Front HazCam image of sampling of the Skinner Ridge target (NASA/JPL-Caltech)

NASA's *Perseverance* Rover Mission and Mars Sample Return

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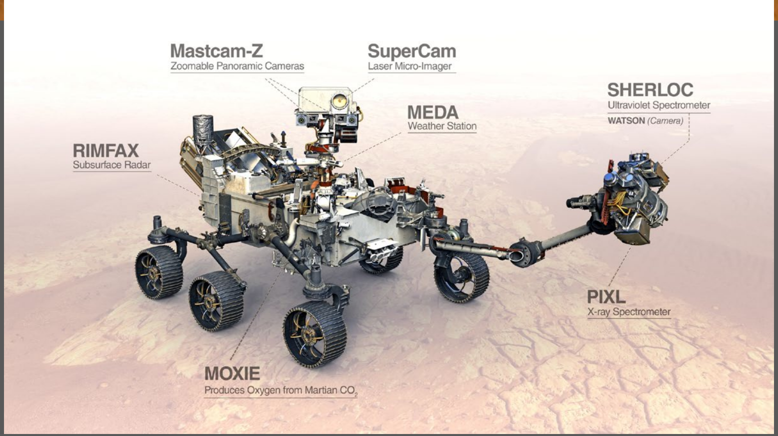
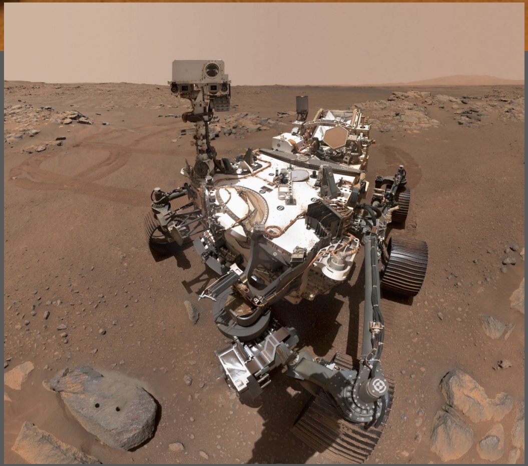
Mars 2020 Returned Sample Science (RSS) Participating Scientist, RSS PSG co-rep

FISO Telecon 09-25-2024

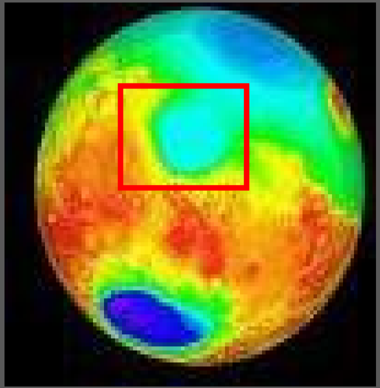
Jet Propulsion Laboratory
California Institute of Technology

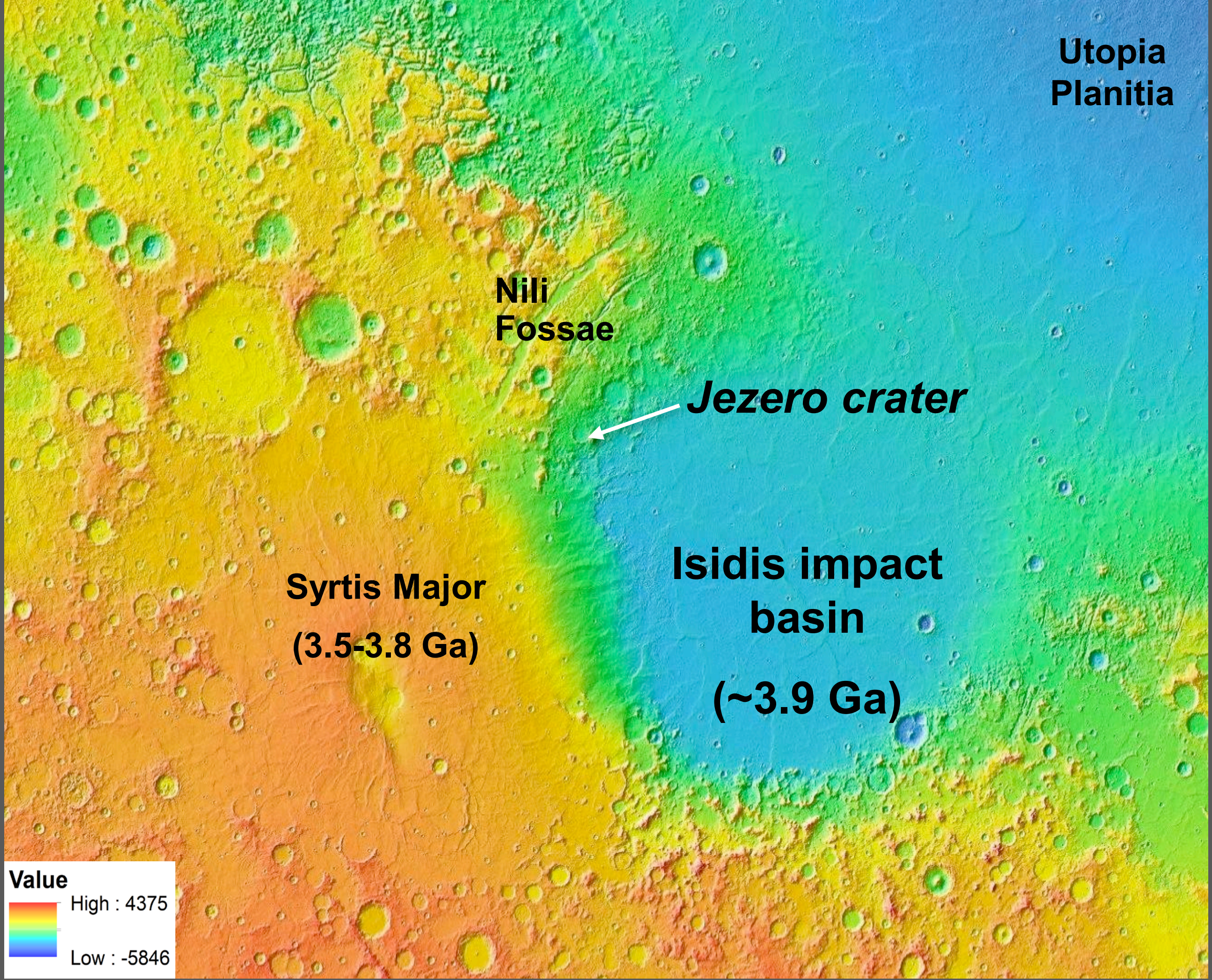

UNDERSTANDING THE POSSIBILITIES FOR LIFE ON MARS
ANCIENT MICROBIAL LIFE
HUMAN LIFE
Objective A: Geology
Objective B: Astrobiology
Objective C: Sample Caching
Objective D: Prepare for Humans


Mastcam-Z
Zoomable Panoramic Cameras
SuperCam
Laser Micro-Imager
SHERLOC
Ultraviolet Spectrometer
WATSON (Camera)
MEDA
Weather Station
RIMFAX
Subsurface Radar
PIXL
X-ray Spectrometer
MOXIE
Produces Oxygen from Martian CO_2

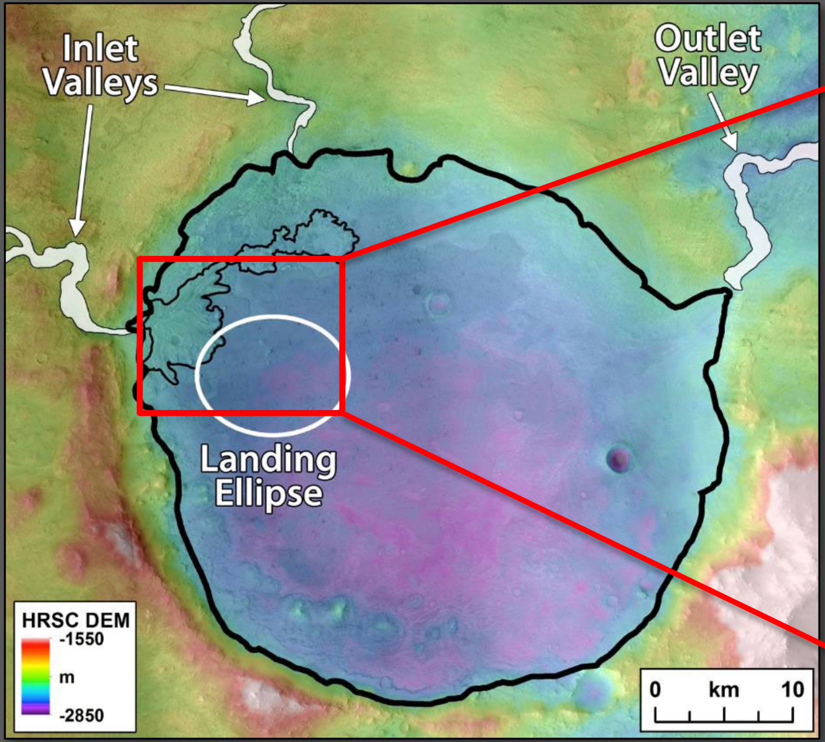


Where are we, and why?

