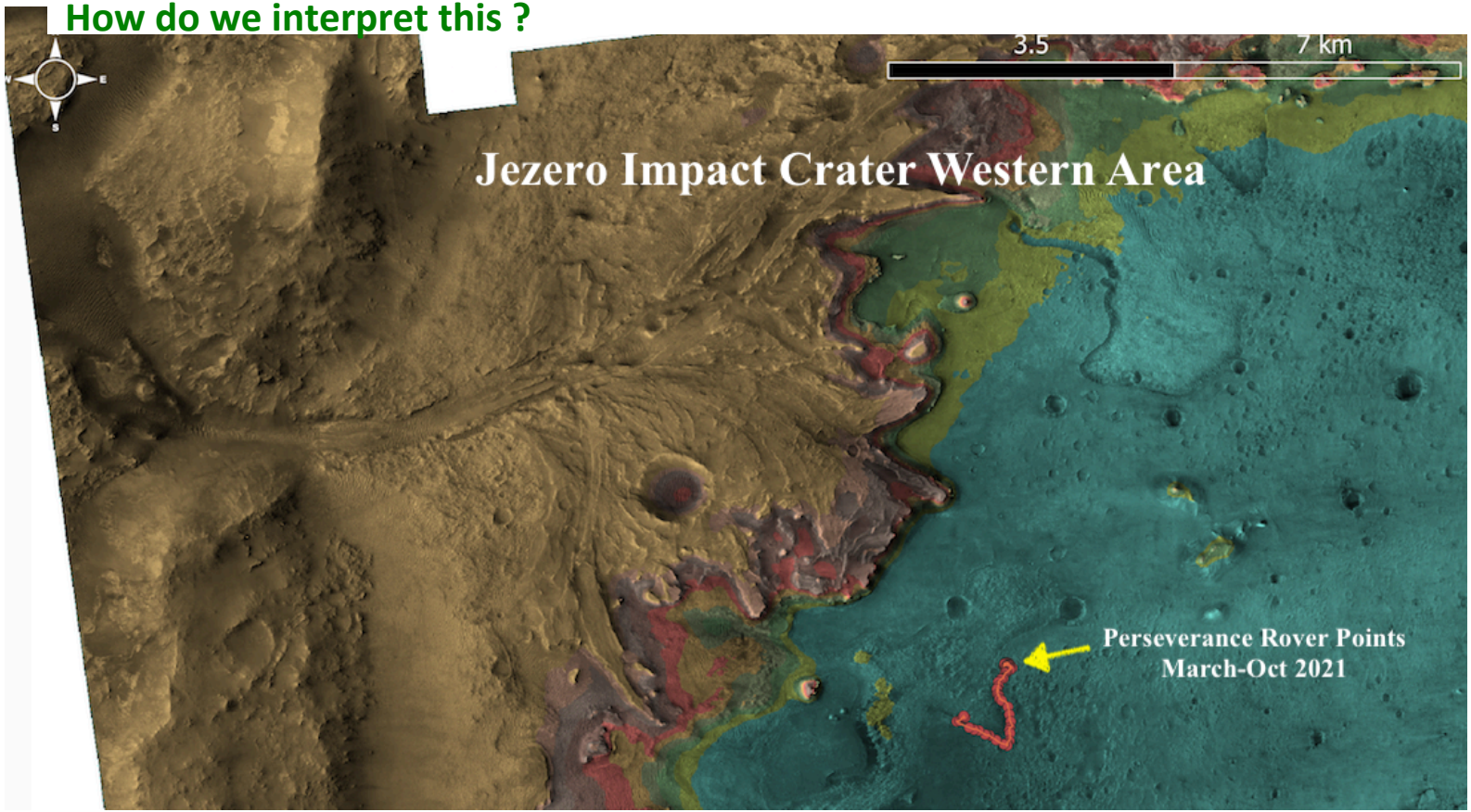
Mars: An Interim Geological Interpretation of Latest Rover Exploration

How do we interpret this ?



Talk outline

- Mars: Mystery wrapped in an enigma
- Explorer Rovers: Perseverance & Curiosity where are they?
- Quick Fly around
  Google Earth/Mars
  QGIS project
- Perseverance and Jezero Impact crater What is scale? Geological Context
  - Rocks near and far: abrade & drill & return!
- Quick dips into web resources
  - Gigamacro/Gigapan
  - Mars NASA
  - Unmanned Spaceflight
  - Mars 2020 Perseverance Rover FB group

Enigma and Mystery − scale

Mars & Comparisons to?

Earth: The planet we know well & has water and life!

- **plate tectonics**
- **large moon**

<u>Mars</u>

~ third of Earth gravity

~ half size of Earth

~ twice size of moon

~ Av atmospheric pressure =27km elevation on Earth

~ Daily Temp change -50°C

~ 95% CO2 +N2+O2

Impact Craters & Volcanoes

Data from: Mars Fact Sheet NASA and https://nineplanets.org/questions/how-big-is-the-moon/#:~:text=our%20Solar%20System.-,How%20big%20is%20the%20Moon%3F,the%20size%20of%20its%20planet

Enigma: Impacts, Volcano, Water **Mystery:** Life & rocks

Archaean Rocks

On Earth: We find unusual rocks:

- Komatiite: Ultramafic volcanics (Olivine rich), common in Archaean, rare afterwards. Lava flows greater than 1600 °C (Extreme activity and high radioactivity/heat of Archaean mantle); modern lava max ~ 1350 °C) Flow Viscosity "Like olive oil". So on Mars with much less gravity? More fluid than Kilauea Fissure 8 Eruption - Lava Flow in Leilani Estates-June 2018 ?

  https://www.youtube.com/watch?v=BgjpSlzU9oU

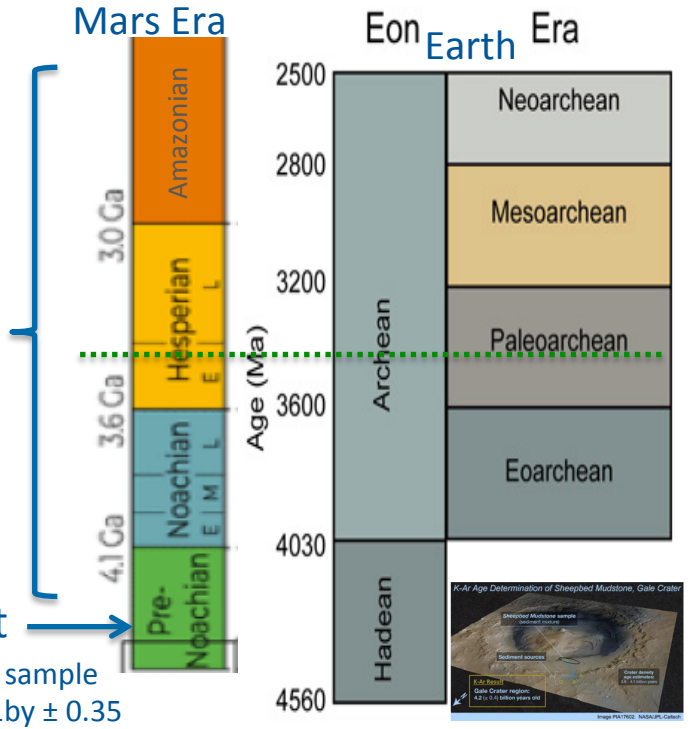
- Stromatolite

Jezero Impact

Earth: "Earliest Life" Stromatolite 3.4by

Gale Impact

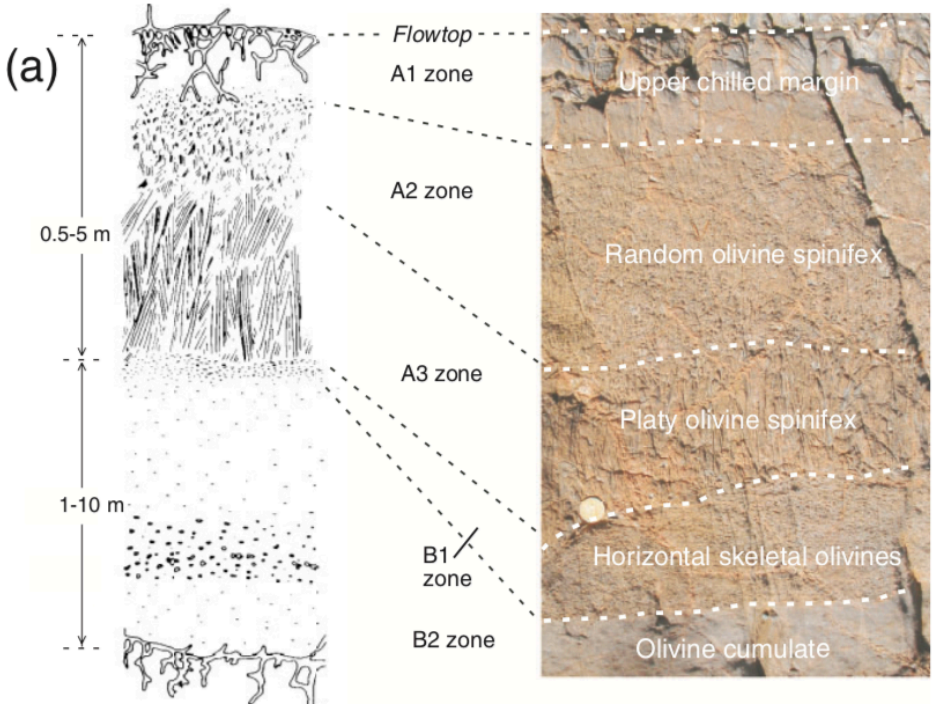
"Mudstone" bulk sample
Crater Flank: 4.21by ± 0.35

