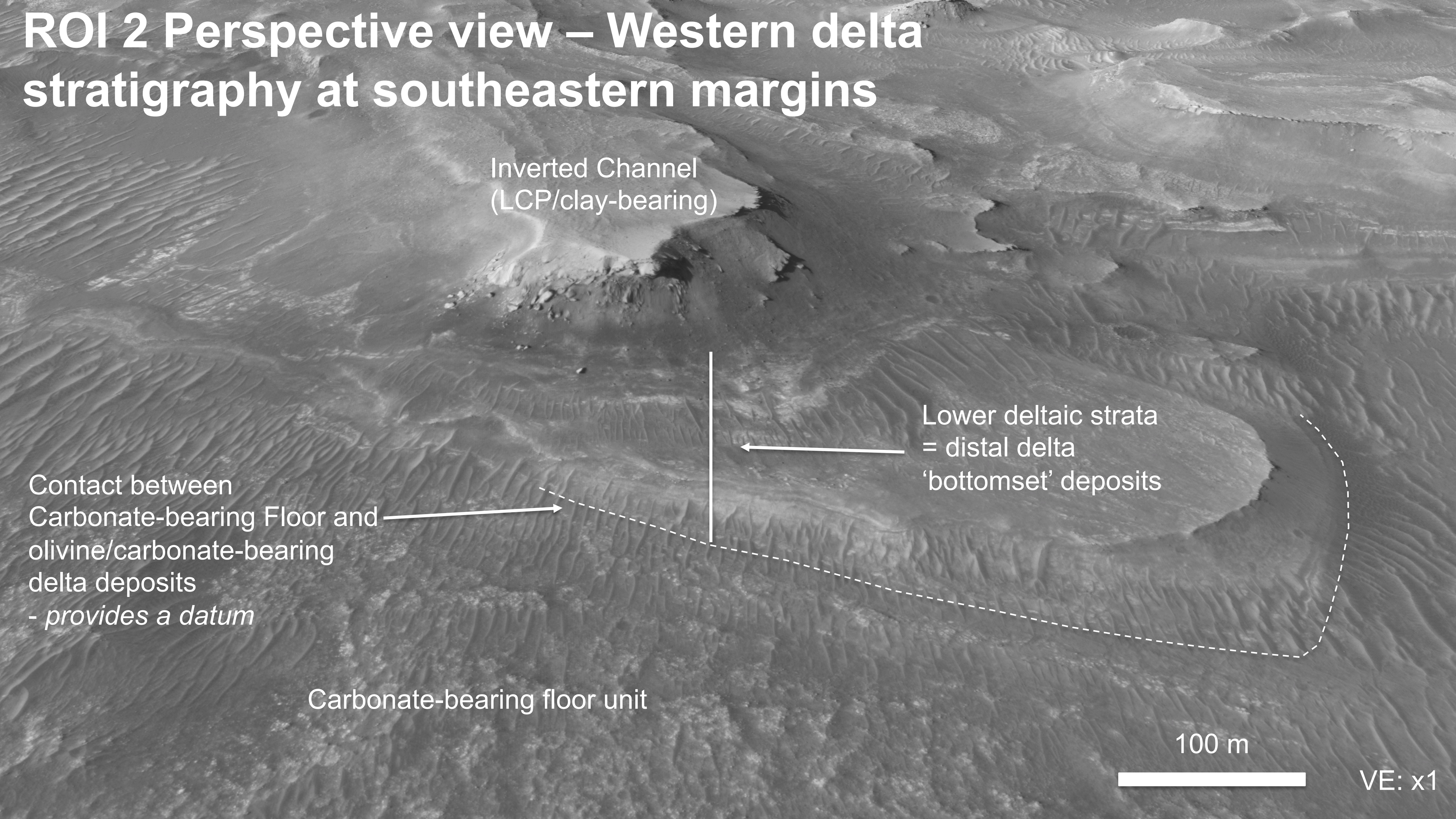

ROI 3
ROI 2
Waypoint 3
1 km
ROIs 2 and 3 – Exploring delta stratigraphy

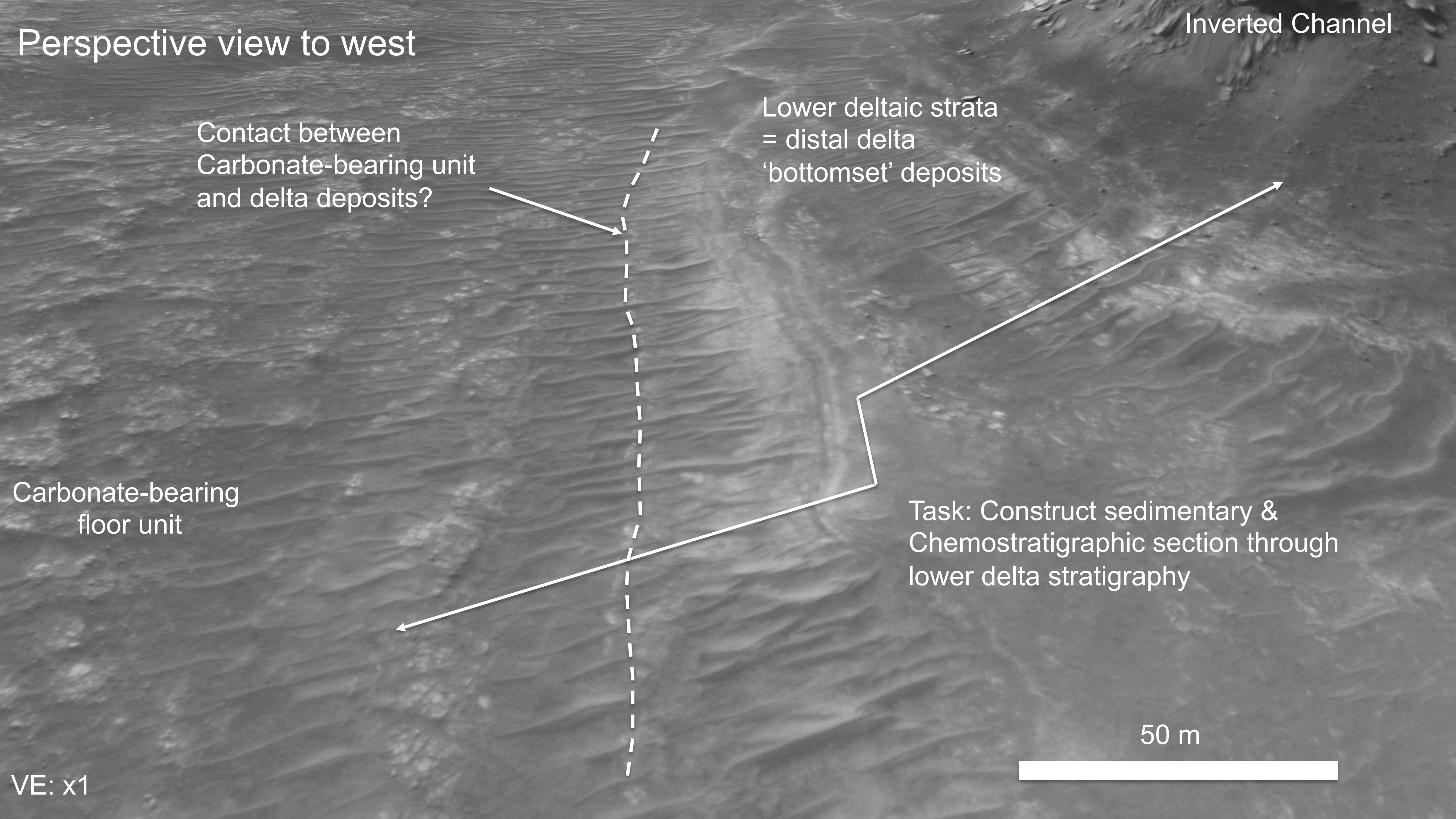
ROI 2 Overview – Lower Delta stratigraphy

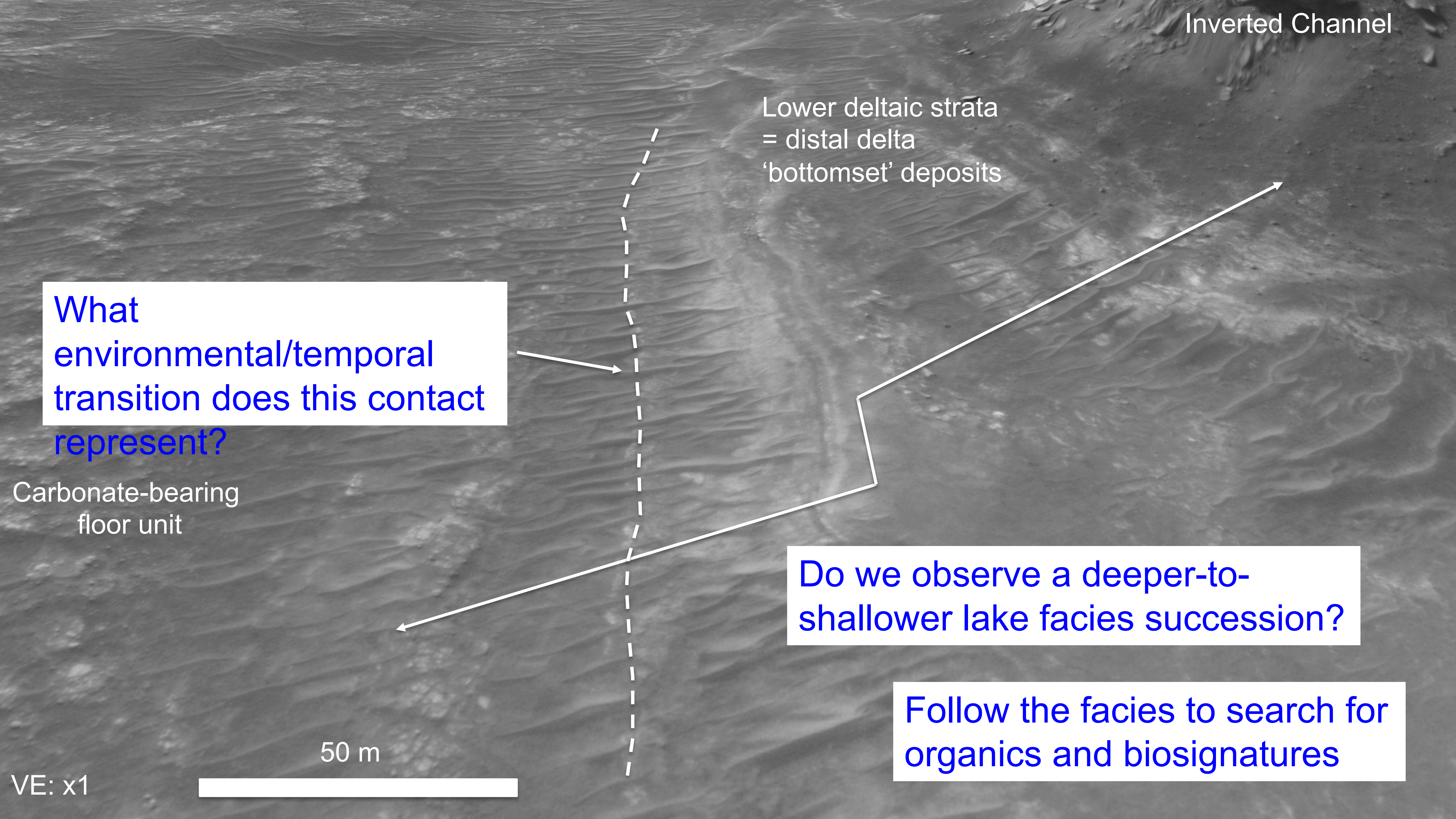
- Objective: Investigate delta stratigraphy
- Well preserved and mappable bedrock stratigraphy.
- Walkabout of transition from Carbonate-bearing Floor unit to lower distal deltaic strata
- Construct facies and chemostratigraphic section(s)
- Characterize vertical and lateral facies variability to build depositional model
- Identify facies with highest potential for biosignature preservation & search for organics with SHERLOC/SuperCam



ROI 2 Perspective view – Western delta stratigraphy at southeastern margins

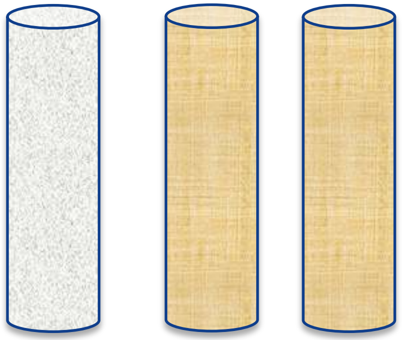



Perspective view to west
Inverted Channel
Contact between
Carbonate-bearing unit
and delta deposits?
Lower deltaic strata
= distal delta
'bottomset' deposits
Carbonate-bearing
floor unit
Task: Construct sedimentary &
Chemostratigraphic section through
lower delta stratigraphy
50 m
VE: x1


Inverted Channel
Lower deltaic strata
= distal delta
'bottomset' deposits
What environmental/temporal transition does this contact represent?
Carbonate-bearing
floor unit
Do we observe a deeper-to-shallower lake facies succession?
Follow the facies to search for organics and biosignatures
50 m
VE: x1