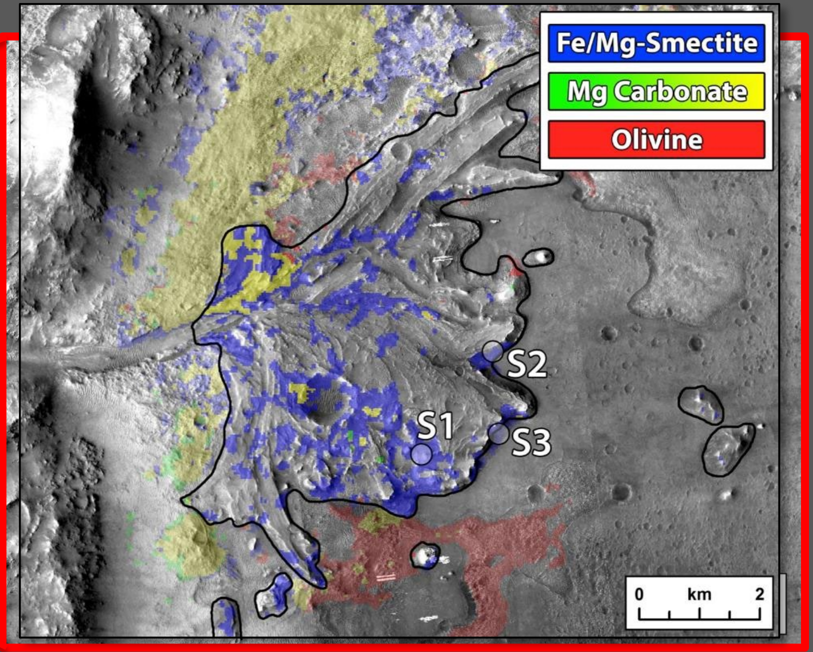




Delta Deposit Inside Jezero Crater



HRSC topography overlain on CTX mosaic

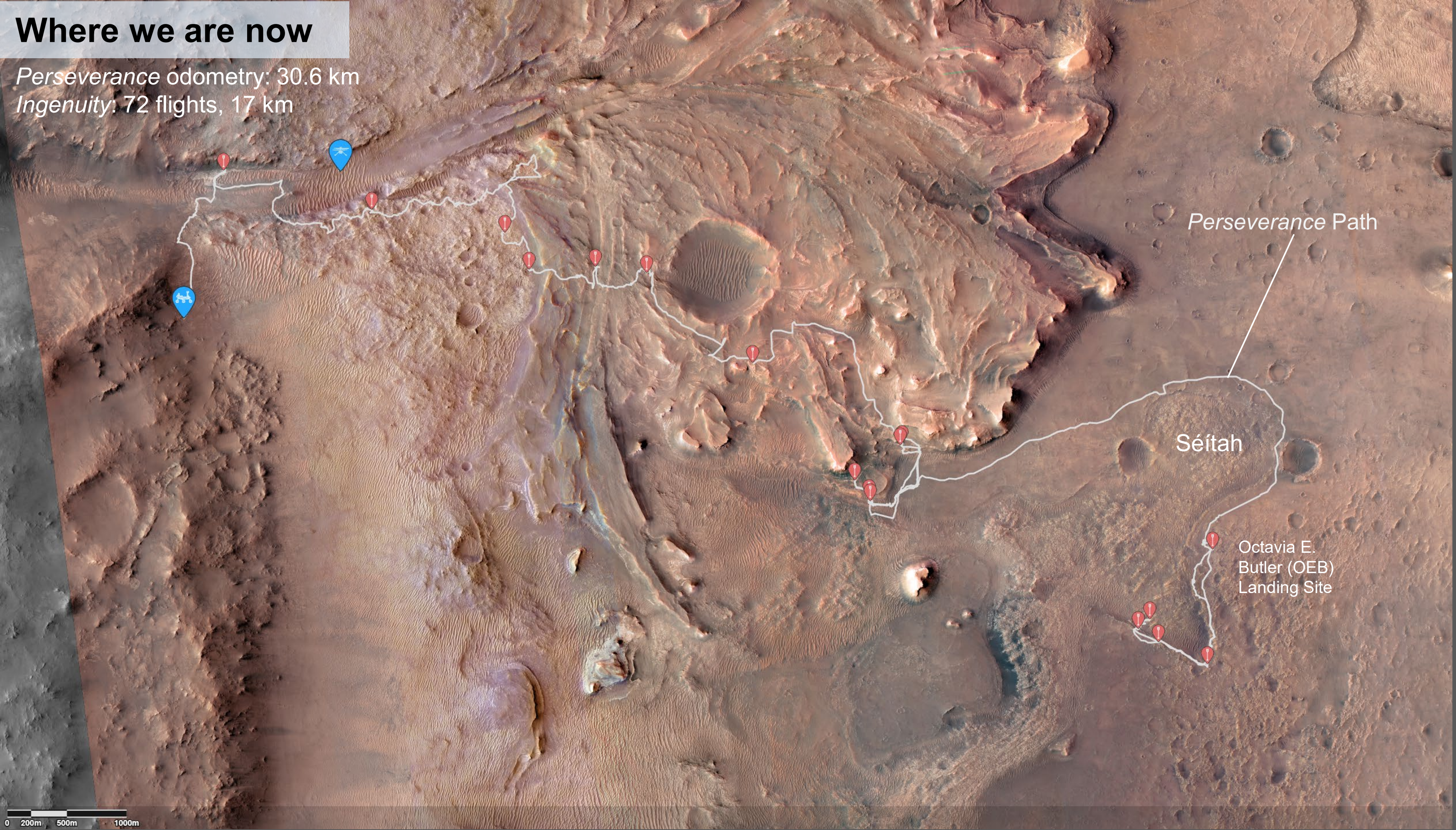


Modified from T. Goudge LSW3

For a map of the region, see https://pubs.er.usgs.gov/publication/sim3464

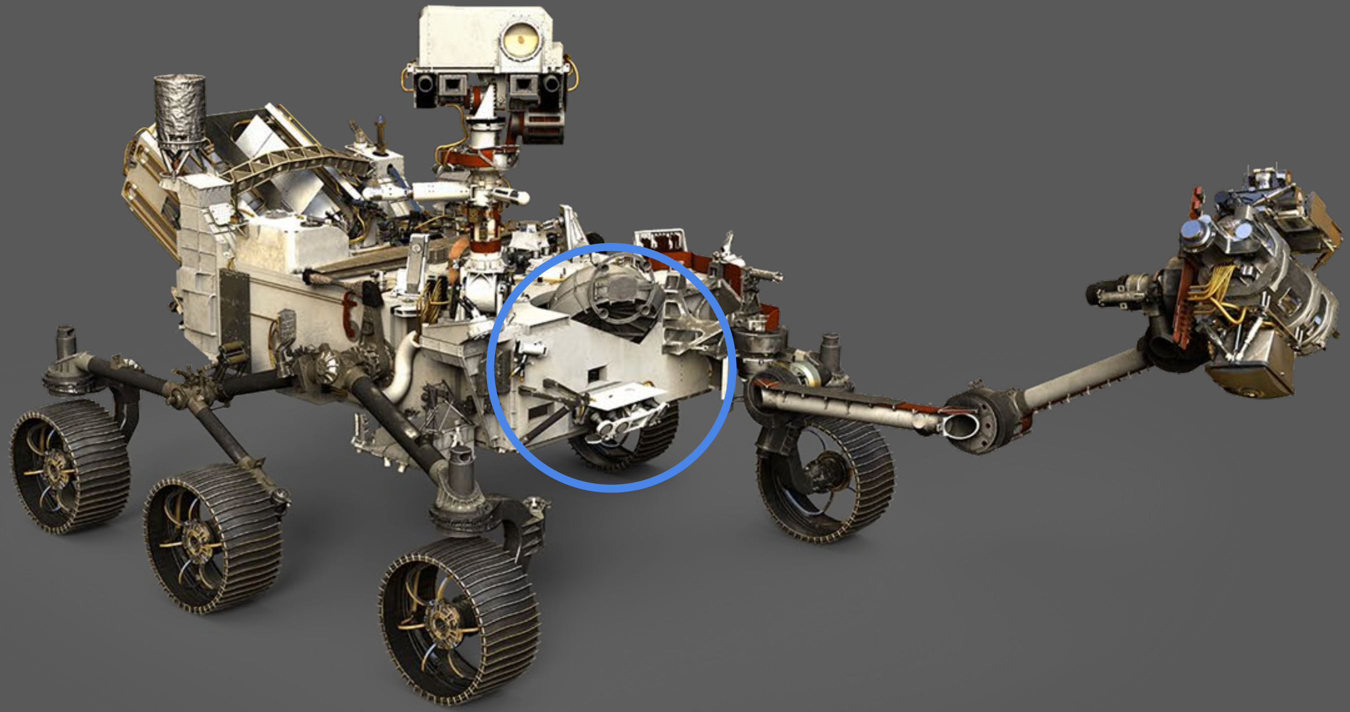
Where we are now

Perseverance odometry: 30.6 km
Ingenuity: 72 flights, 17 km



From https://mars.nasa.gov/mars2020/mission/where-is-the-rover/ NASA/JPL-Caltech

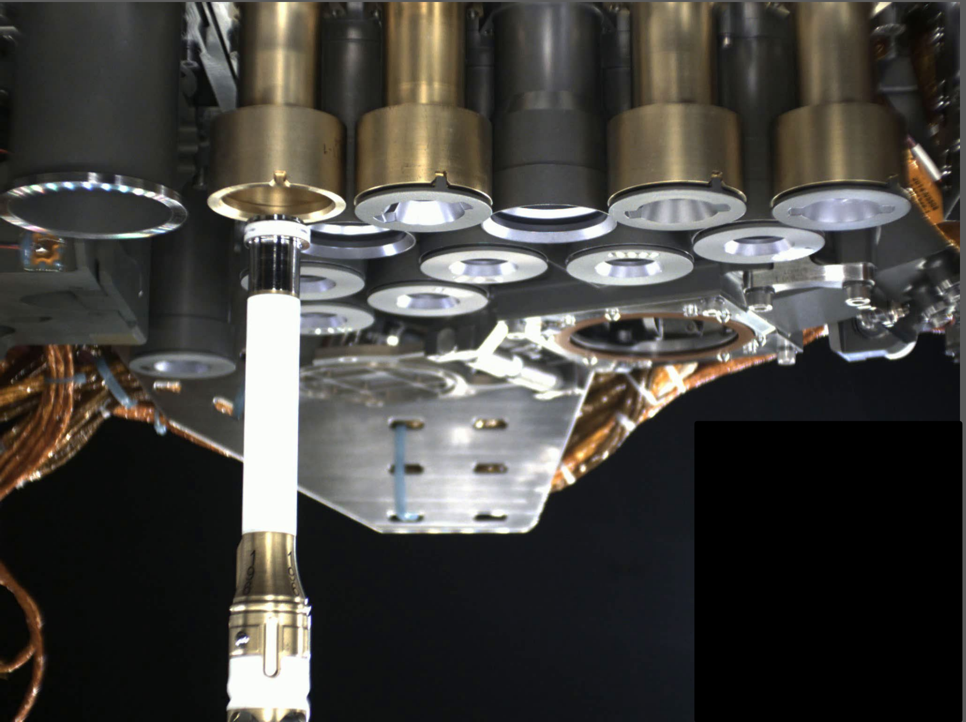
In its belly, and at the core of the mission, the rover carries a sample caching system



It is designed to help the rover collect and store pristine Mars rock on the planet's surface

MARS 2020

Front HazCam image of sampling the Ch-al member (*Hahonih*) NASA/JPL-Caltech



Perseverance carries

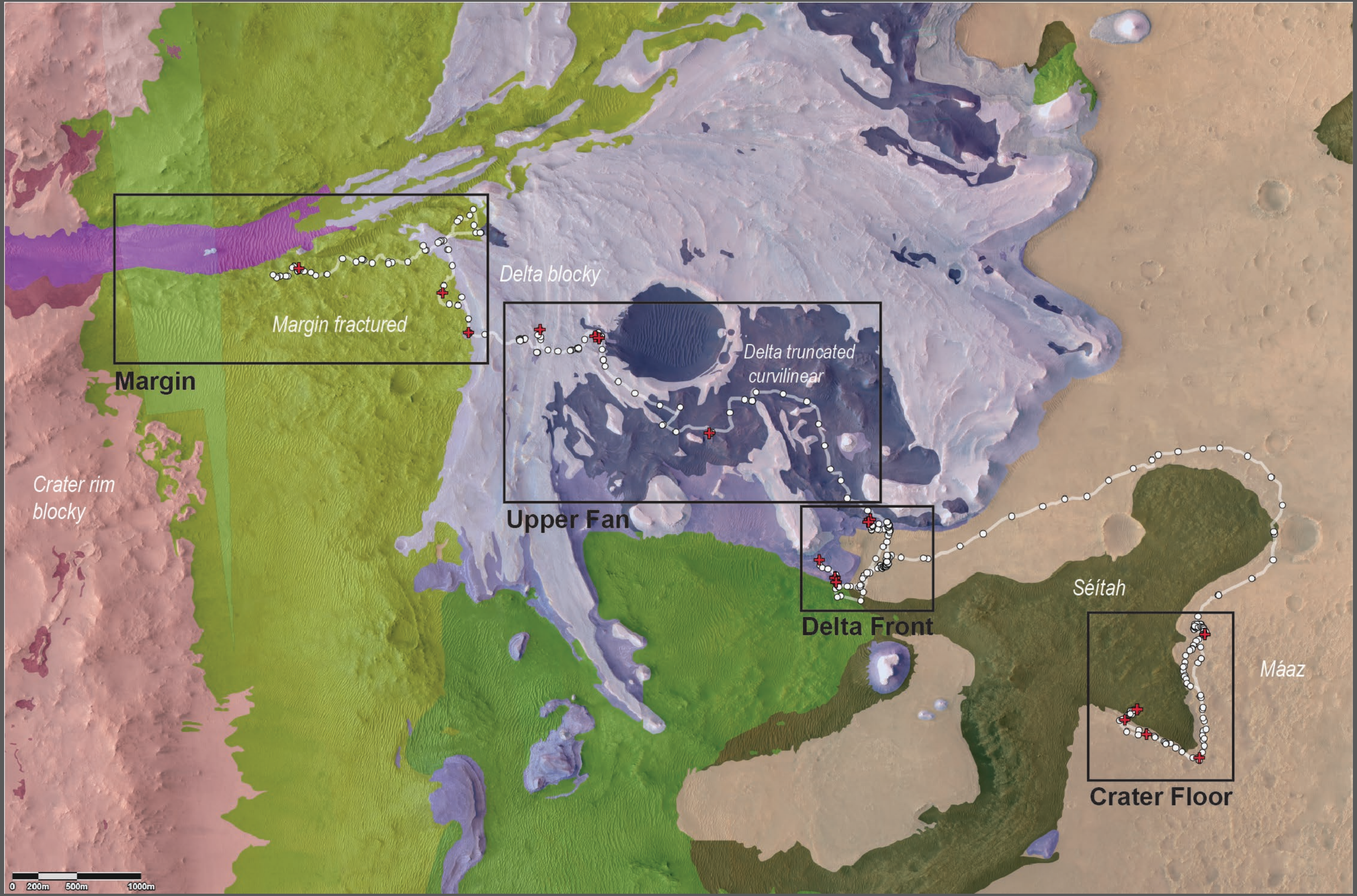
- 38 identical sample tubes
  - for rock, regolith, atmosphere

- 5 witness tubes
  - for contamination knowledge

Of these, 28 tubes have been used so far, including 21 rock samples, 2 regolith samples,1 atmospheric sample, and 3 witness tubes

Effectively 12 sample tubes remain, and 2 witness tubes

Perseverance has completed 4 Campaigns and is starting the 5th

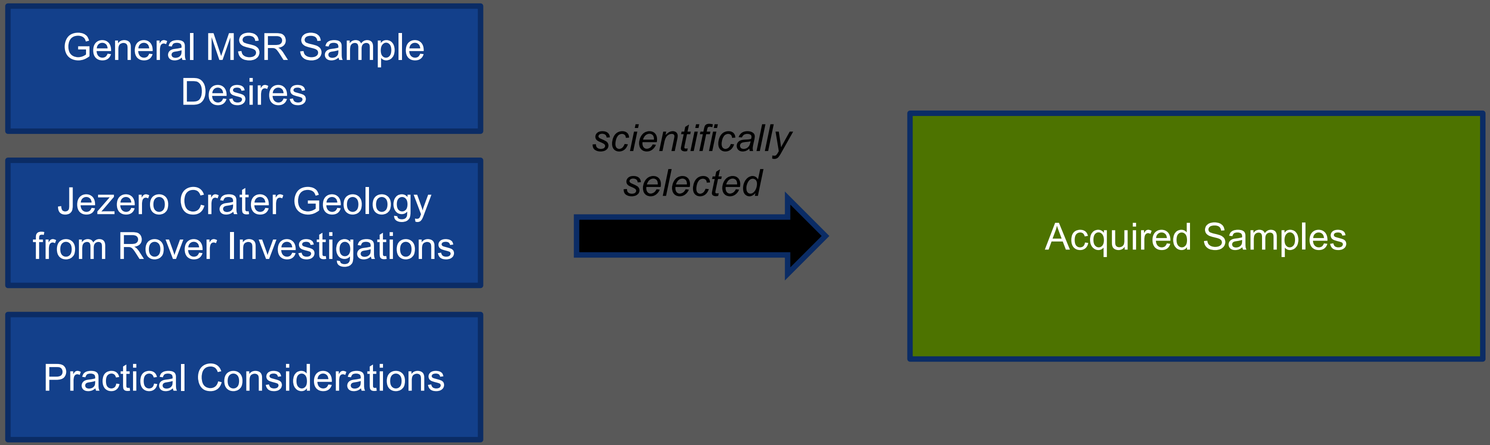


Map showing mission progress, superimposed on geologic map of Jezero crater, after Stack et al. (2020). Rover traverse and waypoints shown with white line and dots, respectively; sampling locations shown with red crosses. Labeled black boxes show approximate extent of each campaign. Names of major units or formations encountered – or expected to be encountered – are labeled in white italics. After Herd et al. (*In Review*).

Sampling Details

<u>How Are Samples Selected?</u>

Sample priority guided by community desires expressed in published documents, e.g., iMOST Report*, as interpreted and applied to Jezero crater by the Mars 2020 Science Team, especially its Returned Sample Science Participating Scientists



*iMOST (2018), The Potential Science and Engineering Value of Samples Delivered to Earth by Mars Sample Return, (co-chairs D. W. Beaty, M. M. Grady, H. Y. McSween, E. Sefton-Nash; documentarian B.L. Carrier; plus 66 co-authors), 186 p

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Sampling Details

What "Field Notes" are being acquired?

Every sample (or paired sample set) is documented by a standardized set of observations that are executed following an optimized sol path of **10 sols** duration. This **Standardized Observation Protocol (STOP list)** maximizes efficiency and consistency. Includes workspace imaging, remote and proximity science, etc.

How are sample-related data recorded for posterity?

1) ***Sample Dossier***

A digital "one stop shop" file on NASA Planetary data System (PDS) that includes for each sample:

1) Links to all STOP list observations
2) Additional rover-related data associated with sampling (localization, time history, etc)

2) *Initial Reports*

A templatized narrative description of each sample, written by the science team within 3 weeks of collection. Preliminary interpretation, not revised after completion.