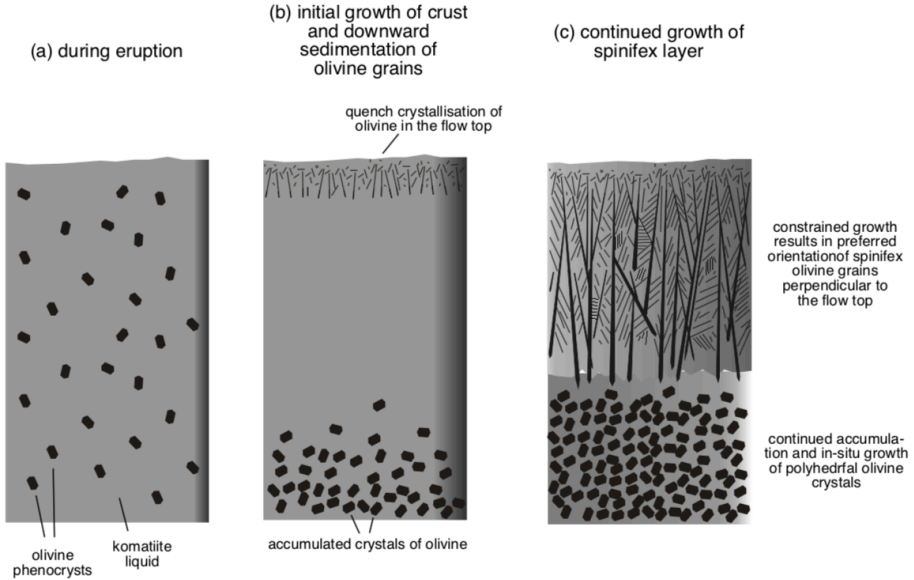


Data modified from: Earth Archaean: https://www.geol.umd.edu/~tholtz/G102/lectures/102archean.html and Mars https://www.researchgate.net/figure/Timeline-of-major-processes-in-Mars-history-based-on-martian-meteorite-studies-see-text_fig5_347082108

Komatiite Earth Example

JOURNAL OF PETROLOGY | VOLUME 45 | NUMBER 12 | DECEMBER 2004





Data modified from: Nicholas Arndt, C. M. Lesher. Komatiite.. Encyclopedia of Geology., Elsevier, pp.260-268, 2004. hal-00101712

Stromatolite Earth Examples: Oldest 3.5 billion years

Dresser Formation

Wrinkle mats at the Dresser Formation

An ancient hydrothermal system [edit]

The Dresser Formation is part of the mostly volcanic Warrawoona Group in the North Pole Dome area of the East Pilbara. At 3.49 billion years old it is stratigrapically lower than the Strelley Pool Chert of the Trendall Locality and other areas - meaning it is a little older. There are large numbers of dykes that criss-cross the area and consist largely of fine-grained chert and the hydrothermal (hot spring) mineral barite.

A number of stromatolite structures are found - low domical types, wrinkle mats, columner and conical.

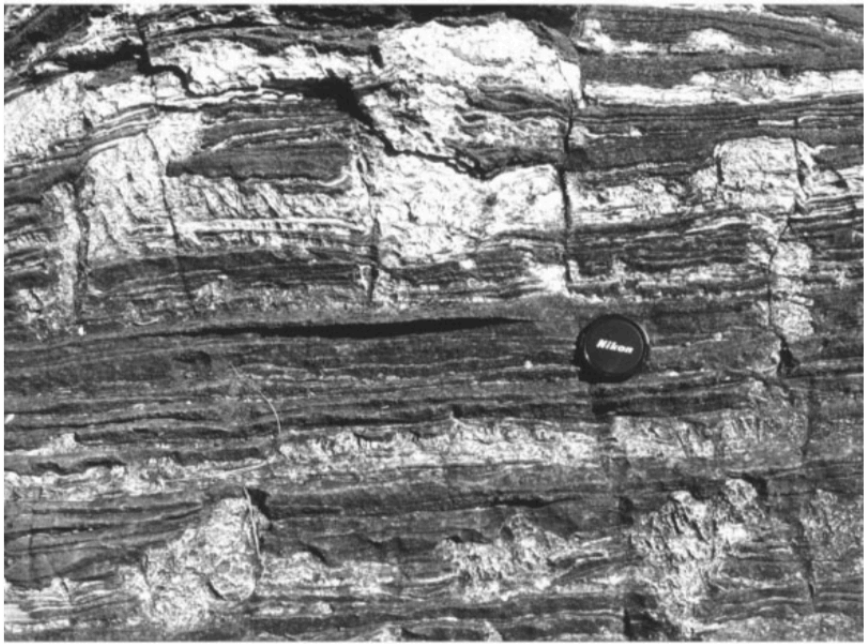
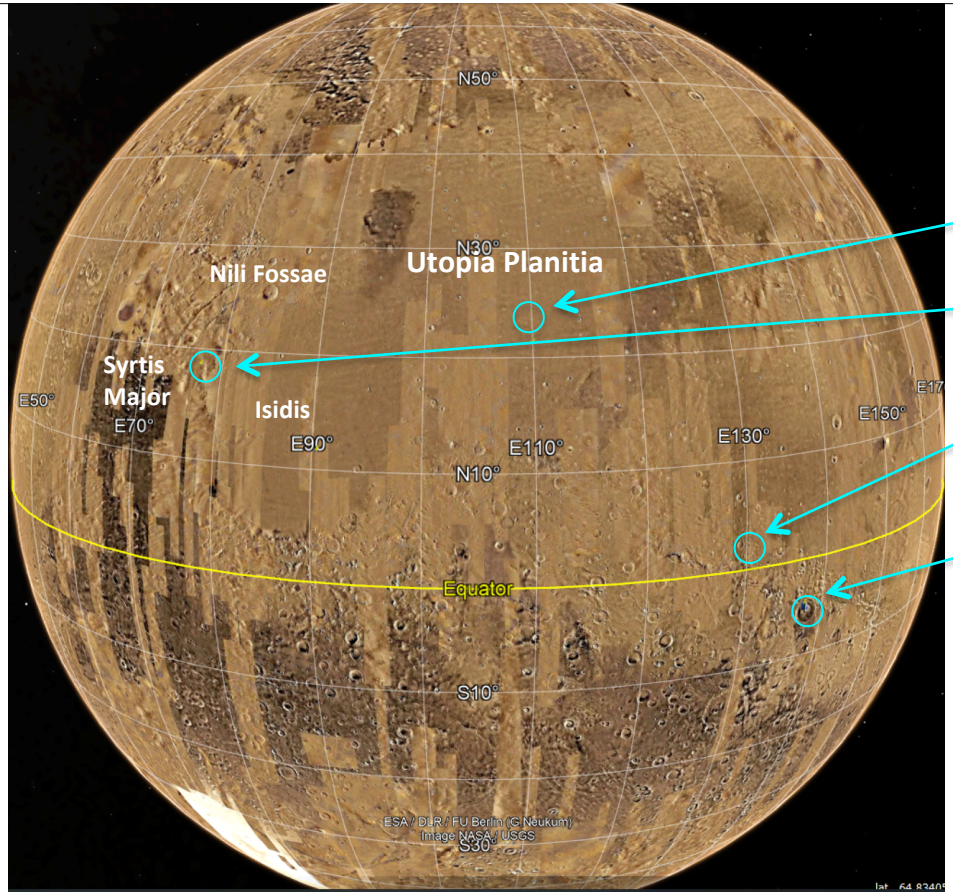


Figure 5 Stromatolites (*light*) within medium-grained to very-coarse–grained quartz sandstones (*dark*) of the Neoproterozoic Bildah Member where it onlaps the Witvlei Arch, central Namibia. Carbonates also form uncommon thin beds, but only in close proximity to stromatolites. These observations are taken to indicate in situ precipitation of fine-grained carbonate. Lens cap is 6 cm.

Rovers: Perseverance & Curiosity



4 rovers active May 2022

(Landing date)

Zhurong (15 May 2021)

Perseverance (18 Feb 2021)
- **Jezero** Crater

Insight (26 Nov 2018)
listening to quakes

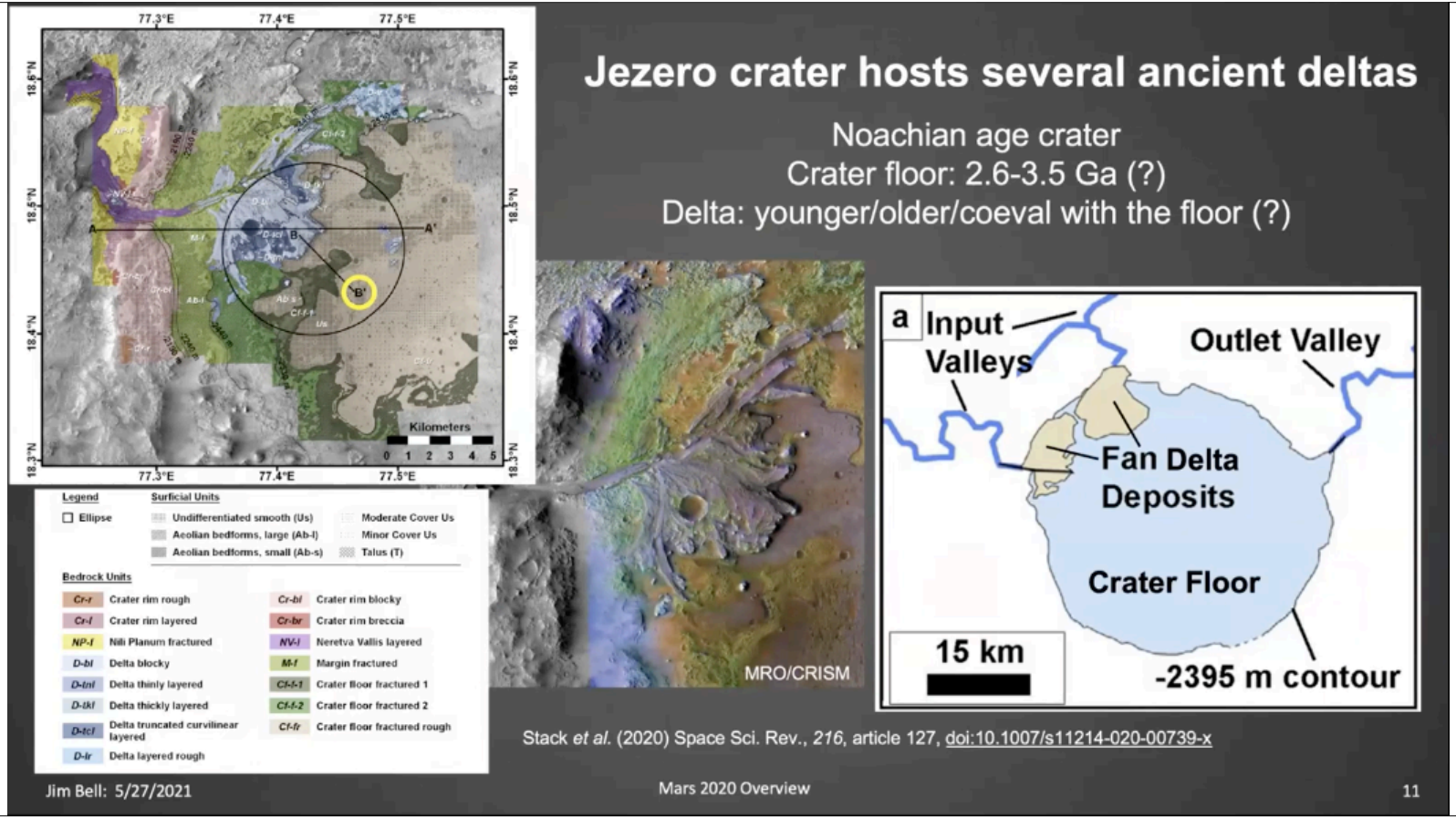
Curiosity (6 Aug 2012)
- **Gale** Crater