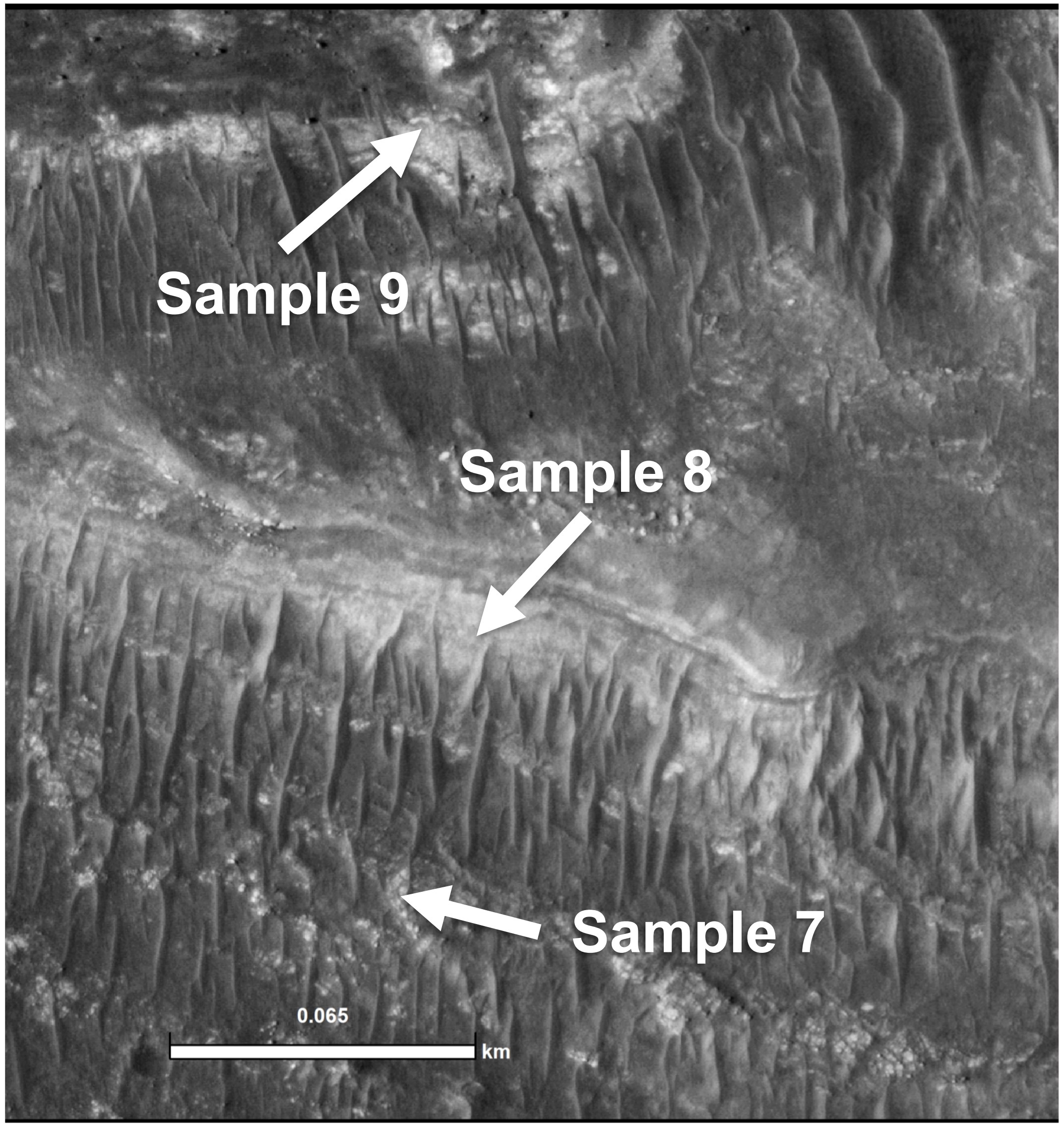
ROI 2 Sampling Strategy

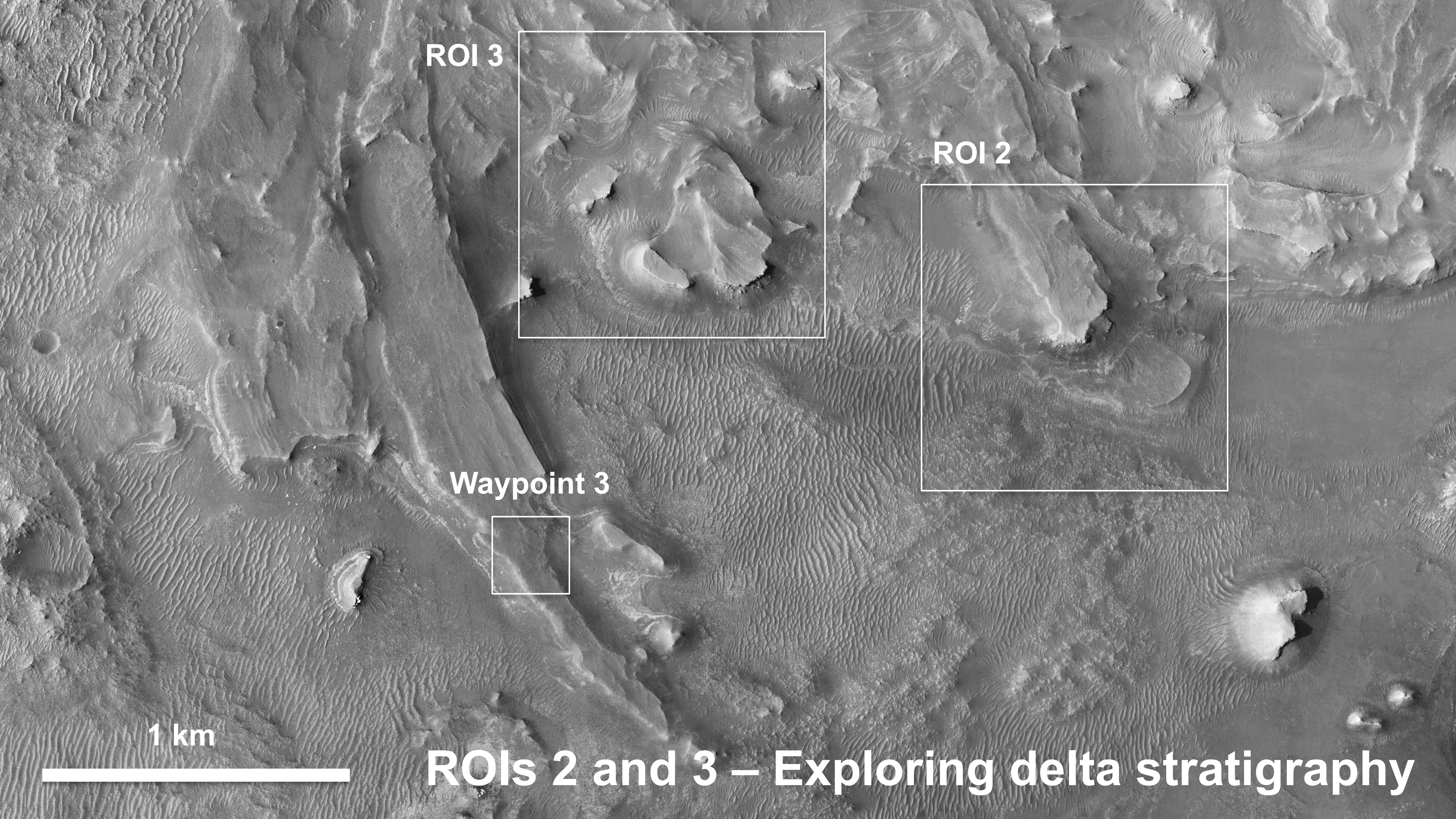
- Sample fine-grained mudstones from a distal deltaic/lacustrine facies, if compelling
  - Search for biosignatures
  - Mineralogy, chemistry of mudstones
  - Diagenesis of mudstones
- Sample of carbonate-bearing floor
  - Likely more recently exposed than in center crater



Sample 7: Carbonate-bearing Floor

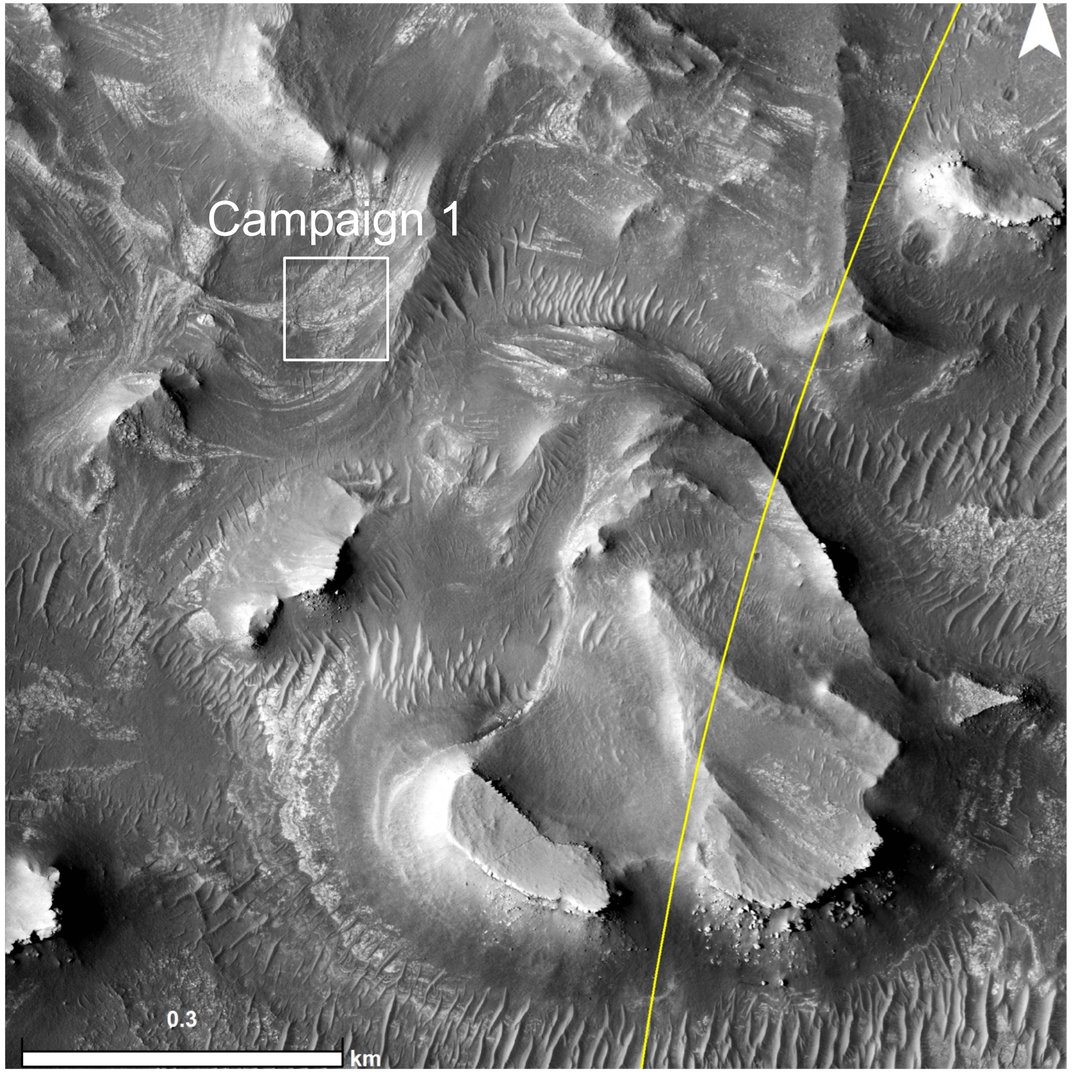
Samples 8/9: Lacustrine mudstones




ROI 3
ROI 2
Waypoint 3
1 km
ROIs 2 and 3 – Exploring delta stratigraphy

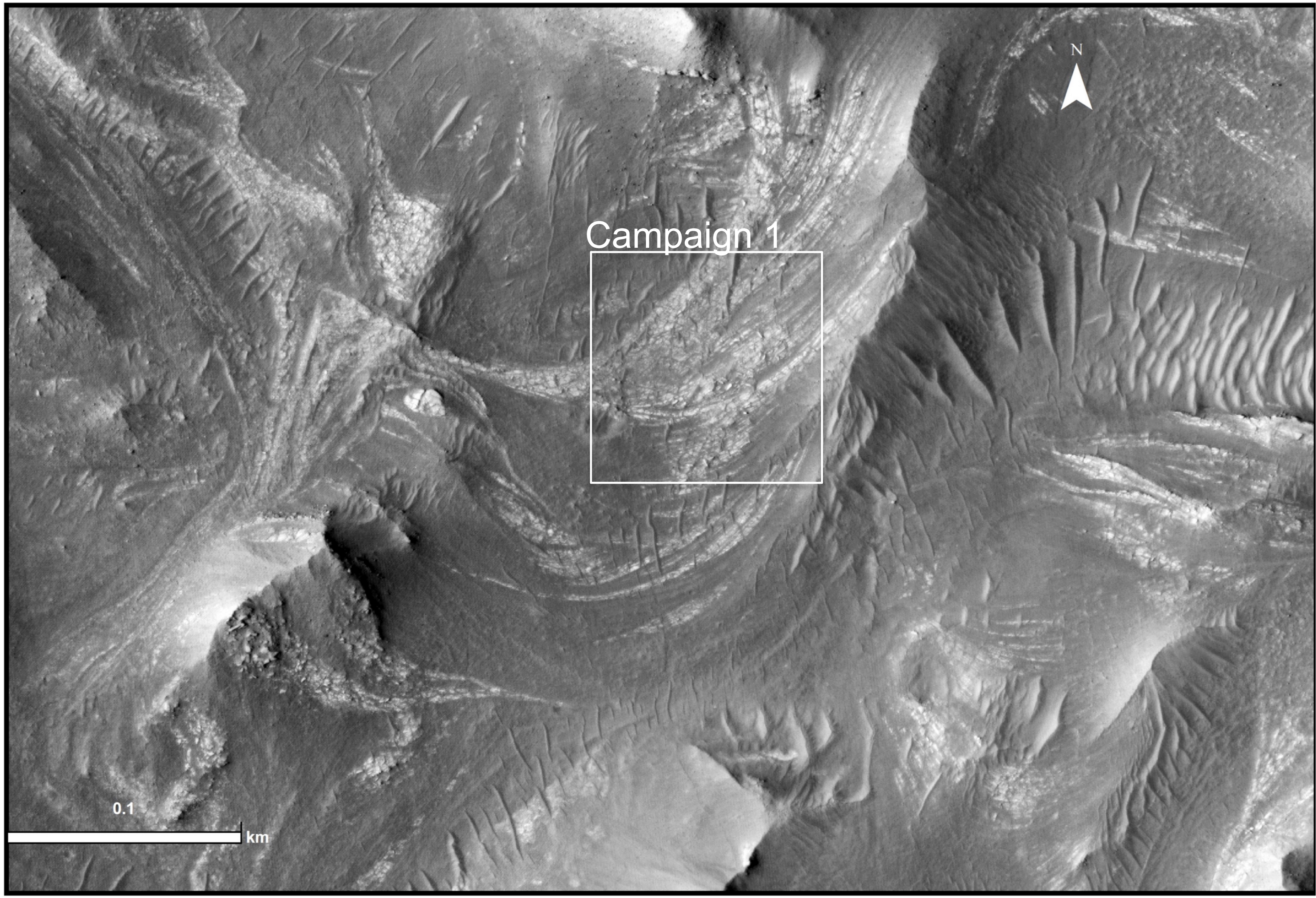
ROI 3 – Campaign: Delta top Point bar strata