MARS 2020 INITIAL REPORTS

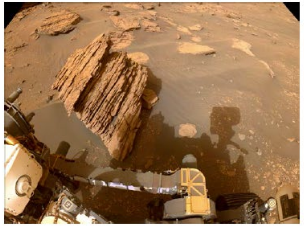
Volume 1

Crater Floor Campaign August 11, 2022

KEN FARLEY, MARS 2020 PROJECT SCIENTIST
CALIFORNIA INSTITUTE OF TECHNOLOGY

KATIE STACK, MARS 2020 DEPUTY PROJECT SCIENTIST
JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY

MARS 2020



MARS 2020 INITIAL REPORTS

Volume 2

Delta Front Campaign February 15, 2023

KEN FARLEY, MARS 2020 PROJECT SCIENTIST
CALIFORNIA INSTITUTE OF TECHNOLOGY

KATIE STACK, MARS 2020 DEPUTY PROJECT SCIENTIST
JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY

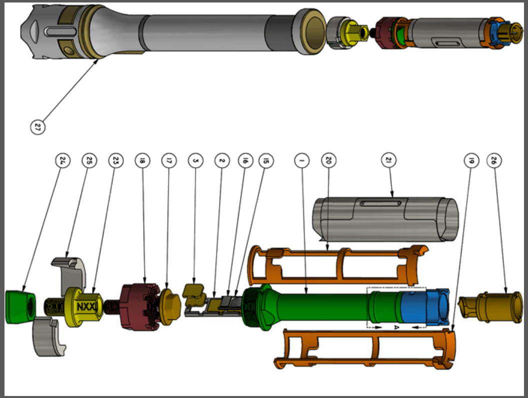
MARS 2020

First 21 samples fully documented in ***Initial Reports*** available to all on NASA PDS:
https://pds-geosciences.wustl.edu/missions/mars2020/returned_sample_science.htm

MARS 2020

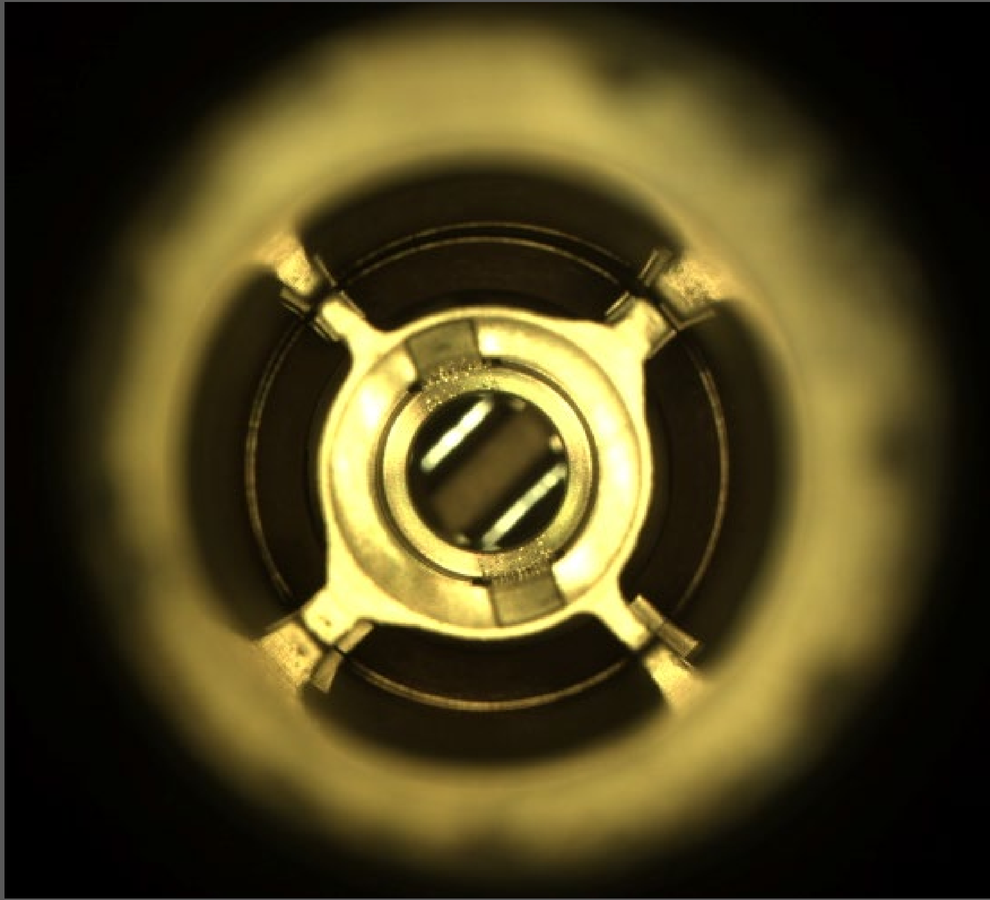
Witness Tube Assemblies (WTAs)

Consist of witness materials of various types in an assembly contained within an otherwise-identical sample tube (Moeller et al. 2021, *Sp. Sci. Rev.*)



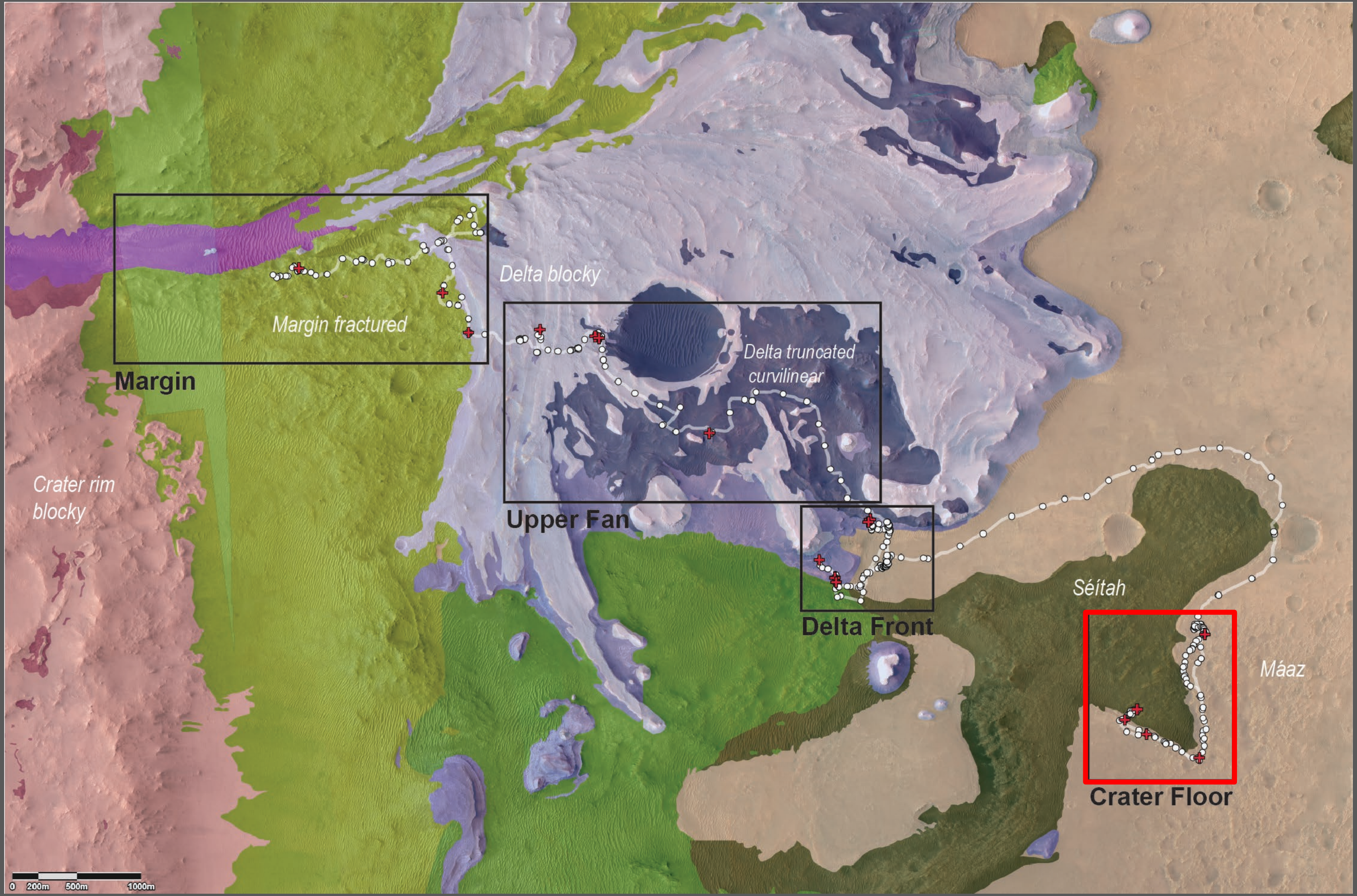
Collected thus far:

- Bit Carousel WTA
- WB2 (first WTA after sampling); collected after the rock samples at Skinner Ridge
- WB3; collected after rock samples at Amalik



CacheCam image of M2020-500-13 WB2 activated, just prior to sealing

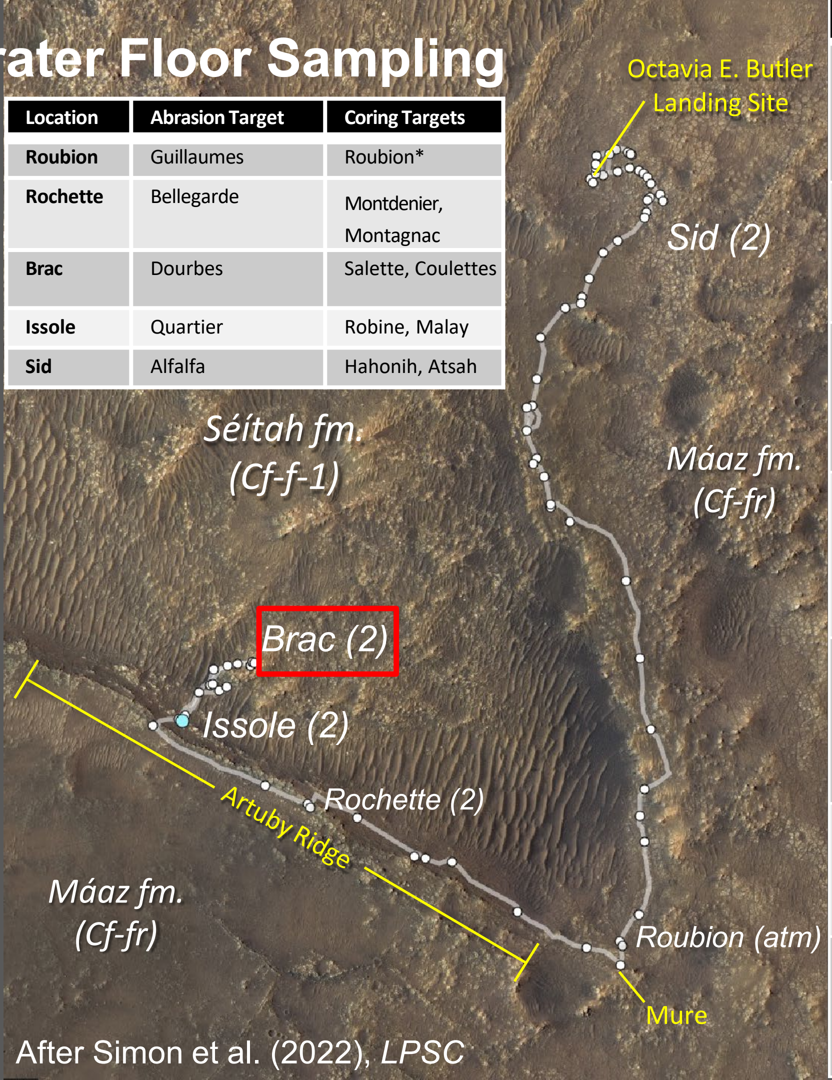
Crater Floor Campaign



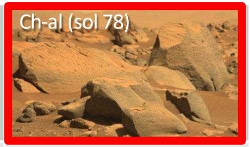
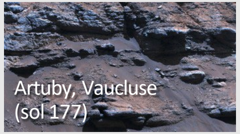
Map showing mission progress, superimposed on geologic map of Jezero crater, after Stack et al. (2020). Rover traverse and waypoints shown with white line and dots, respectively; sampling locations shown with red crosses. Labeled black boxes show approximate extent of each campaign. Names of major units or formations encountered – or expected to be encountered – are labeled in white italics. After Herd et al. (*In Review*).

Crater Floor Sampling

Location	Abrasion Target	Coring Targets
Roubion	Guillaumes	Roubion*
Rochette	Bellegarde	Montdenier, Montagnac
Brac	Dourbes	Salette, Coulettes
Issole	Quartier	Robine, Malay
Sid	Alfalfa	Hahonih, Atsah