Data modified from: NASA: https://mars.nasa.gov/ and Zhurong: https://www.nature.com/articles/s41550-021-01519-5 and GoogleMars map

QGIS project intro

- Public domain data initial load
- Initial Interpreting
- Useful for
  - Vertical Sections slices
  - 3D views and match satellite data to Rover photo Panoramas
  - Geological mapping : next steps!

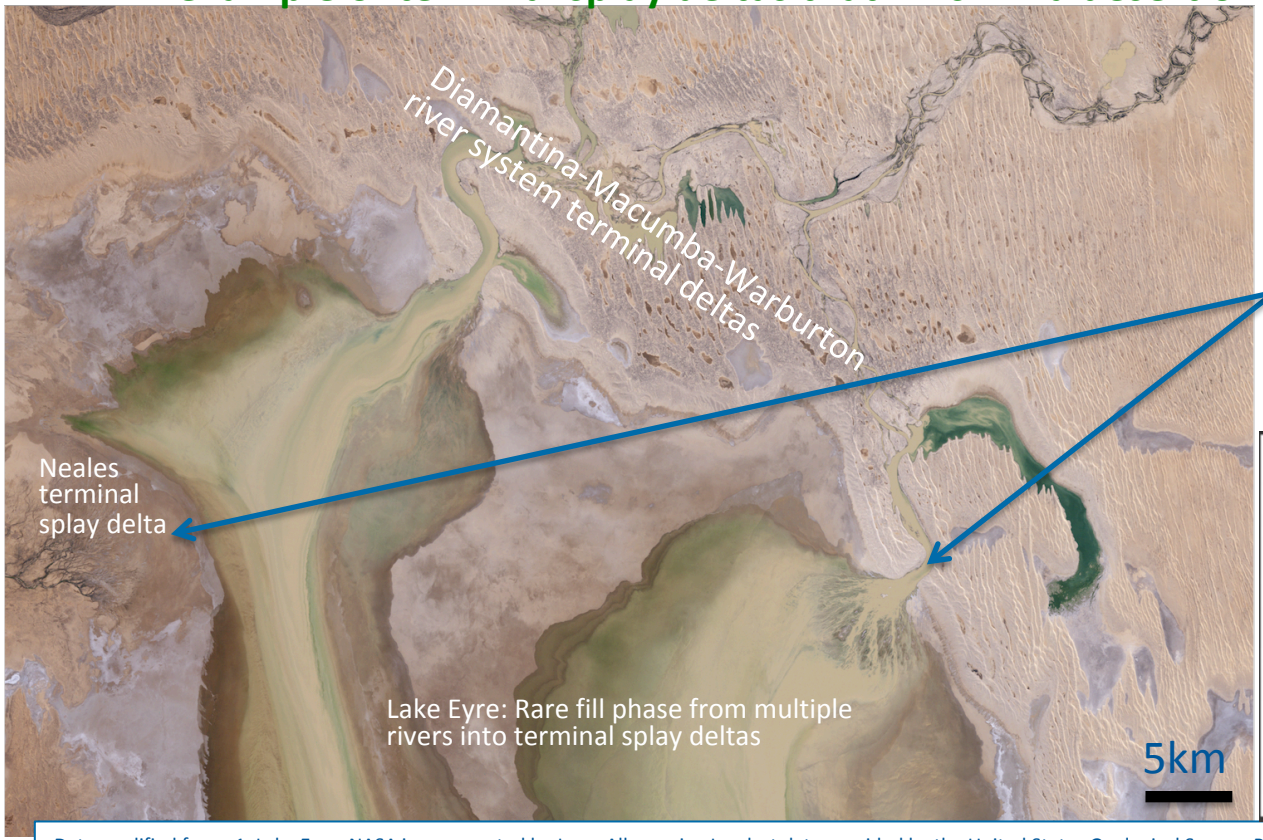
Jezero: Perseverance: NASA: Orbital model- Lake Delta

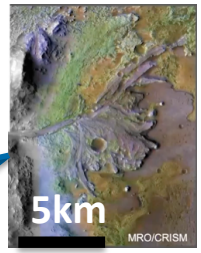


Data from: Slide 11 from Jim Bells presentation May 2021 "Delta Bound: Early Exploits of the Perseverance Rover in Jezero Crater". https://www.lpi.usra.edu/seminars/

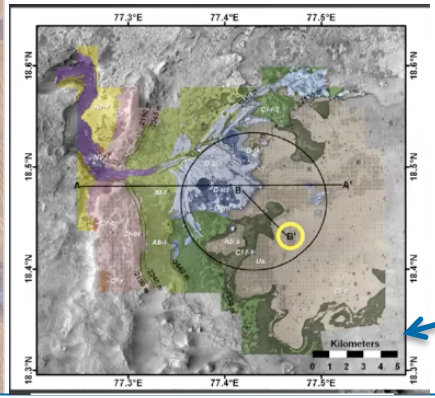
The Jezero Delta & Earthly deltas with similar horizontal scale

An example of terminal splay deltas that finish in a desert or ephemeral lake





Jezero Delta in false colour: Mars Reconnaissance Orbiter (MRO) Compact Reconnaissance Imaging Spectrometer(CRISM) false colour uses detectors that see in visible, infrared and near-infrared wavelengths, reads the hundreds of "colors" in reflected sunlight to detect patterns that indicate certain minerals on the surface



5km

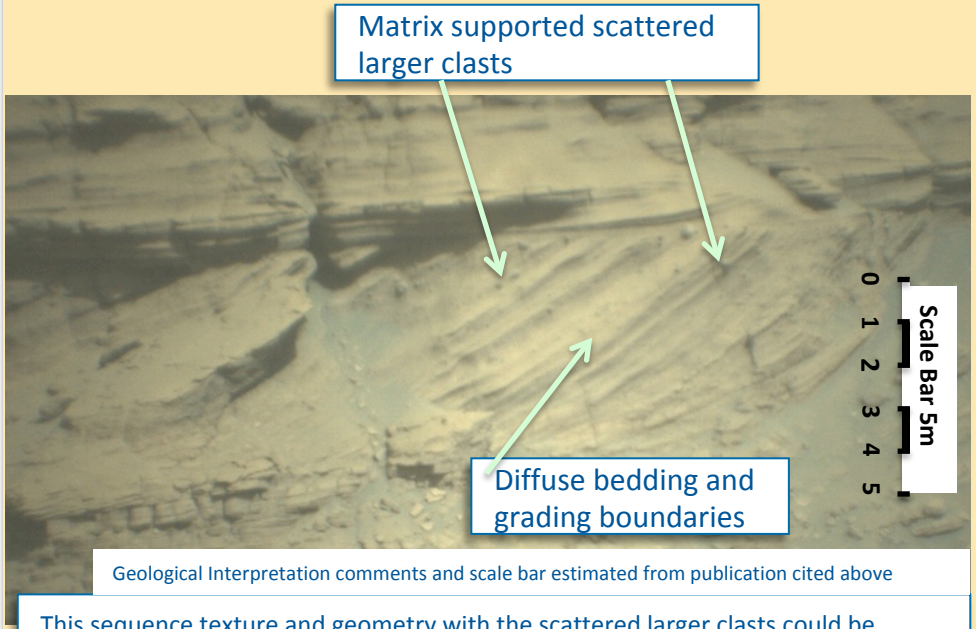
Data modified from: 1. Lake Eyre: NASA image created by Jesse Allen, using Landsat data provided by the United States Geological Survey. Rare Refill of Lake Eyre, Australia's Simpson Desert: https://landsat.visibleearth.nasa.gov/view.php?id=38717.
2. Jezero images cropped from Slide 11 from Jim Bells presentation May 2021 "Delta Bound: Early Exploits of the Perseverance Rover in Jezero Crater". https://www.lpi.usra.edu/seminars/

SOL 239 Volcanic (Pyroclastic flow/surge) texture comparisons

Earth Example of Volcanic surge
Scale bar interpreted from text description below. Photo flipped to match orientation of Kodiak for comparison from cited: Burt, D.M., et al., Surge deposit misidentification at Spor Mountain, Utah and elsewhere: A cautionary message for Mars, Journal of Volcanology and Geothermal Research (2008), doi:10.1016/j.jvolgeores.2008.01.044

Fig. 3. Exposure of sandy flat beds overlying high angle cross-beds in a surge deposit, southeast wall of Kilbourne Hole maar, New Mexico. Photo scale (centimeters/inches) at contact. Near-infrared digital photo by D.M. Burt.

