CURIOSITY

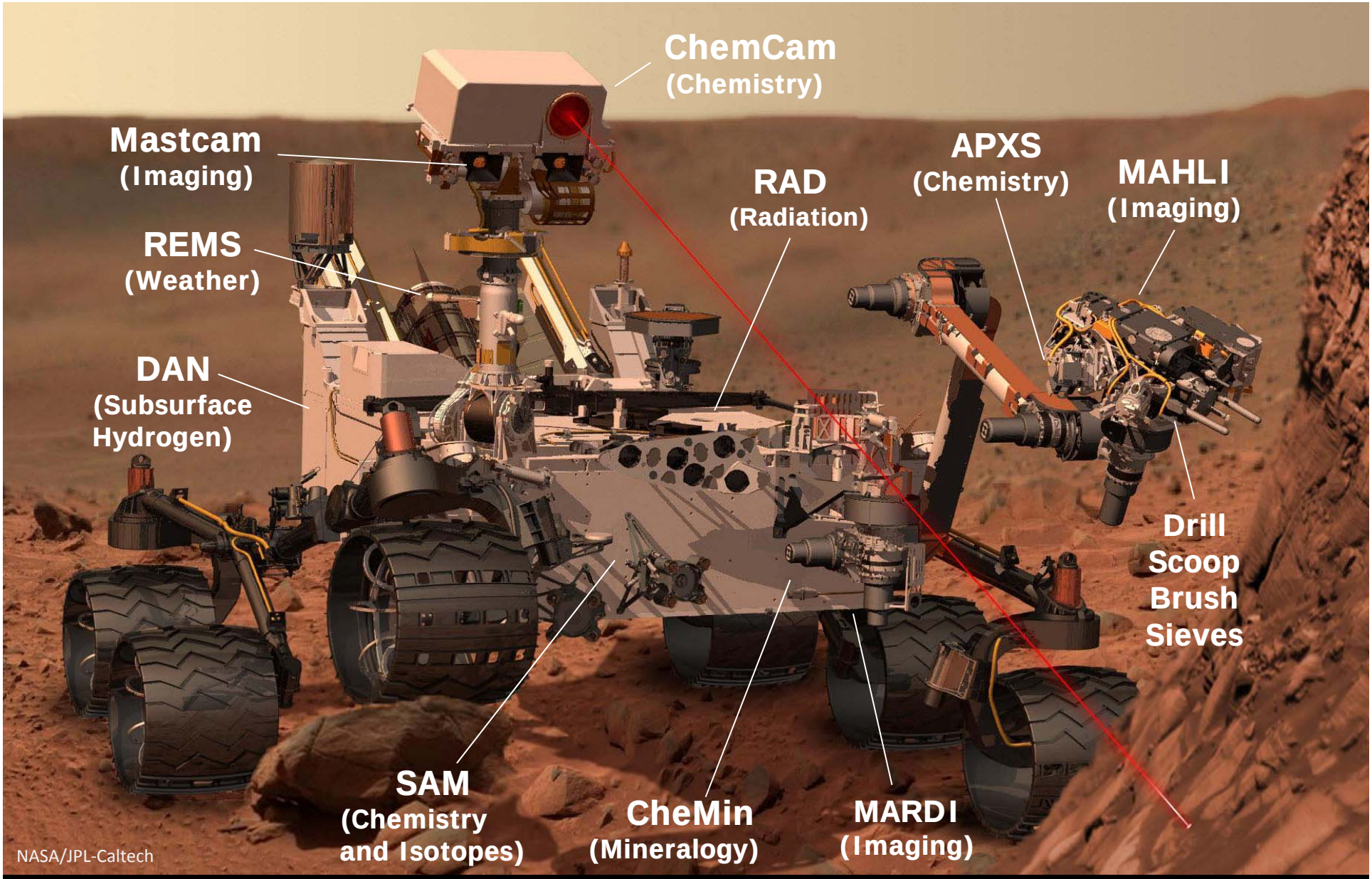
Drilling on the Martian Surface with Curiosity

Luther Beegle
MSL Science Team
4/13/16

Curiosity's primary scientific goal is to explore and quantitatively assess a local region on Mars' surface as a potential habitat for life, past or present

