

Mars Rover Science: Organic Molecules & Ancient Habitats



Caroline Freissinet¹ and Daniel Glavin²

¹CNRS/LATMOS, Guyancourt, France

²NASA Goddard Space Flight Center, Greenbelt, Maryland, USA





Are We Alone in the Universe?

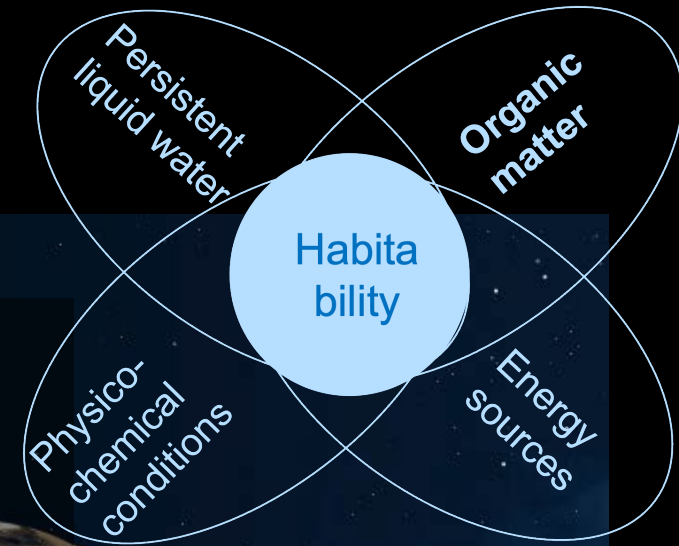
Did life originate on Mars?



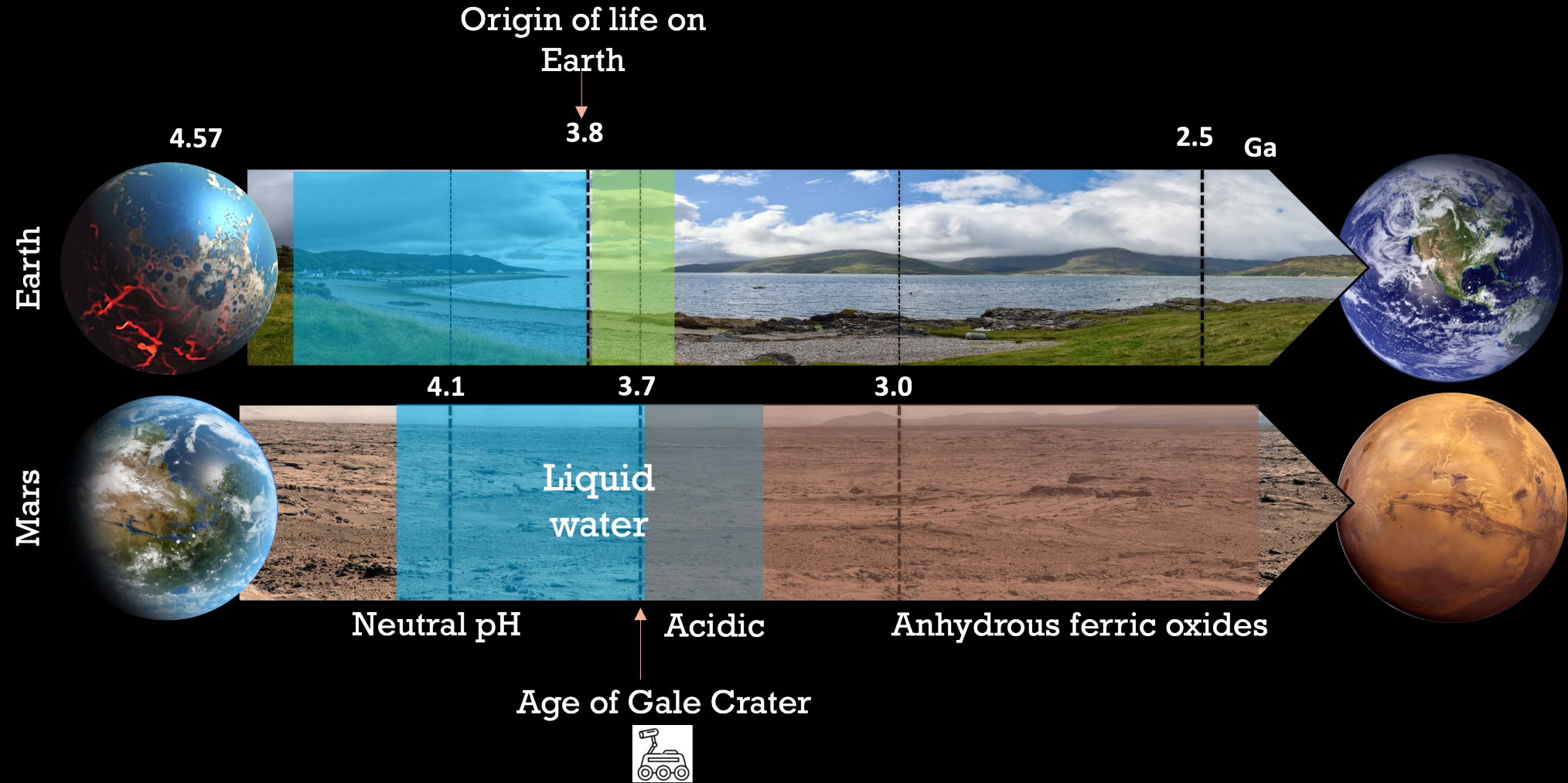
Did Mars have conditions capable of supporting life?



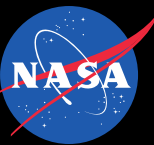
Did Mars have liquid water?



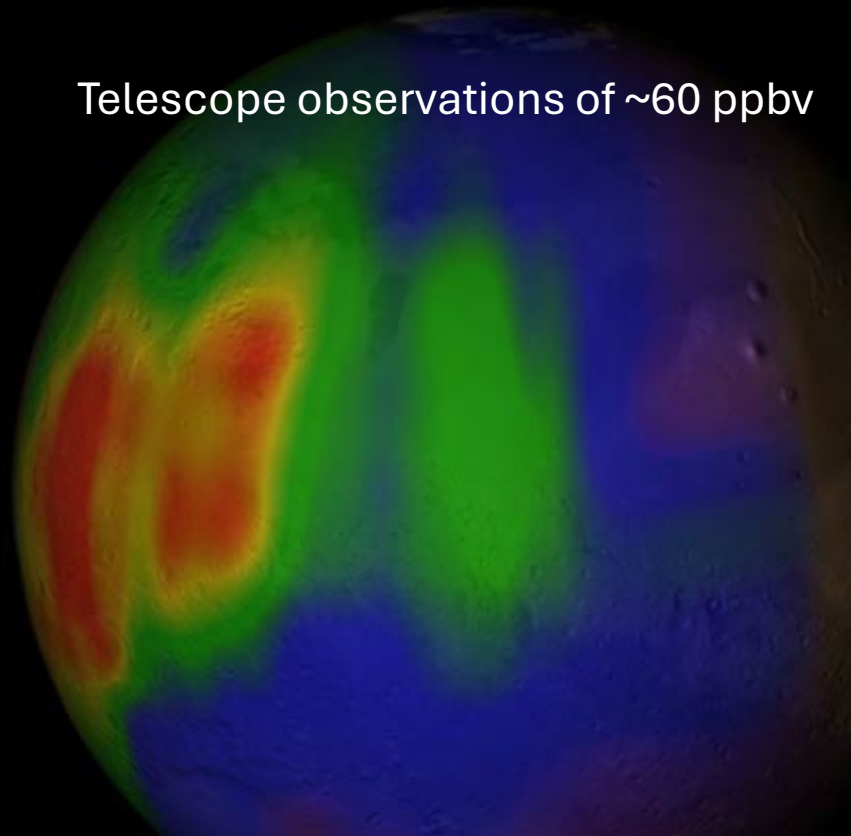
Ancient Water & Habitable Environments



Methane on Mars Indicates an Active Planet



Telescope observations of ~60 ppbv

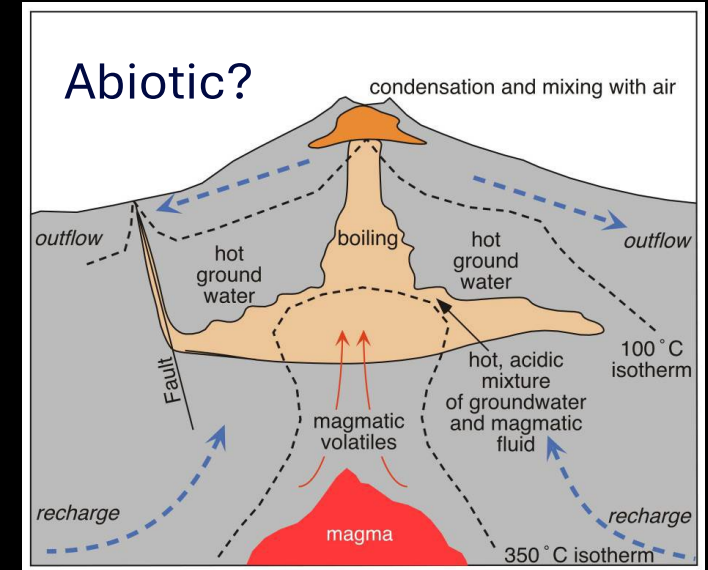


Since CH₄ exists in the Mars atmosphere, could it have come from a present-day or ancient biological source or an abiotic source?

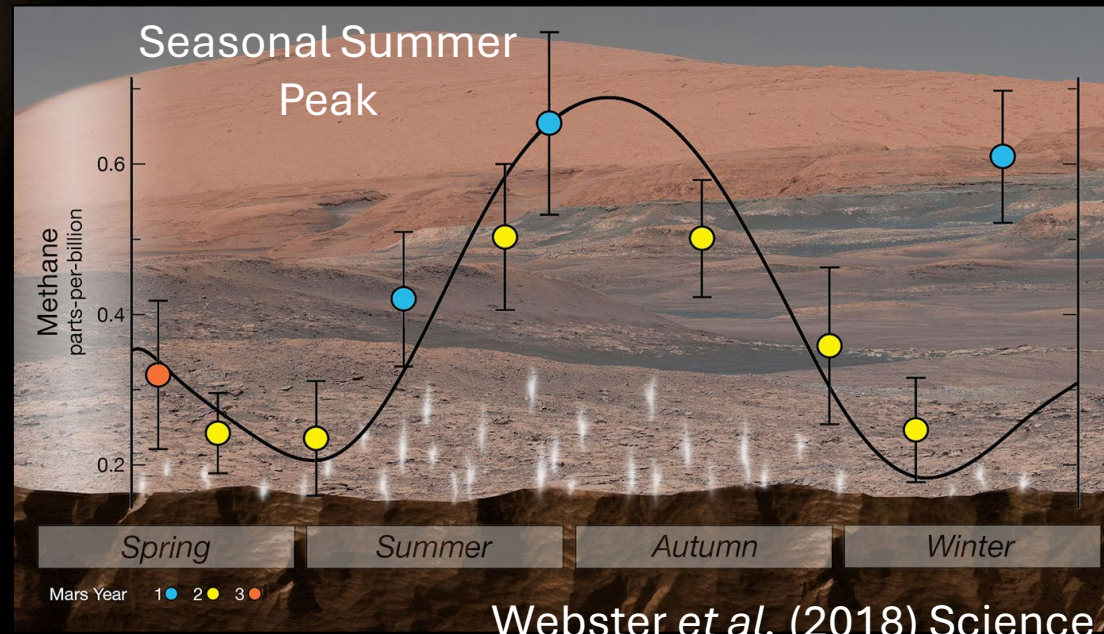
Mumma *et al.* (2009) *Science*



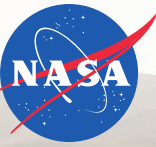
Most of CH₄ in Earth's atmosphere is biologically produced.