- Investigate middle section of delta stratigraphy
- Well preserved and mappable fluvial point bar strata in olivine/carbonate facies, additional spectral signatures potentially attributable to surface weathering
- Characterize sedimentary facies variability to test depositional model
- Investigate nature/habitability of surface environments, and identify facies with potential for biosignature preservation



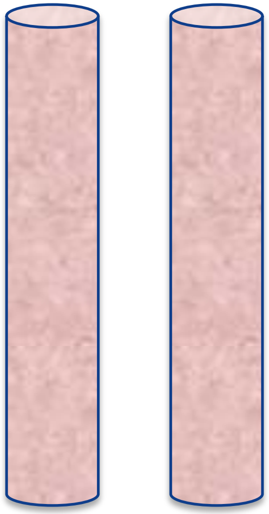
ROI 3 – Campaign 1: Delta top Point bar strata

- Characterize sedimentology of Point Bar unit
- Constrain grain size, texture and sedimentary structures using Mastcam-Z, WATSON, SuperCam
- Constrain composition and search for organics using SuperCam, PIXL, SHERLOC
- Establish provenance, grain mineralogy & ages, diagenesis with returned samples
- RIMFAX to constrain subsurface geometry



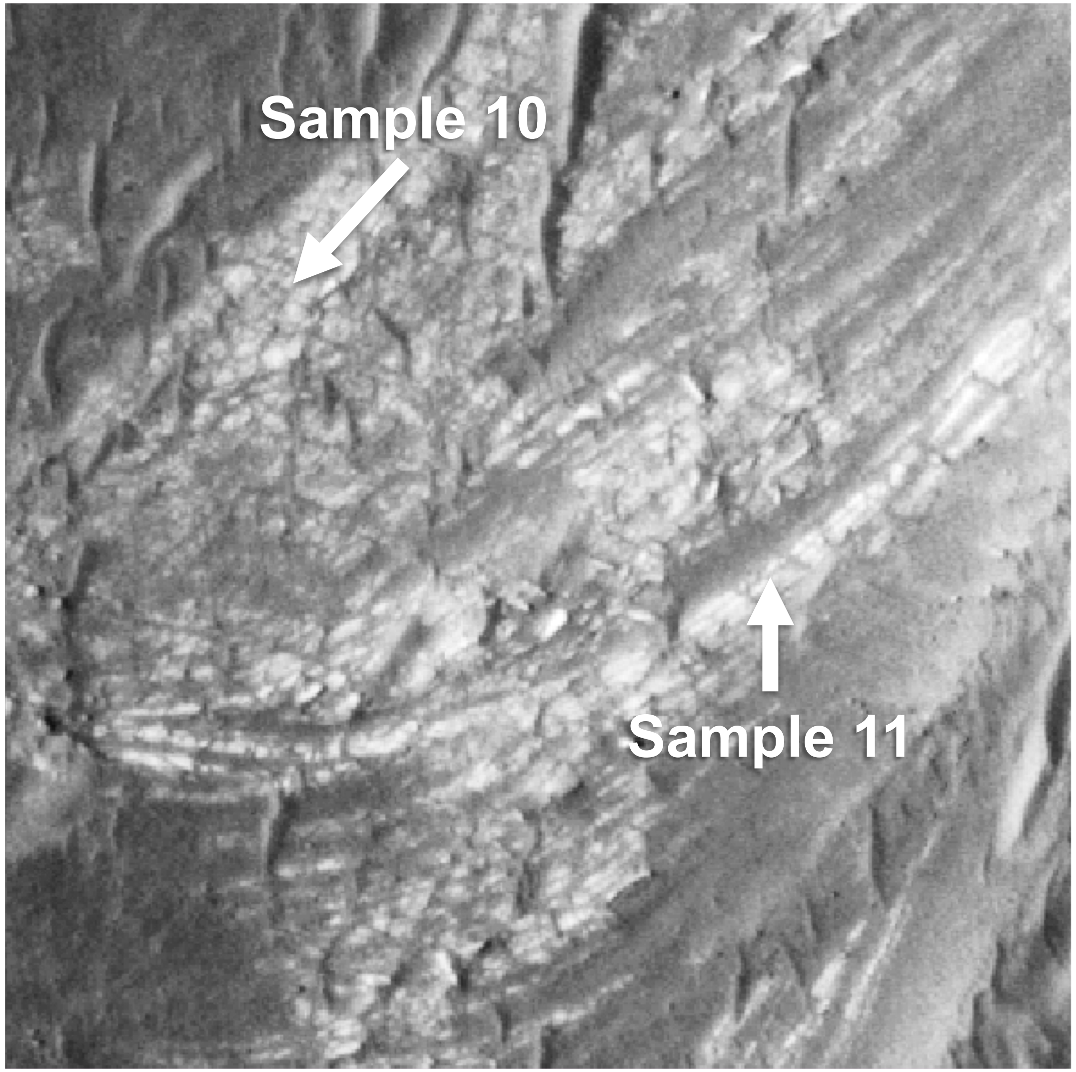
ROI 3 Sampling Strategy for Point Bar unit

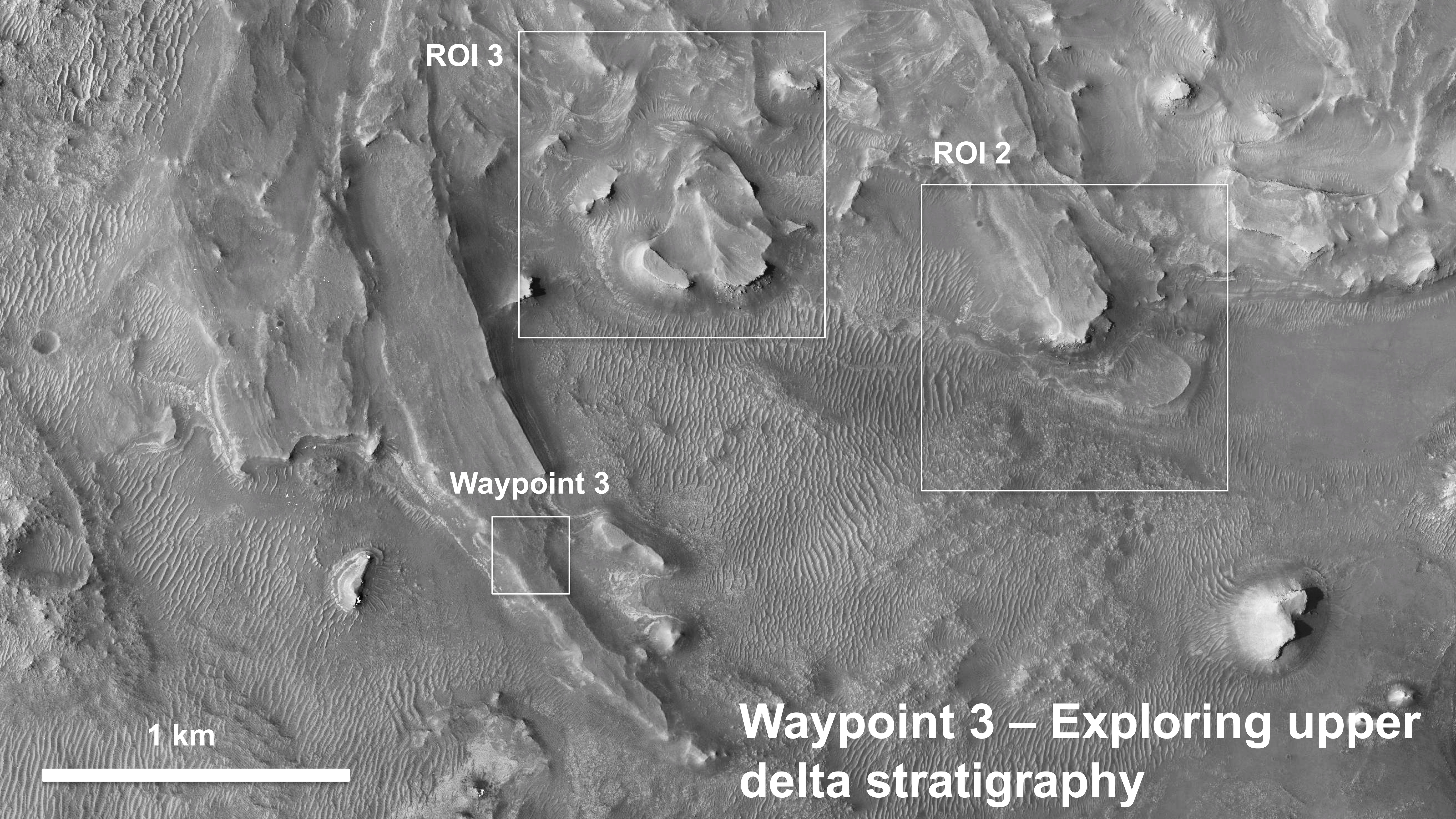
- 2 samples if compelling otherwise 1
  - Characterize mineralogy and chemistry of ol-carbonate-bearing point bar strata
  - Search for organics in delta top environment



Samples 10/11:

Point bar deposits from delta surface paleoenvironments

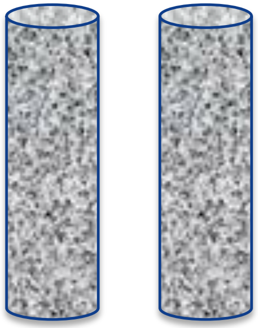




Waypoint 3 – Exploring upper delta stratigraphy

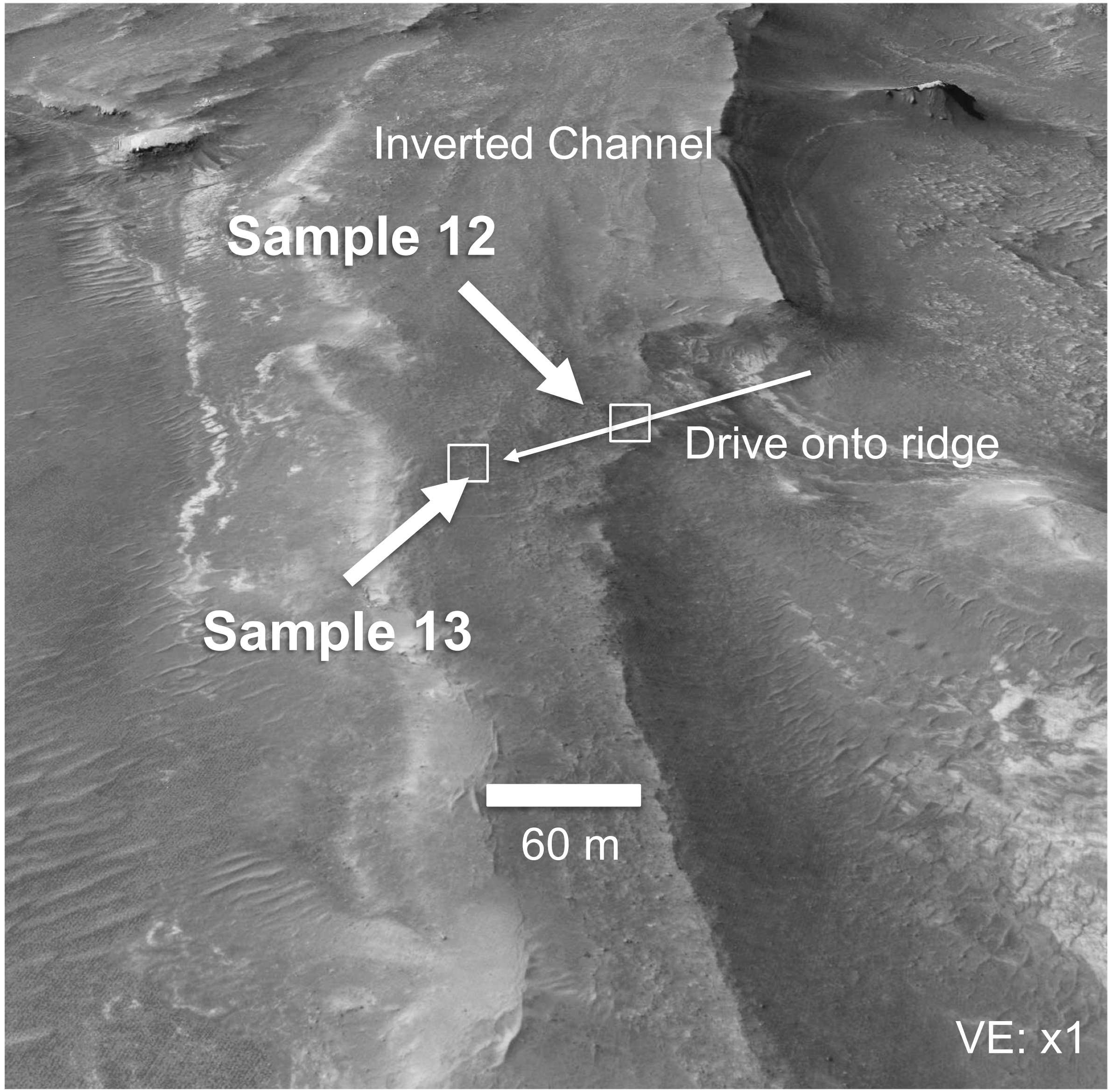
Waypoint 3 – Upper delta stratigraphy
Inverted channel unit