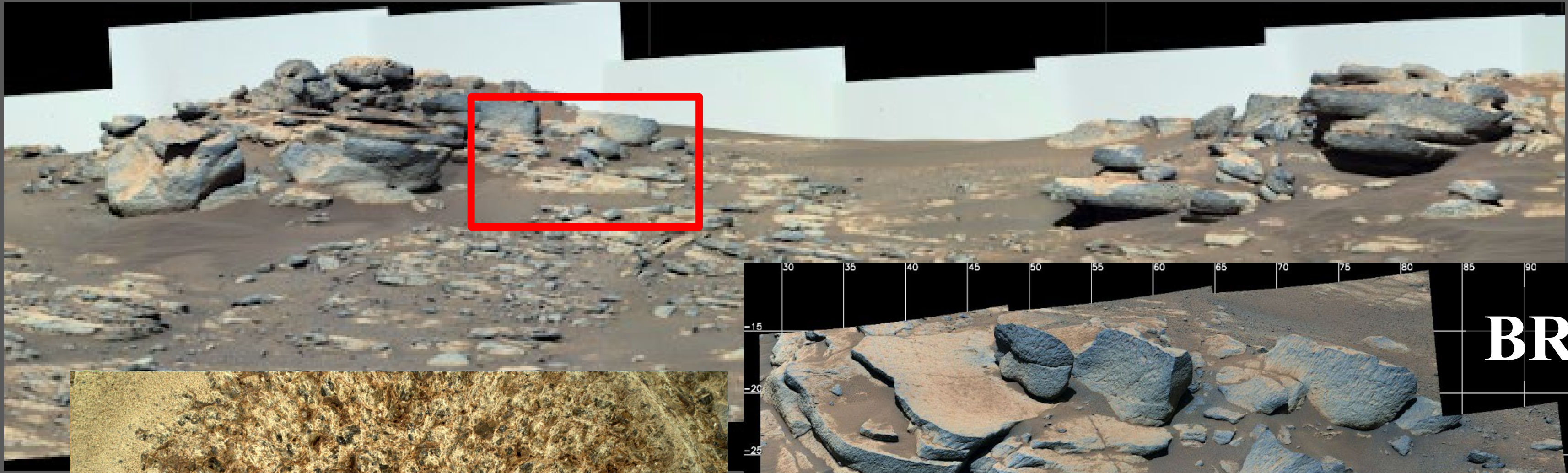


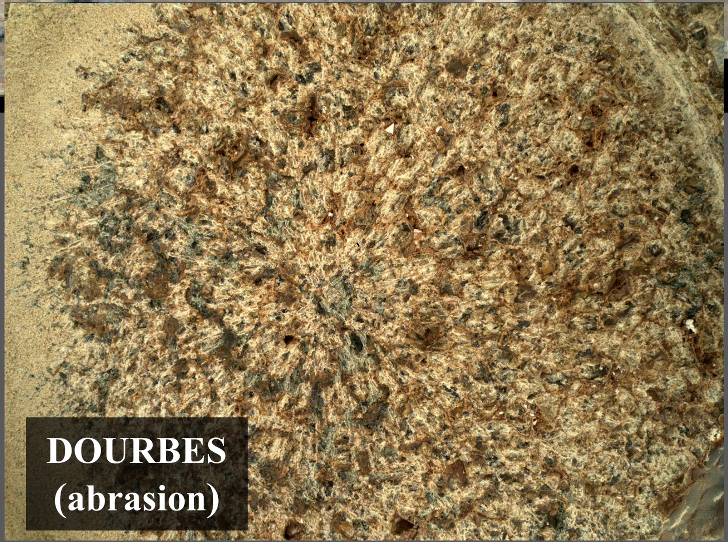
After Simon et al. (2022), *LPSC*

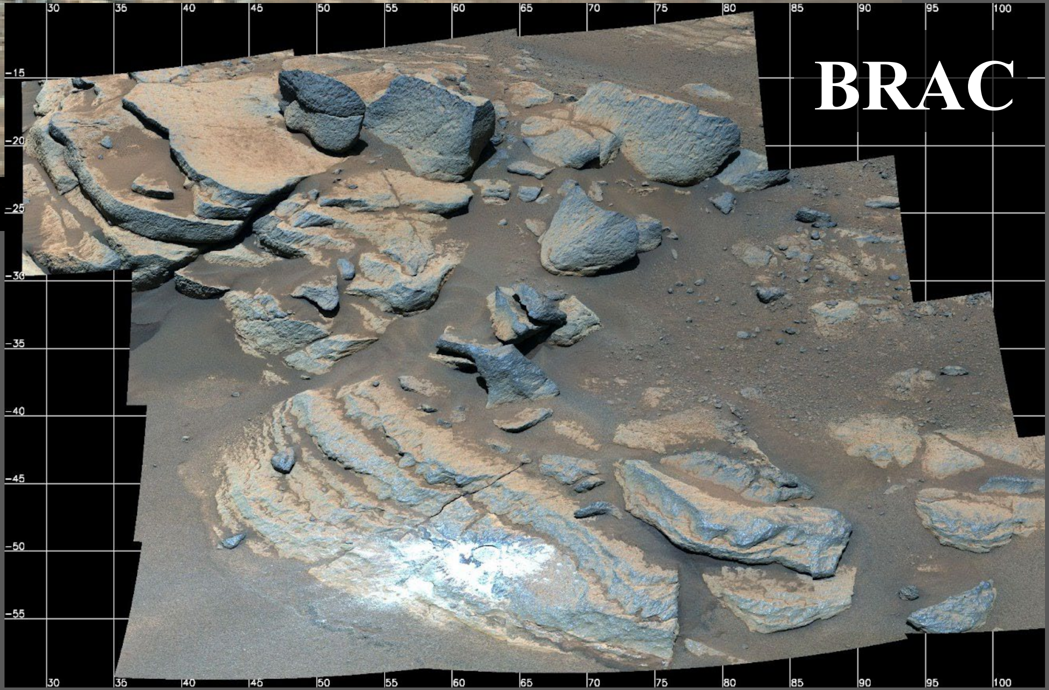
Member	Description	Type Example
Ch'ał *(Máaz fm)*	Massive, blocky, "hummocky" rocks found predominantly east of OEB	
Nataani *(Máaz fm)*	Polygonal, low-lying, granular-weathering "pavers" to the south of OEB	
Rochette *(Máaz fm)*	Variably massive to layered to pitted resistant cap rocks along Artuby ridge	
Artuby *(Máaz fm)*	Granular-weathering, layered outcrops observed at Mure and Artuby	
Roubion *(Máaz fm)*	Polygonal, low-lying, granular-weathering "pavers" in lower elevation Máaz fm	
Content *(Séítah fm)*	Pitted rocks at top of Martre outcrop	
Bastide *(Séítah fm)*	Layered rocks comprising middle-lower part of Martre outcrop	

Máaz formation

Séítah formation







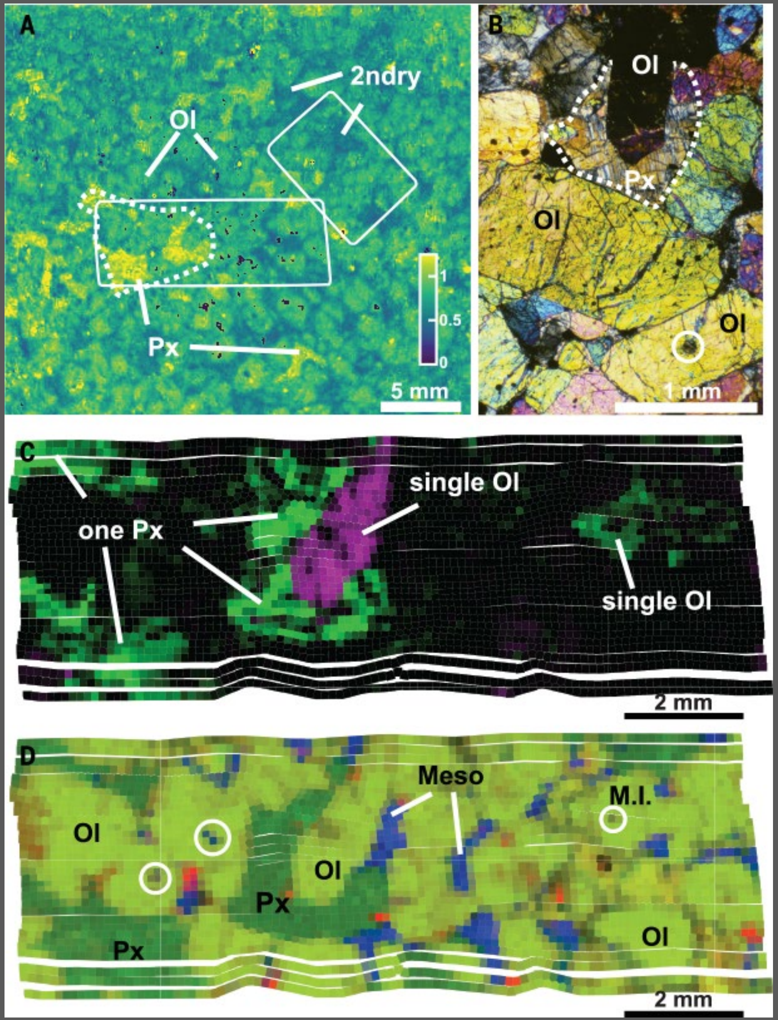
After Hickman-Lewis et al. (2022), *LPSC*

PIXL Results: Dourbes abrasion patch

- [upper left] A cumulate igneous texture with olivine (Ol) grains and a poikilitic texture with secondary (2ndry) mineralogy, including Fe-Mg carbonate, and Fe-Mg-Ca sulfate
- [upper right] Similar to texture found in the Chassigny martian meteorite

- Large (mm-scale) crystals demonstrated by the diffraction data obtained from the PIXL instrument

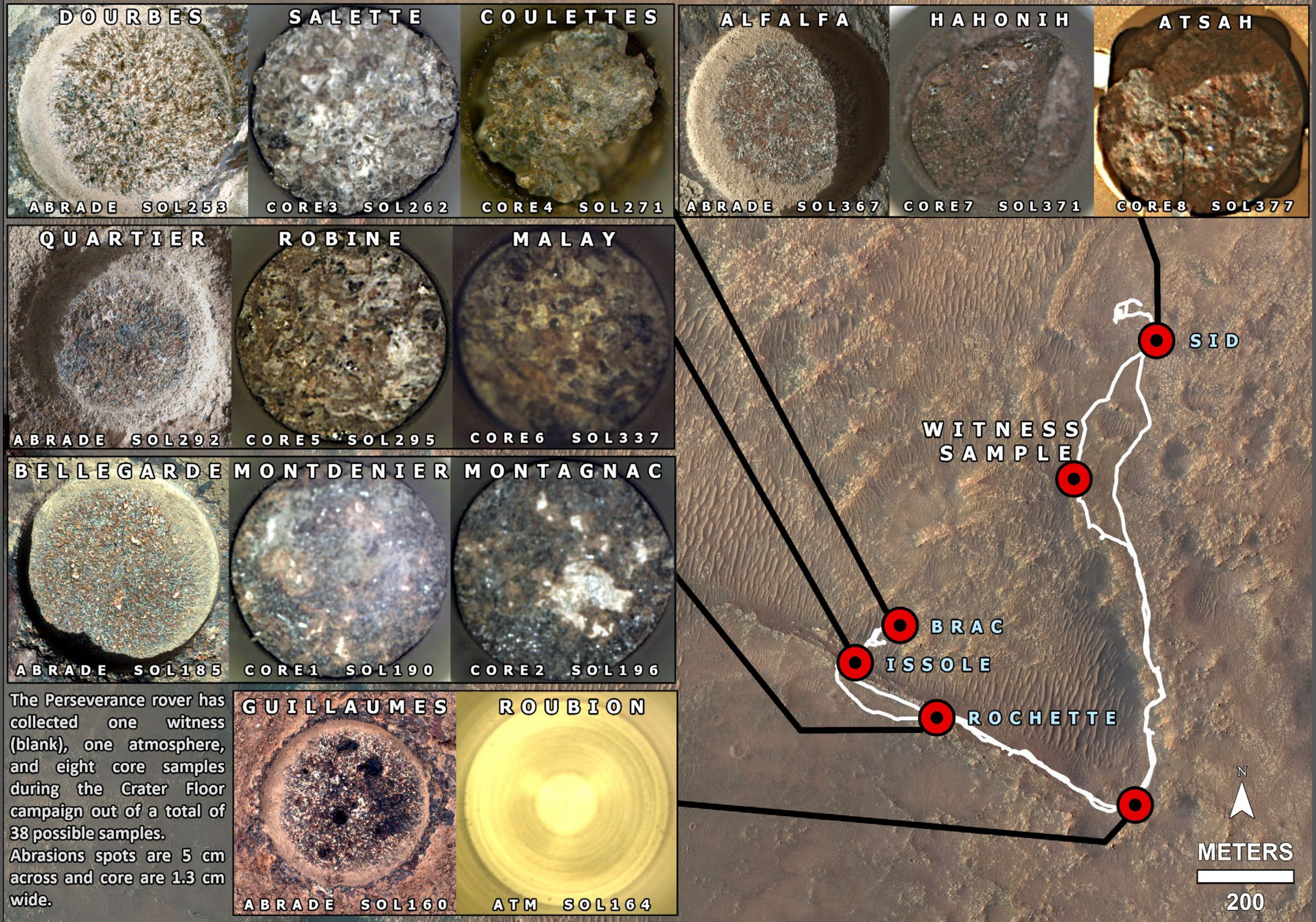
- Consists of olivine (Ol) pyroxenes (Px) and mesostasis (Meso; interstitial igneous material), as well as accessory Cr-Fe-Ti oxide minerals (red)



From Liu et al. (2022), *Science*

MARS 2020

Crater Floor Campaign Samples



The Perseverance rover has collected one witness (blank), one atmosphere, and eight core samples during the Crater Floor campaign out of a total of 38 possible samples. Abrasions spots are 5 cm across and core are 1.3 cm wide.

Máaz:

A series of lava flows of basaltic (pyroxene-plagioclase) **igneous** rock with varying degrees of **alteration by water**

Séítah:

An olivine-rich cumulate **igneous** rock with evidence for **alteration by water**

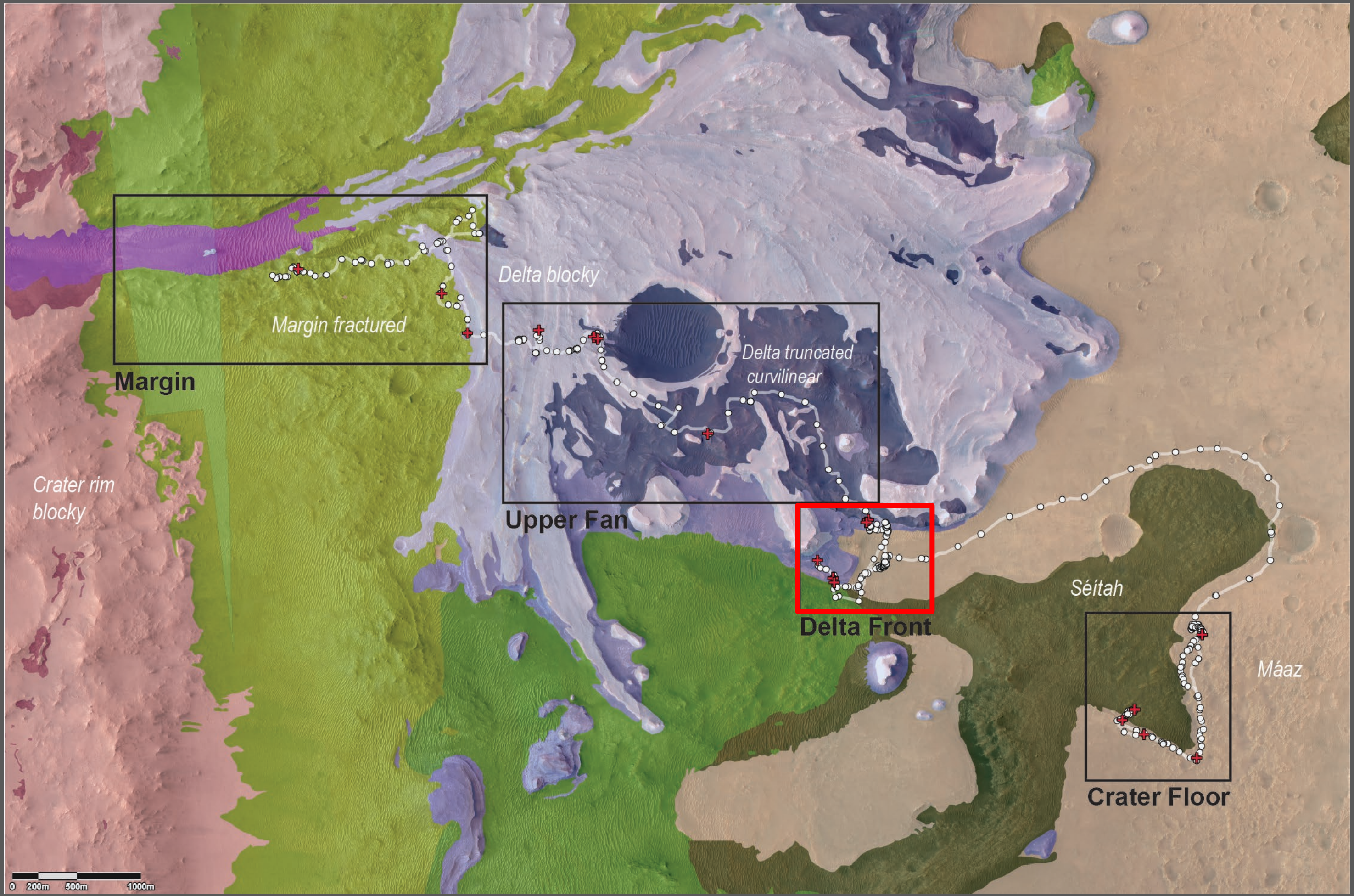
Data published in *Science* and *JGR-Planets*:

Farley et al. (2022), Liu et al. (2022), Scheller et al. (2022), Wiens et al. (2022)

Udry et al. (2022), Simon et al. (2023), Alwmark et al. (2023), Siljeström et al. (2024)

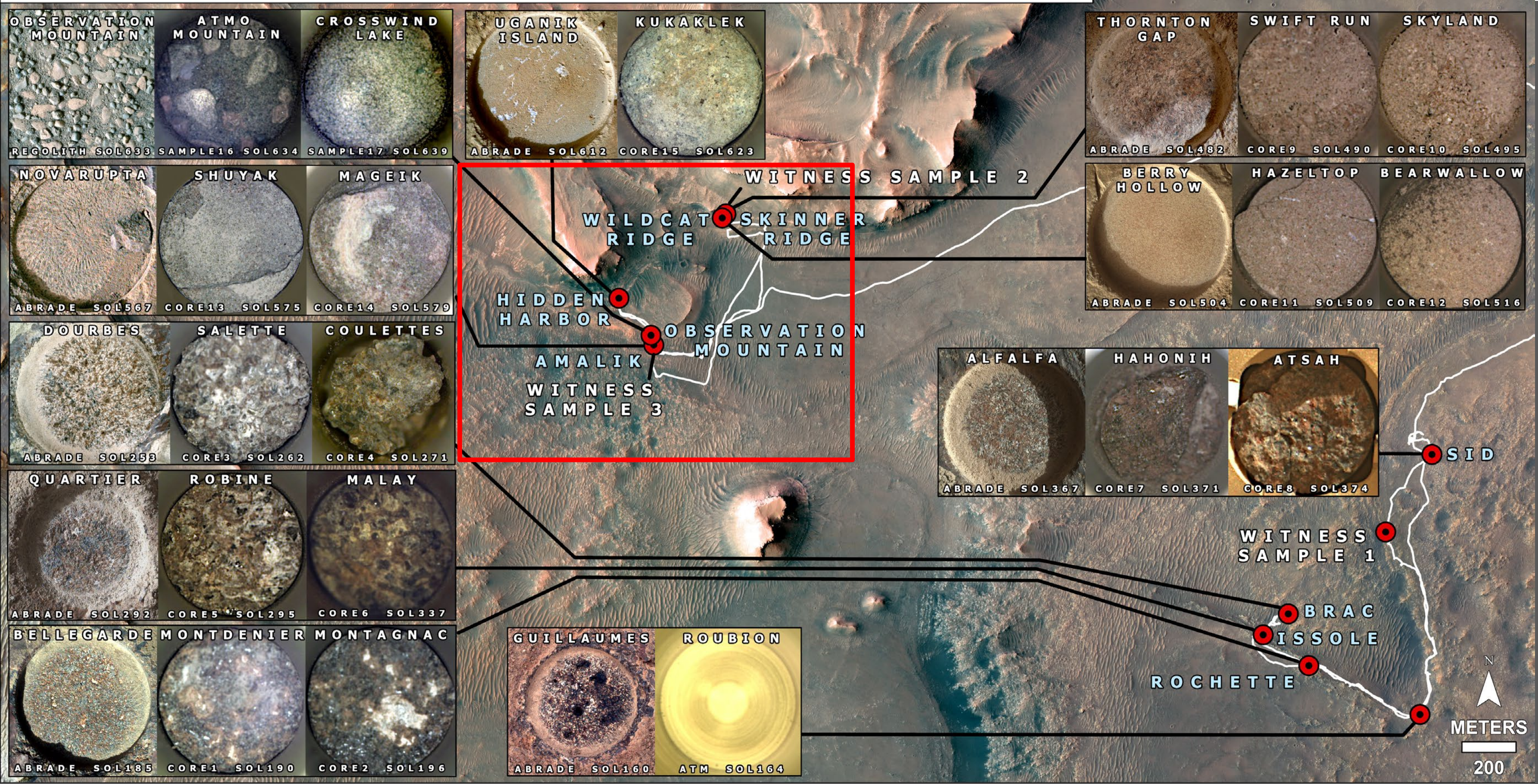
F. Calef/NASA/JPL-Caltech

Delta Front Campaign

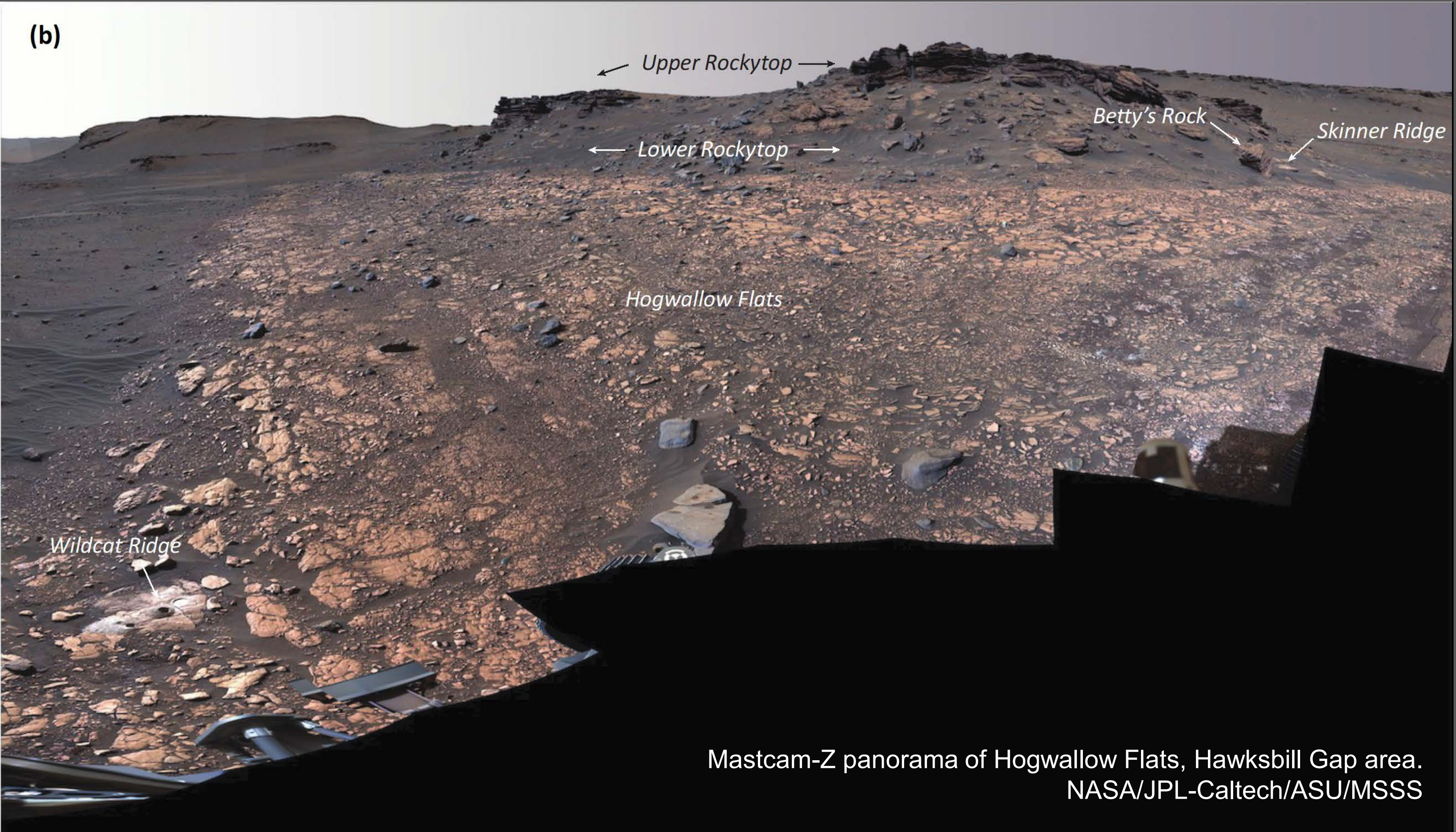


Map showing mission progress, superimposed on geologic map of Jezero crater, after Stack et al. (2020). Rover traverse and waypoints shown with white line and dots, respectively; sampling locations shown with red crosses. Labeled black boxes show approximate extent of each campaign. Names of major units or formations encountered – or expected to be encountered – are labeled in white italics. After Herd et al. (*In Review*).

Sample Collection Map: Tubes 1-21

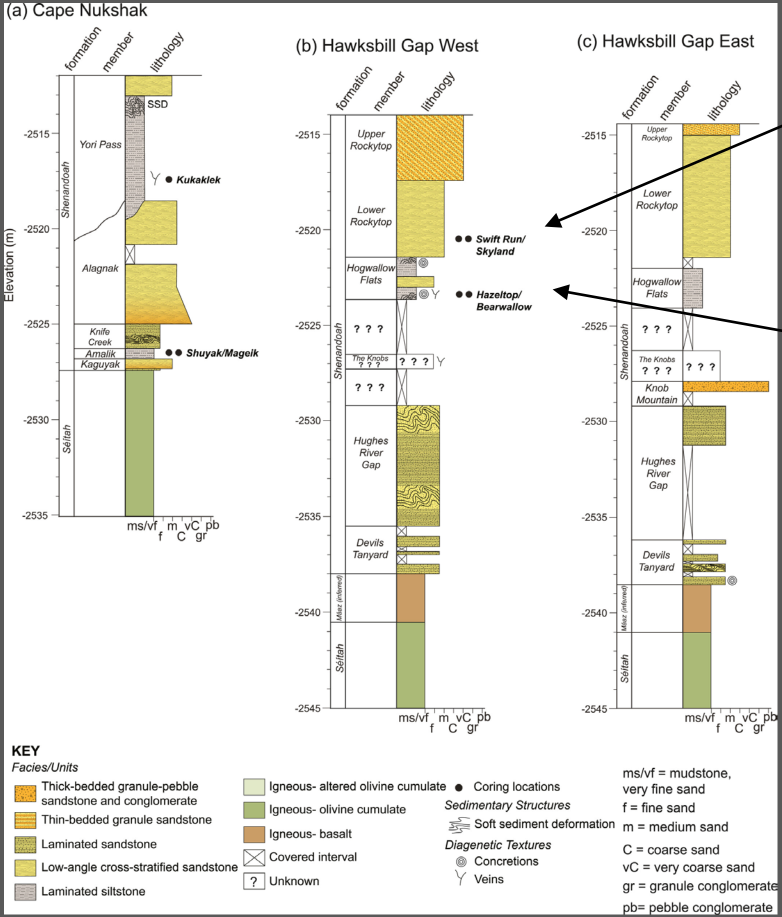


Laboratory
of Technology

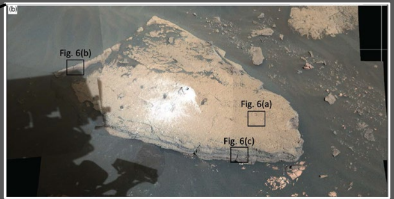


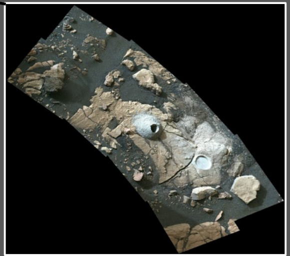
Mastcam-Z panorama of Hogwallow Flats, Hawksbill Gap area.
NASA/JPL-Caltech/ASU/MSSS

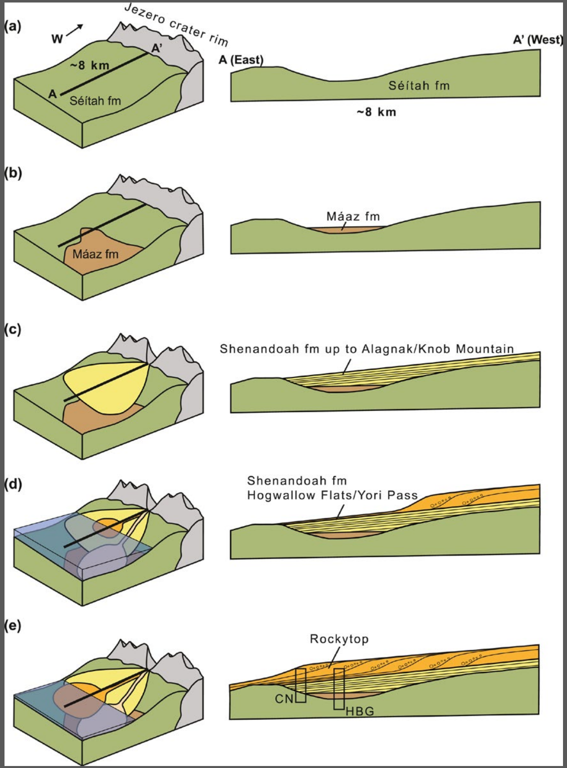
Sedimentology and Stratigraphy of the Western Fan