Seasonal variation in atmospheric CH₄ measured by SAM with spikes up to 20 ppbv



Webster *et al.* (2018) *Science*



Curiosity's Journey in Gale Crater

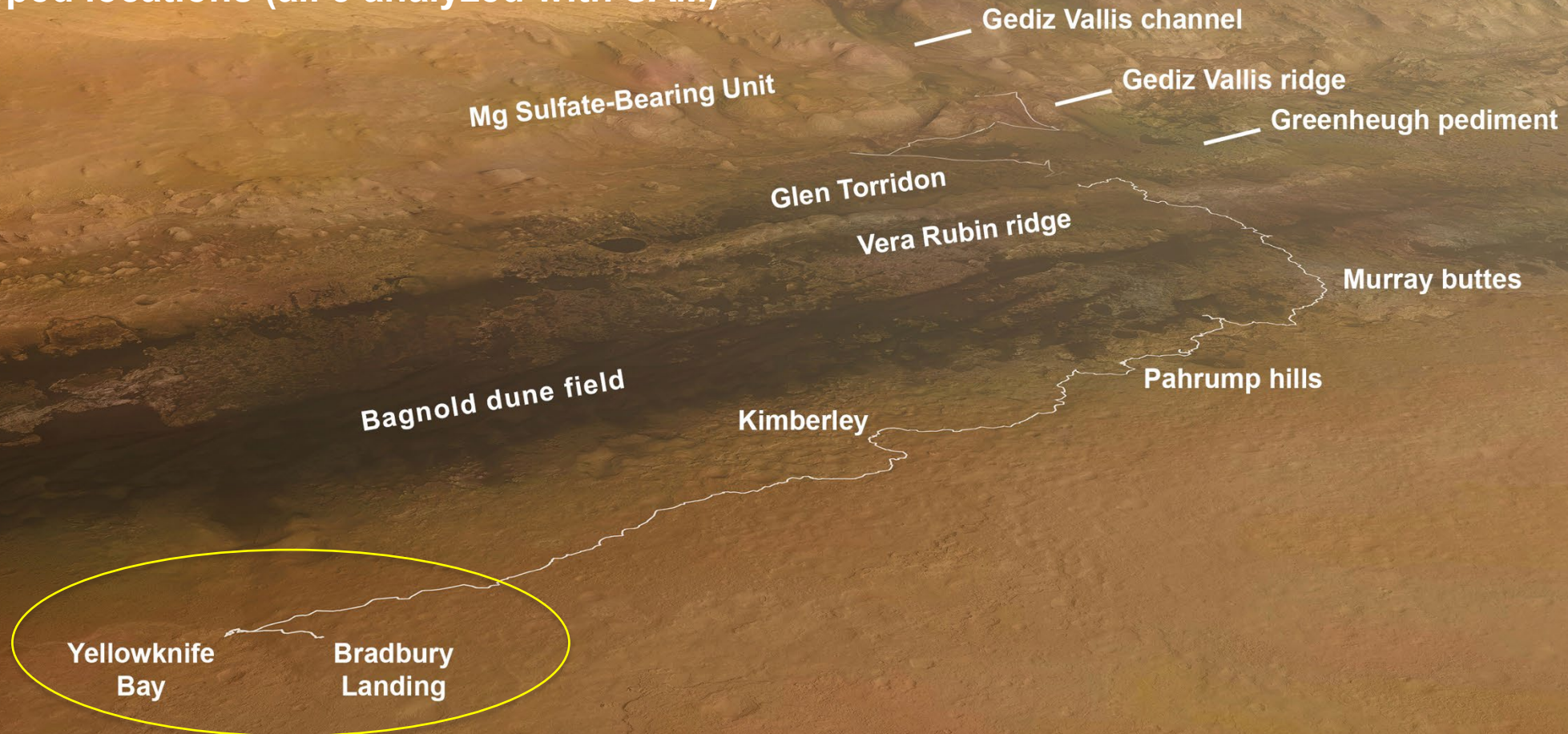
Curiosity since 2012:

> 4600 active sols

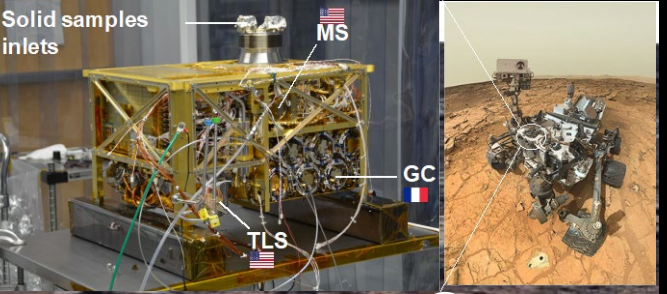
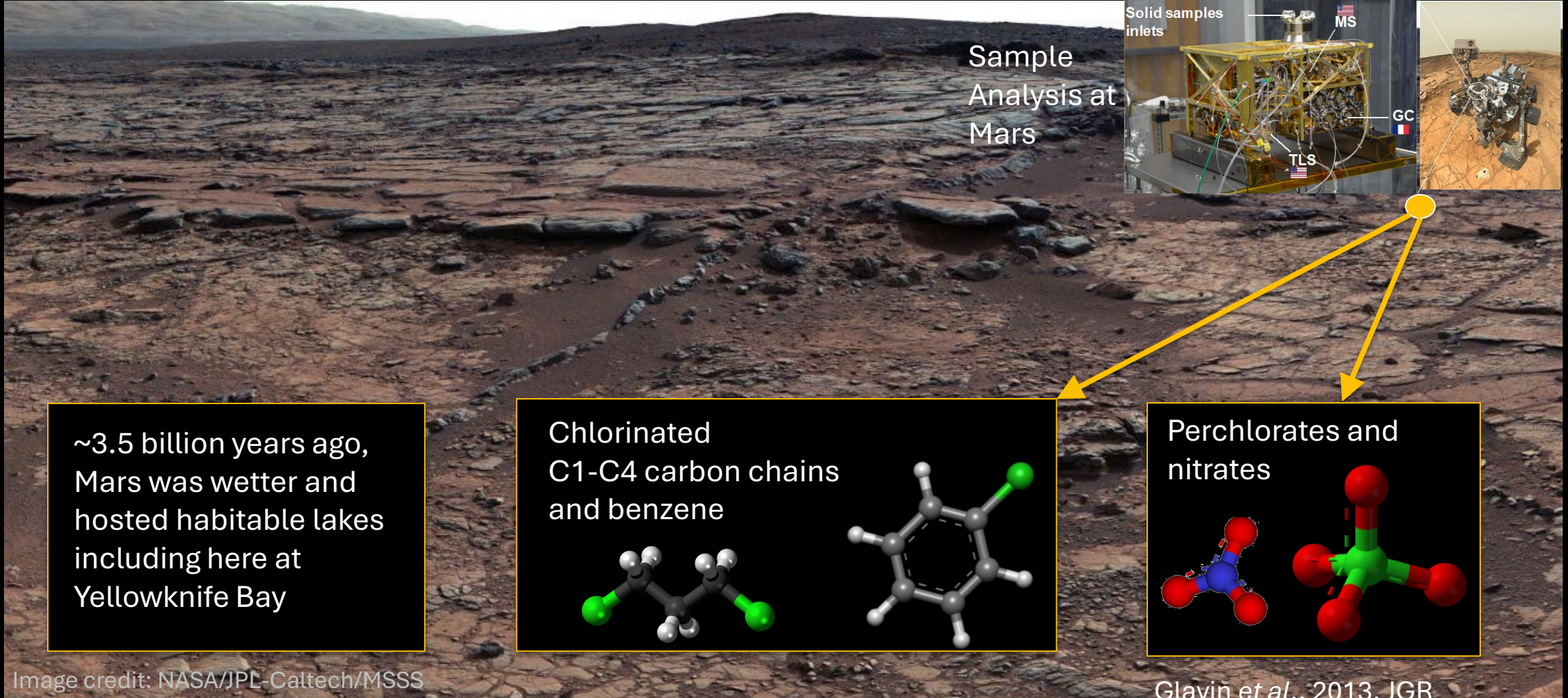
35 km driven, 830 m elevation

43 drilled samples (37 analyzed with SAM)

3 scooped locations (all 3 analyzed with SAM)



Organics and salts in Yellowknife Bay clay-rich sediments indicate ancient habitability



Sample Analysis at Mars

~3.5 billion years ago, Mars was wetter and hosted habitable lakes including here at Yellowknife Bay

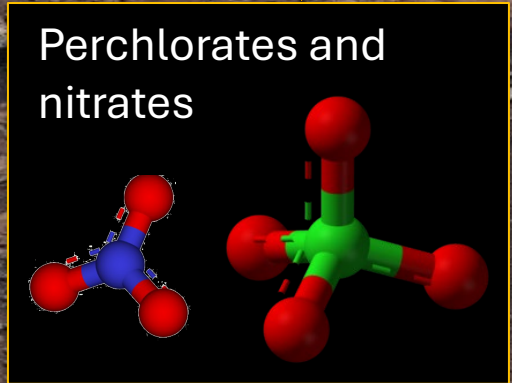
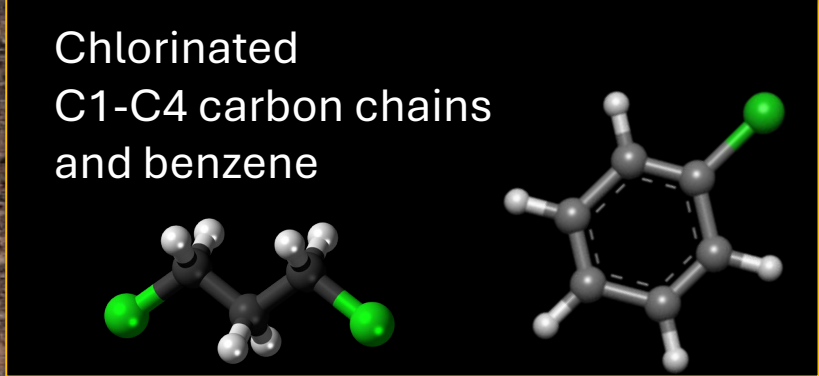