- Characterize sedimentology of LCP/Clay-bearing Inverted Channel unit
- Constrain grain size, texture and sedimentary structures using Mastcam-Z, WATSON, SuperCam
- Constrain composition using SuperCam, PIXL, SHERLOC
- Establish provenance, grain mineralogy & ages, diagenesis with returned samples
- RIMFAX to constrain and test subsurface geometry of capping unit

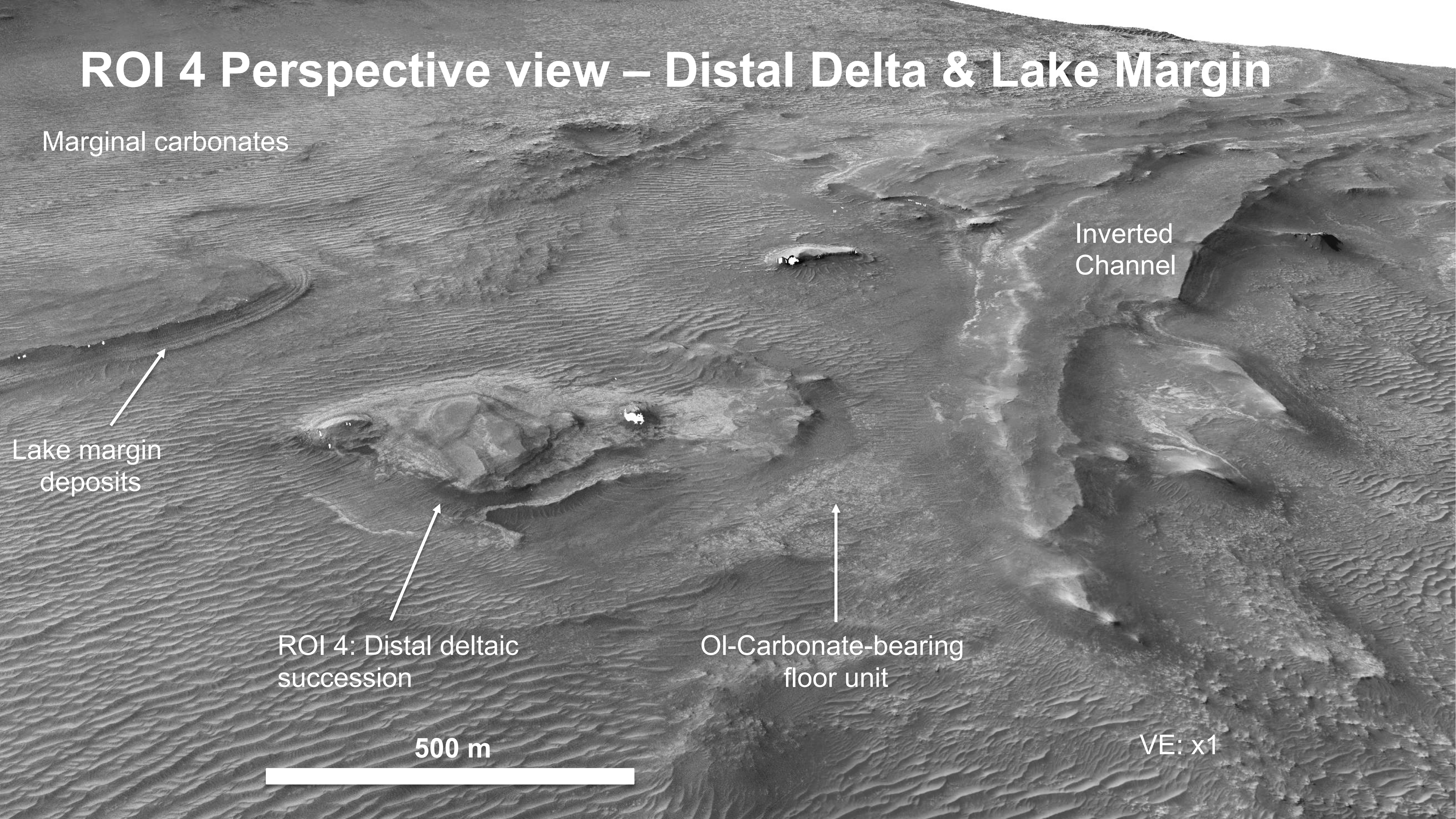


Samples 12/13:

Acquire 2 sandstone samples for reproducibility & contingency

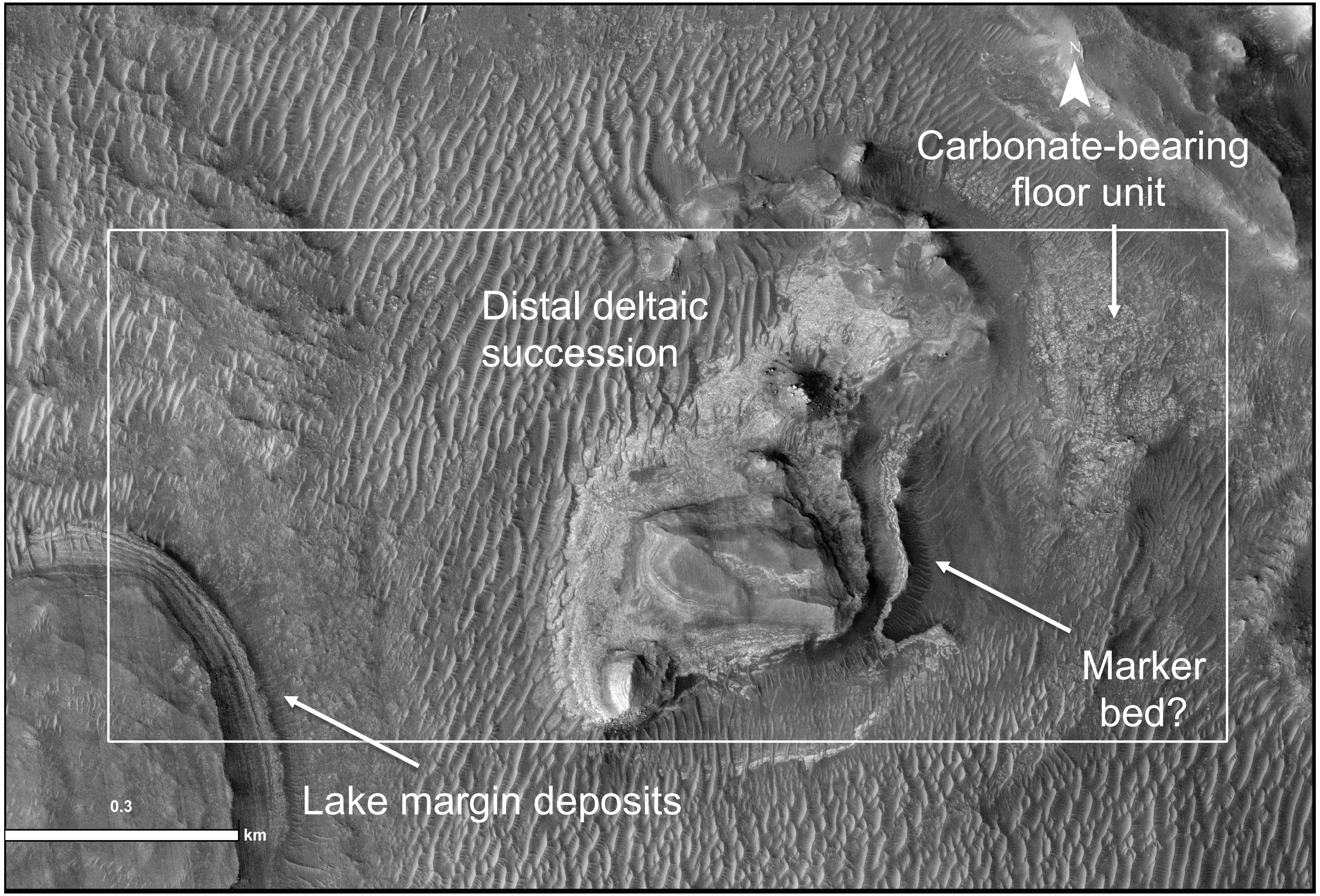


ROI 4 Perspective view – Distal Delta & Lake Margin



ROI 4 Overview – Distal Delta & Lake Margin

- Objective: Characterize distal deltaic and **lake margin strata**
- Opportunity to compare/contrast succession, facies, chemistry with ROI 2
- Identify lithology/facies of lake margin deposits
- Identify facies with best potential for biosignature preservation