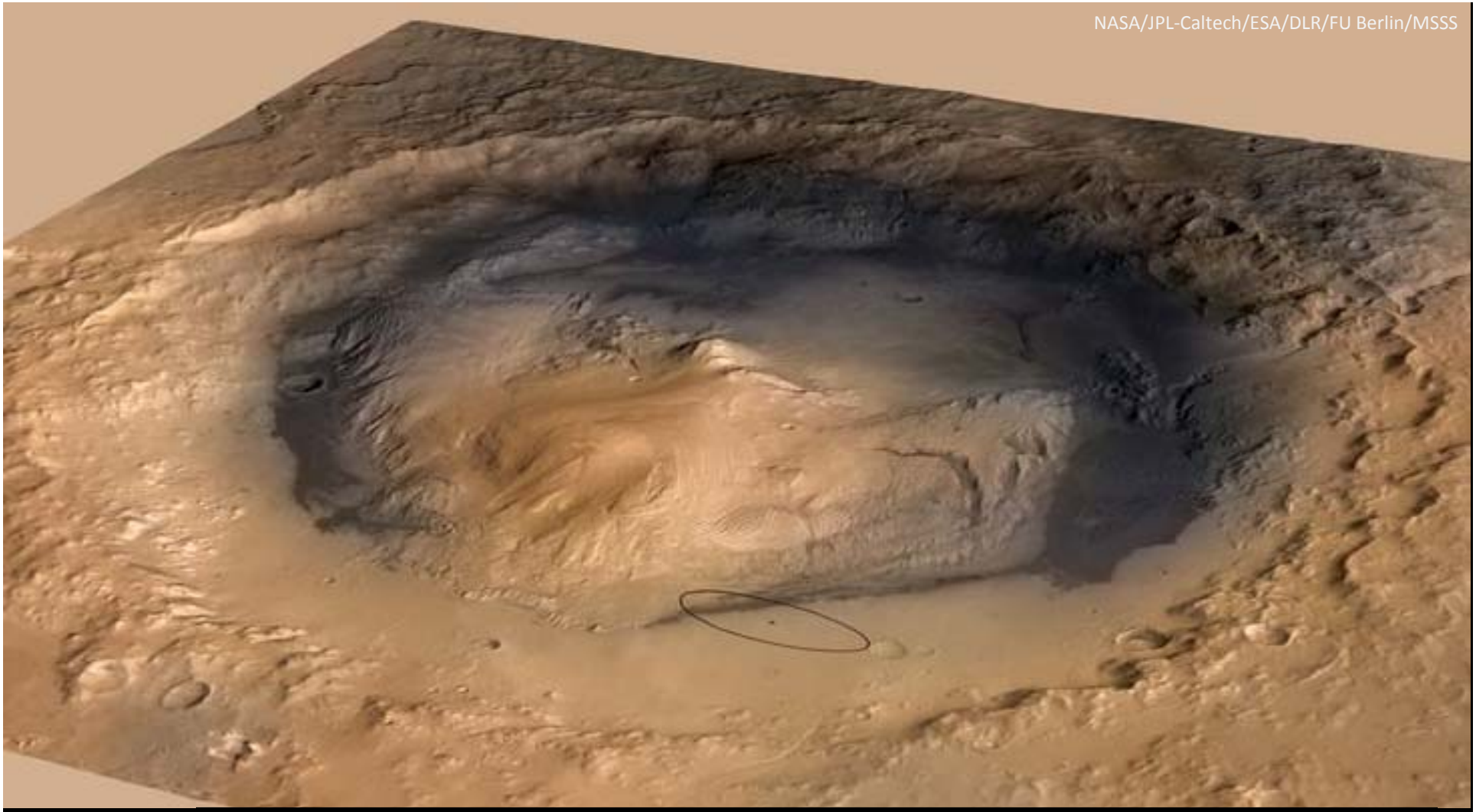
- Biological potential
- Geology and geochemistry
- Water, weather, and climate
- Radiation levels and hazards