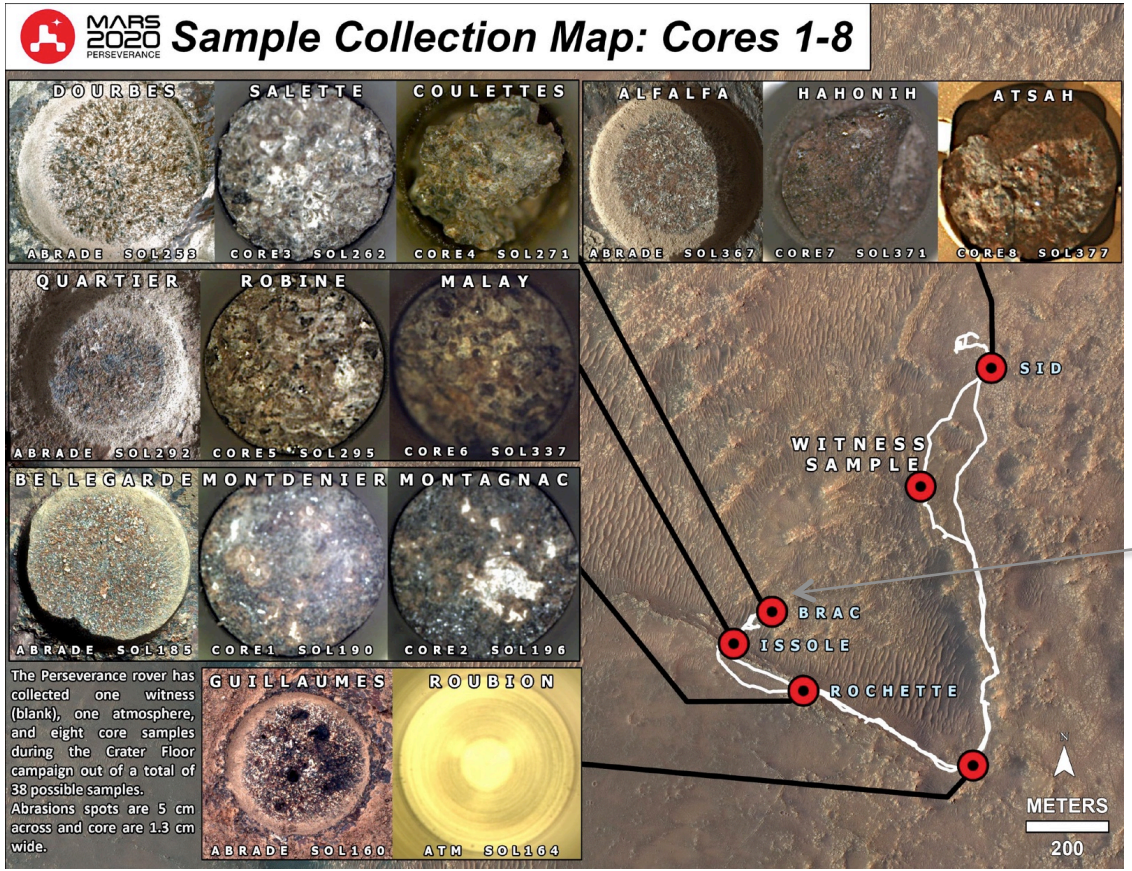
Mars Kodiak portion: Cropped portion of photo from SOL248 (NASA/JPL-Caltech/LANL/CNES/IRAP). Link to original image in footnote below. A better image is in previous presentation taken from Cited Reference: N. Mangold et al., Science 10.1126/science.abl4051 (2021)



Geological Interpretation comments and scale bar estimated from publication cited above

This sequence texture and geometry with the scattered larger clasts could be interpreted as volcanic surge deposits, especially when compared with earthly versions (Left and following slides). The overlying coarse breccia not shown in this image but on the publication cited above would fit with late stage volcanic activity

Perseverance Jezero Samples to Date – NASA “Igneous”



SOL 268 Core bits caused a partial jam in catcher so were ditched. Photos from compilation done by Fred Heller https://www.facebook.com/photo/?fbid=10228026148060876&set=pcb.2861325770826248

Data from: http://www.unmannedspaceflight.com/index.php?s=&showtopic=8681&view=findpost&p=256679 and https://mars.nasa.gov/mars-rock-samples/

Perseverance Samples to April 2022: NASA say all are Igneous

Sample No.	Date	Sol	Sample Name	Rock/Outcrop Name	Location	Sample Type	Core Length cm	Core Length inch	Rock Type
1	8/6/2021	164	Roubion	Roubion	Polygon Valley	Atmospheric	n/a	n/a	n/a
2	9/6/2021	194	Montdenier	Rochette	Artuby Ridge	Rock Core	5.98	2.35	igneous
3	9/8/2021	196	Montagnac	Rochette	Artuby Ridge	Rock Core	6.14	2.42	igneous
4	11/15/2021	262	Salette	Brac	South Séítah	Rock Core	6.28	2.47	igneous
5	11/24/2021	271	Coulettes	Brac	South Séítah	Rock Core	3.30	1.30	igneous
6	12/22/2021	298	Robine	Issole	South Séítah	Rock Core	6.08	2.39	igneous
7	1/31/2022	337	Malay	Issole	South Séítah	Rock Core	3.07	1.21	igneous
8	3/7/2022	371	Ha'ahóni (aka "Hahonih")	Sid	Octavia E. Butler Landing/Ch'ał outcrop	Rock Core	6.50	2.56	igneous
9	3/13/2022	377	Atsá (aka "Atsah")	Sid	Octavia E. Butler Landing/Ch'ał outcrop	Rock Core	6.00	2.36	igneous

Mars Rock Samples Collected By Perseverance Rover

Of the 43 tubes Perseverance brought to Mars, 38 are for collecting samples, and five are "witness tubes" designed to document the cleanliness of its sampling system throughout the mission. The first witness tube was sealed on Sol 160 (June 22, 2021).

Data from: https://mars.nasa.gov/mars-rock-samples/

Perseverance & Jezero Crater: Geological Scale & context

Getting these takes time! Posters (PDF) based on QGIS and from sources below

- NASA website:
  Comprehensive coverage but raw data only and very careful wording, 6 months at least before official interpretations
  https://mars.nasa.gov/mars2020/mission/where-is-the-rover/

- Mars 2020 Perseverance Rover − Public Facebook Group with good technical discussion, a forum to keep up to date
  https://www.facebook.com/groups/2641247092834118

- Neville Thompson: (NeV-T.com) Excellent high resolution Panorama images of both Perseverance and Curiosity
  Link for Perseverance Collection : https://viewer.gigamacro.com/collections?s=Perseverance

  – SOL437 Gigamacro delta front
    https://viewer.gigamacro.com/view/r4PNzcDkaGFdDWID?x1=63849.86&y1=-10121.69&res1=29.20&rot1=0.00

  – SOL419 Gigamacro delta front
    https://viewer.gigamacro.com/view/0M1evwS5CadjESrx?x1=54542.84&y1=-5567.18&res1=27.77&rot1=0.00

- Unmanned spaceflight (Cartographic and excellent enhanced rock image processing) All Mars Rovers, excellent Googlemars projects updated
  http://www.unmannedspaceflight.com/index.php?showforum=80

- Mars Rovers: Mosaics, Panoramas & Updates
  (Great mosaics and panoramas and link with maps)
  https://www.facebook.com/marscuriosityimages/

Perseverance & some “tasters”

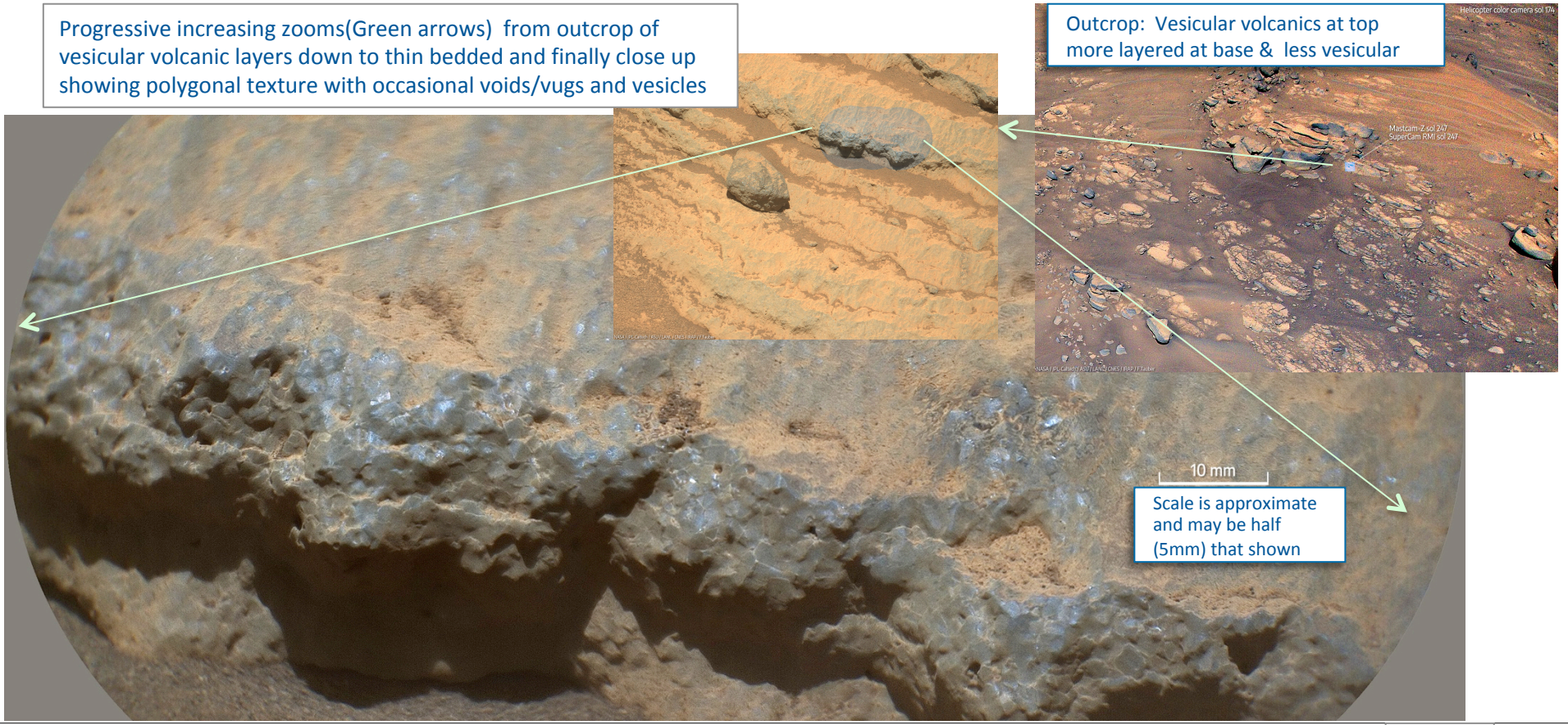
Much more to be said and to come in the future!