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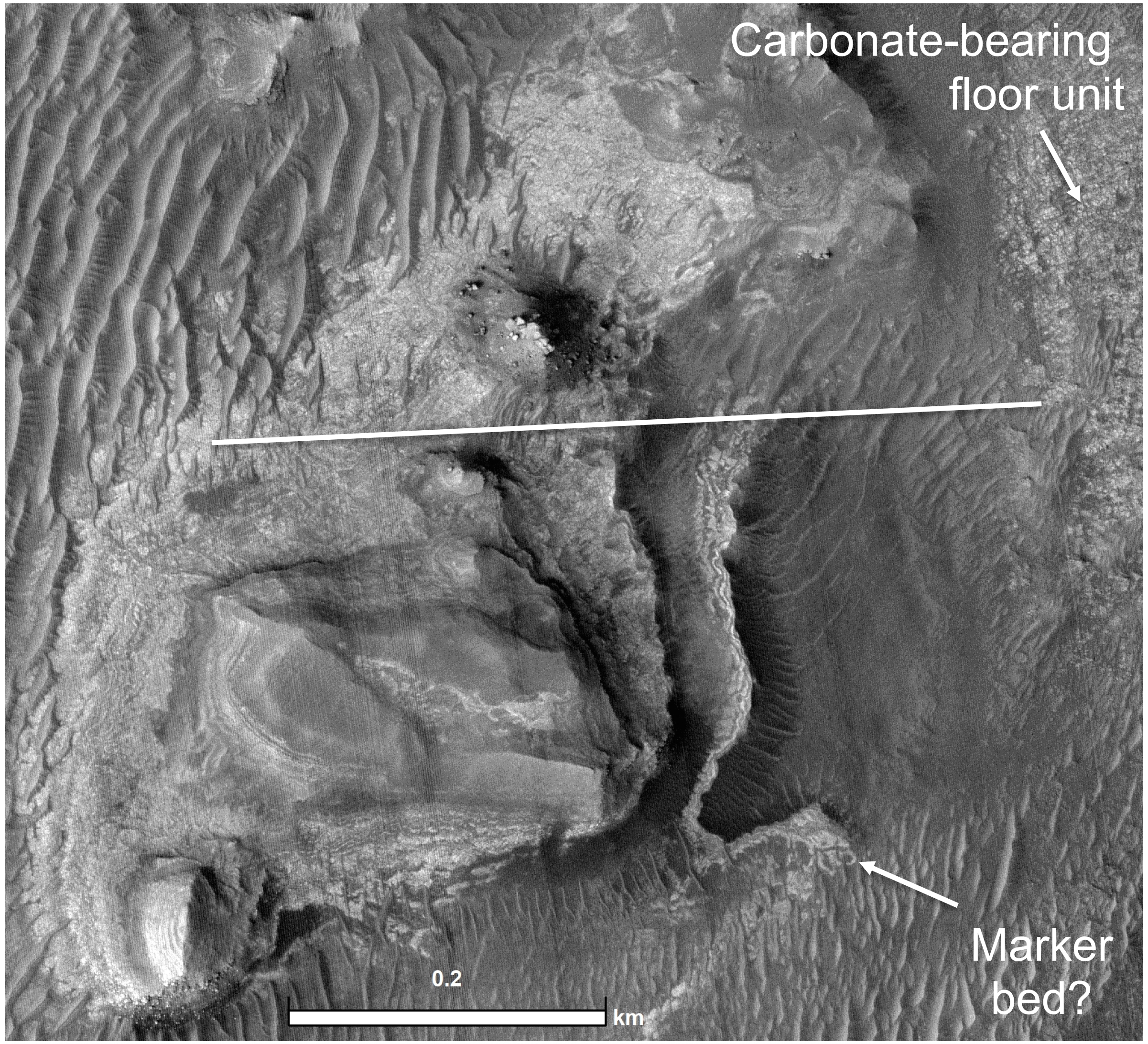
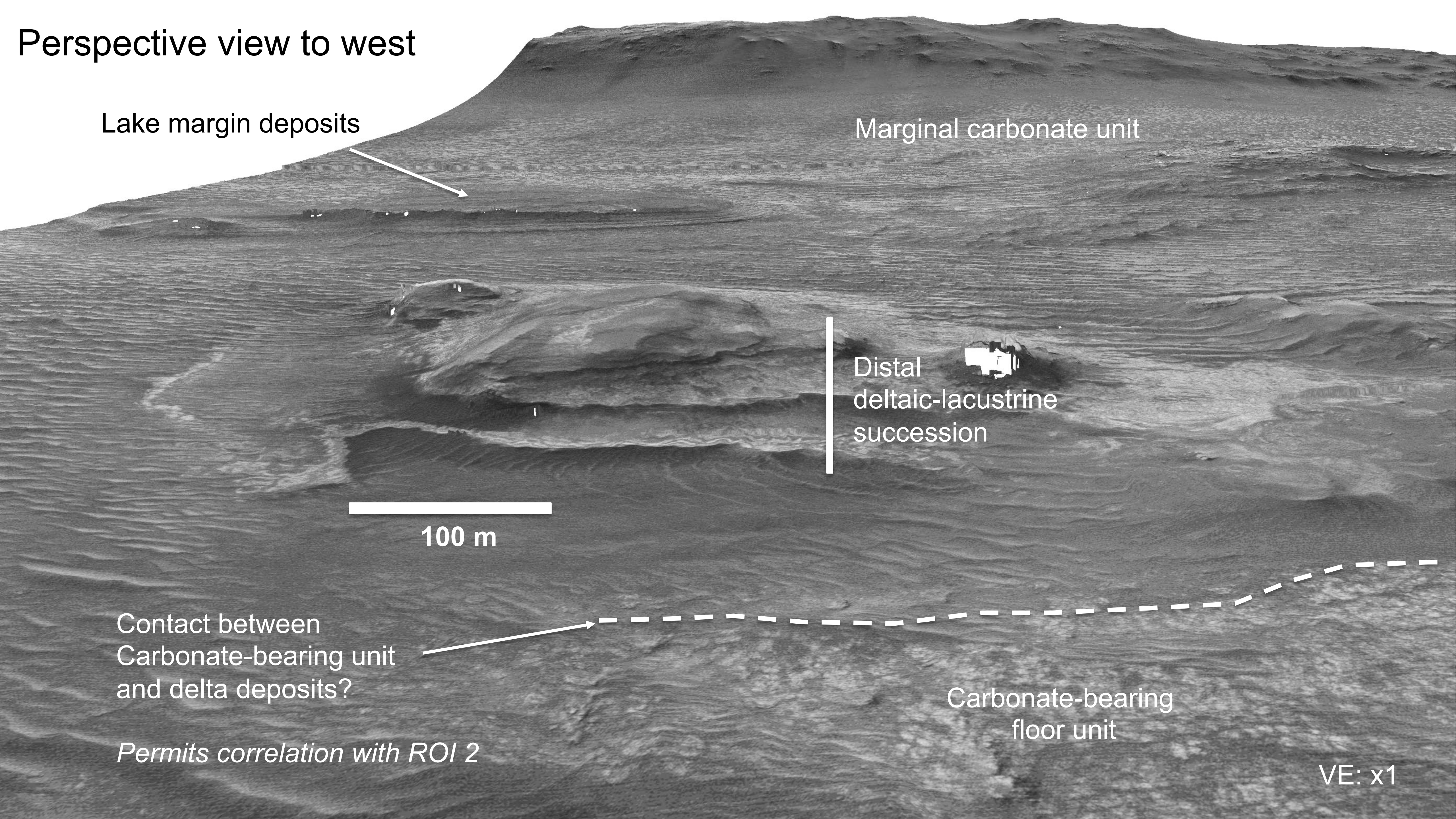
ROI 4 – Campaign 1 – Distal delta succession

- Traverse from Carbonate-bearing floor unit through lower delta strata to compare with ROI 2
- Section appears to be very good
- Characterization of facies in distal deltaic strata – can be rapid if similar to at ROI 2





Perspective view to west
Lake margin deposits
Marginal carbonate unit
Distal
deltaic-lacustrine
succession
100 m
Contact between
Carbonate-bearing unit
and delta deposits?
Carbonate-bearing
floor unit
Permits correlation with ROI 2
VE: x1

ROI 4 Campaign 2 – Lake Margin deposits

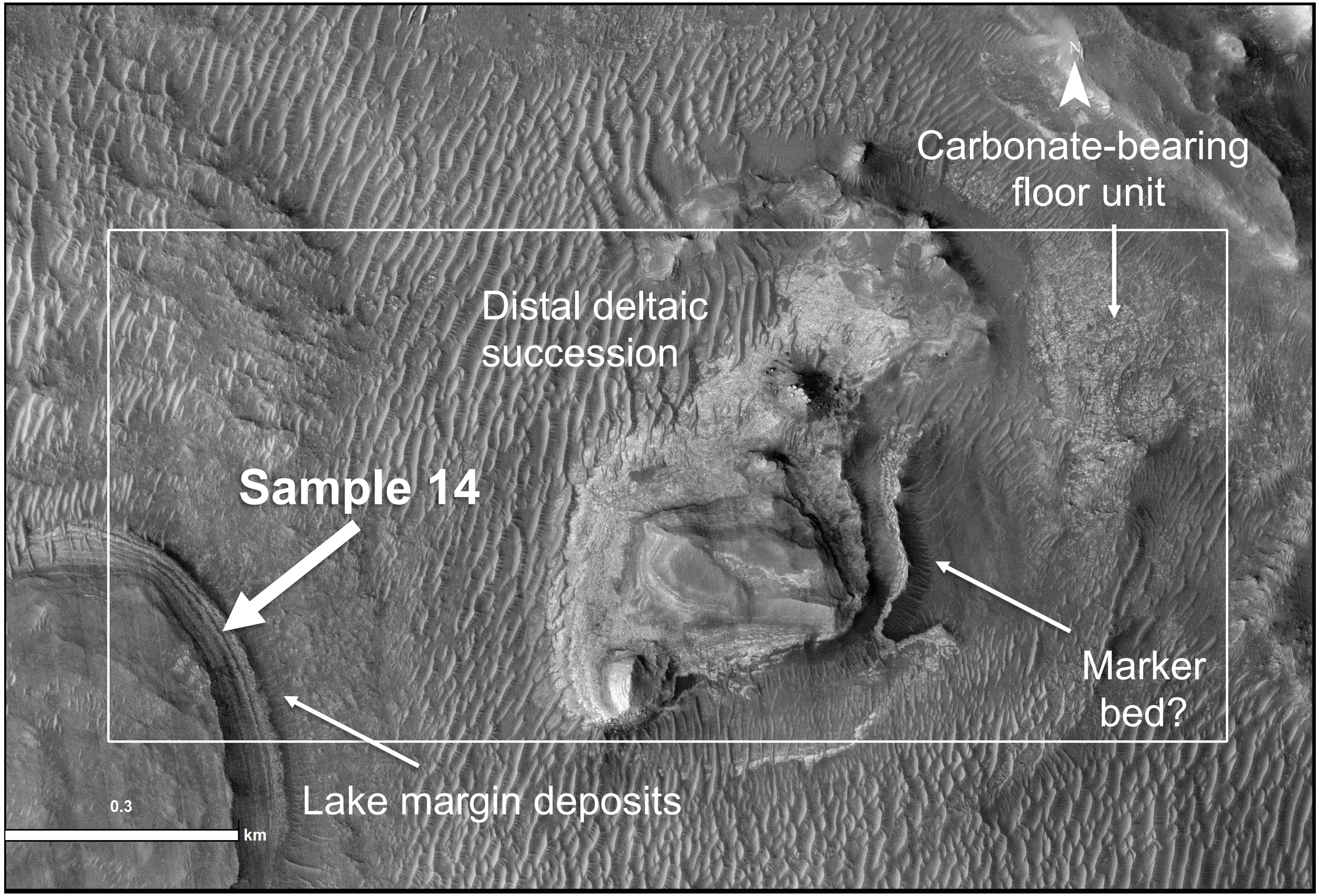
- Thick stack of flat-lying layers – determine whether or not this area is distinct from deltaic outcrops
- First opportunity to sample quiescent lake margin environment, could have high biosignature preservation potential

ROI 4 Sampling Strategy

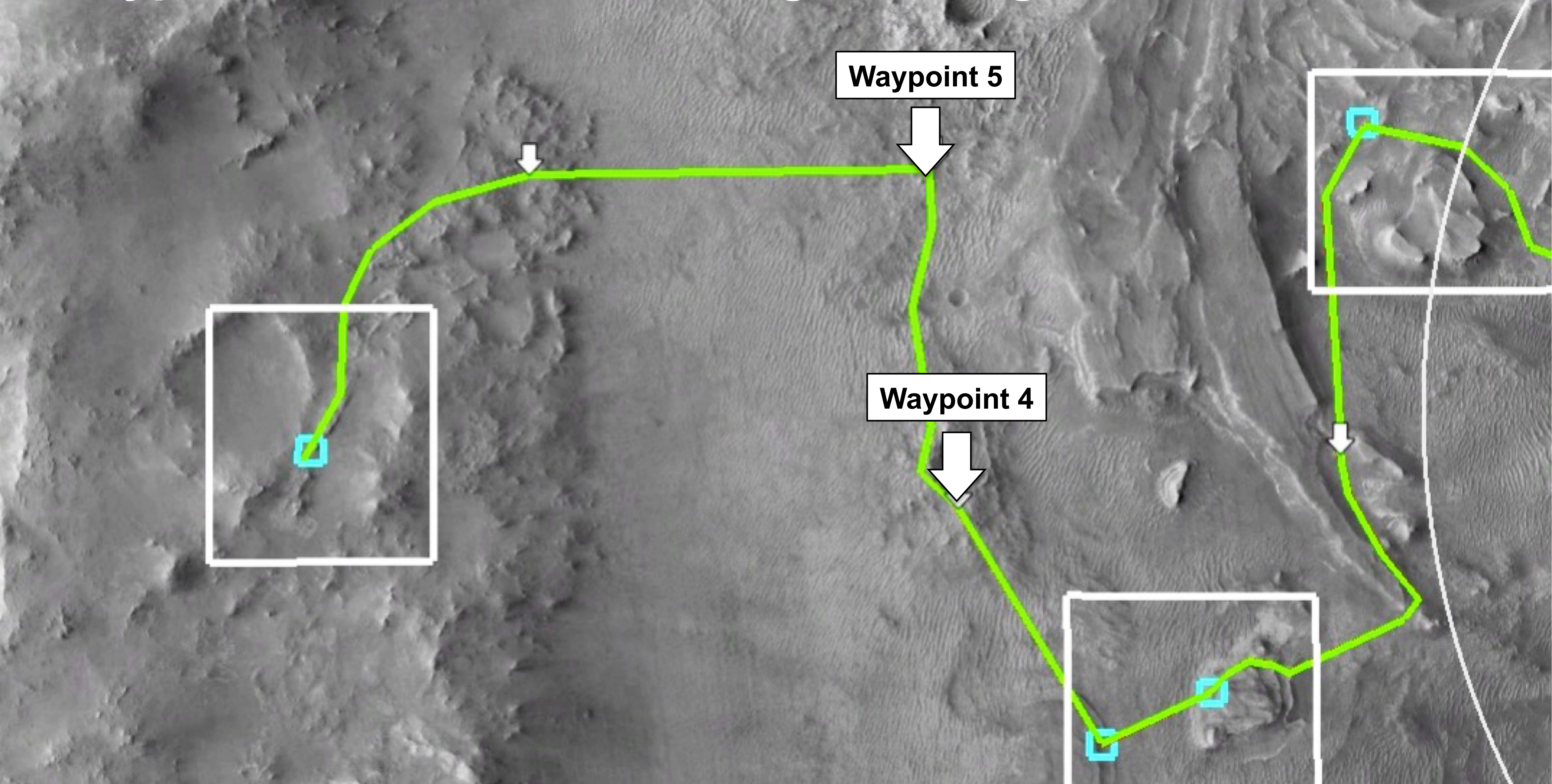
- Either Sample: Distal delta/lacustrine sample
  - ☐ Search for organics
- Or Sample: Lake margin sample
  - ☐ Search for organics
  - ☐ Martian carbon cycle (if carbonate)
  - ☐ Lake chemistry

Sample 14:

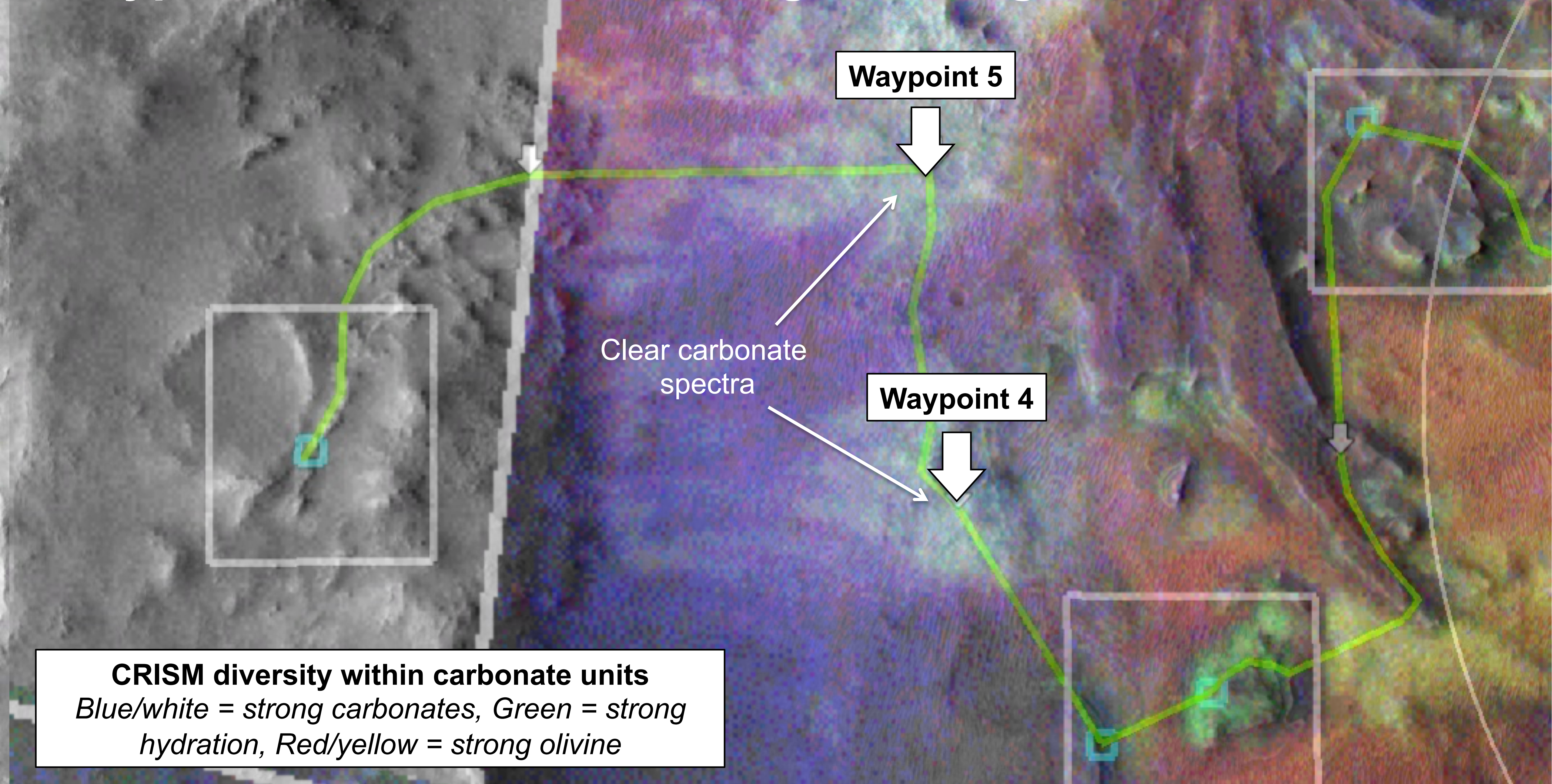
Lake margin sediments



Waypoints 4/5 – Characterizing the Marginal Carbonates



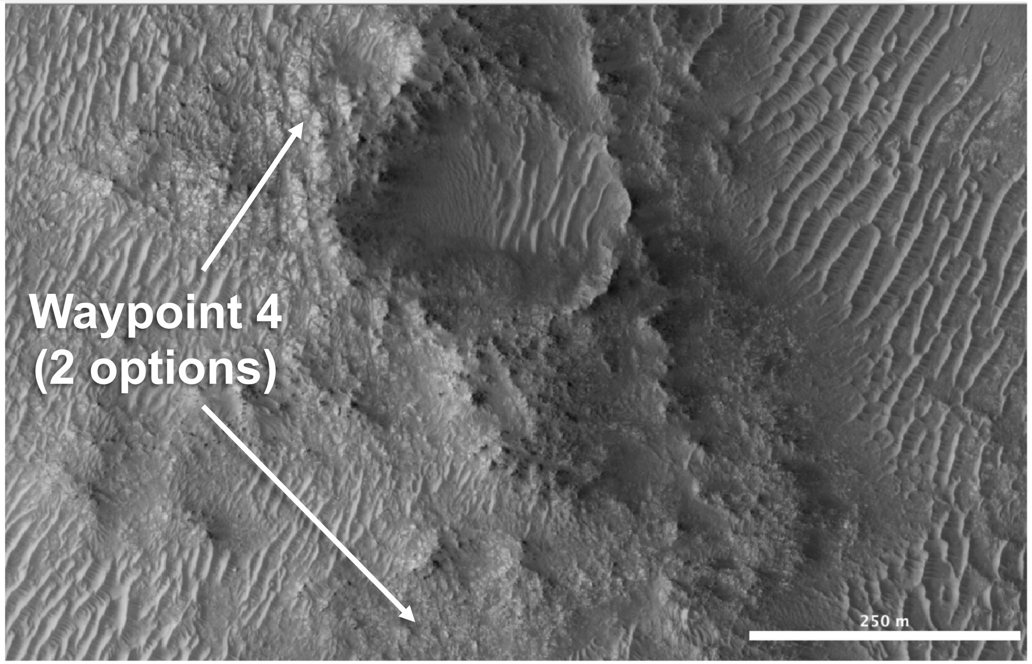
Waypoints 4/5 – Characterizing the Marginal Carbonates

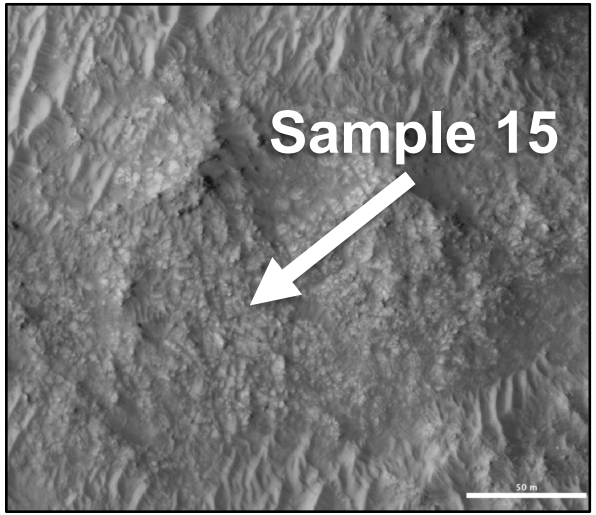


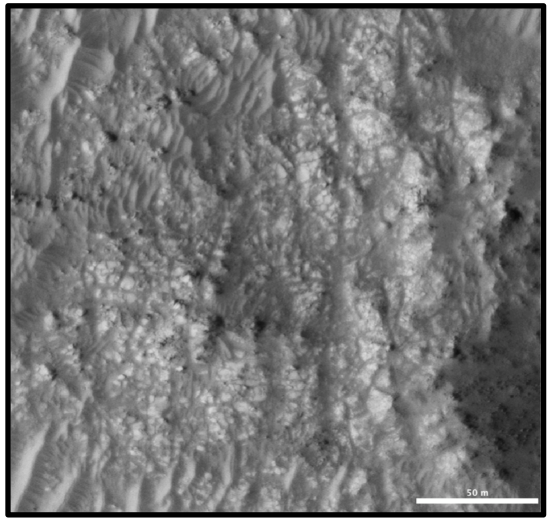
CRISM diversity within carbonate units
Blue/white = strong carbonates, Green = strong hydration, Red/yellow = strong olivine

Waypoints 4/5 – Marginal Carbonates

- Compare composition/texture/stratigraphy to Carbonate-bearing Floor and detrital carbonates in delta – do they have a distinct depositional and/or alteration history?
- Determine depositional environment – contributions from fluvial vs. lacustrine processes, origin of linear ridges. Do these parallel possible shorelines?
- Search for macro- and micro-scale textural biosignatures and organics (Mastcam-Z, SuperCam, SHERLOC)
- If lacustrine precipitates are present, evaluate their mineralogy and chemistry with SuperCam, SHERLOC, PIXL

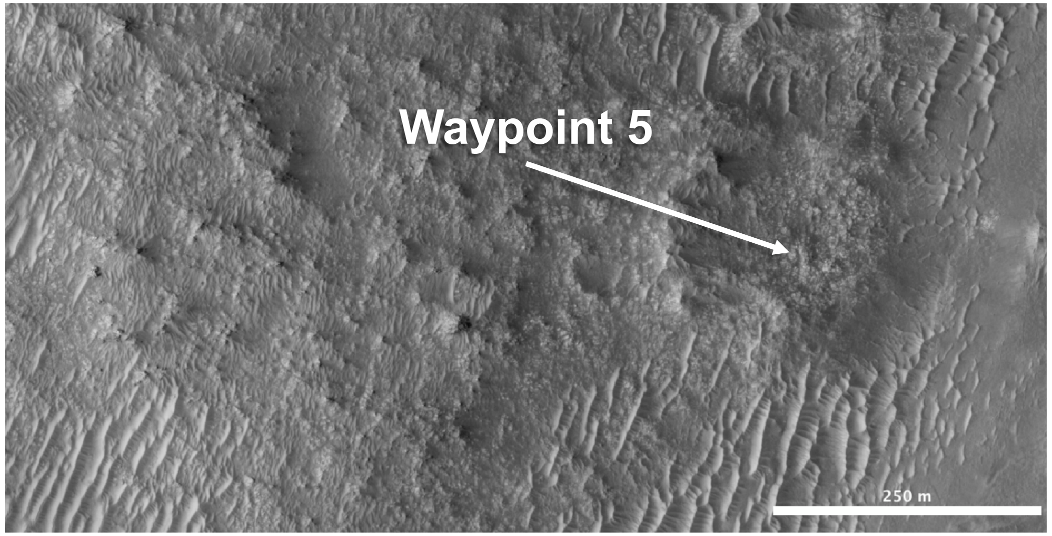






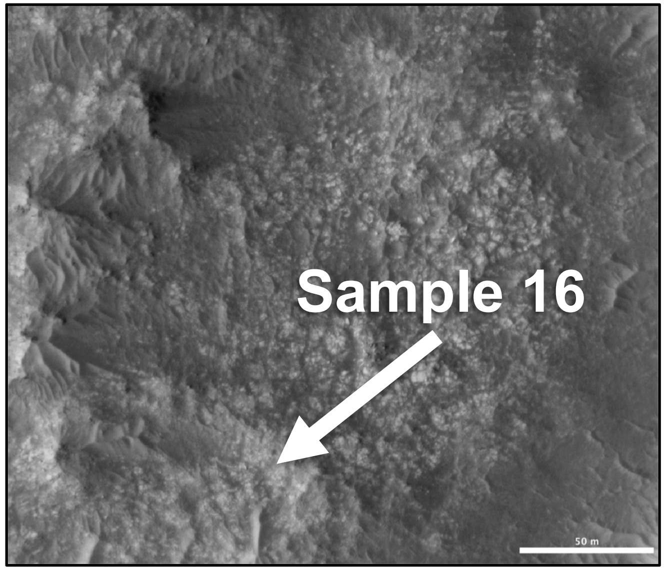
Waypoints 4/5 –
Marginal Carbonates Sampling Strategy

- 2 samples of the Marginal Carbonates
  - Sample diversity of mineralogies, compositions, textures