NASA/JPL-Caltech



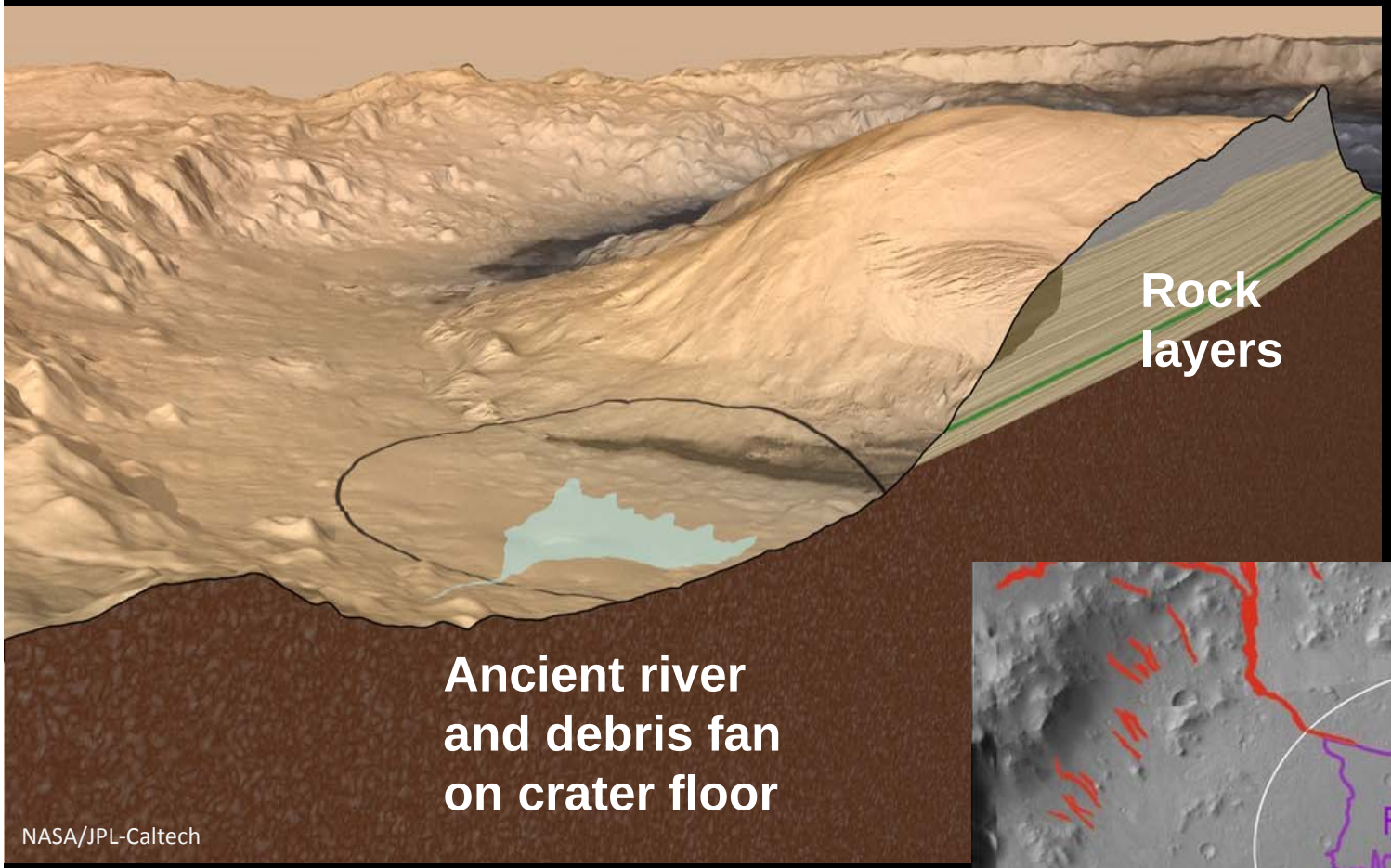
CURIOSITY

Curiosity's Science Payload

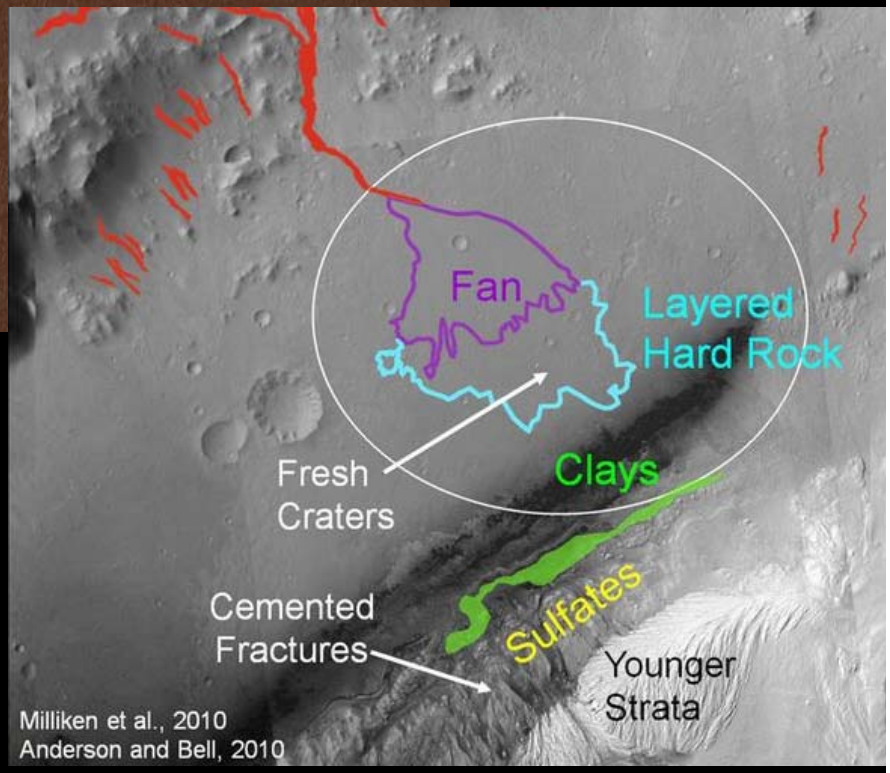


150-km Gale Crater contains a 5-km high mound of stratified rock. Strata in the lower section of the mound vary in mineralogy and texture, suggesting that they may have recorded environmental changes over time.