Stratigraphic columns for the Shenandoah formation at (a) Cape Nukshak, (b) Hawksbill Gap West, and (c) Hawksbill Gap East. From Stack et al. (2024)

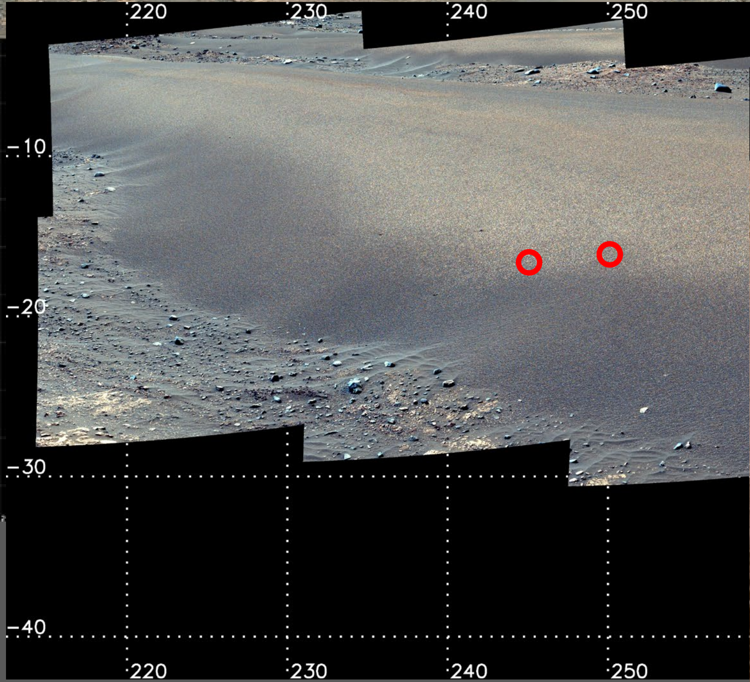


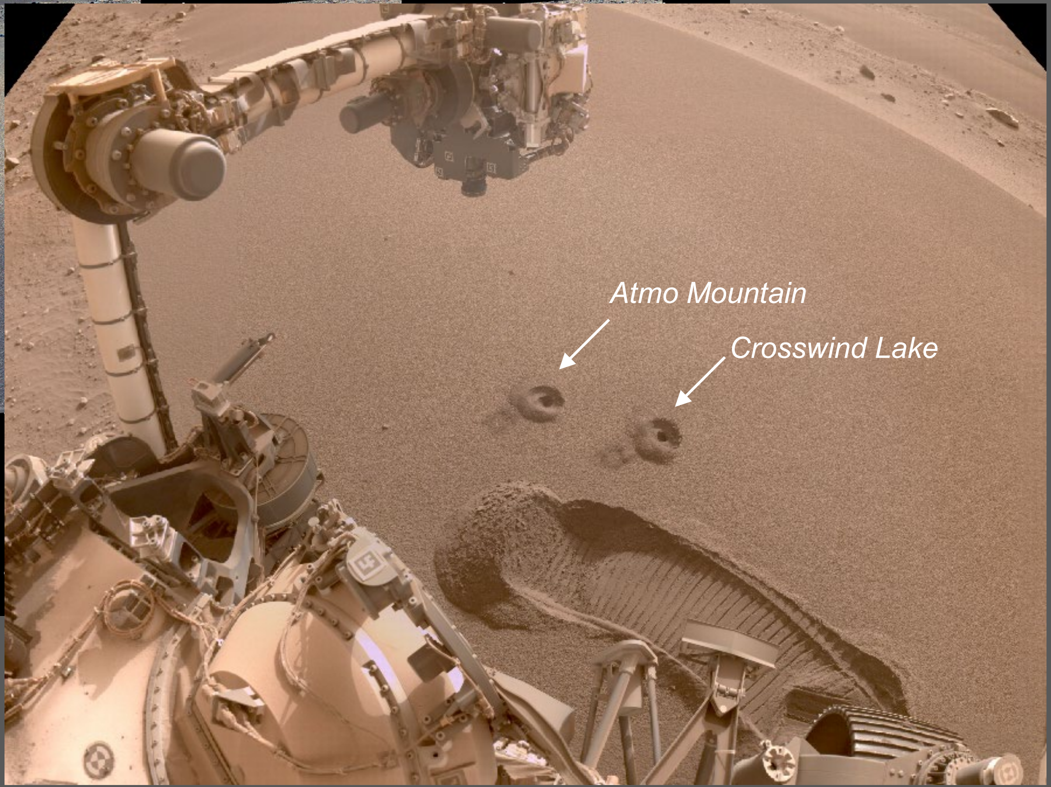




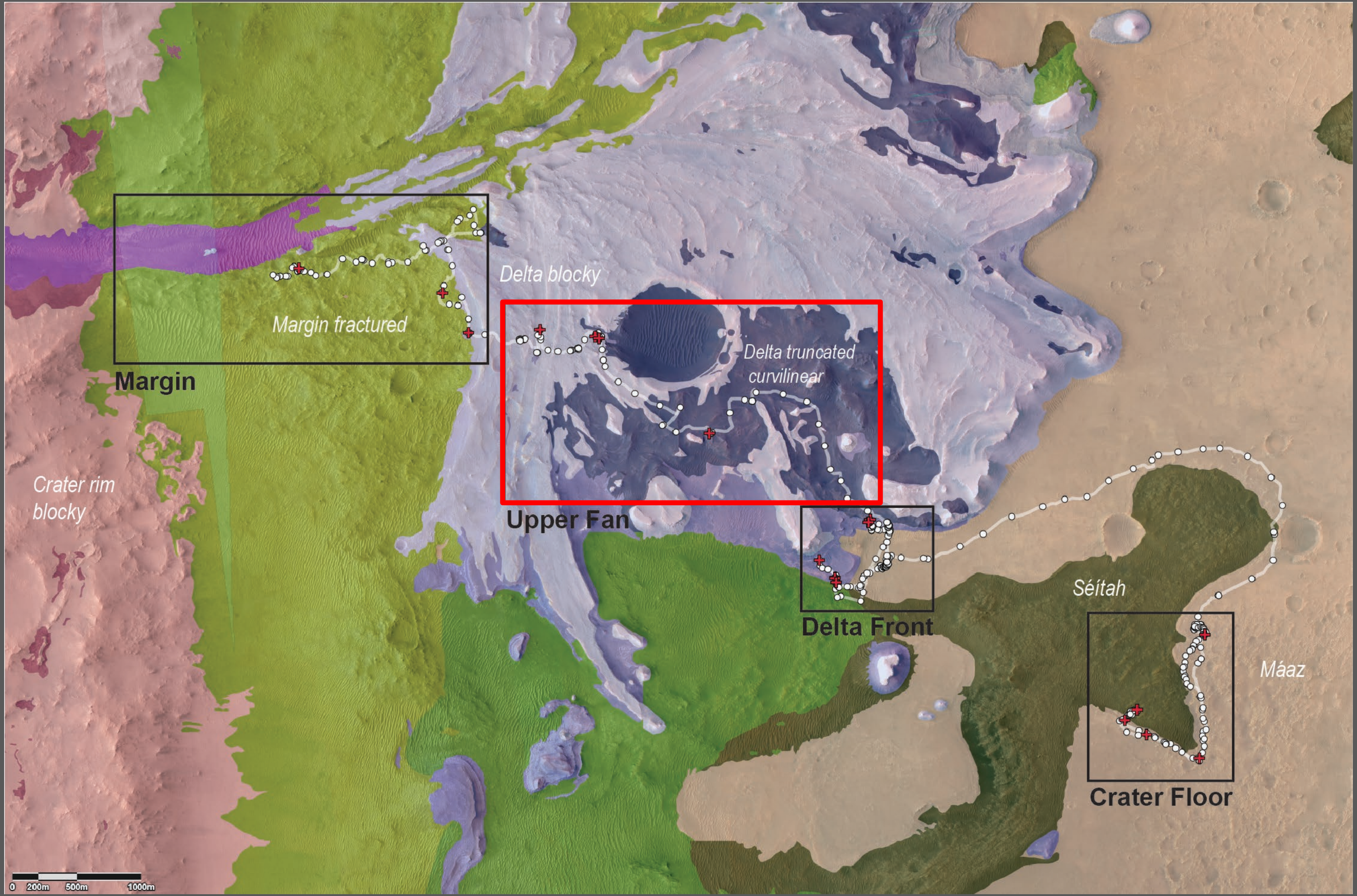
Schematic depositional model for the Shenandoah formation. From Stack et al. (2024)

Observation Mountain: First regolith sample





Mastcam-Z and NavCam images of Amalik and Observation Mountain, in the Cape Nukshak area.
NASA/JPL-Caltech/ASU/MSSS
See also Hausrath et al. (*forthcoming*)

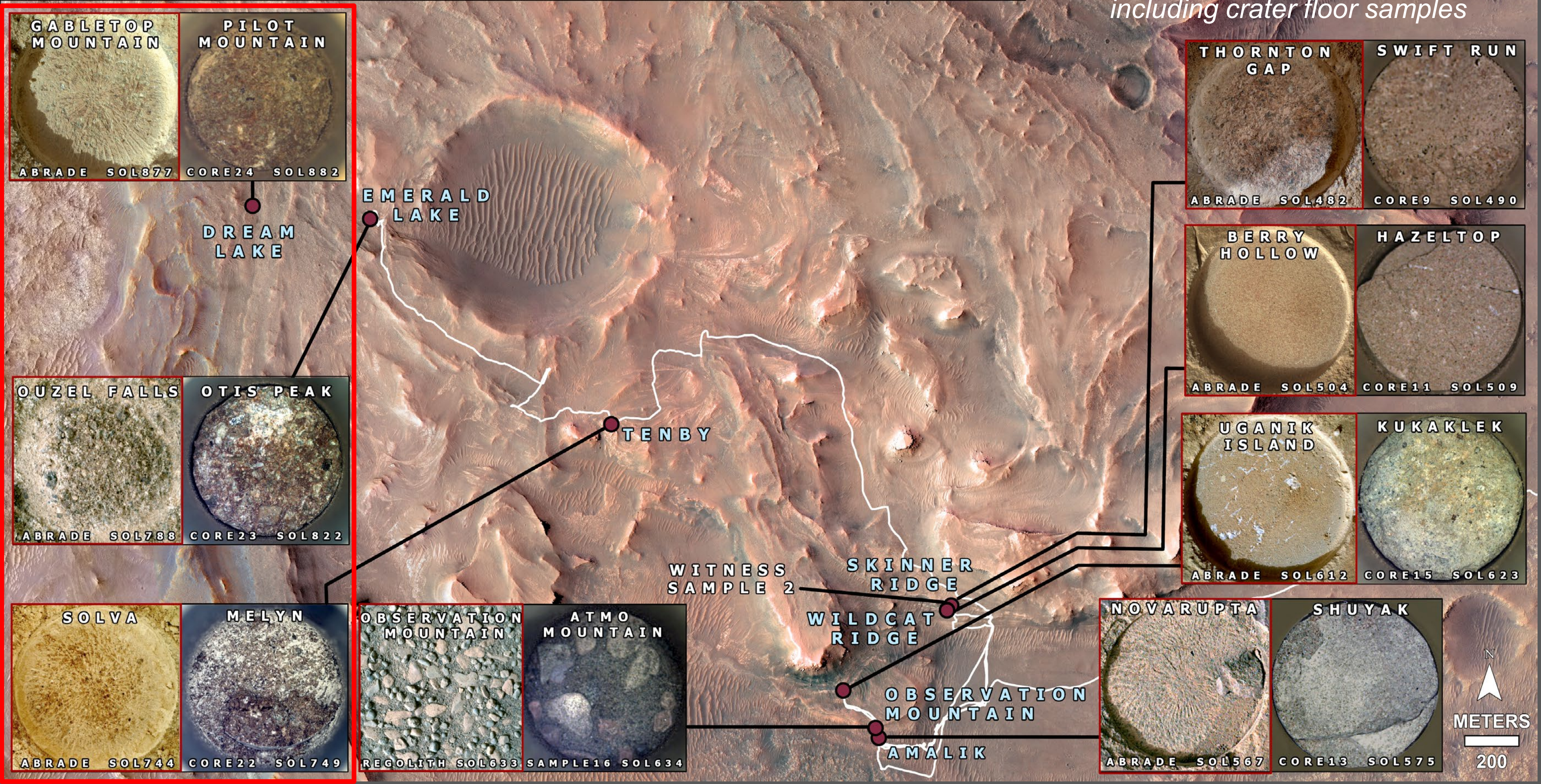


Upper Fan Campaign

Map showing mission progress, superimposed on geologic map of Jezero crater, after Stack et al. (2020). Rover traverse and waypoints shown with white line and dots, respectively; sampling locations shown with red crosses. Labeled black boxes show approximate extent of each campaign. Names of major units or formations encountered – or expected to be encountered – are labeled in white italics. After Herd et al. (*In Review*).