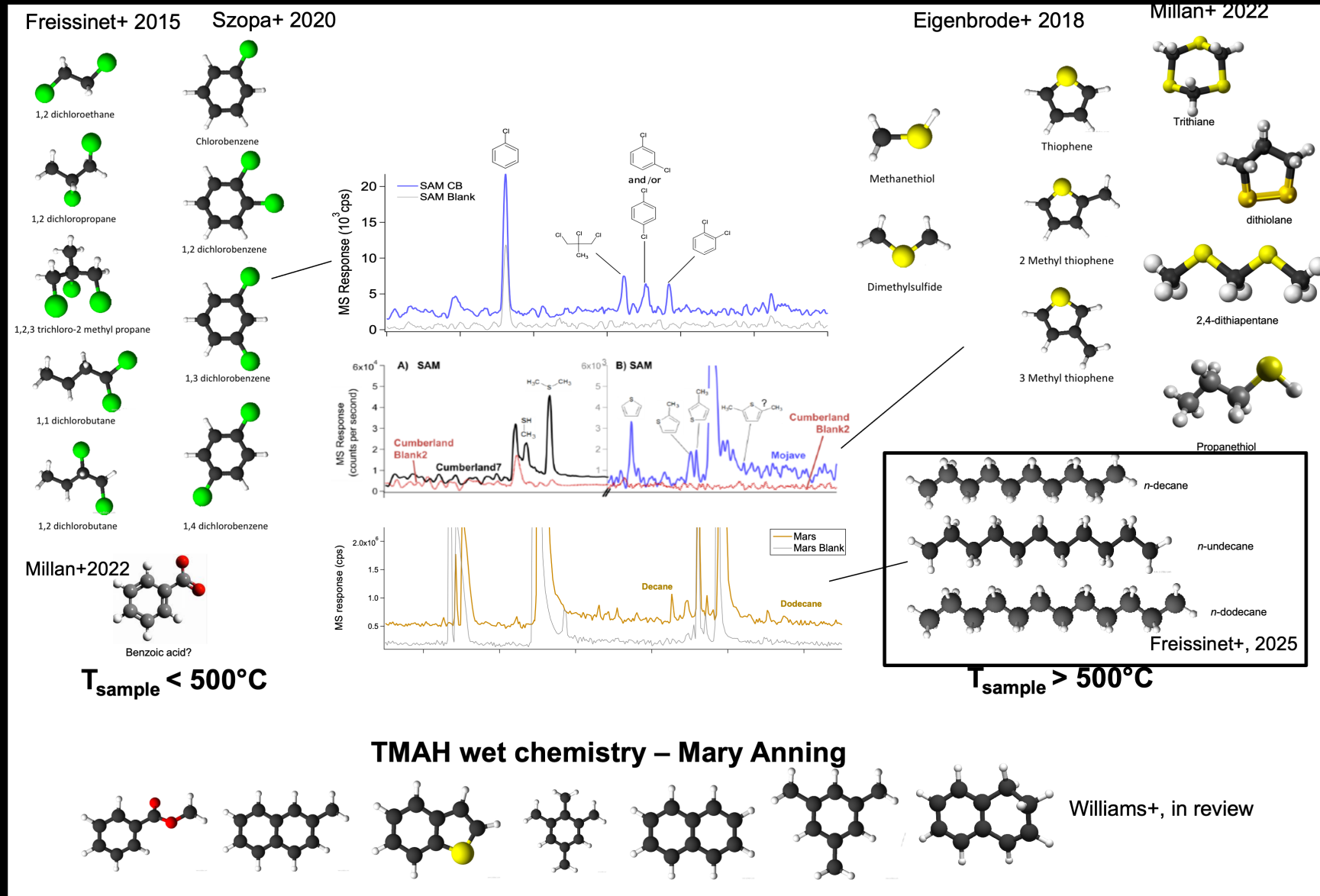
Image credit: NASA/JPL-Caltech/MSSS

Grotzinger *et al.*, 2015, Science

Freissinet *et al.*, 2015, JGR
Szopa *et al.*, 2020, Astrobiology

Glavin *et al.*, 2013, JGR
Ming *et al.*, 2014, Science
Stern *et al.*, 2015, PNAS

Inventory of molecules identified



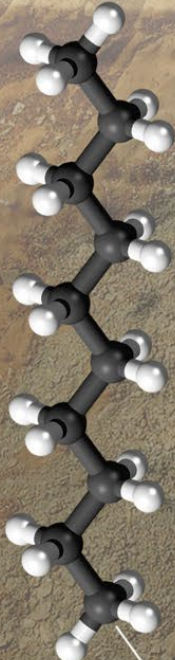
New evidence for ancient fatty acids?



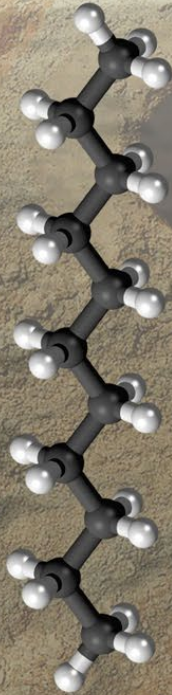
Fragile and linear molecules can be preserved for 3.7 billion years on Mars

LARGE ORGANICS ON MARS

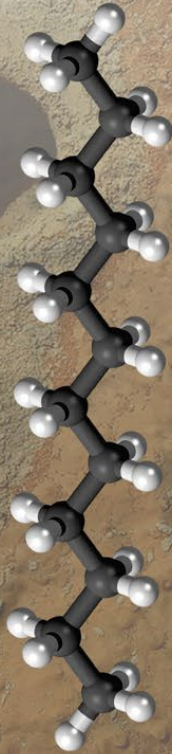
Decane



Undecane



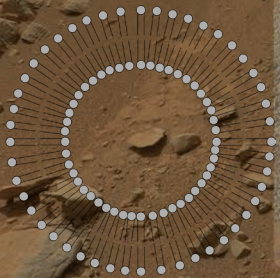
Dodecane

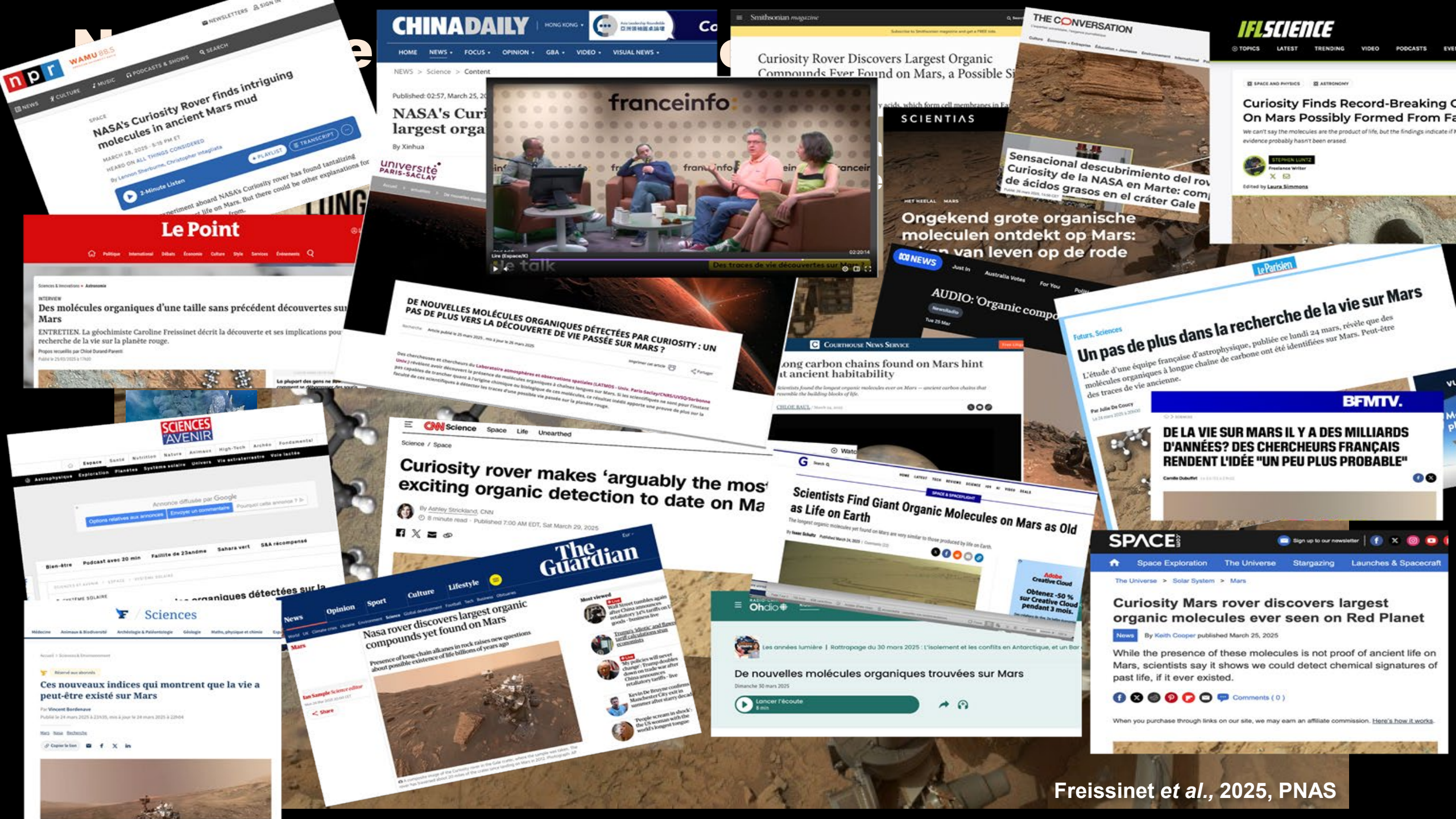


CARBON
HYDROGEN



Geological or biological?





npr WAMU 88.5
 NEWS CULTURE MUSIC PODCASTS & SHOWS SEARCH SIGN IN
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NASA's Curiosity Rover finds intriguing molecules in ancient Mars mud
 MARCH 28, 2025 - 8:16 PM ET
 HEARD ON ALL THINGS CONSIDERED
 By Lennon Sherborne, Christopher Intagliata
 2-Minute Listen

CHINA DAILY HONG KONG
 HOME NEWS FOCUS OPINION GBA VIDEO VISUAL NEWS
 NEWS > Science > Content
 Published: 02:57, March 25, 2025
NASA's Curiosity rover finds largest organic molecules ever on Mars
 By Xinhua

Smithsonian magazine
 Subscribe to Smithsonian magazine and get a FREE gift.
Curiosity Rover Discovers Largest Organic Compounds Ever Found on Mars, a Possible Sign of Ancient Life

THE CONVERSATION
 Culture, Economics, Environment, Education, Journalism, Environment, International Politics
Sensacional descubrimiento del rover Curiosity de la NASA en Marte: compuestos de ácidos grasos en el cráter Gale
 Published: March 28, 2025, 11:48 AM CDT

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Curiosity Finds Record-Breaking Organic Molecules on Mars Possibly Formed From Fossilized Life
 We can't say the molecules are the product of life, but the findings indicate if life ever existed on Mars, evidence probably hasn't been erased.
 STEPHEN LUNTZ
 Freelance Writer
 Edited by Laura Simmons

Le Point
 Politique International Mars Économie Culture Style Services Événements



SCIENTIAS
 MET HEELAL MARS
Ongekend grote organische moleculen ontdekt op Mars: teken van leven op de rode planeet
 AUDIO: 'Organic compounds found on Mars hint at ancient habitability'

Sciences & Innovation > Astronomie
Des molécules organiques d'une taille sans précédent découvertes sur Mars
 ENTRETIEN. La géochimiste Caroline Freissinet décrit la découverte et ses implications pour la recherche de la vie sur la planète rouge.
 Propos recueillis par Chloé Brand Parent
 Publié le 25/03/2025 à 17h00

DE NOUVELLES MOLÉCULES ORGANIQUES DÉTÉCTÉES PAR CURIOSITY : UN PAS DE PLUS VERS LA DÉCOUVERTE DE VIE PASSÉE SUR MARS ?
 Des chercheurs et chercheuses du Laboratoire atmosphères et observations spatiales (LATMOS - Univ. Paris-Saclay/CNRS/UVSQ/Université Paris-Saclay) ont découvert la présence de molécules organiques à chaînes longues sur Mars. Si les scientifiques ne sont pas capables de trancher quant à l'origine chimique ou biologique de ces molécules, ce résultat inédit apporte une preuve de plus sur la capacité de ces scientifiques à détecter les traces d'une possible vie passée sur la planète rouge.