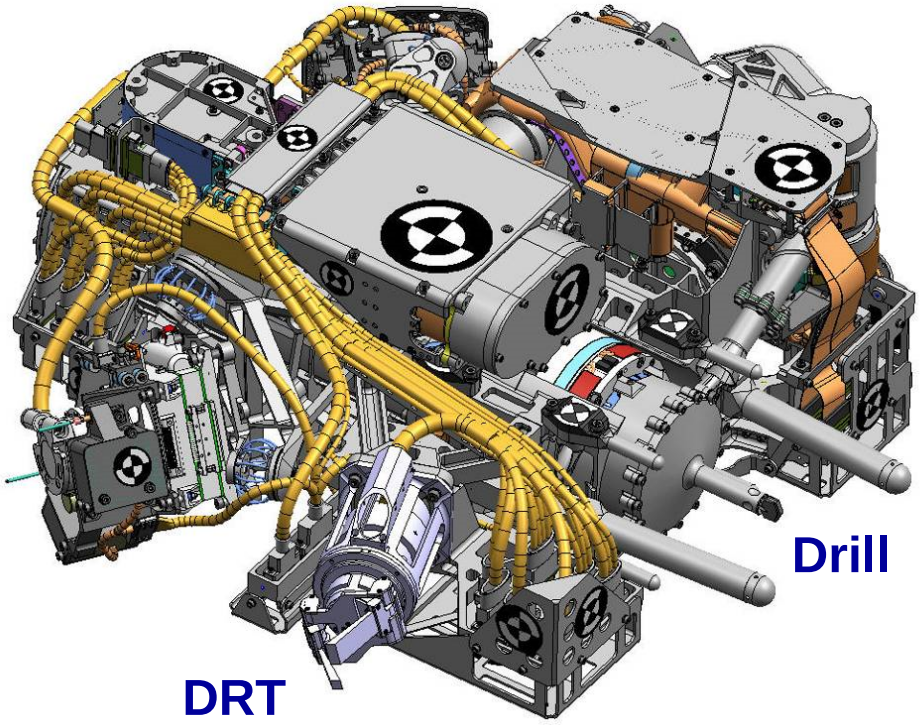
CURIOSITY



Water-Related Geology and Minerals around Mount Sharp



The Turret



A PARTIAL list of people who helped design SASPaH subsystem

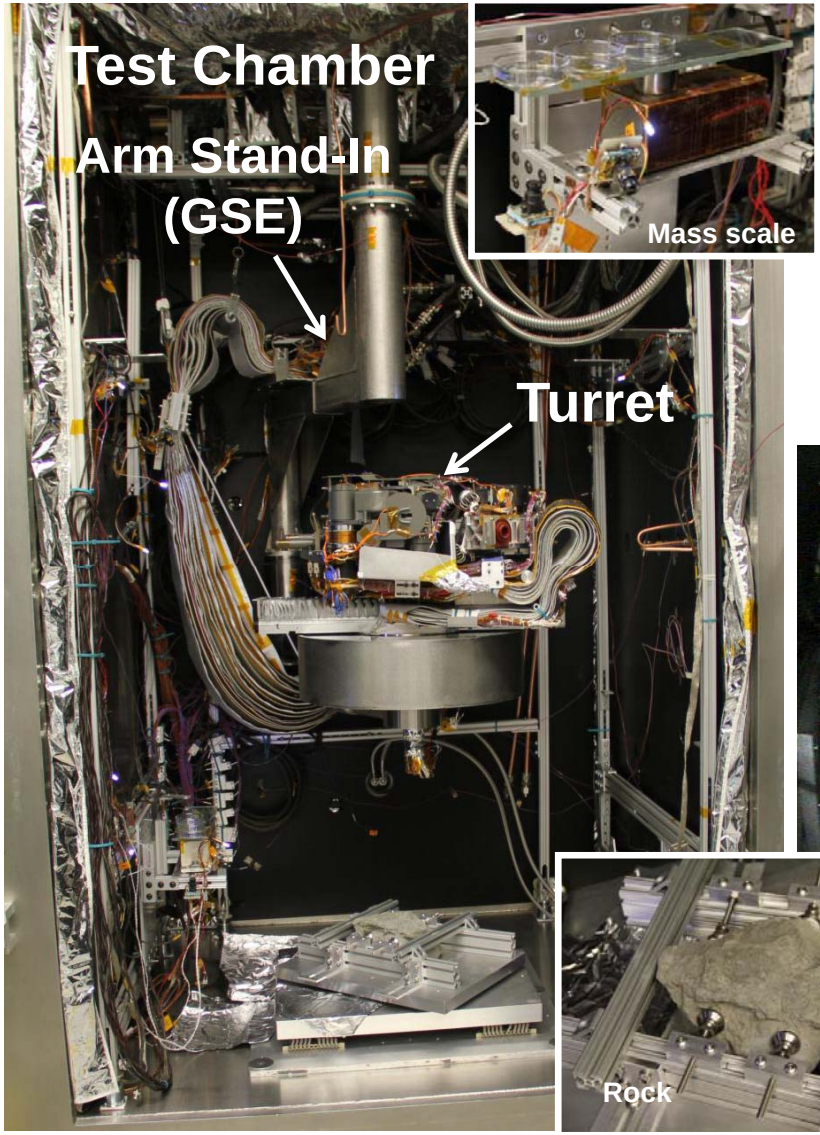
Aaron Stehura
Aaron Yazzie
Aderic Lo
Antonio Fonseca
Avi Okon
Bob Anderson
Bob Kovac
Brandon Florow
Brian Blakkolb
Brian Stark
Bruce Scardina
Calina Seybold
Cao Tran
Cambria Logan
Charlie Engelhardt
Chris Leger
Chris Roumeliotis
Chris Voorhees
Chris White
Curtis Collins
Dan Flores
Dan Helmick
Dan Sunshine
Daniel Barber
Daniel Limonadi
Dave Putnam
David Levine
Diana Trujillo
Don Sevilla
Elizabeth Duffy
Eric Holbrook
Faz Keyvanfar
Frank Moo
Frank Ramirez
Gareth Thomas
Gary Wang
Greg De Los Santos
Ian Cady
Ira Katz
Jack Aldrich
Jackelynne Silva
Jeff Umland
Jennifer Knight
Joe Melko
Joel Hurowitz
Joel Johnson
John Bousman
John Guenthner
John Hendrickson
John Michael Morookian
Jonathan Buck
Jordan Evans
Julia Stalder
Justin Lin
Ken Glazebrook
Kerry Klein
Kevin Burke
Kristo Kriechbaum
Kyle Brown
Lorraine Valenzuela
Louise Jandura
Luther Beegle
Maggie Scholtz
Maria Silva
Mark Anderson
Mark Balzer
Mason Brody-Carney
Mats Engwall
Matt Haberland
Matt Orzewalla
Matt Robinson
Max Von der Heydt
Megan Richardson
Mihail Petkov
Mike Burger
Mike Johnson
Mike Lih
Mindy Jacobson
Moogega Cooper
Natalia Lord
Nathaniel Thompson
Paul McGrath
Pete Sorci
Ray Andres
Richard Barela
Richard Rainen
Richard Redick
Robert Uyeda
Russell Segawa
Ryan Kinnett
Sarah Marshall
Saverio D'Agostino
Scott McCloskey
Sean Mach
Shyh-Shiuh Lih
Stephen Kuhn
Suparna Mukherjee
Arakelian Taguhi
Tim Connors
Vandi Tompkins
Victoria Harris
William Green
Will Raff
Zahi Tarzi
And countless others