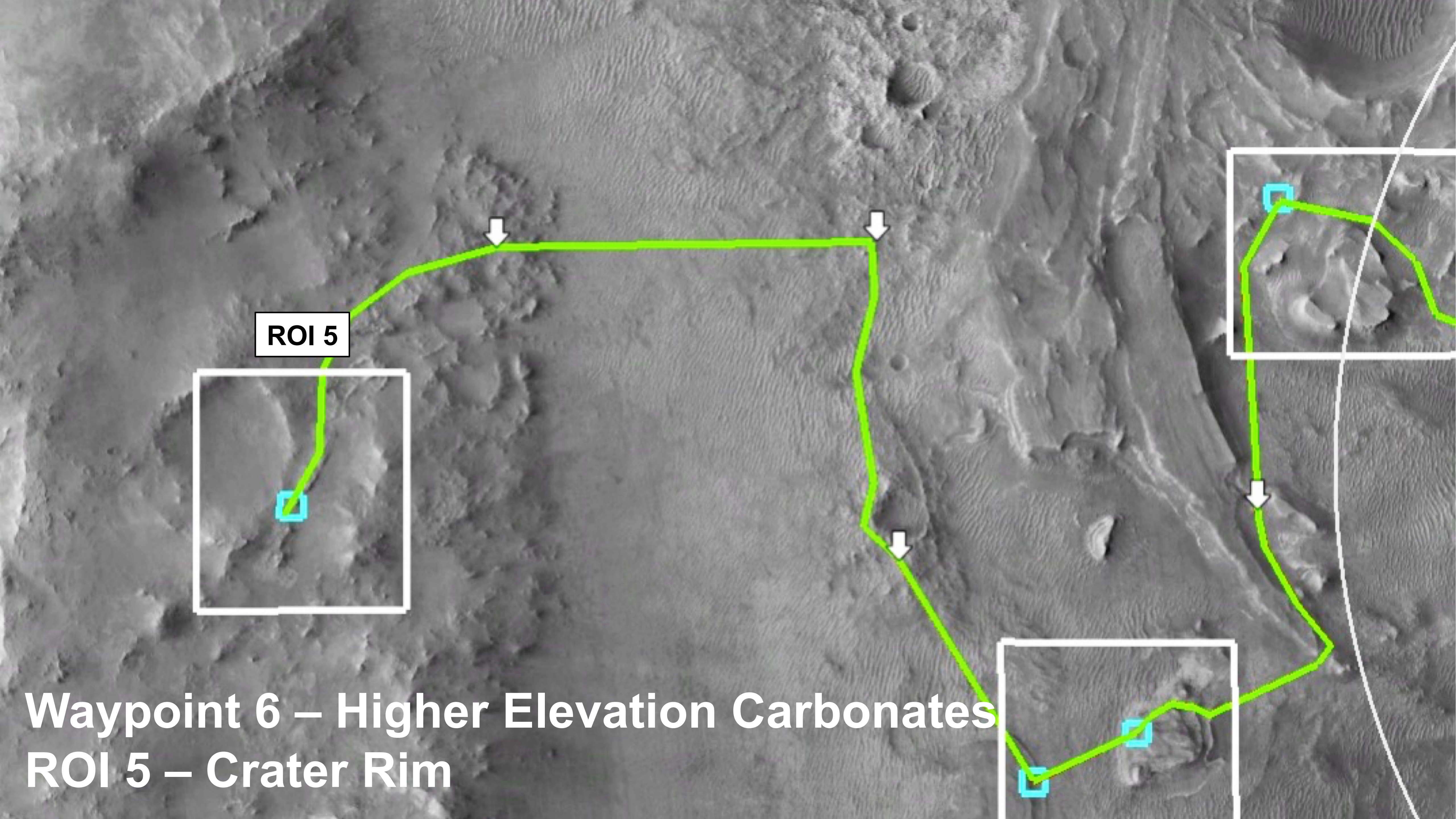


Samples 15-16

Acquire 2 samples of the Marginal Carbonates unit

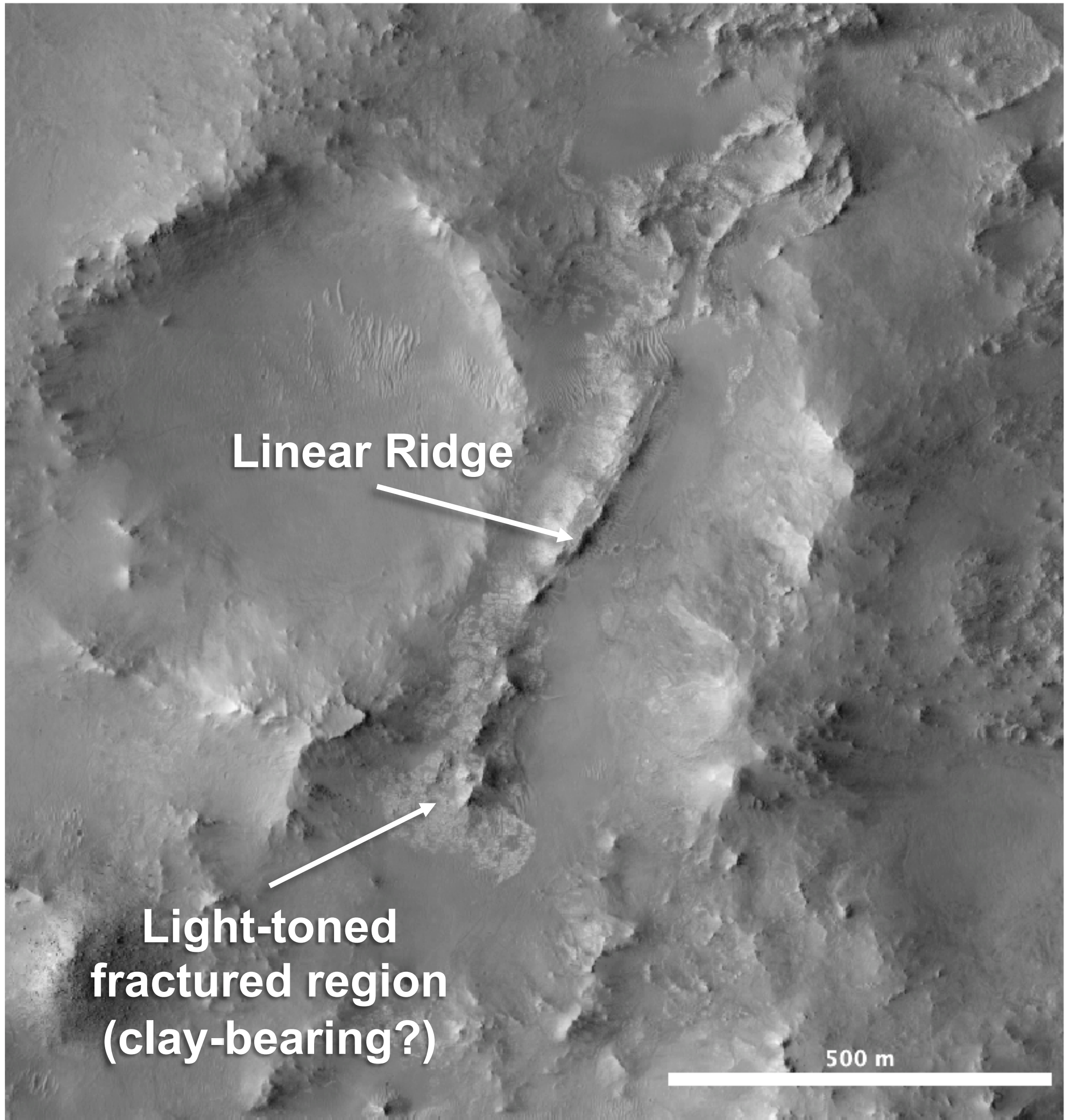


Waypoint 6 – Higher Elevation Carbonates
ROI 5 – Crater Rim



ROI 5 – Basement unit in crater rim

- Rim is dominated by LCP and clay of regional basement. No CRISM coverage here but similar morphology to clay-bearing basement in rim
- Long linear feature may be similar to long linear fractures in basement unit elsewhere
- Investigate origin, composition, and alteration history of basement unit. How much alteration occurred due to the Jezero impact?
- Mastcam-Z and Supercam to characterize physical and compositional properties of units, RIMFAX to probe subsurface structure
- PIXL/SHERLOC to map microscale chemistry and texture to determine origin and alteration
- SHERLOC to look for organics in clay-bearing areas

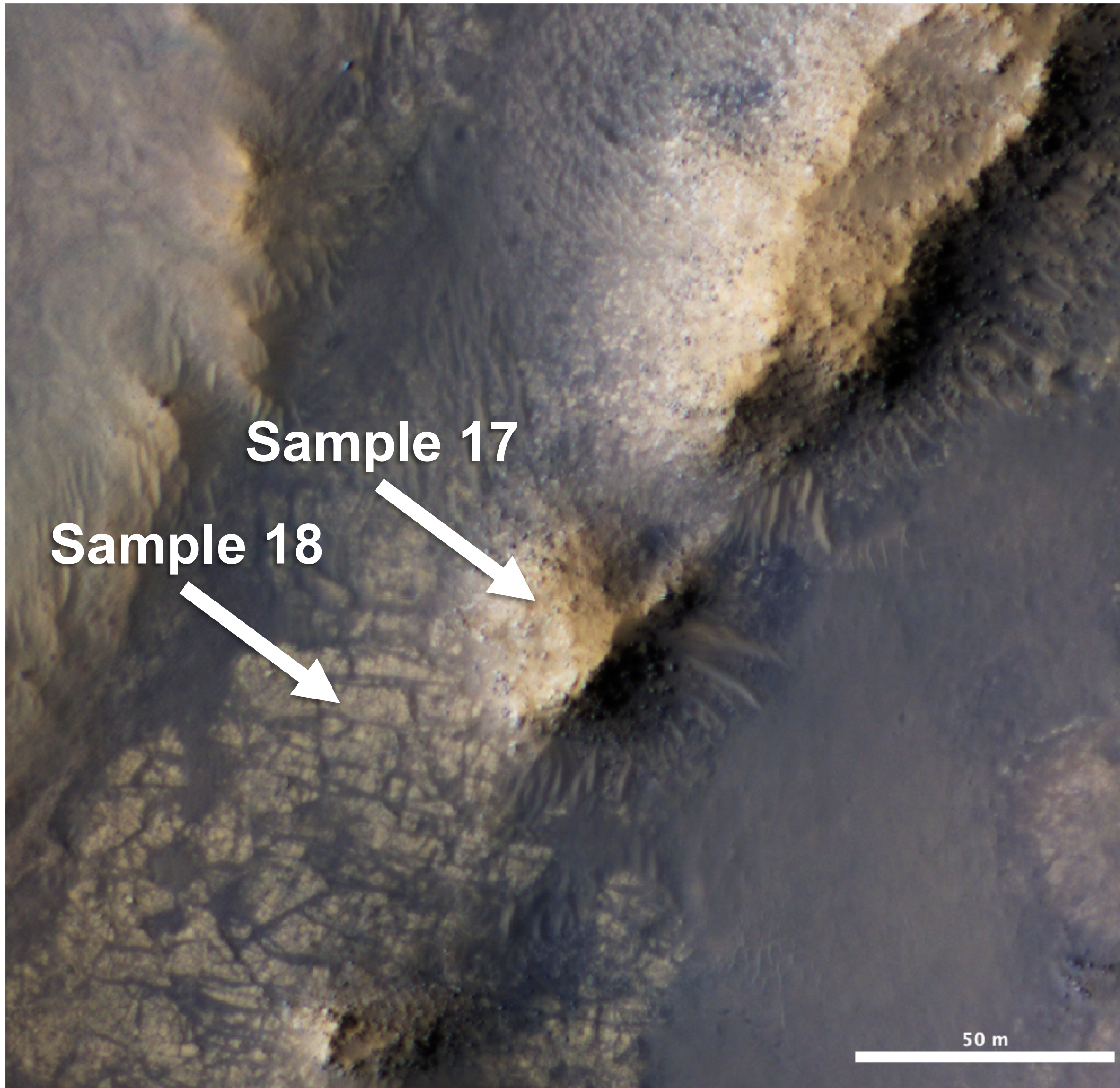


ROI 5 – Crater Rim Sampling Strategy

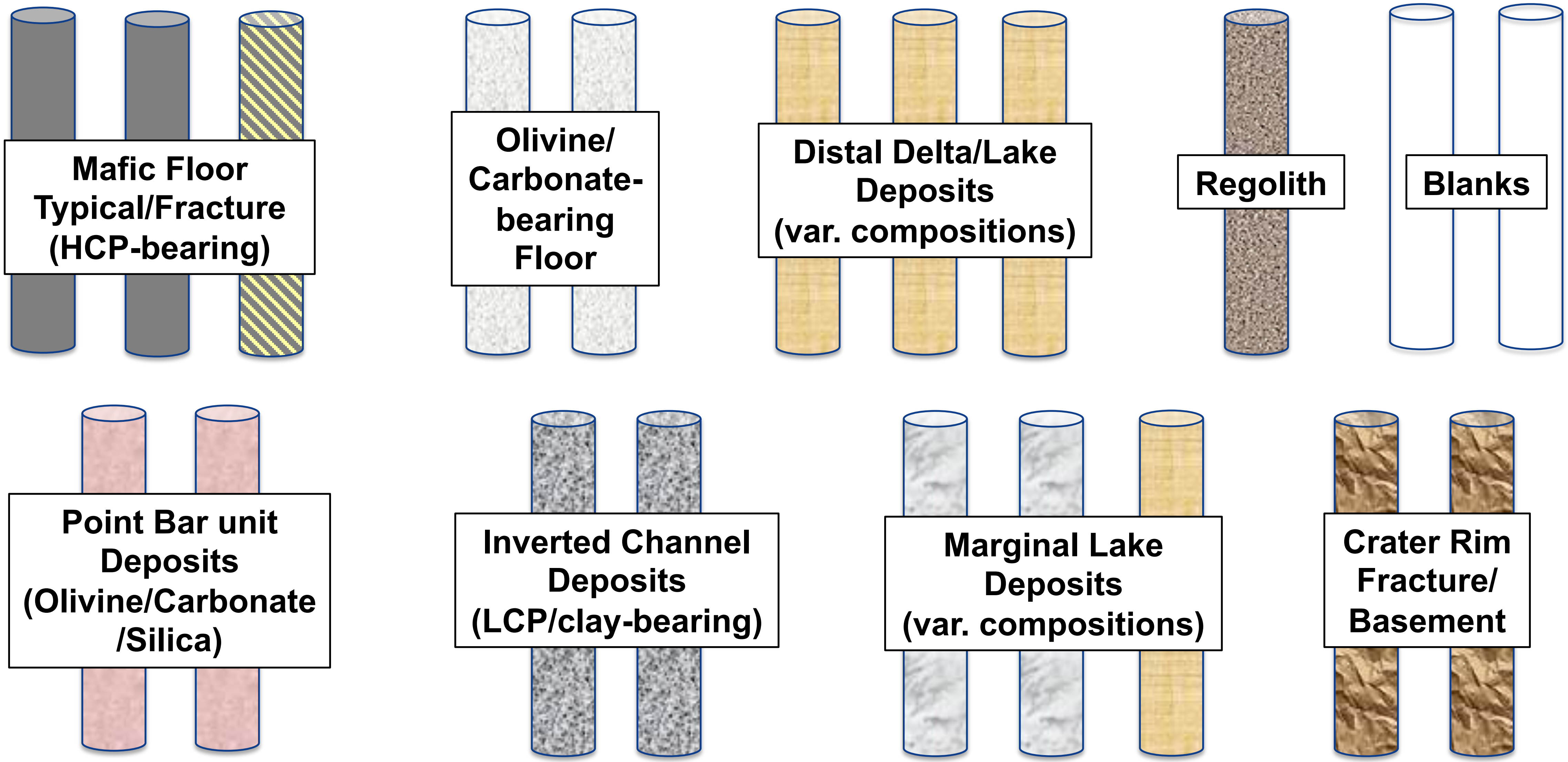
- Sample both altered and unaltered basement in crater rim
  - ☐ Provides insights into pre-Jezero alteration and perhaps Jezero hydrothermal circtculation
  - ☐ Provides information on age, differentiation, and magmatic history of Noachancrust