COURTHOUSE NEWS SERVICE
Long carbon chains found on Mars hint at ancient habitability
 Scientists found the longest organic molecules ever on Mars — ancient carbon chains that resemble the building blocks of life.
 CHELSEA SAULT, March 26, 2025

Le Parisien
 Futurs, Sciences
Un pas de plus dans la recherche de la vie sur Mars
 L'étude d'une équipe française d'astrophysique, publiée ce lundi 24 mars, révèle que des molécules organiques à longue chaîne de carbone ont été identifiées sur Mars. Peut-être des traces de vie ancienne.
 Par Julie De Courcy
 Le 24 mars 2025 à 20h00

BFMTV
DE LA VIE SUR MARS IL Y A DES MILLIARDS D'ANNÉES? DES CHERCHEURS FRANÇAIS RENDENT L'IDÉE "UN PEU PLUS PROBABLE"
 Camille Dubuffet

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CNN Science Space Life Unearthed
 Science / Space
Curiosity rover makes 'arguably the most exciting organic detection to date on Mars'
 By Ashley Strickland, CNN
 8 minute read - Published 7:00 AM EDT, Sat March 29, 2025

Scientists Find Giant Organic Molecules on Mars as Old as Life on Earth
 The longest organic molecules yet found on Mars are very similar to those produced by life on Earth.
 By Isaac Schick, Published March 24, 2025 | Comments (2)

Sciences
Ces nouveaux indices qui montrent que la vie a peut-être existé sur Mars
 Par Vincent Bourdeau
 Publié le 24 mars 2025 à 23h35, mis à jour le 24 mars 2025 à 22h04

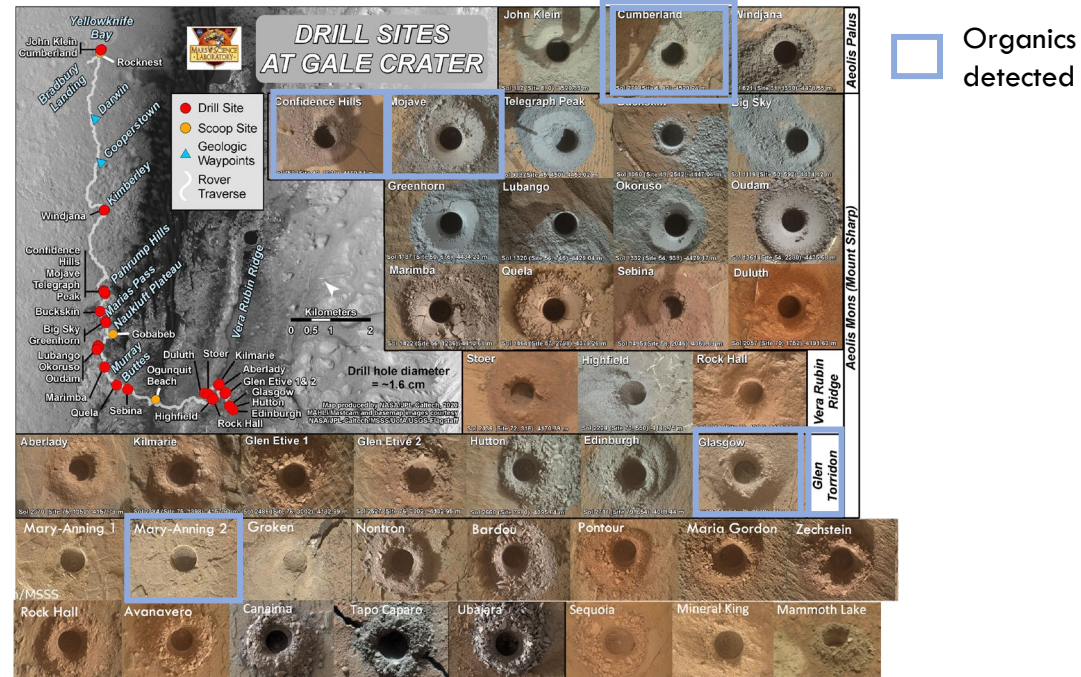
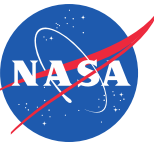
The Guardian
Nasa rover discovers largest organic compounds yet found on Mars
 Presence of long-chain alkanes in rock raises new questions about possible existence of life billions of years ago
 Sam Sample, Science editor
 Published: 24 March 2025, 11:00 AM GMT

Ohdio
 Les années lumière | Rapprochement du 30 mars 2025 : L'isolement et les conflits en Antarctique, et un Bar...
De nouvelles molécules organiques trouvées sur Mars
 Dimanche 30 mars 2025
 Lancer l'écoute 8 min

SPACE.com
 Space Exploration The Universe Stargazing Launches & Spacecraft
Curiosity Mars rover discovers largest organic molecules ever seen on Red Planet
 By Keith Cooper published March 25, 2025
 While the presence of these molecules is not proof of ancient life on Mars, scientists say it shows we could detect chemical signatures of past life, if it ever existed.
 Comments (0)
 When you purchase through links on our site, we may earn an affiliate commission. Here's how it works.

Freissinet et al., 2025, PNAS

Cumberland – a very special place on Mars



Cumberland, a place with a unique geochemical history

Long chain hydrocarbons (*Freissinet+ 2025*)

Simple/primordial molecules (*Freissinet+ 2015, Eigenbrode+ 2018, Szopa+ 2020, Millan+ 2022...*)

Interesting S isotopes fractionation (*Franz+ 2017*)

Depleted carbon isotope composition (*House+ 2022*)

More chances of sulfides (*Wong+ 2020*)

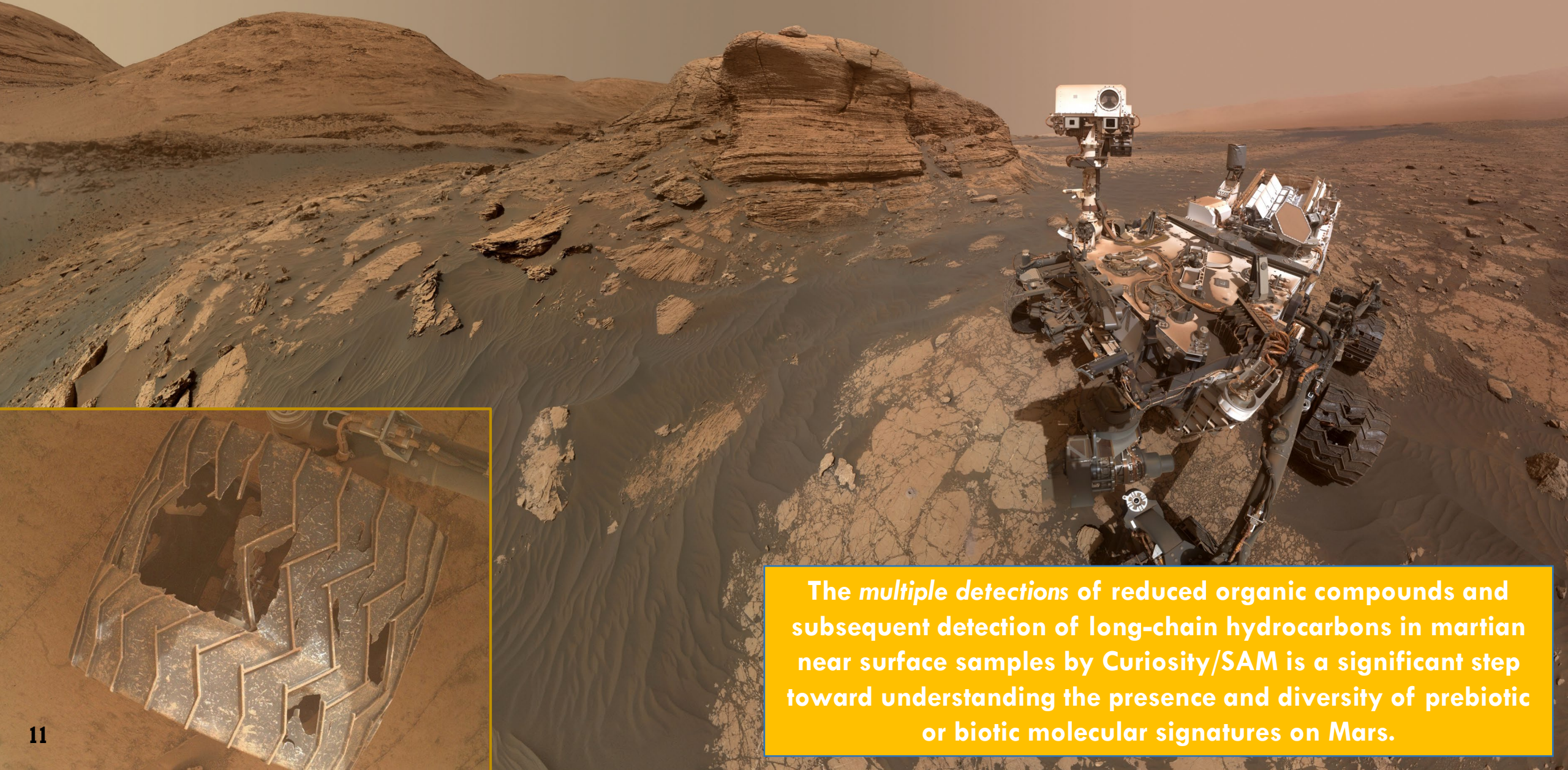
Presence of nitrates (*Stern+ 2015*)

Tens to hundreds of ppm of carbon (inorganic + organic) (*Sutter+ 2017, Freissinet+ 2020, Stern+ 2022*)

Freshly exposed sample (*Farley+ 2014*)

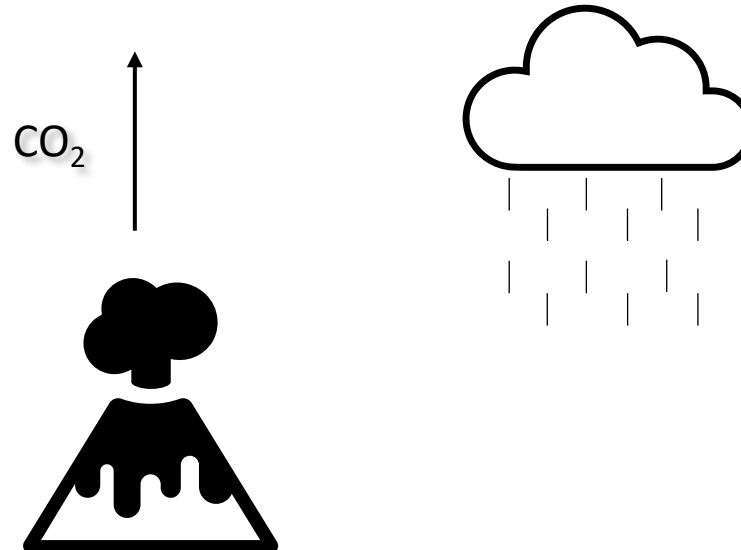
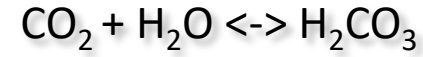
Optimal mineralogy (*Rampe+ 2020*)