Sampling Capability

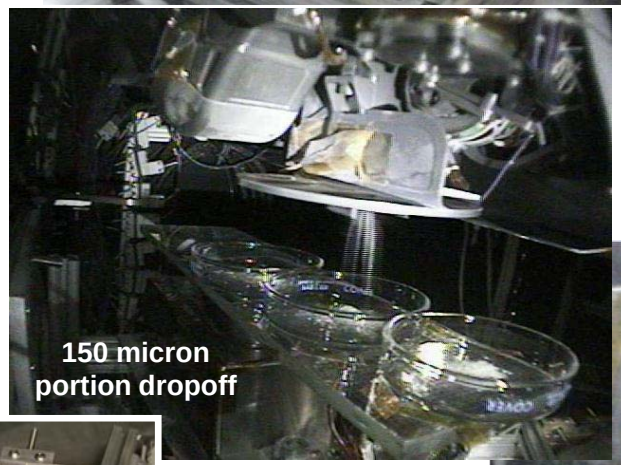
- SA/SPaH acquires rock and regolith samples
  - Powdered rock at depths of 20 to 50 mm from a wide variety of rocks (Drill)
  - Loose regolith with the Scoop (CHIMRA)
- SA/SPaH sieves the acquired material into fine particles (CHIMRA)
  - Sub-150 micron or sub-1 mm size sieving
- SA/SPaH delivers small portions to SAM and Chemin (CHIMRA)
  - Multiple portions of 45 to 65 mm^3 from sub-150 micron material
  - Single portion of 45 to 130 mm^3 from sub-1 mm material