- Mars_rocks_part2_22052021.pdf
- Mars_A0_flight10_triple_junction.pdf
- Mars_A0_SOL158_ridge panorama.pdf
- Mars_A0_SOL168_ridge_APEX_part1.pdf
- Mars_A0_SOL180_197_Volcanic_texture.pdf
- **Mars_rocks_Jezero_SOL202_RIMFAX.pdf**
- Mars_rocks_Jezero_water levels_SOL210.pdf
- **Mars_rocks_Jezero_SOL213_Kodiak sections.pdf**
- **Mars_rocks_SOL239_TEXTURES.pdf**

Mars Rocks: Jezero: Unusual thickness, texture?

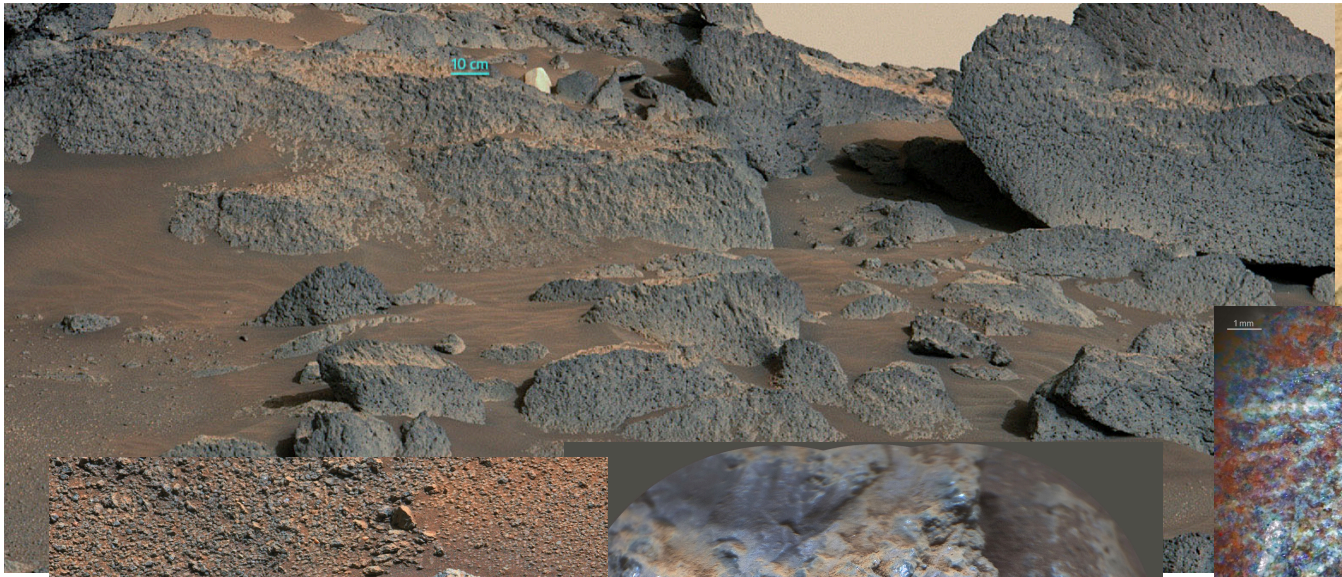
Progressive increasing zooms(Green arrows) from outcrop of vesicular volcanic layers down to thin bedded and finally close up showing polygonal texture with occasional voids/vugs and vesicles

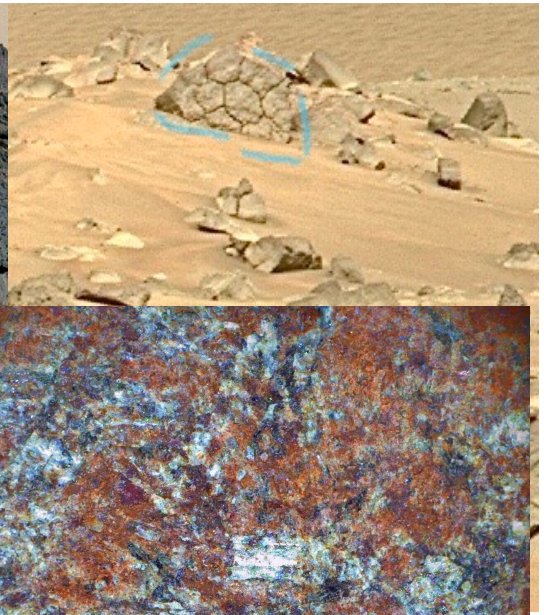
Outcrop: Vesicular volcanics at top more layered at base & less vesicular

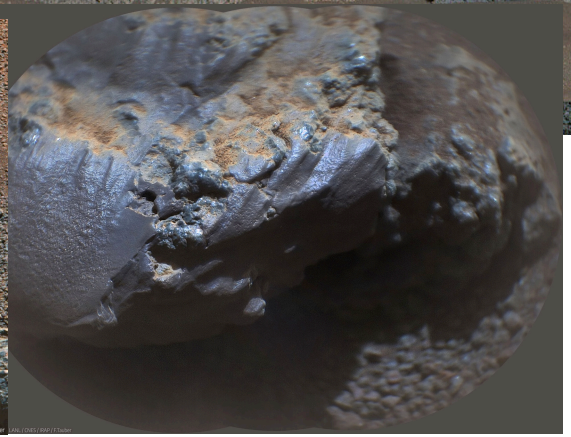


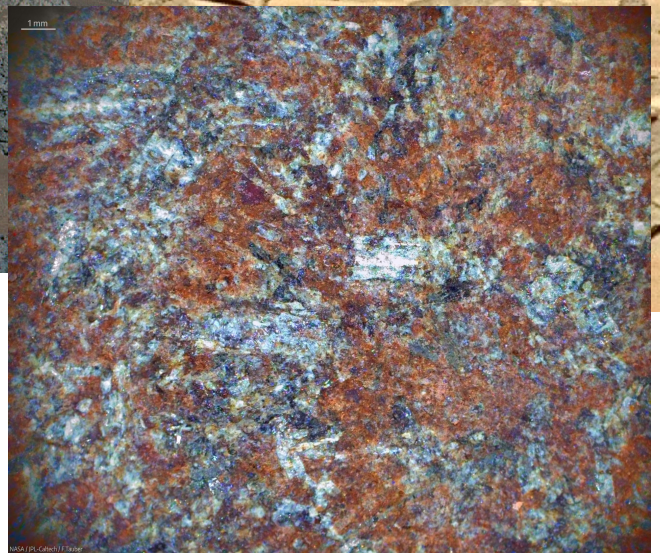
Scale is approximate and may be half (5mm) that shown