Curiosity / Mars Science Laboratory 2011

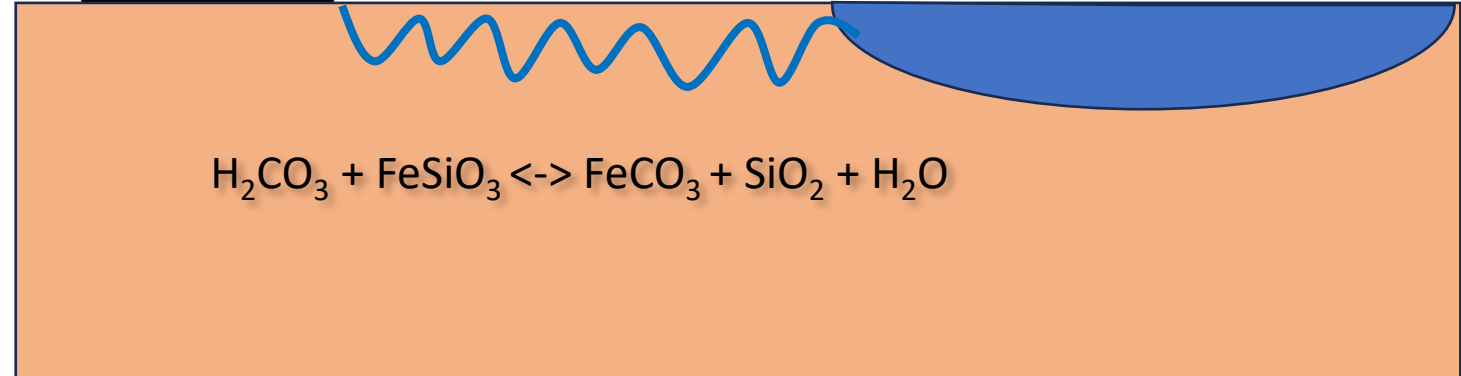
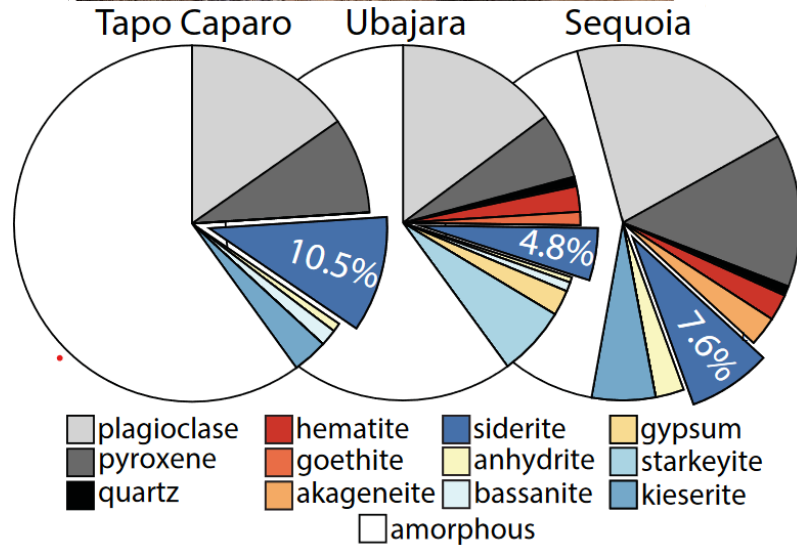


The *multiple detections* of reduced organic compounds and subsequent detection of long-chain hydrocarbons in martian near surface samples by Curiosity/SAM is a significant step toward understanding the presence and diversity of prebiotic or biotic molecular signatures on Mars.

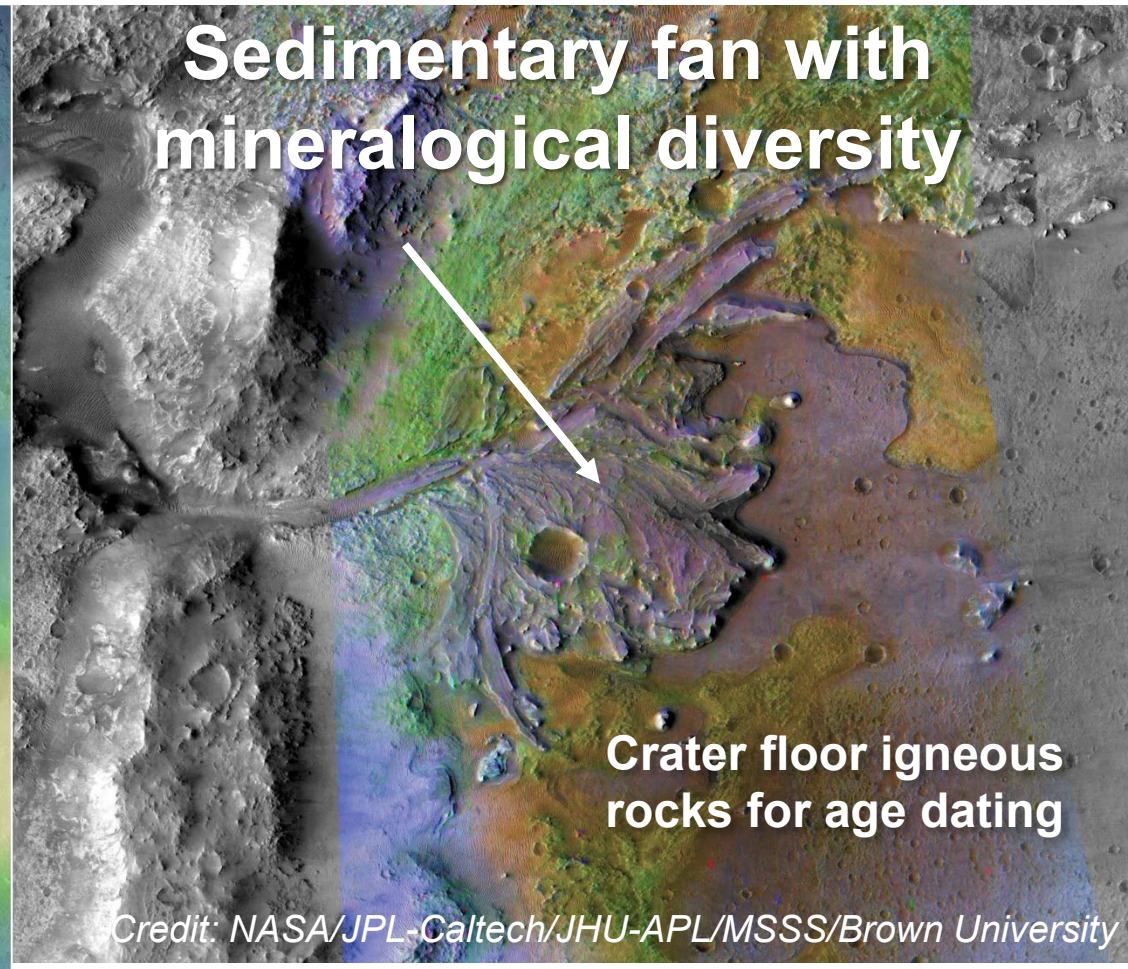
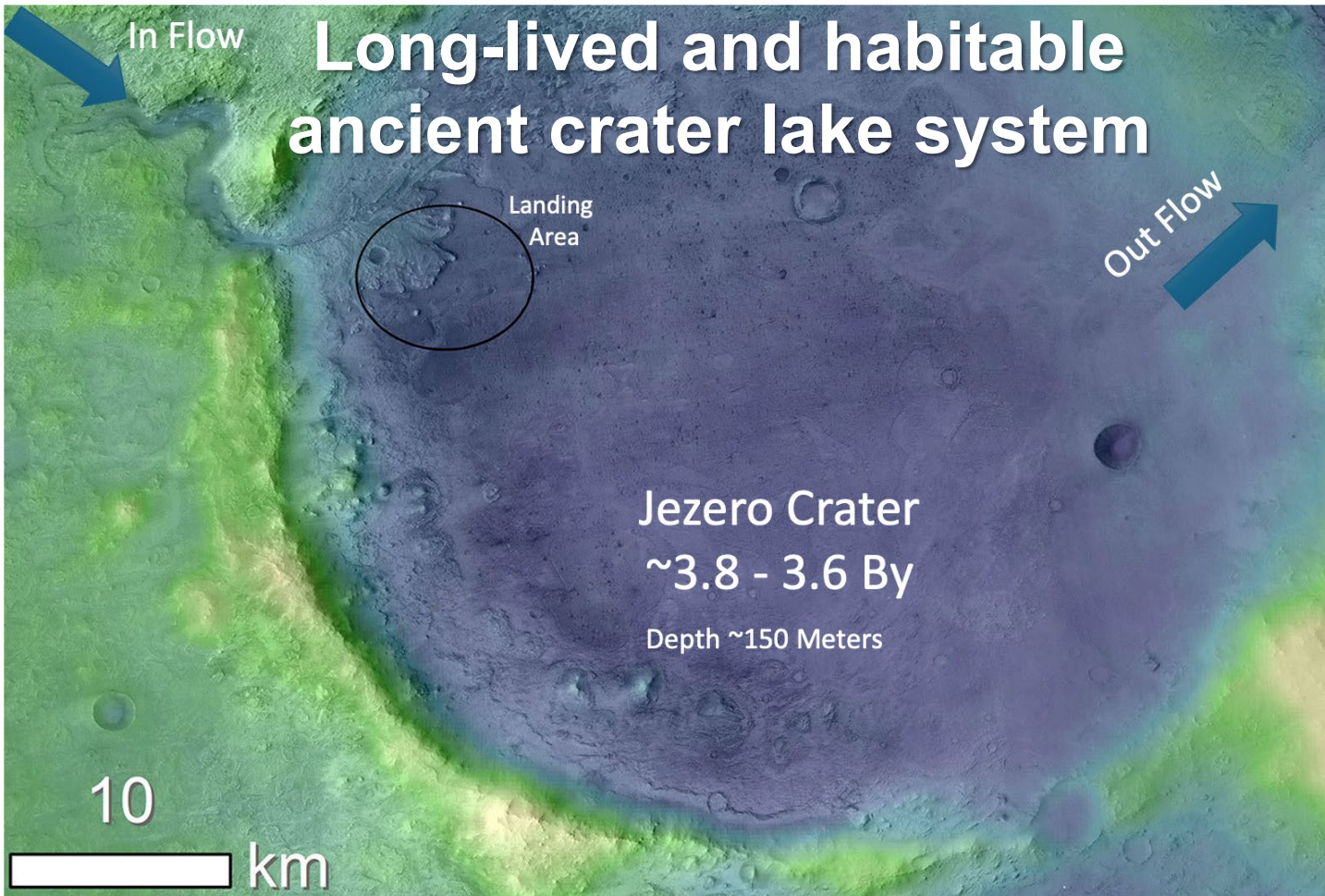
Evidence of an ancient carbon cycle on Mars!