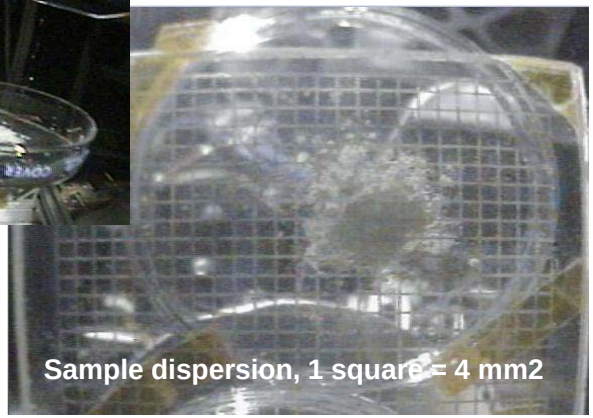
Curiosity's Sampling System

Testing at Mars conditions



Camera views during test





Rocknest Scooping Campaign

Processing with CHIMRA

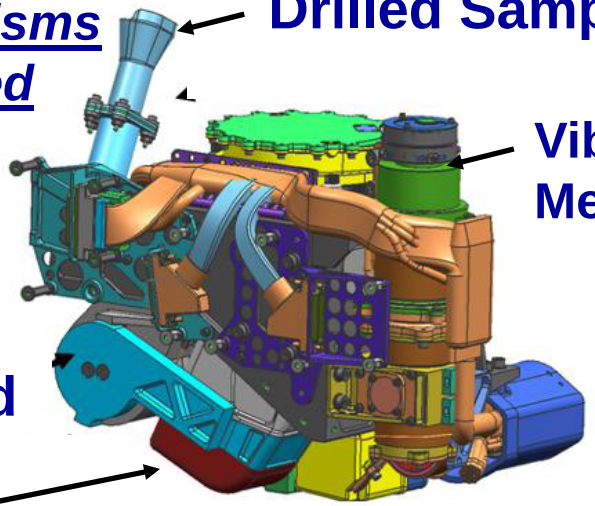
Mechanisms Closed

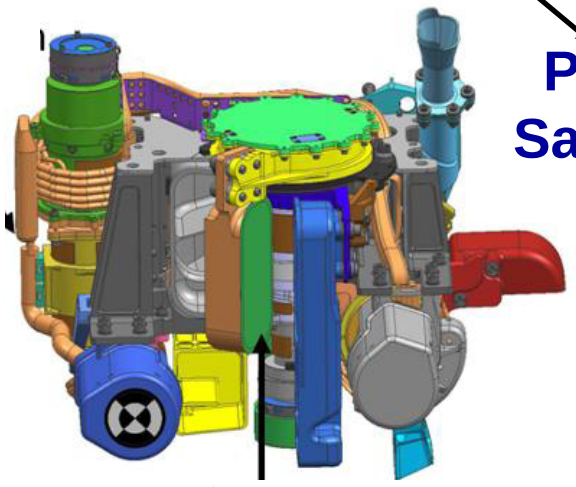