Mars Rocks: Jezero: Igneous & volcanic textures

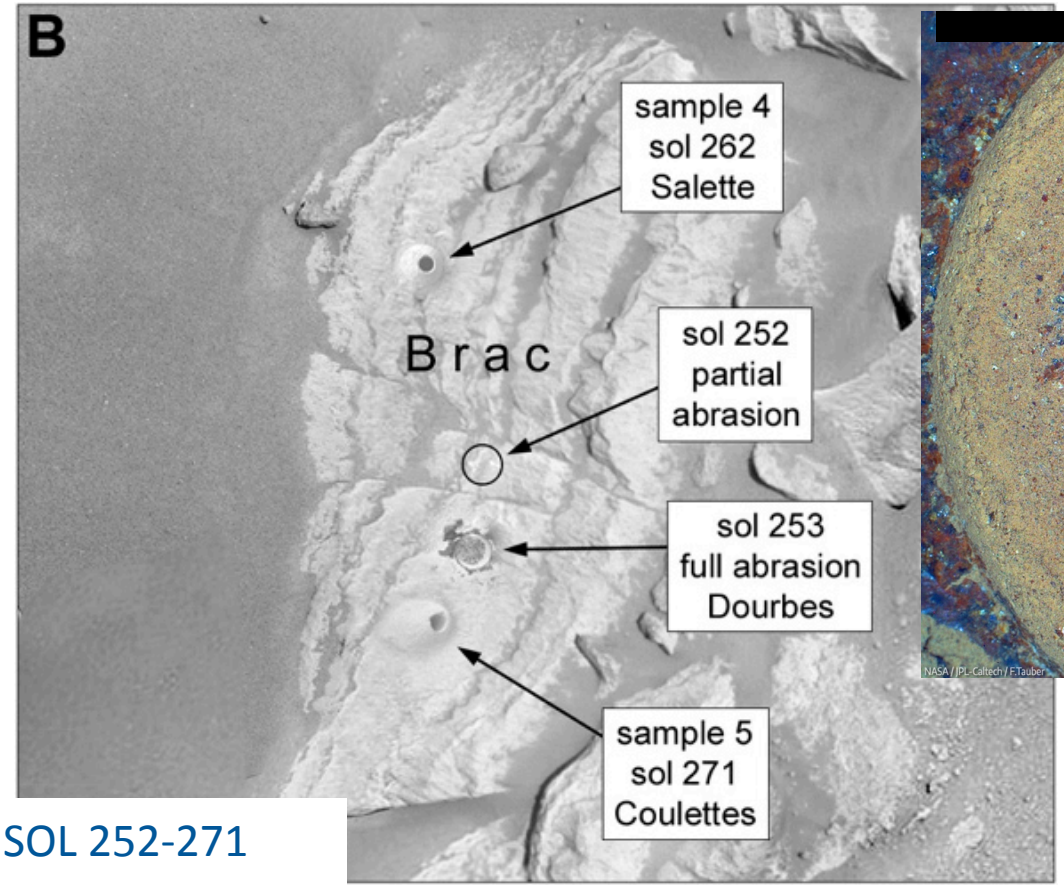




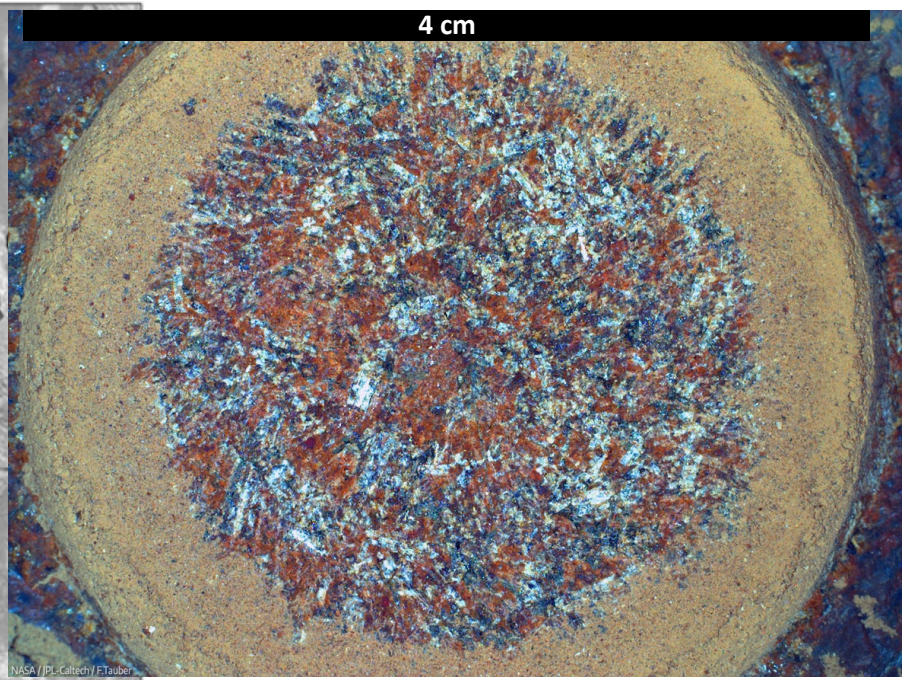




Perseverance: Abrade & Drill Example SOL 252-271. SOL367



SOL 252-271



SOL 367 Alfalfa

Data from: http://www.unmannedspaceflight.com/index.php?act=attach&type=post&id=49953 and http://www.unmannedspaceflight.com/index.php?showtopic=8661&st=300&p=256442&#entry256442

Kodiak Area panoramas Links with good panoramas

Neville Thompson: (NeV-T.com) Link :
https://viewer.gigamacro.com/collections?s=Perseverance

- SOL 416 Kodiak as close as it gets to the foresets
  https://viewer.gigamacro.com/view/KxFYsKcLnp7BjoGy?x1=82382.84&y1=-6209.10&res1=11.73&rot1=1.26
- SOL 414 close to Kodiak and view of the top of satellite cones
  https://viewer.gigamacro.com/view/xUQbaoOV6ZZgPP3X?x1=26045.18&y1=-4742.77&res1=12.98&rot1=6.99
- SOL 408-409 Kodiak and full view of satellite cones and boulder fall and track to match satellite image
  https://viewer.gigamacro.com/view/EzBghR394ypeAx3M?x1=96901.20&y1=-2907.85&res1=76.65&rot1=5.08

Curiosity & some “tasters”

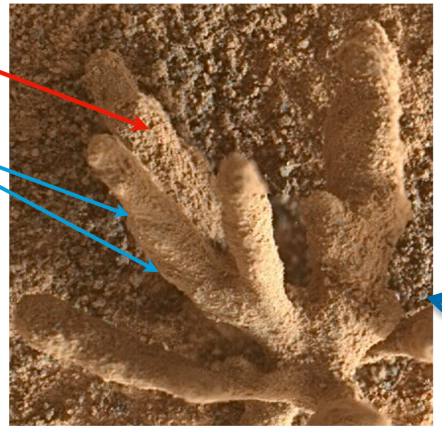
Much more to be said and to come in the future!

- Mars_rocks_Gale_Curiosity_SOL3312_Hill Fractures.pdf

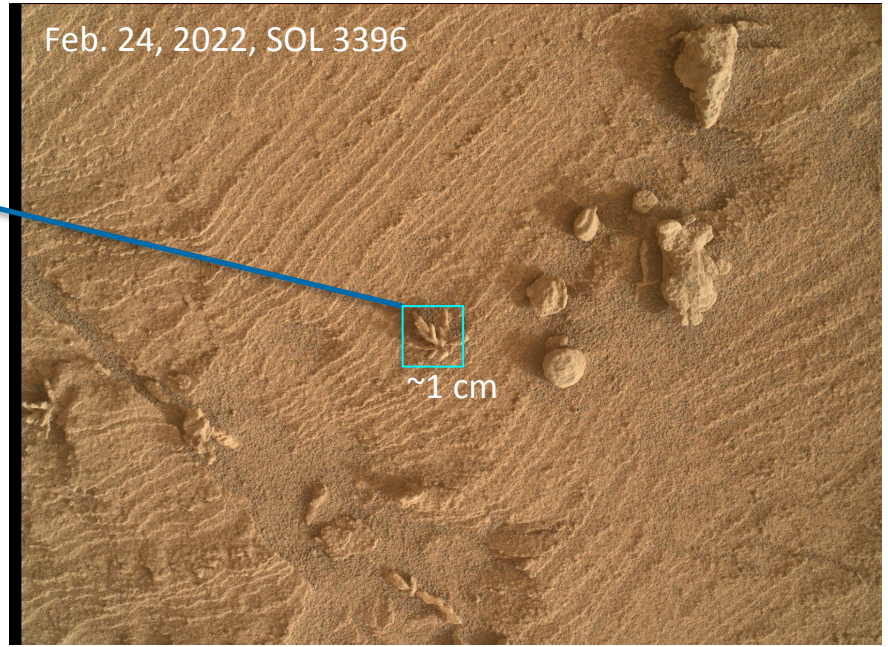
Mars Rocks: Gale Crater: Bryozoan? or Gypsum Sinter?

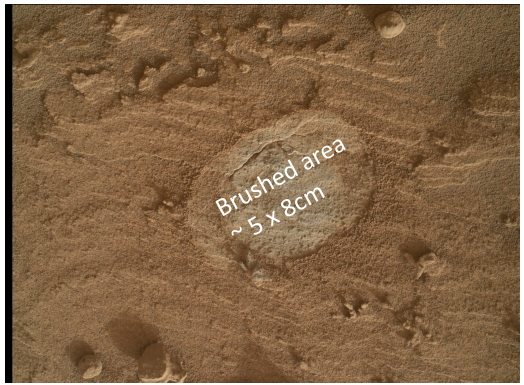
Possible micro pores in a semi-regular ? pattern texture on broken fragment in focus ? Oblique growth pattern?

Close up cropped image with tweak to definition and sharpness From the original https://mars.nasa.gov/raw_images/1029747/?site=msl
Image Credit: NASA/JPL-Caltech/MSSS



Collections: Gigamacro
https://viewer.gigamacro.com/collections/4cMjPjea2yUy4sg0

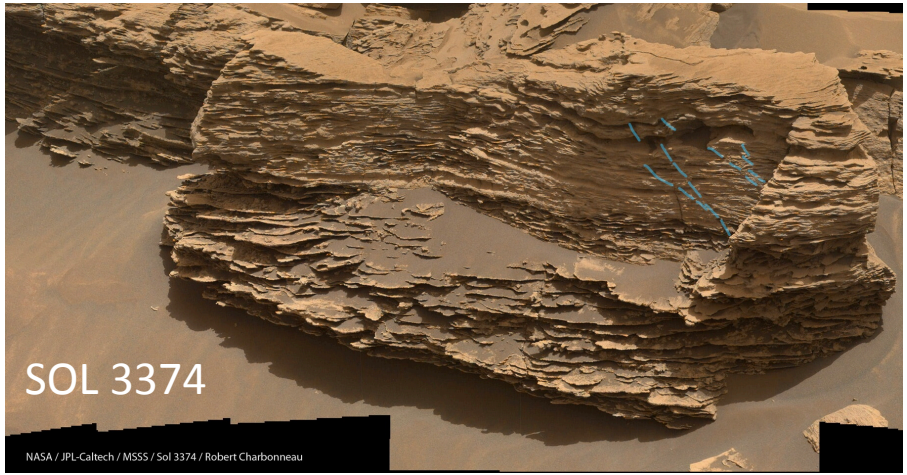




NASA analyzed similar elsewhere with laser - Mg and sulphate

SOL 3395 Complex layers
https://viewer.gigamacro.com/view/oJ9VPR7v2x57R9vR?x1=75167.92&y1=-35111.29&res1=50.04&rot1=0.00&cid=4cMjPjea2yUy4sg0