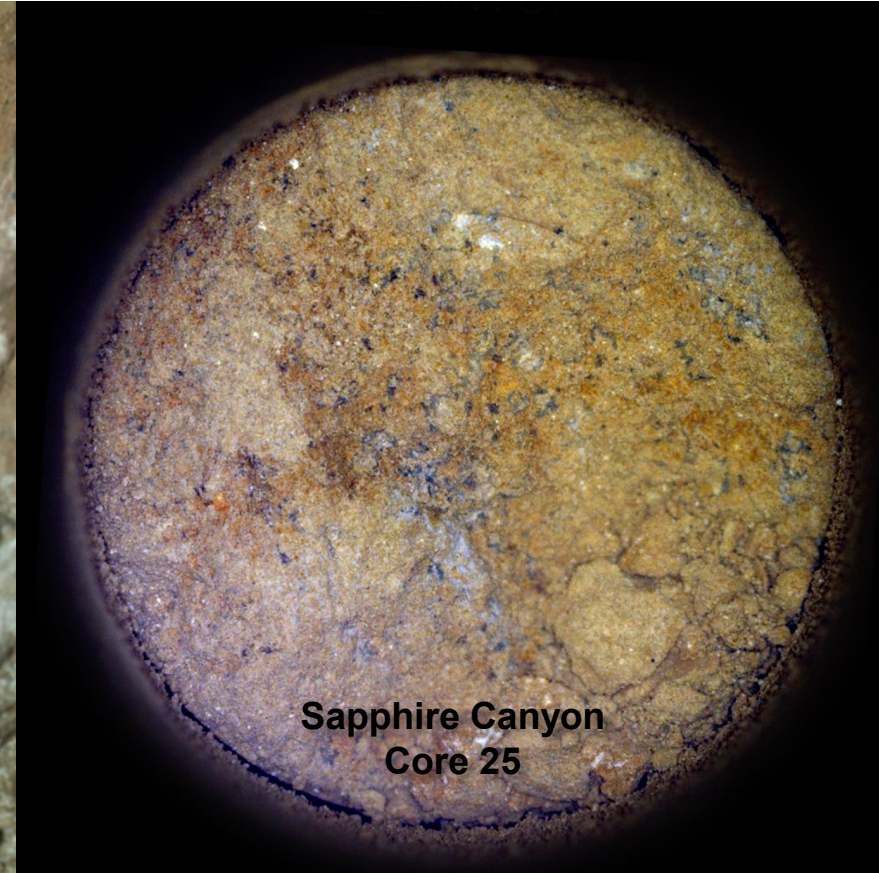
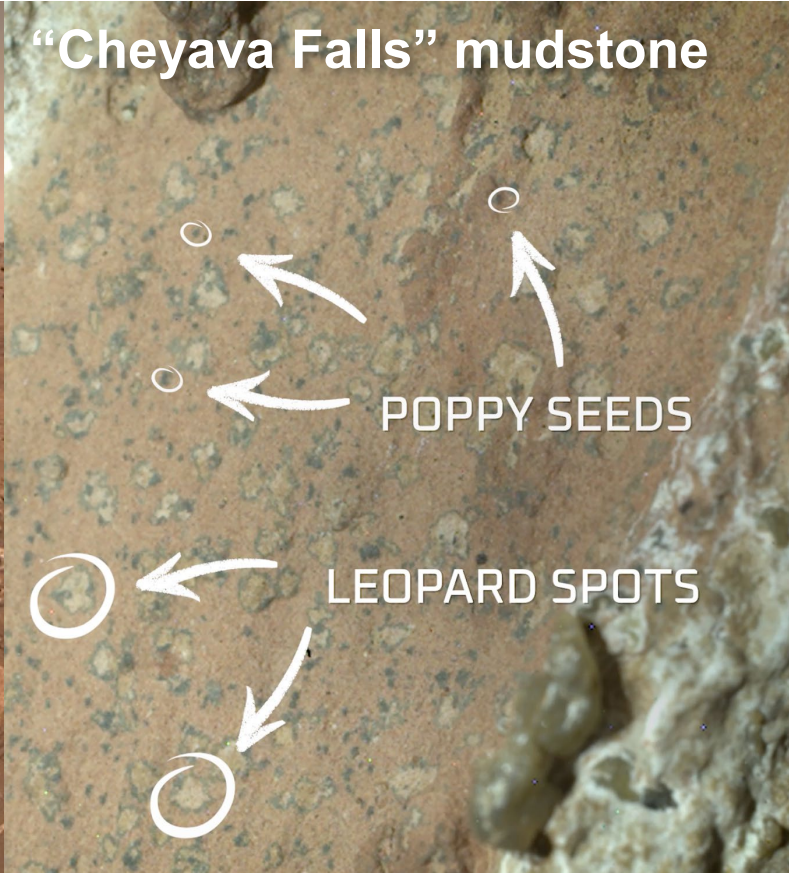
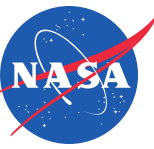
Carbonate detections confirm models that predicted that CO_2 was abundant in the martian atmosphere ~3.5 Ga and helped keep the planet warm enough for liquid water on the surface.



Jezero Crater, Mars



Possible Biosignature Found by Perseverance



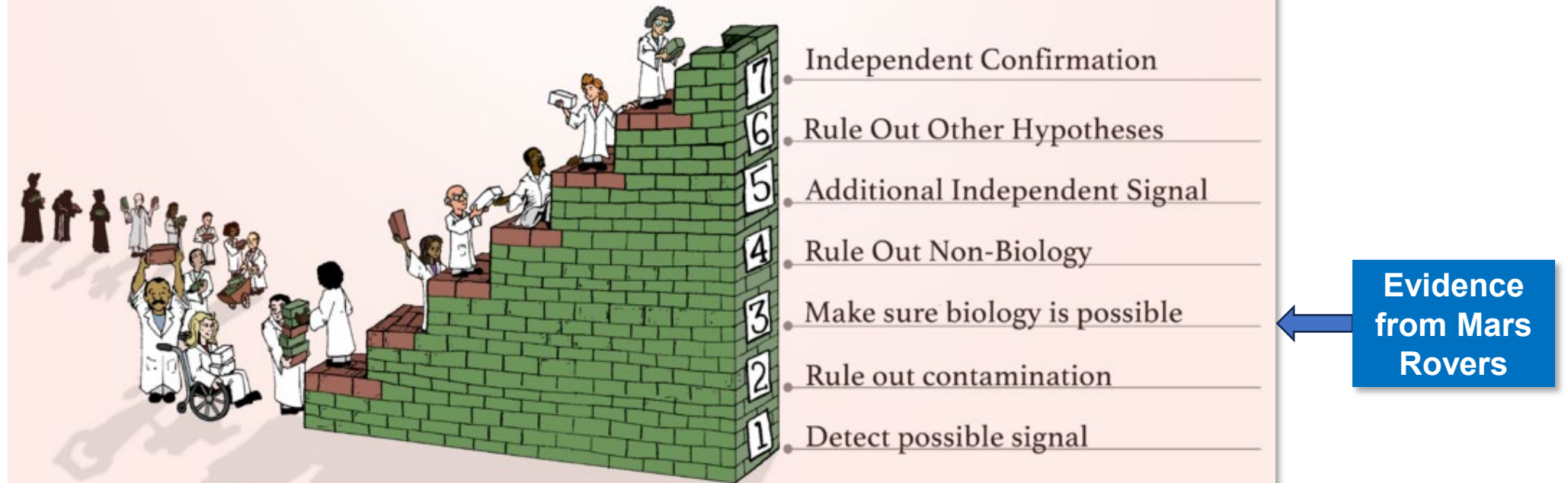
Structures "reduction spheroids" provide evidence of minerals formed in water at modest temperatures in the presence of organics that could have provided an energy source for life.

Analysis of the core in labs on Earth is needed to determine if these features are actual fossilized remnants of martian life, or not.

Hurowitz *et al.* (2025) *LPSC*, 2581

CoLD SCALE

Confidence of Life Detection

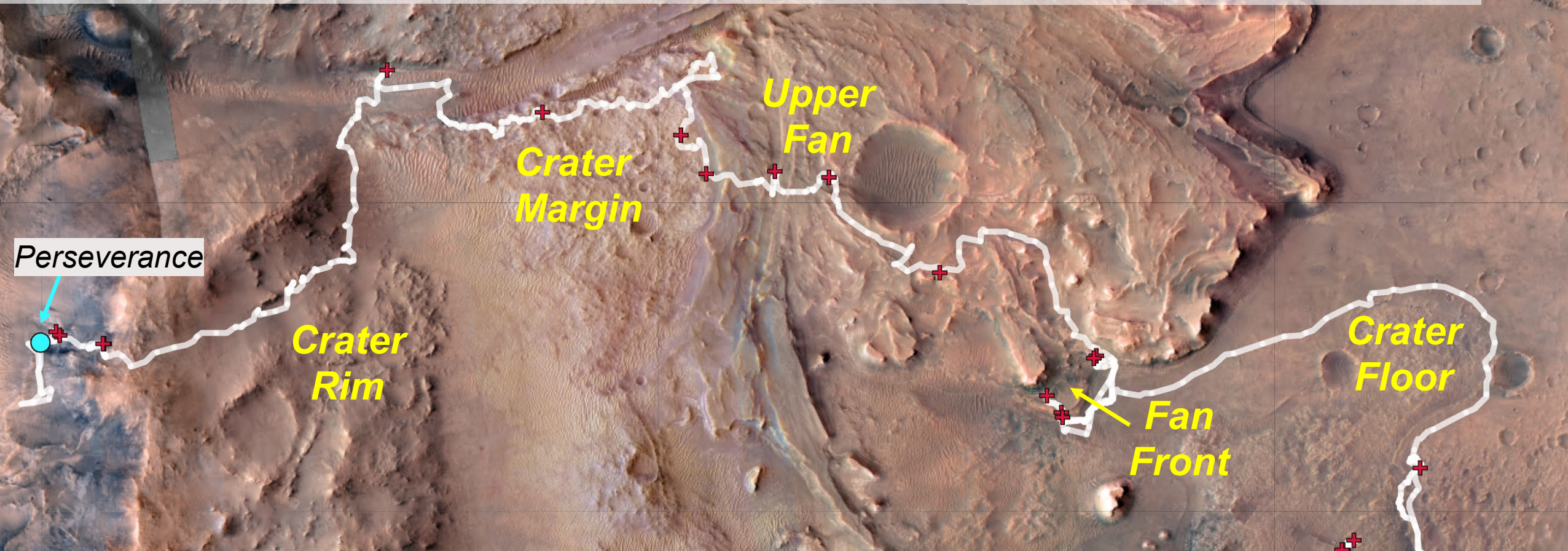


Mars 2020 Perseverance Status

Perseverance status: Sol 1575 planning (July 25)

Rover Odometry: 37.6+ km

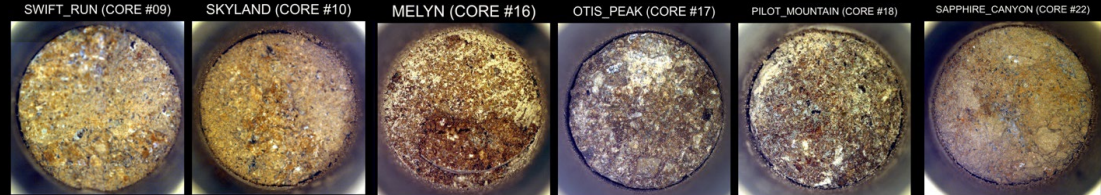
+ Samples collected



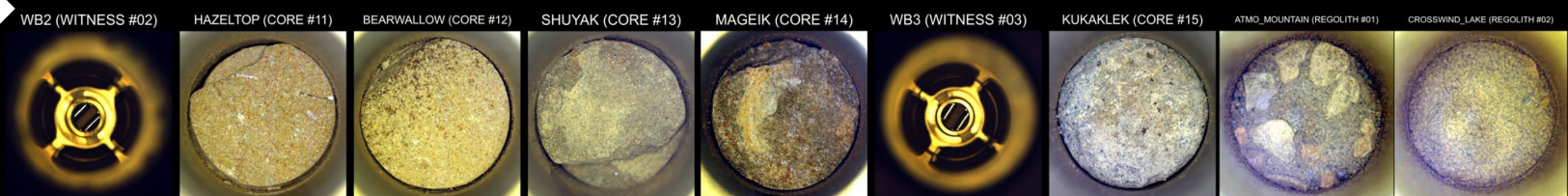
Sampling status:

- 33 sample tubes filled: 27 rock cores, 2 regolith, 1 atmosphere, 3 witness tubes
 - Three Forks Depot: 7 rock cores, 1 regolith, 1 atmosphere, 1 witness tube
 - Onboard Perseverance: 18 sealed rock cores, 2 unsealed rock cores, 1 regolith, 2 witness tubes
- **Remaining, unfilled tubes: 6 sample tubes, 2 witness tubes**

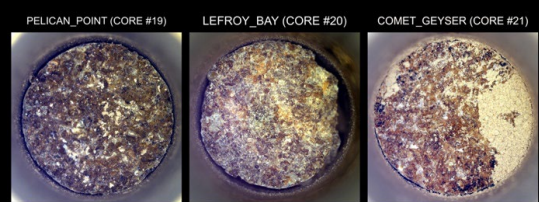
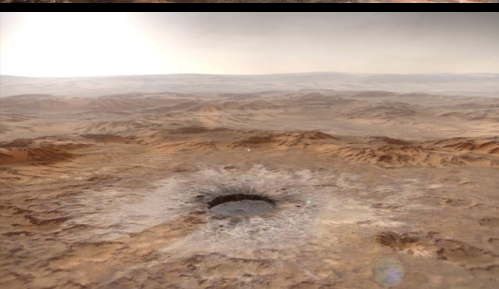
Younger: <3.7 Ga