Samples 17-18

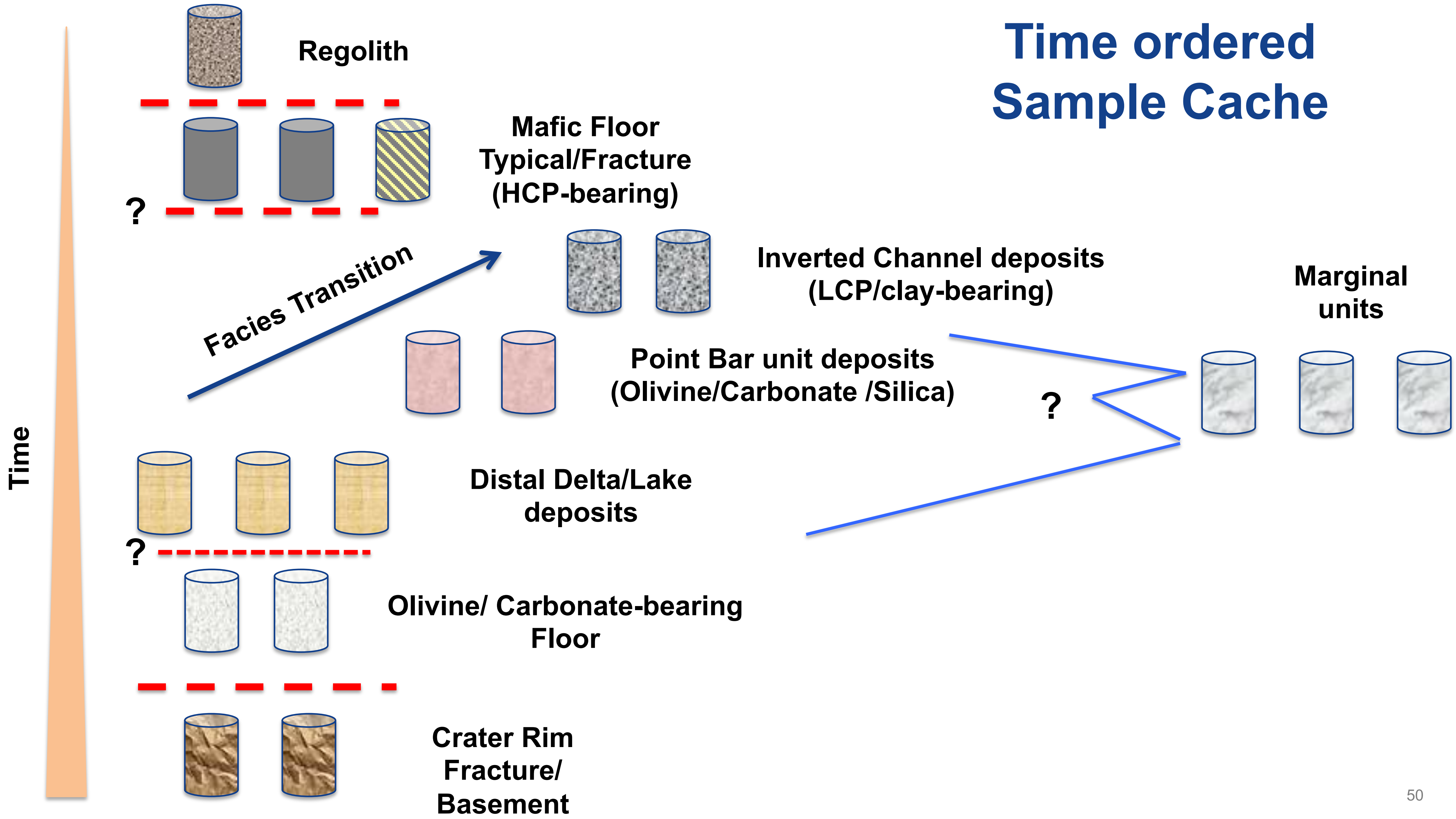
Altered and unaltered basement materials



Baseline Mission Sample Cache



Time ordered Sample Cache



Summary of returned sample science mission strategies and objectives

Jet Propulsion Laboratory
California Institute of Technology

- **LIFE** - Determine if fine-grained lower delta strata and carbonate-bearing units contain biosignatures, and show evidence for past Martian life.
- **GEOCHRONOLOGY** – Seek to determine age of basement materials and Isidis impact, Jezero impact, and carbonates from detrital sediments and in-situ samples. Constrain fluvio-lacustrine history.
- **CRATER CHRONOLOGY -** IF VOLCANIC determine the absolute age of the Mafic Floor unit using multiple geochronometers and combine with crater count statistics to place quantitative bounds on relative age dating of Martian surfaces.
- **IGNEOUS HISTORY** - Determine igneous petrogenesis of Mafic Floor unit, igneous detrital grains, and crater rim basement using petrology and isotope geochemistry
- **CARBON CYCLE** - Investigate the Martian carbon cycle through geochemical analysis of detrital deltaic, lacustrine precipitate, and in situ alteration-derived carbonates.
- **LAKE CHEMICAL EVOLUTION -** Determine the chemistry/temperature/timing of the Jezero lake through isotope geochemistry analysis of fine-grained delta succession and bound water/fluid inclusions
- **EARLY MARS CLIMATE –** Determine the timing of valley network activity from deltaic samples and bounding units, atmospheric density and escape rates from carbonate isotopes

Science Value and Potential of Baseline Mission Sample Cache

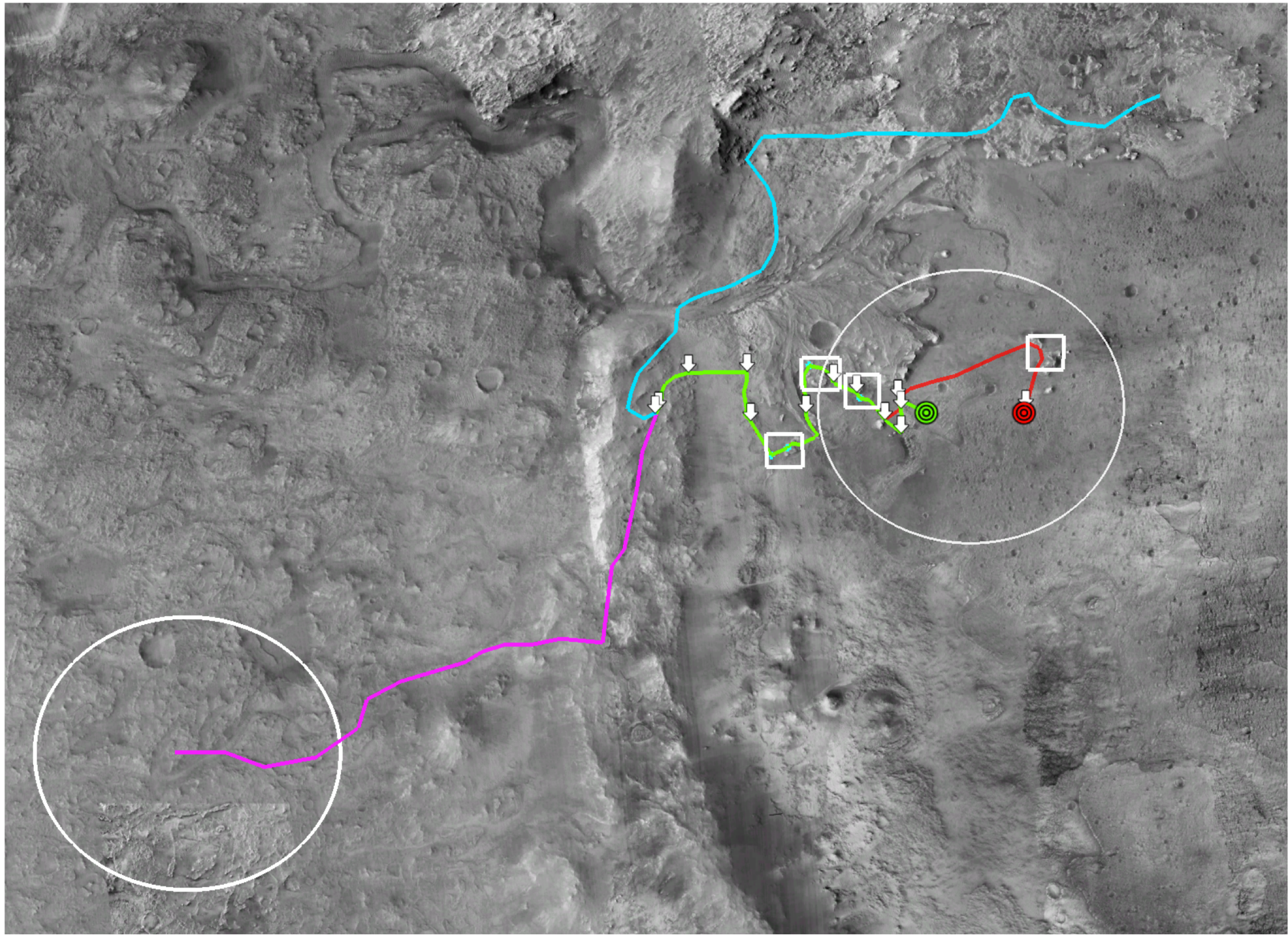
- **Habitability and life**
  - Did life ever exist on Mars?
- **Chronology**
  - When did deposition occur in Jezero, and what can this tell us about the global era of valley network activity?
  - What is the formation age of Jezero crater? Are habitable, impact-generated hydrothermal environments preserved?
- **Late Noachian surface environments**
  - How did the lake environment and martian climate evolve during lacustrine deposition? What was the weathering environment?
  - What were the chemical properties of Lake Jezero? Was the lake inhabited?
  - Were delta surface environments habitable, and what can they tell us about surface conditions during the Noachian/early Hesperian?
  - Did carbonate precipitation co-occur with, or postdate lacustrine deposition? Are marginal, alkaline habitats preserved?
- **Evolution of Martian carbon cycle and paleoatmosphere composition**
  - How did the Martian carbon cycle evolve? [Ol-carbonate unit and marginal carbonate samples]
  - Is the composition of the Martian atmosphere preserved in the mineral record?
- **Crustal composition and petrogenesis**
  - What is igneous composition and alteration history of the mafic floor unit?
  - What information about planetary evolution is recorded in the diverse materials derived from the Jezero watershed?

Extended Mission Exploration

- Two options for extended missions from Jezero:

  (1) Traverse to Midway to explore and sample ancient Noachian crust and source units for Jezero sediments

  (2) Drive to northern Jezero, to explore and sample the full diversity of carbonate units and fluvio-lacustrine deposits that may predate the Noachian olivine-carbonate unit (the northern fans)



Benefits of a Mars 2020 mission at Jezero crater 1

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- **Jezero crater delta fan offers a well-defined geomorphic and stratigraphic target on orbital imagery**
  - Morphostratigraphy and clear orbital spectral signatures will guide ***efficient*** exploration strategy
  - Apply ‘Follow the Facies’ strategy to search for strata with highest potential to preserve biosignatures
- **Multiple distinct targets with high biosignature preservation potential, with clear analogs in the ancient terrestrial record**
  - Multiple carbonate-bearing lithologies provide insight into search for biosignatures associated with carbonates as well as quantitative constraints on the martian carbon cycle
  - Delta-lacustrine deposits concentrate organics from the lake environment and surrounding units, as well as providing a petrologic record of those units. Organic concentration in (younger?) martian mudstones confirmed by MSL.
  - Also allows access to subsurface environments that may be preserved in diagenesis of sediments and crater rim, as well as possible hydrothermal environments in crater rim.

Benefits of a Mars 2020 mission at Jezero crater 2

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- **Age dates will contribute to constraining both Mars cratering and valley network activity**
  - Mafic Floor unit provides potential for absolute age dating of igneous unit
  - If we can also date emplacement of regional olivine/carbonate unit and location in the Jezero strat section, we can also age bracket a significant portion of regional valley network activity
- **Provides constraints on early atmosphere, climate, and surface environments**
  - Carbonates and other precipitated minerals constrain composition and loss rates of the early atmosphere
  - These factors are reflected in the history (long-lived, short-lived, periodic), chemistry (alkaline, acidic), and detrital mineralogy of the fluvio-lacustrine system
- **Complete investigation of Jezero system in prime mission and begin traverse across rim and plains to Midway to sample NE Syrtis-like stratigraphy**

Mars 2020 Science Team Concerns About Jezero crater

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- Orbital data strongly suggests presence of open-lake basin in Jezero crater, however, difficult to confirm from orbit whether lower delta deposits are fine-grained strata consistent with distal delta/lacustrine mudstones
- Duration (10’s of ky, many My?) and timing (Noachian, Hesperian?) of aqueous activity not well understood from orbit.
- Mafic floor origin (igneous vs. sedimentary) is poorly constrained from orbit, and even if igneous, burial/erosional history may make tying to cratering record difficult
- If we cannot reach crater rim in the prime mission then difficult to address crustal evolution questions with baseline samples

Summary

- A mission to Jezero crater would explore an ancient lake system on Mars, including deltaic, lacustrine, shoreline, and sub-aerial environments
  - Depending on landing location, may also be able to reach crater rim and exposed Noachian crust in prime mission
- A sample cache from Jezero could provide age constraints on the timing of valley network activity, the composition and loss of the atmosphere, and the nature of early surface environments
- The combination of a likely lake delta with diverse lithologies and possible marginal lacustrine carbonate precipitates presents multiple targets with good biosignature preservation based on clear analogs in the terrestrial record

Baseline Mission Sample Cache