Upper Fan Campaign Samples

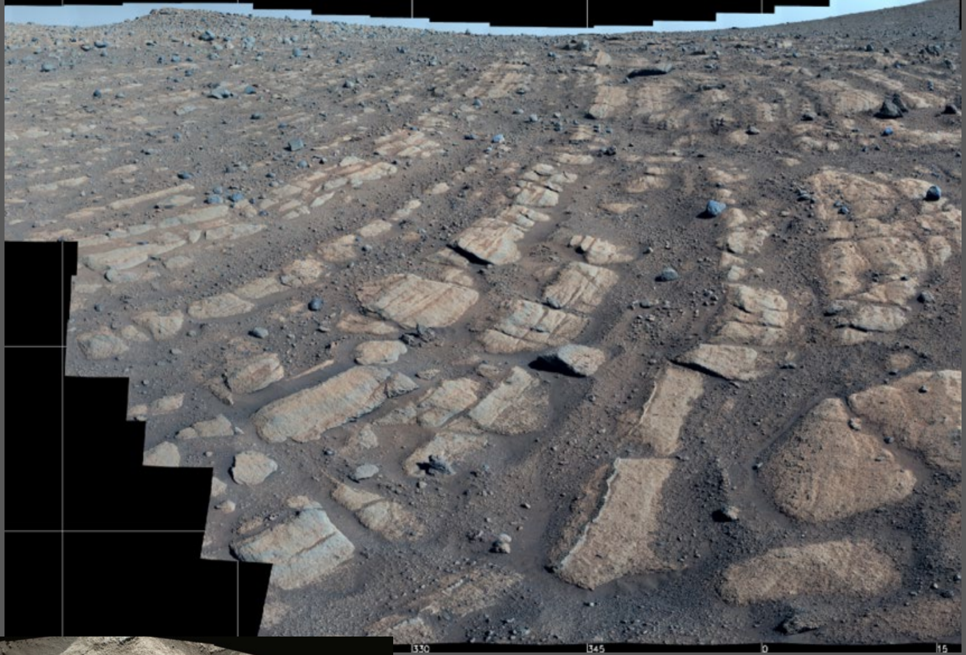
*Here showing only those on board Perseverance, not including crater floor samples



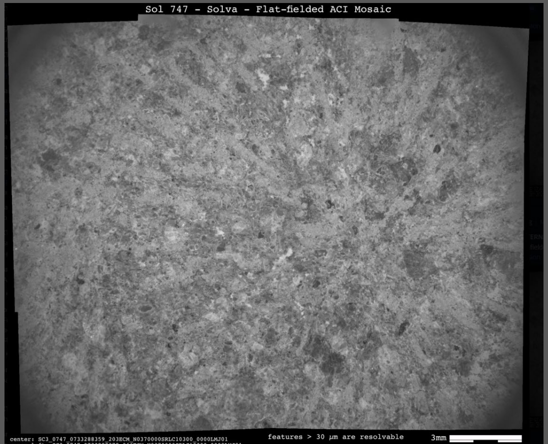
M2020-749-22 *Melyn*

Characteristics and Origin:
This core is a *medium-grained fluvial sandstone* consisting of typical mafic minerals cemented by Mg-Fe carbonate. Also contains aqueous alteration products such as sulfate and phyllosilicates.

Science Value:
Sample documents the "curvilinear" stage of fan development produced by a slowly flowing river as it entered Jezero crater. Sample of an important potentially habitable environment. Alteration products record fluid and climatic characteristics of an early martian aqueous surface environment. Some clasts are large enough to document outside-Jezero characteristics and environmental conditions.



Mastcam-Z images. NASA/JPL-Caltech/ASU/MSSS



WATSON ACI mosaic of *Solva* abrasion. NASA/JPL-Caltech

CacheCam image. NASA/JPL-Caltech

M2020-819-23 *Otis Peak*

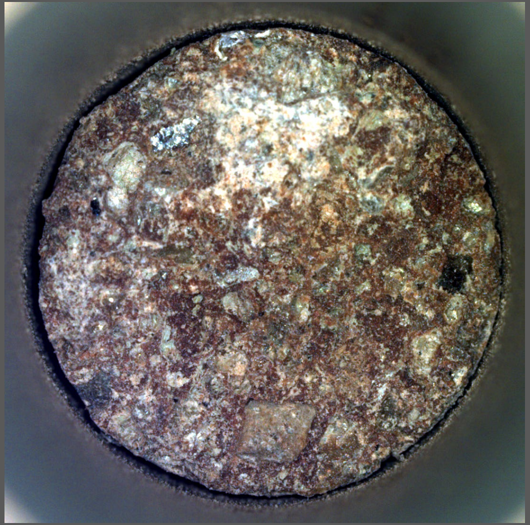
Characteristics and Origin:
This core is from a *fluvial conglomerate* and consists of numerous crystals and rock fragments of few mm size, transported into Jezero from somewhere in the Neretva Vallis watershed.

Science Value:
Numerous specimens of materials from regions that will likely never be explored by Perseverance. Includes clasts indicative of aqueous alteration that may predate transport into Jezero (remote potentially habitable environments). Enhances diversity and potentially provides numerous unique specimens for geochronology and paleomagnetism.


Mastcam-Z image. NASA/JPL-Caltech/ASU/MSSS

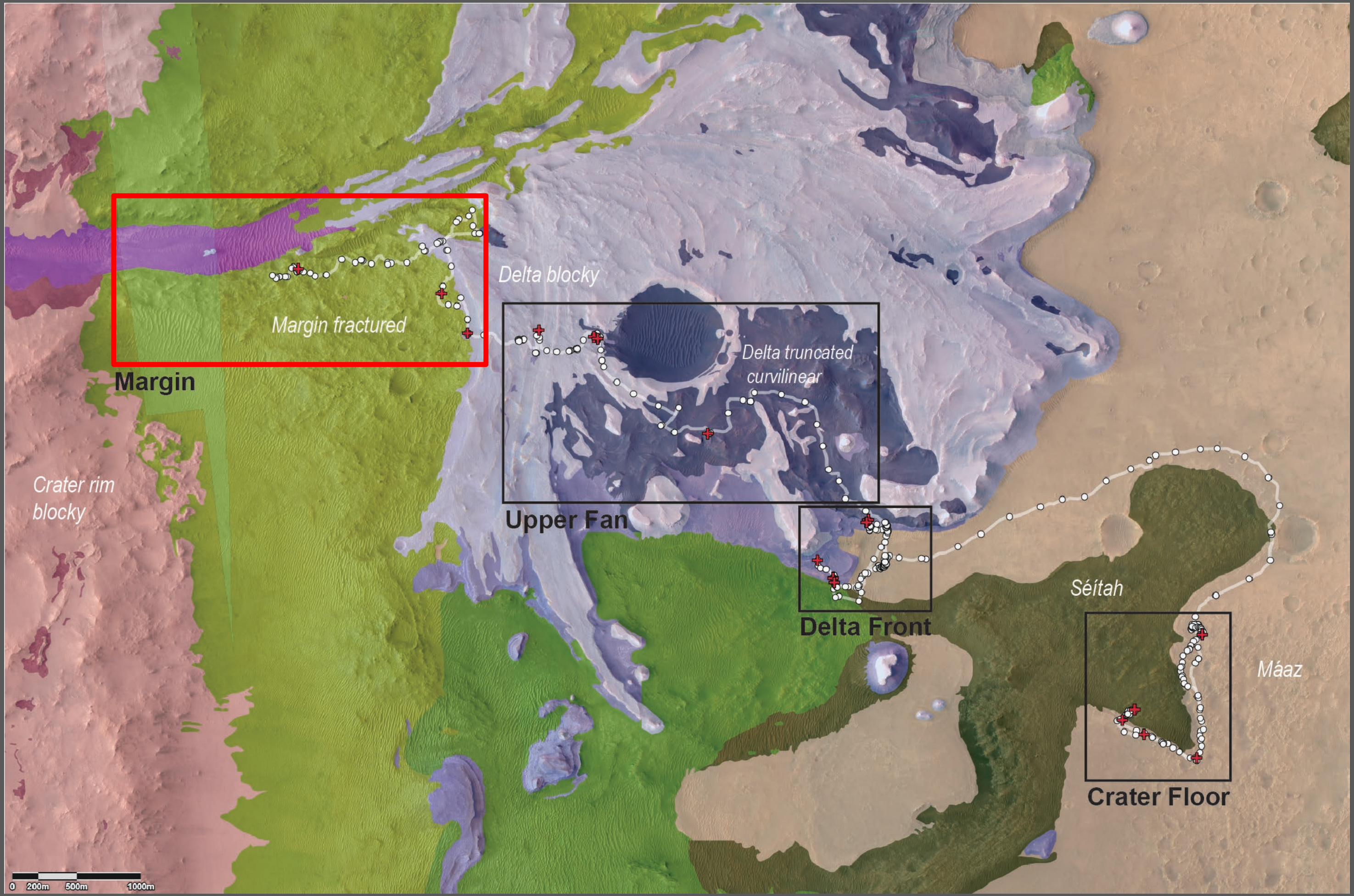

NavCam image. NASA/JPL-Caltech


WATSON image of *Ouzel Falls* abrasion. NASA/JPL-Caltech


CacheCam image. NASA/JPL-Caltech

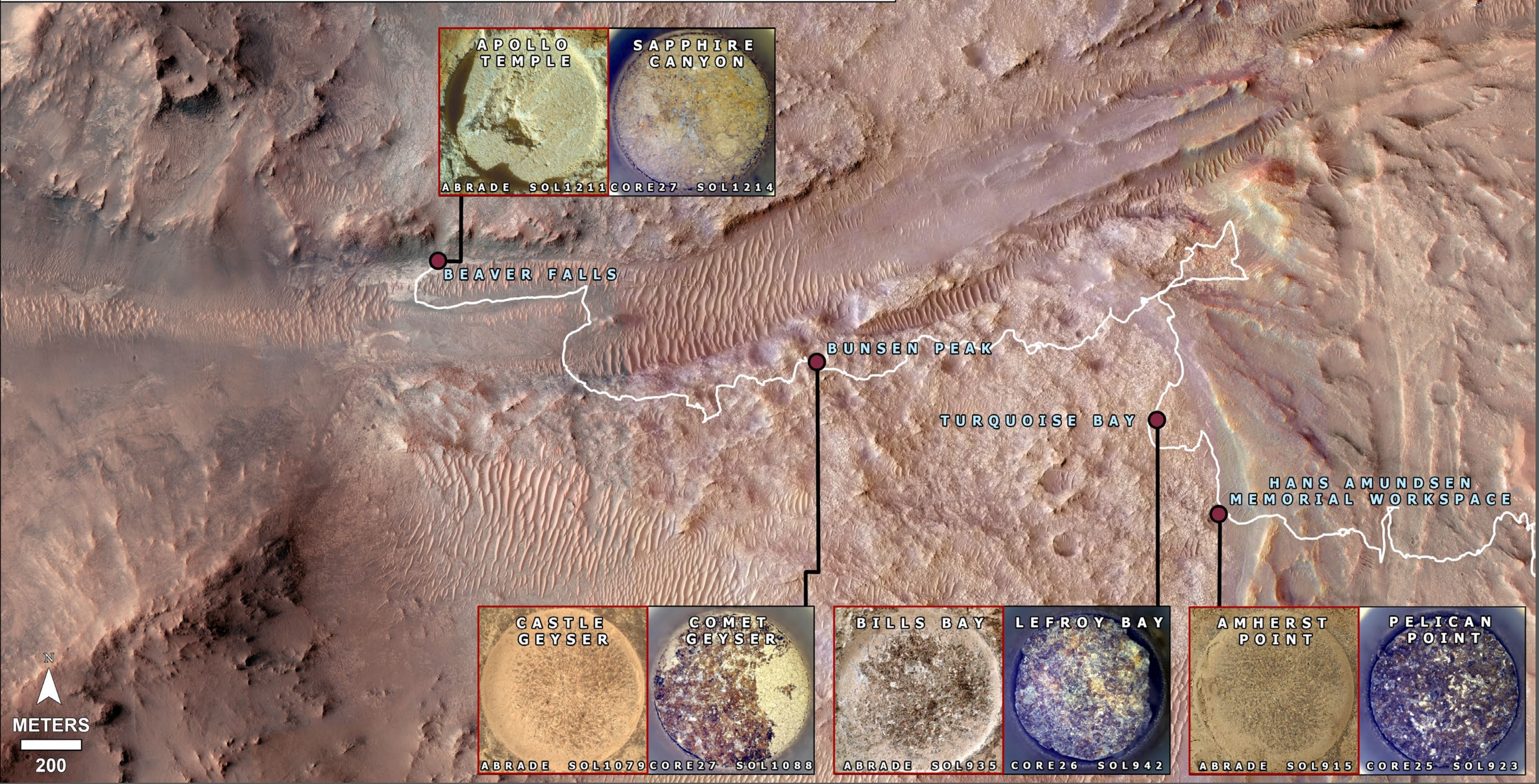
MARS 2020

Margin Campaign
(*Just completed*)

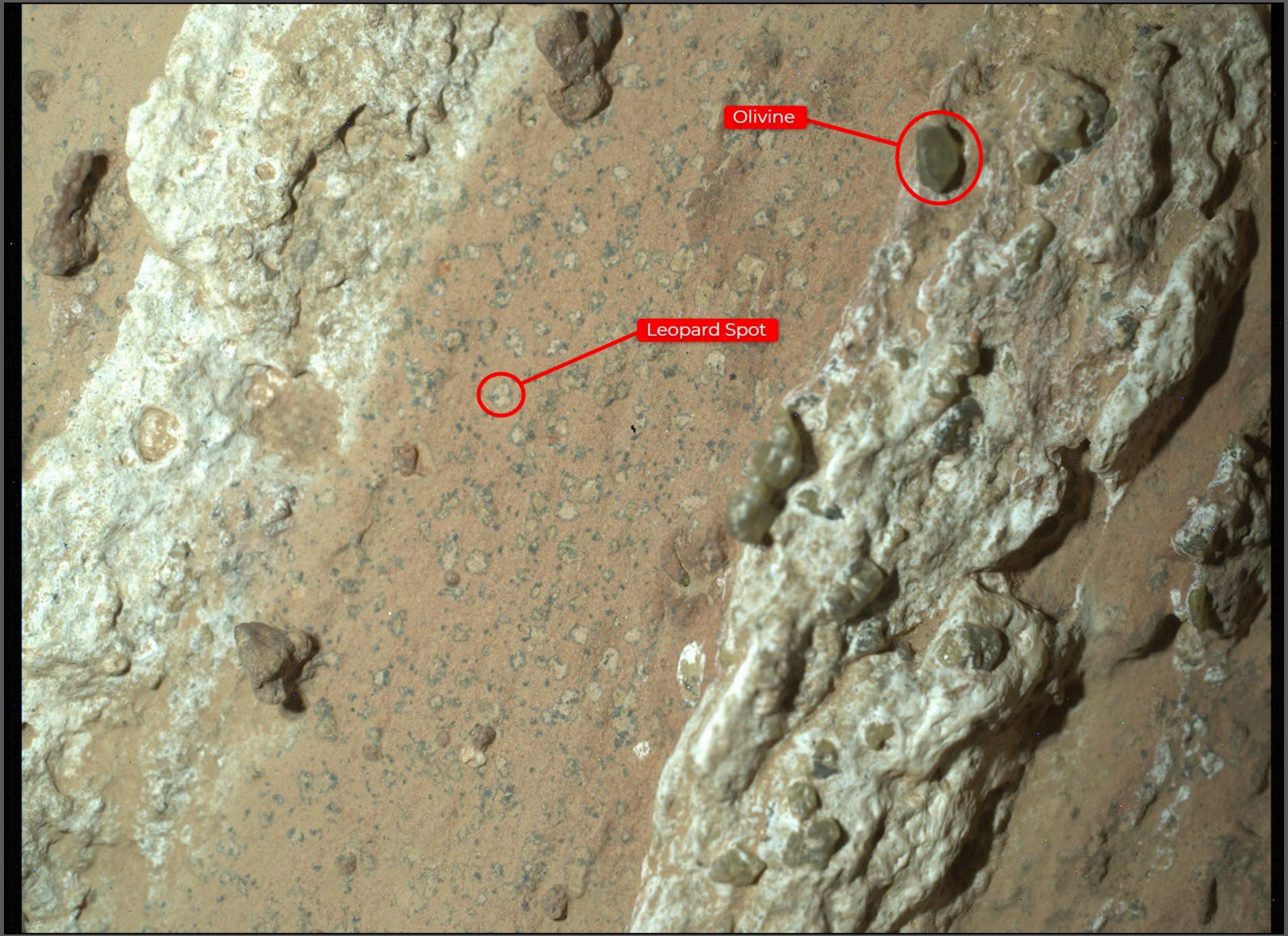


Map showing mission progress, superimposed on geologic map of Jezero crater, after Stack et al. (2020). Rover traverse and waypoints shown with white line and dots, respectively; sampling locations shown with red crosses. Labeled black boxes show approximate extent of each campaign. Names of major units or formations encountered – or expected to be encountered – are labeled in white italics. After Herd et al. (*In Review*).