Neretva Vallis
Upper Fan

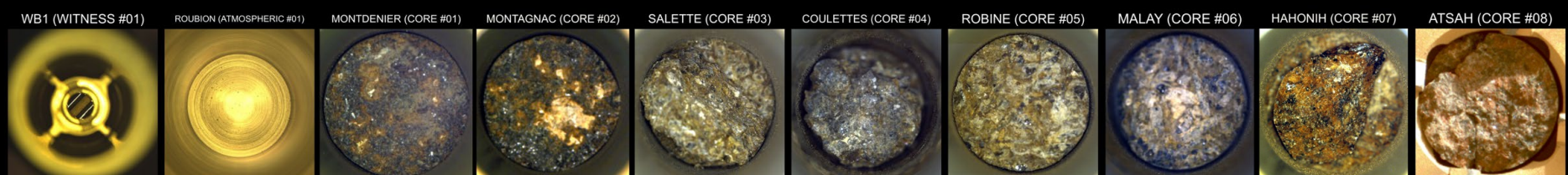


Fan
Front

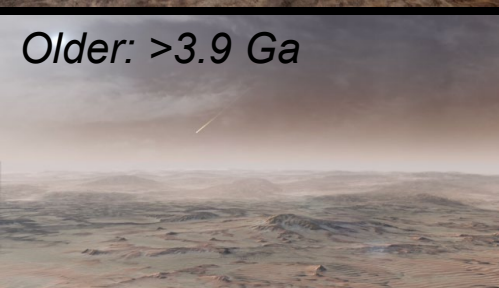


Margin Unit

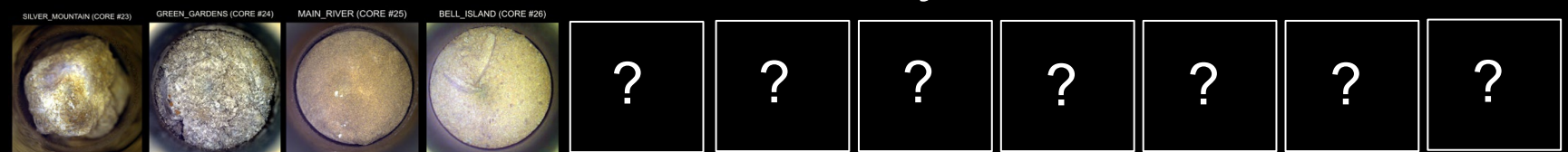
Crater Floor



N. Crater Rim and Beyond

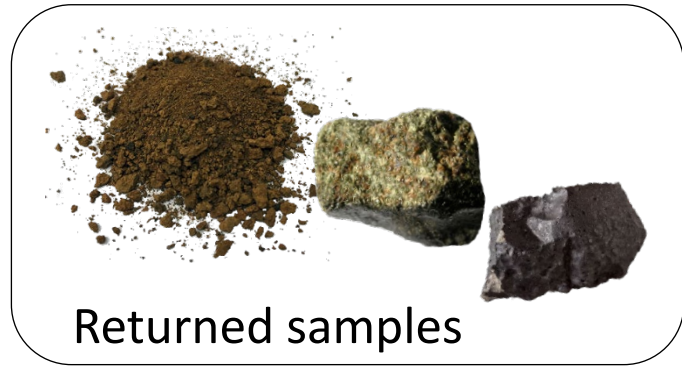
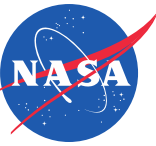


Older: >3.9 Ga

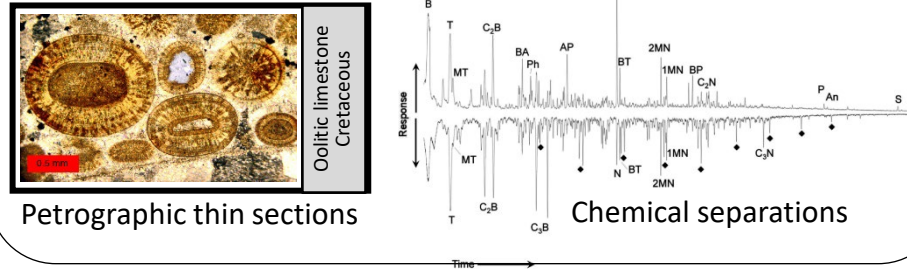


Perseverance Sample Collection
Through Geologic Time

Why Returning Samples is so Important

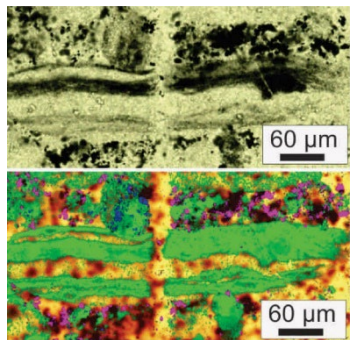


Observation-guided sample preparation,
coordinated analyses and wet chemistry



Much more flexibility to modify experimental design in labs and respond to new discoveries

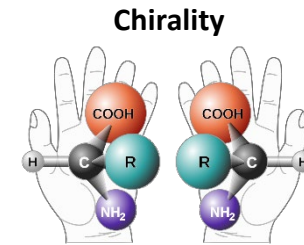
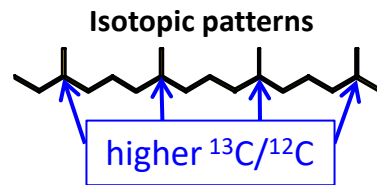
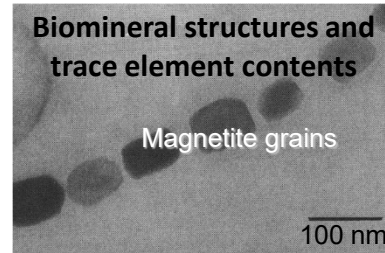
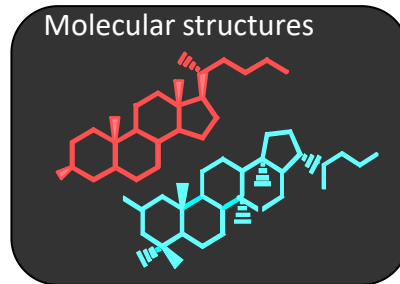
Ability to interrogate potential biosignatures and determine their origin!



Chemical patterns



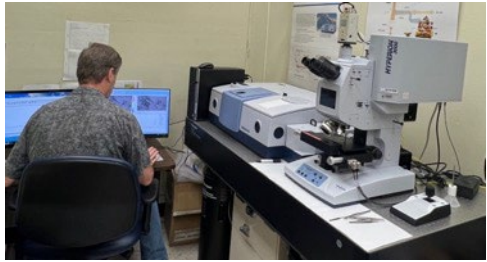
Microfabrics & fossils



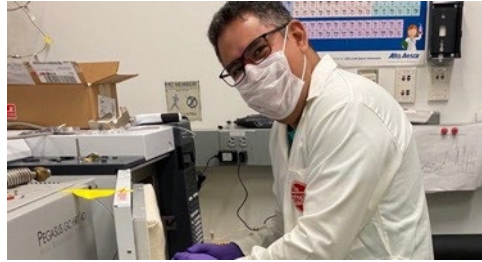
Access to state of the art facilities & instruments with technologies that improve rapidly over time

Apollo 17 samples still being studied now by scientists who were not born in 1972 using techniques that were not yet invented!

State-of-the-Art Instruments That Can't be Flown on Spacecraft



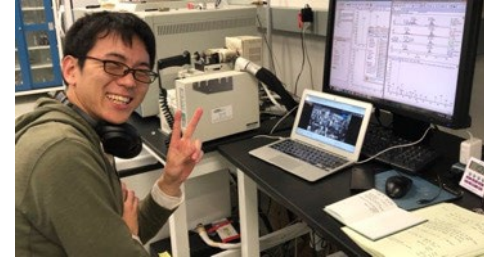
Fourier Transform Infrared Microscopy



2D Gas Chromatography High Resolution Mass Spectrometry



Liquid Chromatography Fourier Transform Mass Spectrometry



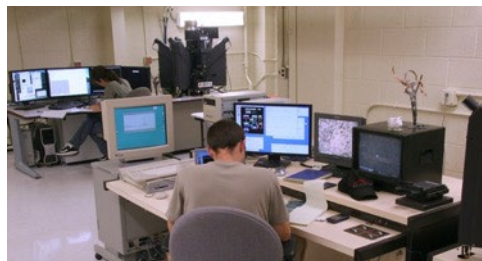
Gas Chromatography Mass Spectrometry



Compound Specific Isotopic Ratio Mass Spectrometry



Transmission Electron Microscopy



Electron Microprobe Analysis



Inductively Coupled Plasma Mass Spectrometry



Nanoscale Secondary Ion Mass Spectrometry



Visible Light Microscopy



Scanning-Electron Microscopy Energy-Dispersive X-ray Spectroscopy



X-ray Absorption Near-Edge Structure Spectroscopy



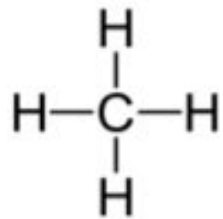
Accelerator Mass Spectrometry



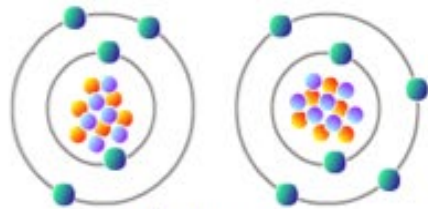
Archive Samples for the Future

← Reasonable Doubt Suggestive Life Signature →

(or processed beyond attribution)



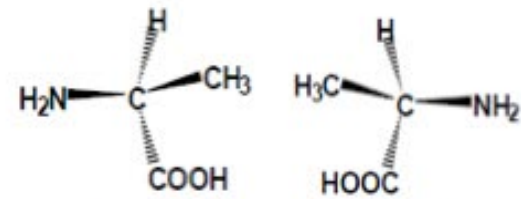
Food



Isotopes



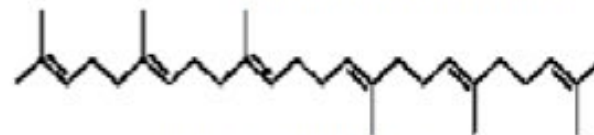
Cell-like Structures



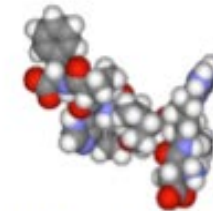
L-alanine

D-alanine

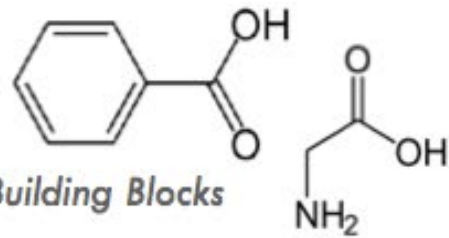
Enantiomeric Excess



Structural Preferences



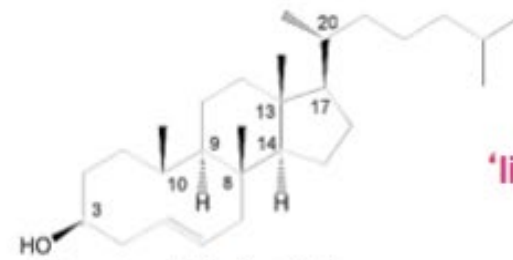
Informational Polymers



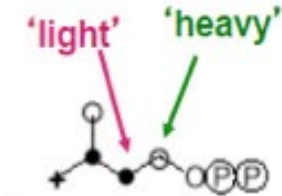
Building Blocks



Biofabrics



Structural Selectivity



Isotopic ordering

- ✓ Multiple life signatures provide high confidence
- ✓ Abiotic signatures provide important context

To detect chemical biosignatures advanced mass spectrometers must be combined with sample processing and gas or liquid separation techniques. Very challenging in a space environment.