Mars Rocks: Gale Crater: Climbing & adhesion ripples & faults

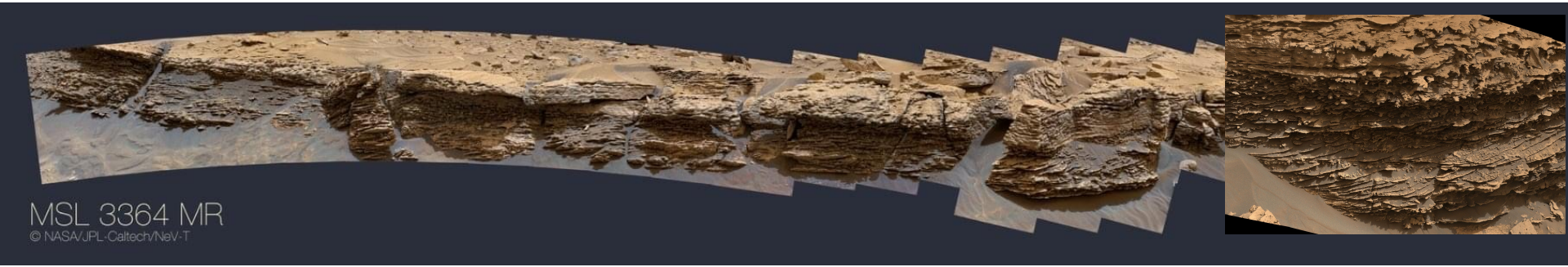


The “Prow Outcrop” SOL 3354 to SOL 3371: Rippled deposit between the “aeolian dunes”
Collections: Gigamacro
https://viewer.gigamacro.com/collections/4cMjPjea2yUy4sg0

SOL 3365 The Prow Context and scale
https://viewer.gigamacro.com/view/LGfCWw2lkuKWCMK6?x1=29115.53&y1=-7134.66&res1=28.35&rot1=0.00&cid=4cMjPjea2yUy4sg0

SOL3354 –Climbing Ripples
https://viewer.gigamacro.com/view/BTmiqj76ckU4YUeR?x1=24489.78&y1=-19085.92&res1=80.35&rot1=0.00&cid=4cMjPjea2yUy4sg0

MSL 3371 Panorama (SOL 3371)
https://viewer.gigamacro.com/view/ydWra3ha0gssnZav?x1=47873.98&y1=-8947.54&res1=12.33&rot1=0.00&cid=4cMjPjea2yUy4sg0



https://viewer.gigamacro.com/view/dBsj510S2cVCDB35?x1=51528.00&y1=-8787.50&res1=57.09&rot1=0.00

Backup slides

Earthly Examples of Tuff/Tephra – Volcanic surge deposits

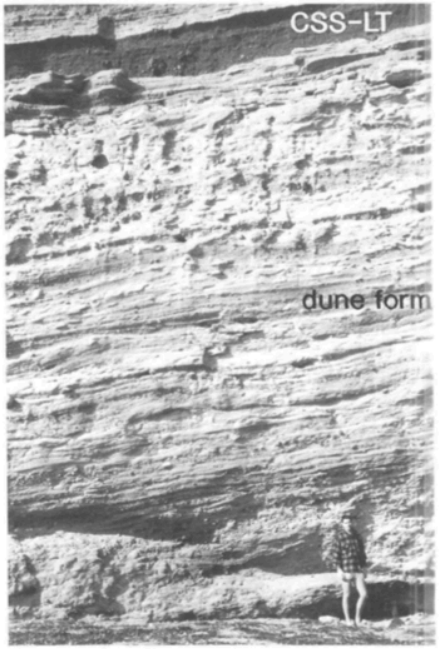


Fig. 4 Motukorea tuff-ring of lower matrix-supported facies and transitional black, clast-supported, stratified CSS-LT facies.

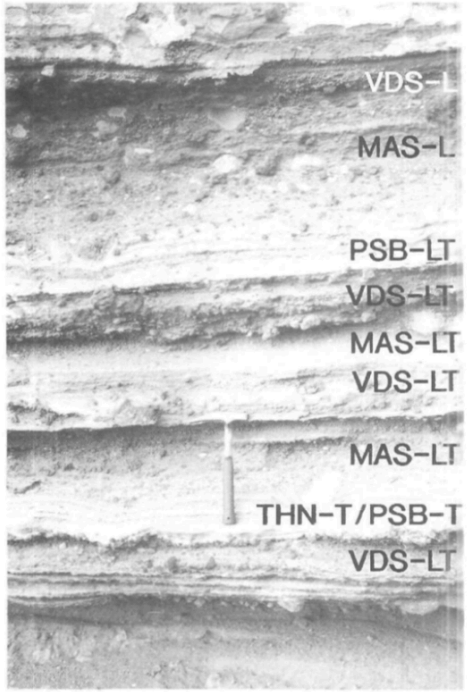


Fig. 14 Motukorea lower tuff-ring of matrix-supported facies showing alternating sequences of stratifed facies (THN-T/PSB-T, VDS-LT, VDS-L) grading into massive facies (MAS-LT, MAS-L).

Facies analysis of pyroclastic deposits within basaltic tuff-rings of the Auckland volcanic field, New Zealand. Allen et al., 1996. NewZealandJournalofGeologyandGeophysics,1996,Vol.39:309—327

Link: https://www.tandfonline.com/doi/abs/10.1080/00288306.1996.9514714

Eruption and Emplacement Mechanisms and Paleoenvironment of Phreatomagmatic Tephra at Koko Crater Tuff Cone, O'ahu, Hawaii. MSc.Thesis. Elizabeth Louise Simoneau. University of Central Missouri, 2006

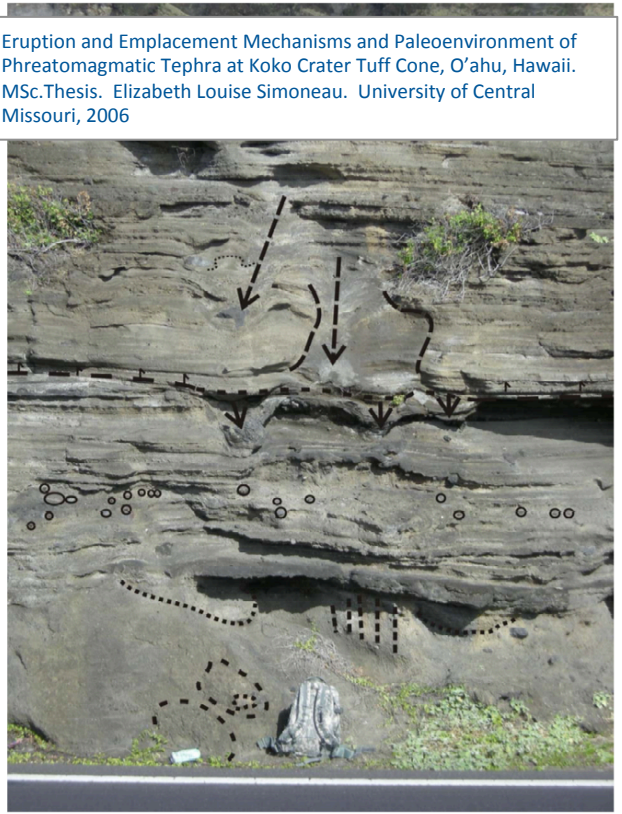
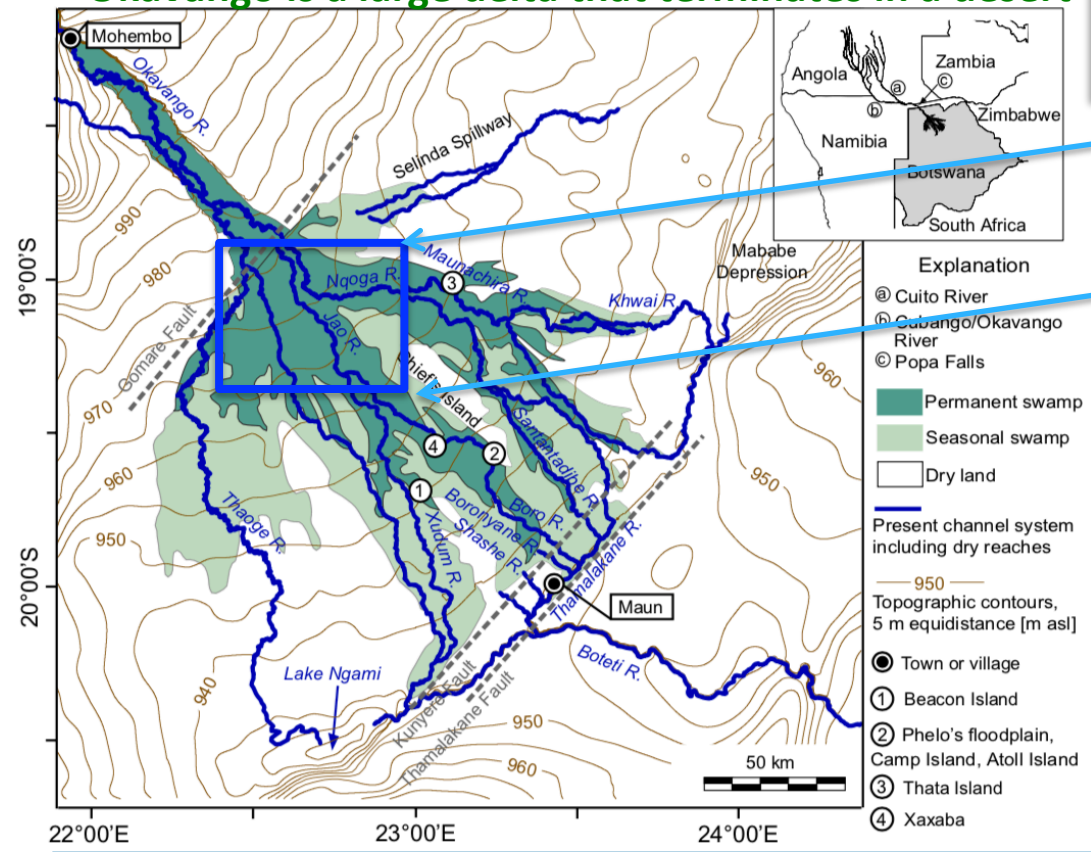


Figure 6. Log 1, location 1.