Margin Campaign Samples



The most recent sample is the most intriguing!



WATSON image of the Cheyava Falls location = *Sapphire Canyon* rock sample
NASA/JPL-Caltech/MSSS

MARS 2020

The list…so far

SAMPLES COLLECTED TO DATE		
Perseverance	Three Forks	Description
	Roubion	Atmosphere
Montagnac	*Montdenier*	Igneous
Salette	*Coulettes*	Igneous
Robine	*Malay*	Igneous
Hahonih	*Atsah*	Igneous
Swift Run	*Skyland*	Sedimentary
Hazeltop	*Bearwallow*	Sedimentary
Shuyak	*Mageik*	Sedimentary
Kukaklek		Sedimentary
Atmo Mountain	*Crosswind Lake*	Regolith
Melyn		Sedimentary
Otis Peak		Sedimentary
Pilot Mountain		Sedimentary
Pelican Point		Sedimentary?
Lefroy Bay		Sedimentary?
Comet Geyser		Sedimentary?
Sapphire Canyon		Sedimentary

28 tubes have been filled (including 3 witness tubes)

14 tubes remain (incl 2 witness)

10 tubes were cached at Three Forks Depot (incl 1 witness)

18 sealed tubes are now stored on Perseverance (incl 2 witness)

Summary:

- Samples include both ***sedimentary*** (lake, river, flood) and ***igneous*** (intrusive, extrusive)
- Samples include ***multiple habitable or potentially habitable environments***
- Samples include both ***inside Jezero and outside Jezero lithologies***
- Sedimentary rocks include ***mudstone, sandstone, and conglomerate***
- All samples tubes appear to have sealed properly
- With the exception of the atmosphere sample, all samples exceed 3 cm in length (ave 5.3 cm)
- Sampling ahead (especially on rim and beyond) would greatly enhance sample diversity

Perseverance has successfully collected many of the sample types that motivated sample return, and can continue to do so in Extended Prime Mission

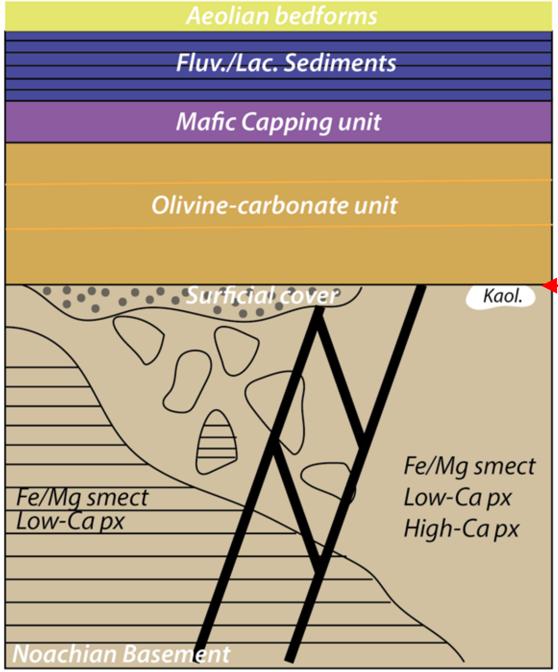
Where we are going

From https://mars.nasa.gov/mars2020/mission/where-is-the-rover/ NASA/JPL-Caltech

Outside Jezero and crater rim geology

Jet Propulsion Laboratory
California Institute of Technology

?
~3.8 Ga
~3.8 Ga
~4.0 Ga



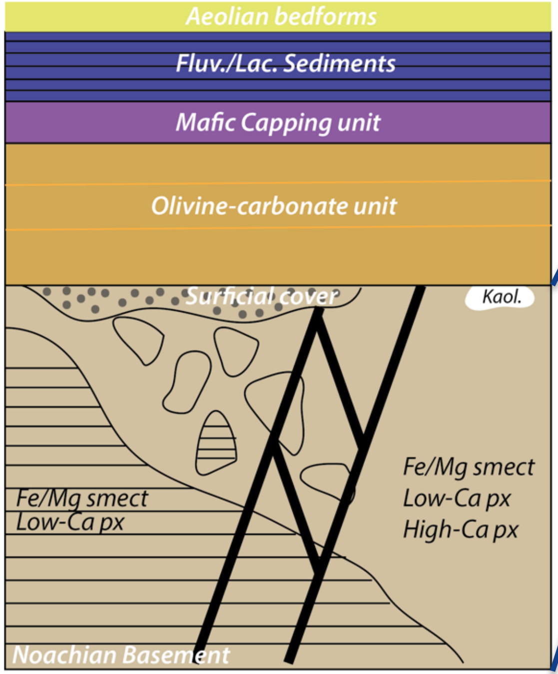
3 major geological units **(up to ~1.5 Ga) older** than the Jezero delta with well-characterized crater chronology

Jezero crater formation

Only Noachian Basement (NB) is older than the Jezero crater and **is uplifted in the rim**

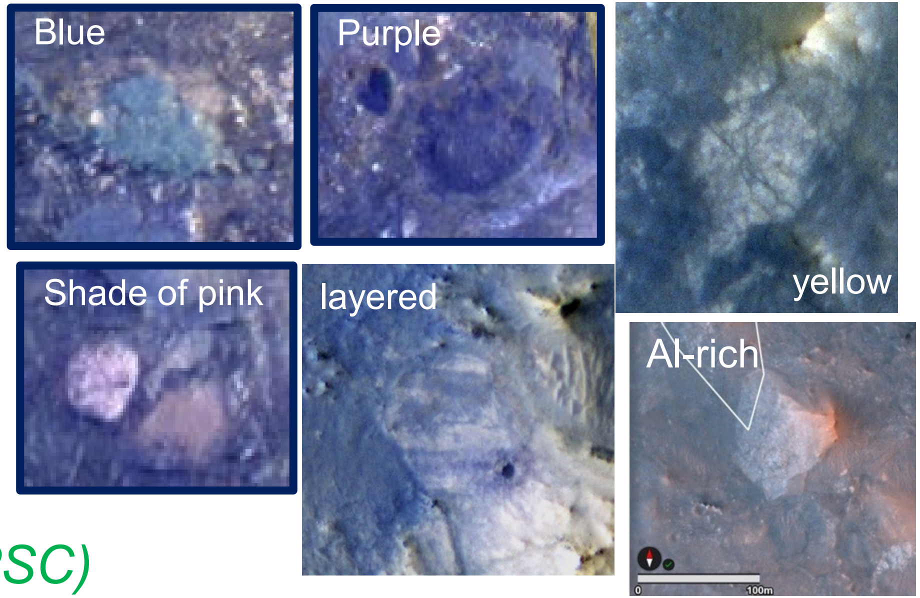
From Mayhew et al. (2024; LPSC)

High priority exploration targets for Jezero crater rim – *megabreccia diversity*



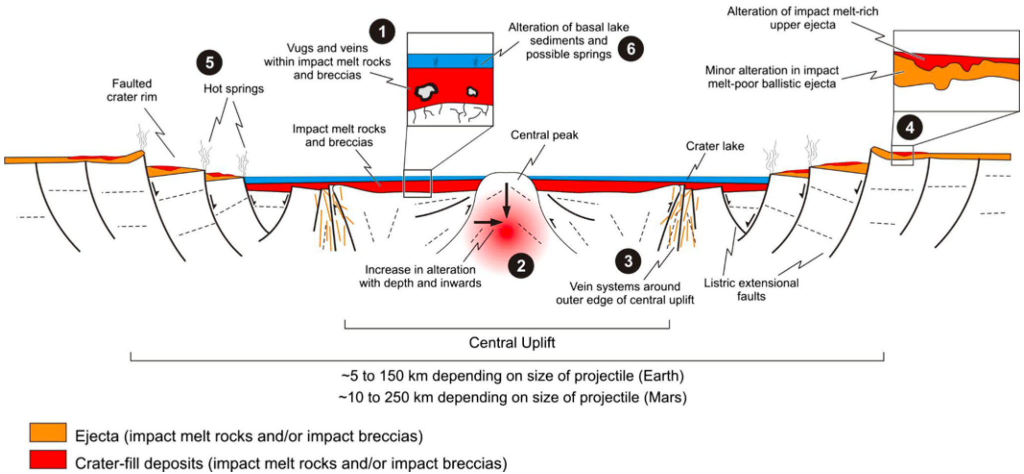
Megabreccia diversity (blue, purple, pink, yellow, layered, Al-rich blocks)

Rationale: common globally but never studied in-situ, provides a large sample of the wide diversity of the crust before Isidis impact



From Mayhew et al. (2024; LPSC)

High priority opportunistic exploration targets for Jezero crater rim



Osinski et al., 2013

- *hydrothermal precipitates/mineralized vein*

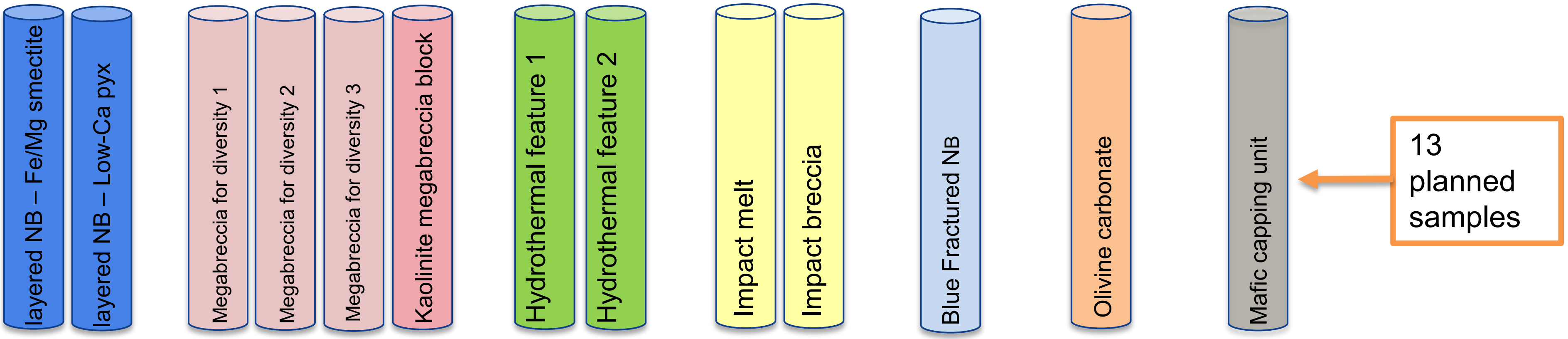
Rationale: Understand hydrothermal activity/alteration (linked to crater formation?). Understand deep groundwater circulation, creating long lived habitable environments. Potentially high astrobiological/biosignature potential.

- *impact melt (+ breccia if part of impactite stratigraphy)*

Rationale: Impacts are one of the most important processes on planetary surfaces, but a major impact deposit has not yet been investigated outside of Earth. Potential opportunity to date Jezero and/or Isidis impacts.

From Mayhew et al. (2024; LPSC)

Jezero crater rim samples expand the scientific value of the current sample cache



Crater rim samples access:

(1) A diversity of ancient >4 Ga Martian crust materials that preserve records of:
   - (a) ancient climate,
   - (b) habitability,
   - (c) magnetic dynamo,
   - (d) igneous processes,
   - (e) uplifted, potentially habitable subsurface environments for biosignature investigations

From Mayhew et al. (2024; LPSC)

(2) Samples from crater retaining surfaces to calibrate Mars' surface crater chronology

Enabling investigation of Dedacal-level science questions

iMOST Objectives	Samples 3, 4, 9, 10: Basaltic Igneous	Samples 5, 6, 7, 8: Cumulate Igneous	Samples 11, 12: Medium sedimentary	Samples 14, 15, 16, 17, 19: Fine sedimentary	Samples 20, 21: Regolith	Samples 22, 23, 24: Medium to coarse sed.	Samples 25, 26, 27: Clastic sed. ? (+ carbonates, silica)
	Crater Floor		Delta Front			Upper Fan	Margin
1. Geol. Environ. (Jezero)							
1.1 Sedimentary system	○	○	●	●	◗	●	●
1.2 Hydrothermal	◗	◗	○	○	○	○	◗
1.3 Deep groundwater	◗	◗	○	○	○	○	◗
1.4 Subaerial	◗	◗	●	●	◗	●	●
1.5 Igneous terrain	●	●	◗	○	●	◗	◗
2. Life							
2.1 Carbon/organic chem.	◗	◗	◗	●	◗	◗	◗
2.2 Ancient hab./biosig.	◗	◗	●	●	●	●	●
2.3 Modern hab./biosig	●	●	●	●	●	●	●
3. Geochronology	●	●	●	○	◗	●	●
4. Volatiles	◗	◗	◗	◗	◗	◗	◗
5. Planetary Scale Geology	◗	◗	◗	◗	○	◗	◗
6. Environmental Hazards	◗	◗	◗	◗	●	◗	◗
7. ISRU	○	○	◗	◗	◗	◗	◗

Sample 1 = WTA 1; Sample 2 = Rubion (atm); Sample 13: WTA 2; Sample 18: WTA 3

● =Likely to fully address objective; ◗ =Likely to partly address objective; ○ =Unlikely to address objective

Traceability matrix between the samples collected by Perseverance and the community objectives for Mars Sample Return ("iMOST Objectives"; Beaty et al. 2019).
After Herd et al. (*In Review*).