Rosalind Franklin Mission (RFM)

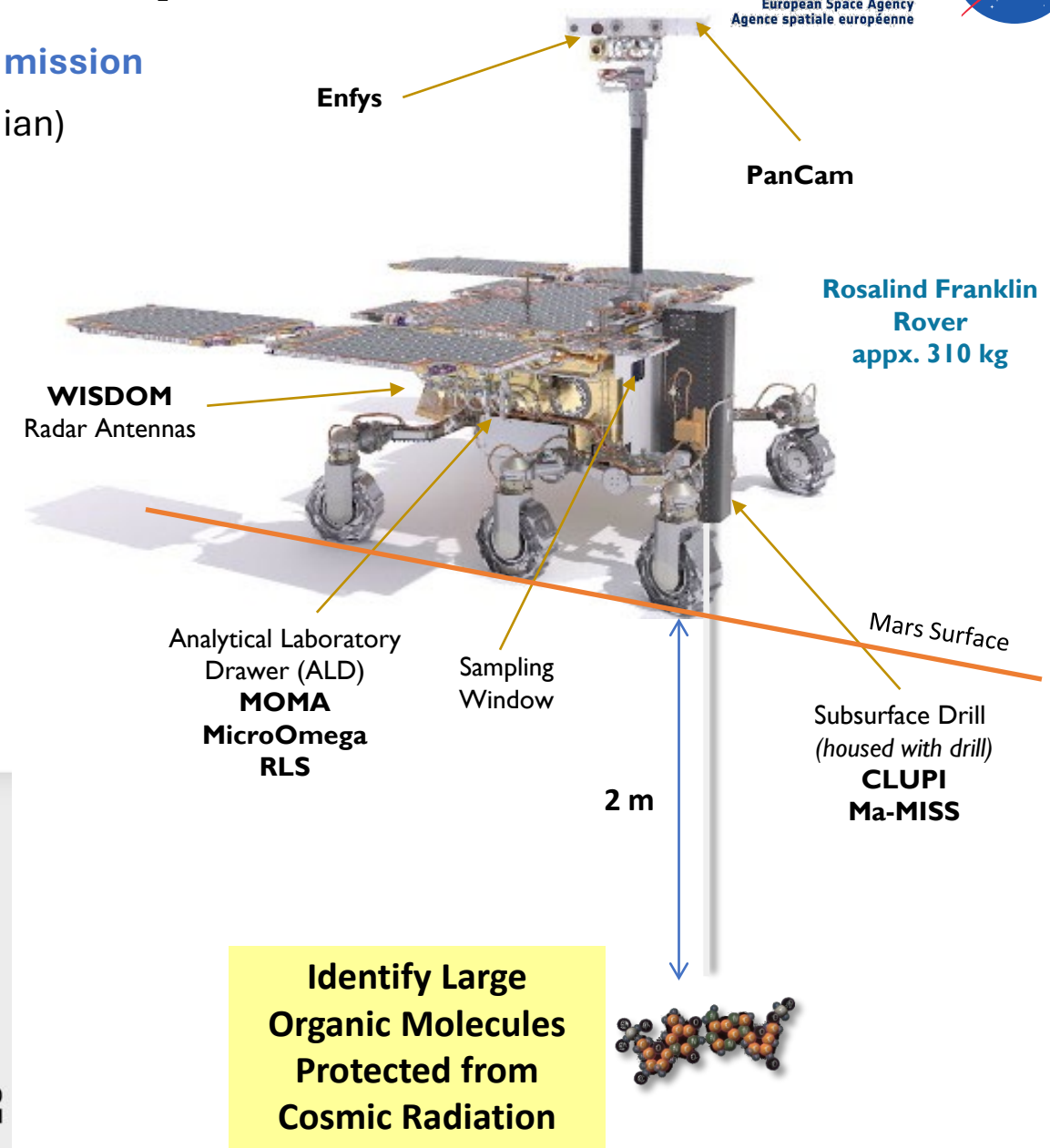


Main Science Objective: Seek the signs of life on Mars over 218-sol mission

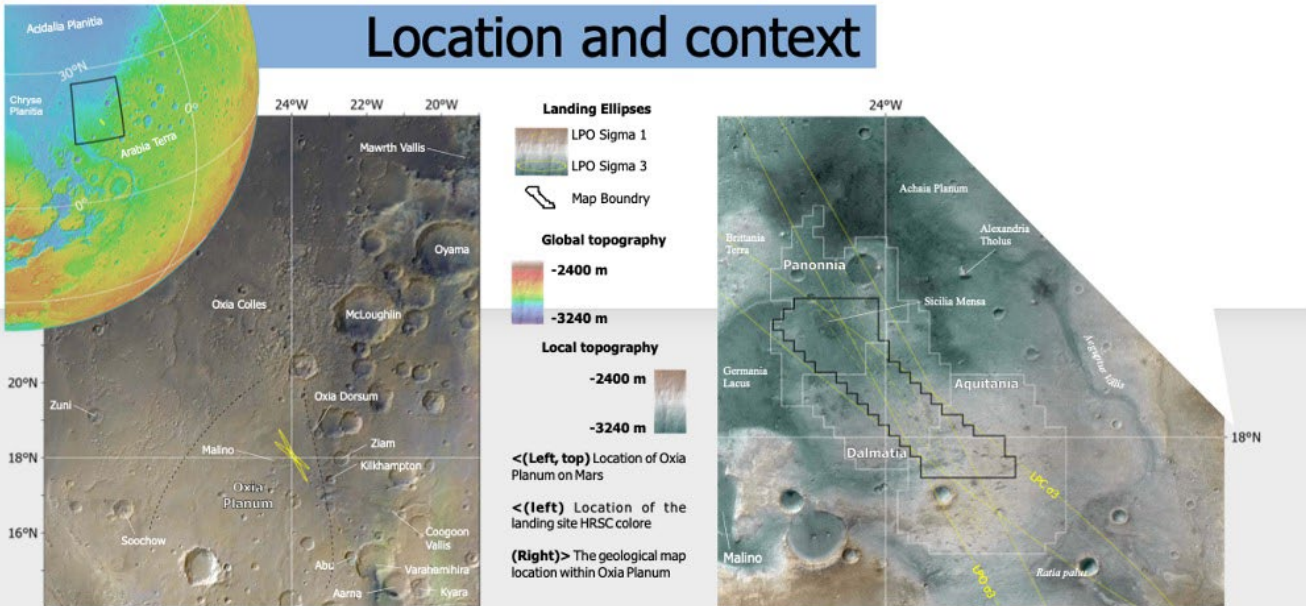
Landing Site: *Oxia Planum* (~18°N) with a large area of ancient (Noachian) terrain hosting expansive clays

- High potential preservation of organic compounds
- Evidence of long-term overlaying followed by exposure

Key Dates	LRD	EDL
Baseline	9/21/2028	12/19/2030
Backup	12/8/2028	7/15/2030

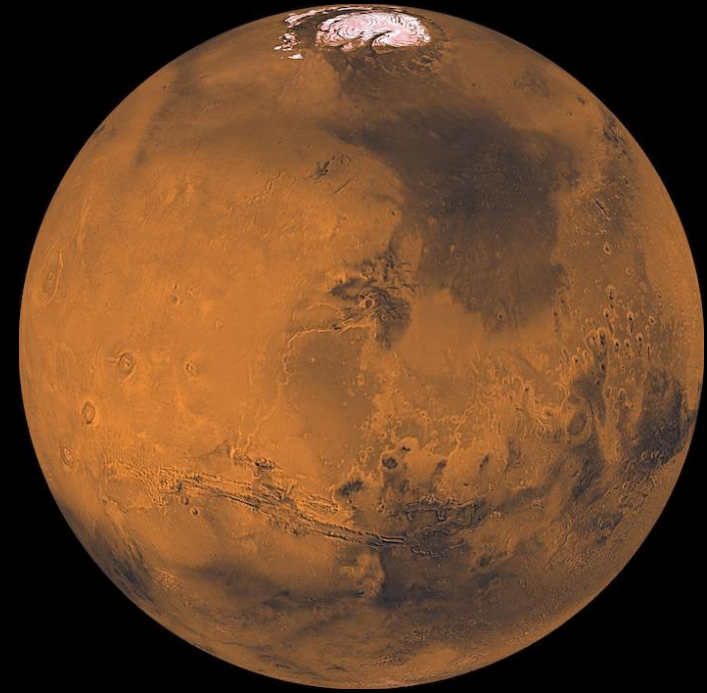
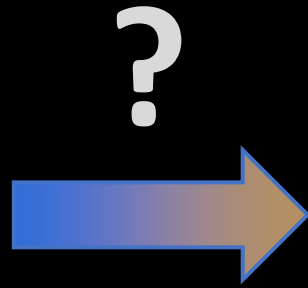
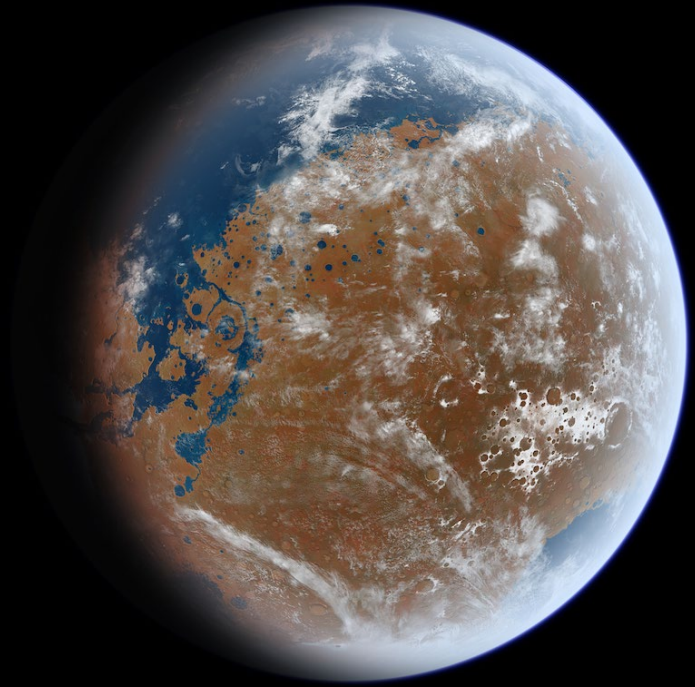


Location and context



The global setting of Oxia Planum on the margin between Southern Acidalia Planitia, Chryse Planitia and North-West Arabia Terra and the landing site within Oxia Planum region.

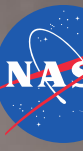
The local setting of the map in norther Oxia Planum. Marked in *italics* are informal names given to the local geography (Fawdon et al; 2021) used to describe the local setting of the map. The landing ellipses and extent the regions containing the map are marked.



Was Mars ever habitable?

Yes! Probably for tens of millions of years, and even longer in the subsurface. Now the question is - was it ever inhabited?

Mars Science Enabled by Human Exploration



- Access to samples from deep subsurface and other areas difficult to reach robotically
- Greater ability to evaluate geologic context
- Real-time decision making in response to environment
- On-site analysis capability to assist with sample triage
- Ability to return more sample mass
- Enhanced sample preservation (e.g. cryogenic storage)