Link: https://core.ac.uk/download/pdf/12210388.pdf

Jezero Crater Delta is ~10 times smaller scale relative to Okavango

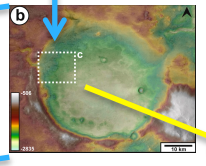
Okavango is a large delta that terminates in a desert



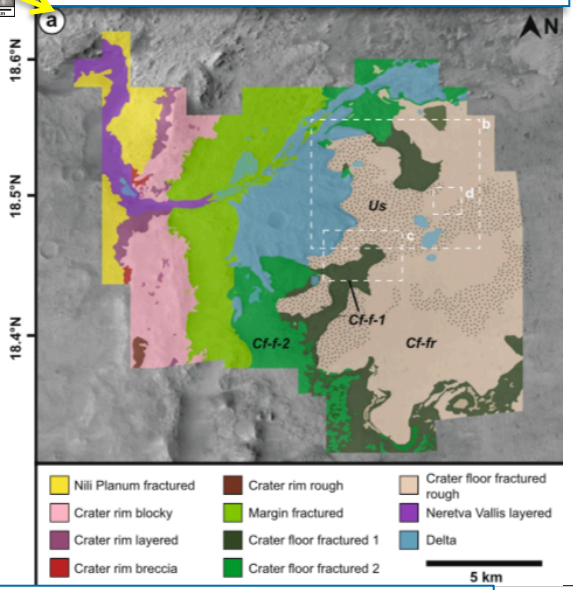
Jezero Crater

At same horizontal scale as Okavango

Inset white box enlarged



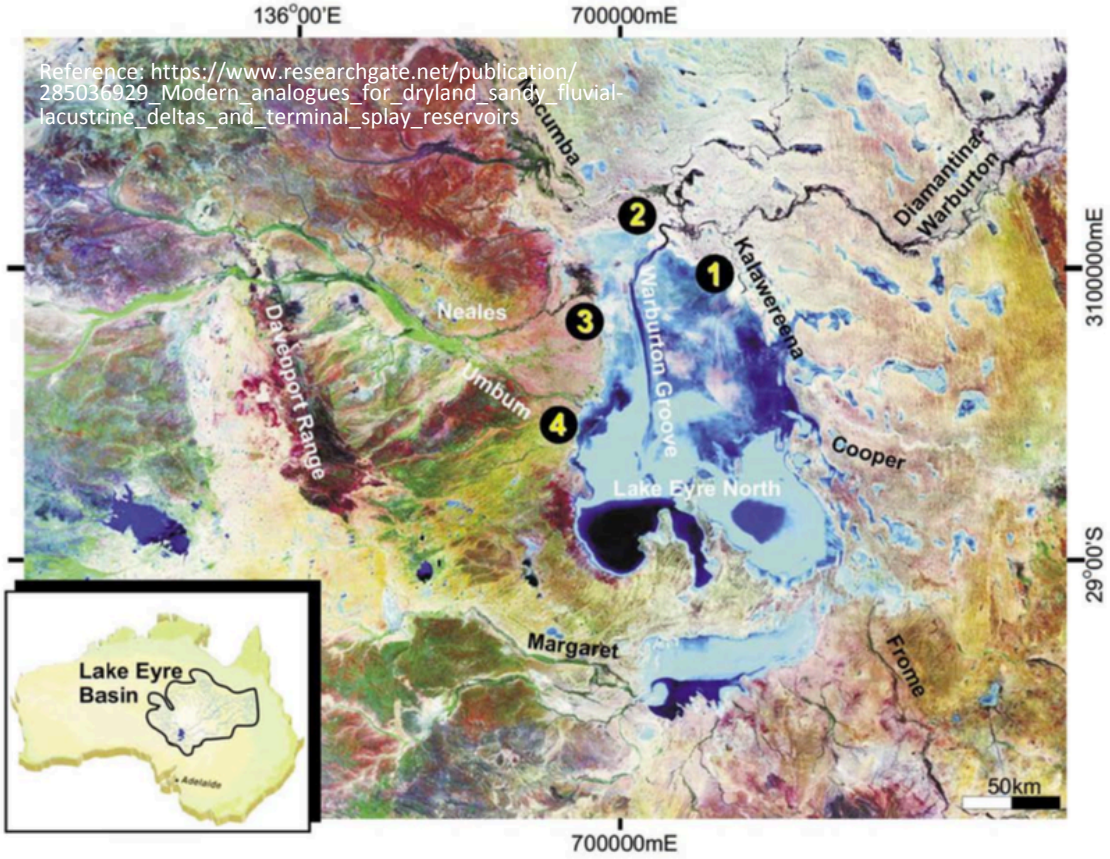
Jezero Crater Delta enlarged scale



Data modified from: Milzow, C; et al. 2009. Regional review: the hydrology of the Okavango Delta, Botswana—processes, data and modeling. Hydrogeology Journal 17: 1297–1328

Jezero Crater modified from : Holm-Alwmark, et al. (2021). Stratigraphic relationships in Jezero crater, Mars: Constraints on the timing of fluvial-lacustrine activity from orbital observations. *Journal of Geophysical Research: Planets*, *126*, e2021JE006840.

Mars Rocks − Jezero crater compared to Lake Eyre basin system



Jezero Crater

At same horizontal scale

Data modified from: Lang et al. 2004. MODERN ANALOGUES FOR DRYLAND SANDY FLUVIAL-LACUSTRINE DELTAS AND TERMINAL SPLAY RESERVOIRS. APPEAJOURNAL 2004-329

Jezero Crater modified from : Holm-Alwmark, et al. (2021). Stratigraphic relationships in Jezero crater, Mars: Constraints on the timing of fluvial-lacustrine activity from orbital observations. *Journal of Geophysical Research: Planets*, *126*, e2021JE006840.

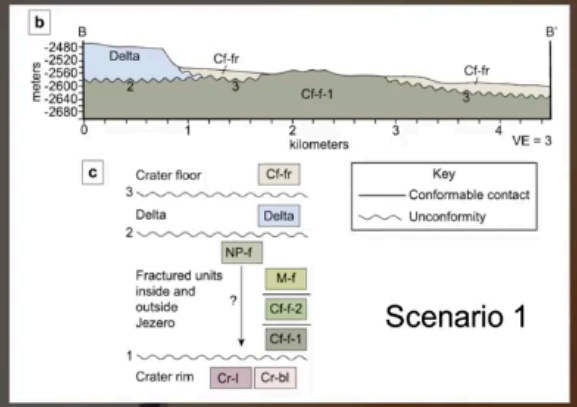
Jezero: Perseverance: NASA: Orbital model-Delta sections

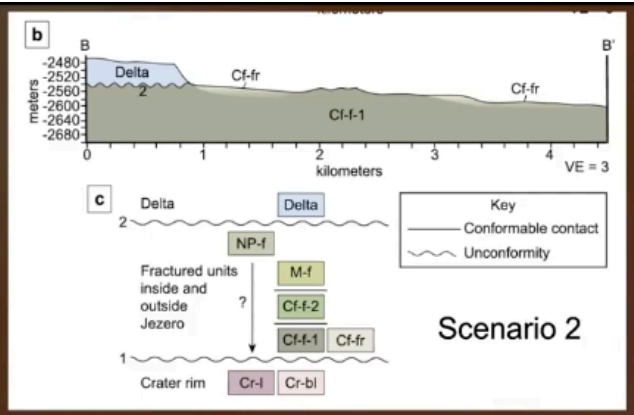
Perseverance landed at B' in these cross-sections

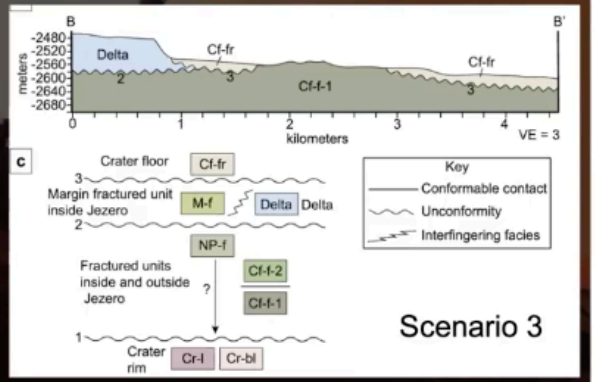
Multiple working hypotheses for the origin, evolution, and relative ages of the major Jezero crater map units!

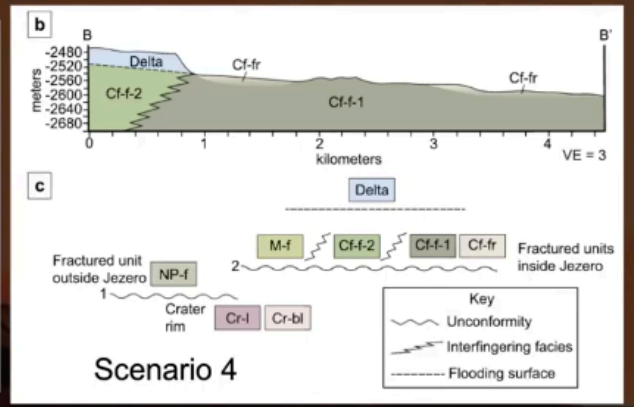
Major science team goal is to collect observations – and wisely choose samples – to characterize these units and distinguish between these hypotheses...

Stack *et al.* (2020) Space Sci. Rev., *216*, article 127, doi:10.1007/s11214-020-00739-x









Jim Bell: 5/27/2021 Mars 2020 Overview 12

Data from: Slide 12 from Jim Bells presentation May 2021 "Delta Bound: Early Exploits of the Perseverance Rover in Jezero Crater". https://www.lpi.usra.edu/seminars/