Drilled Sample enters

Vibe Mechanism

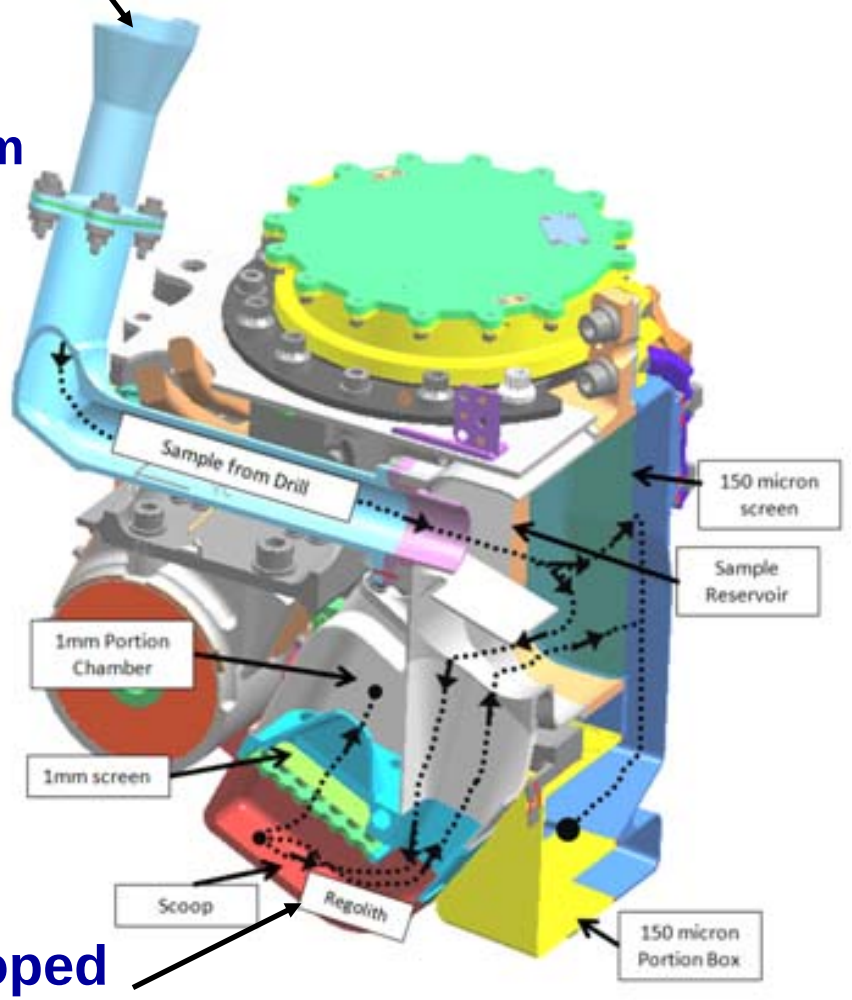
Scooped Sample enters

Processed Sample exits

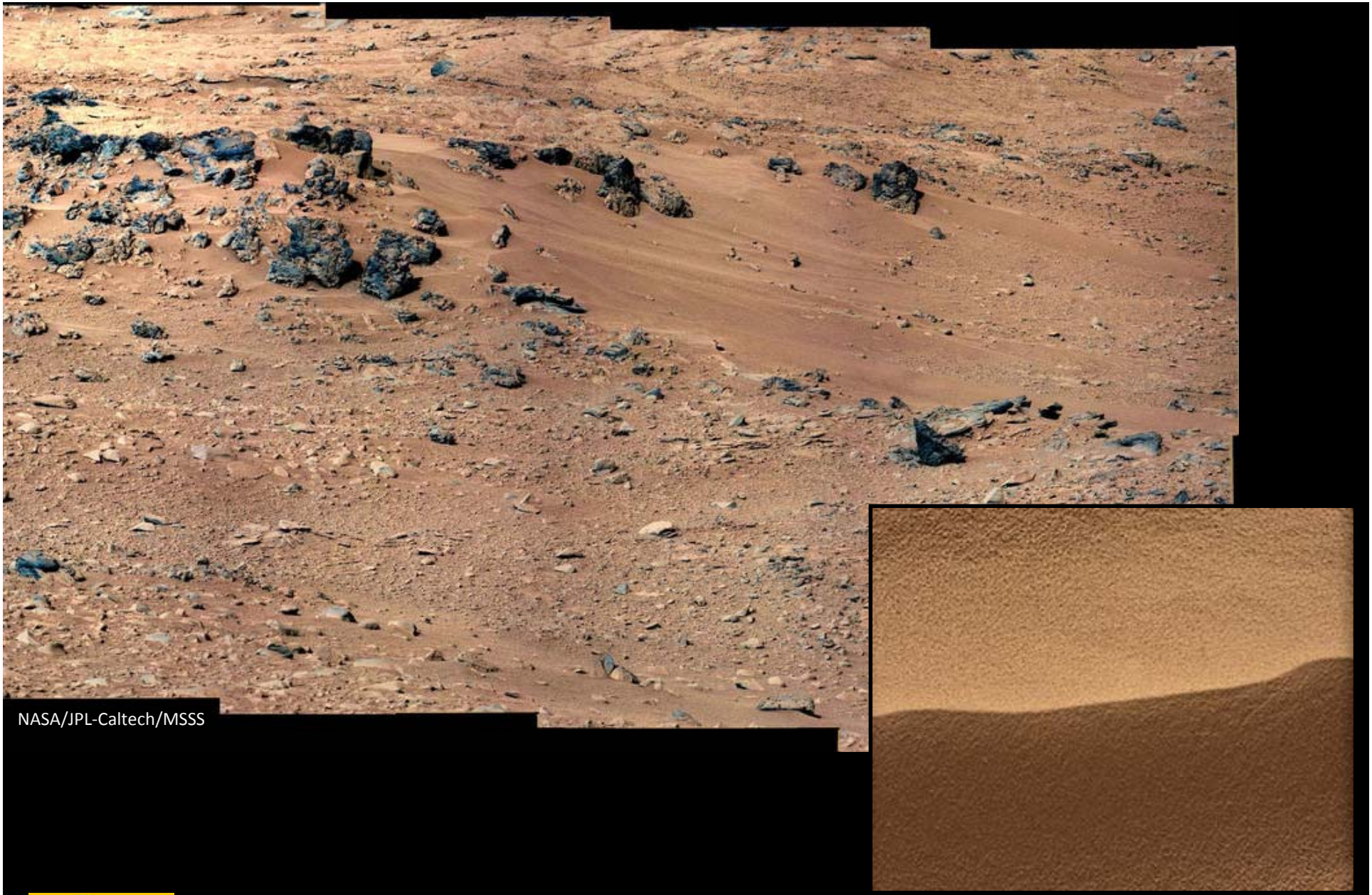




Mechanisms Open



Scooped Sample enters



NASA/JPL-Caltech/MSSS

CURIOSITY

Windblown “sand shadow” at the Rocknest site

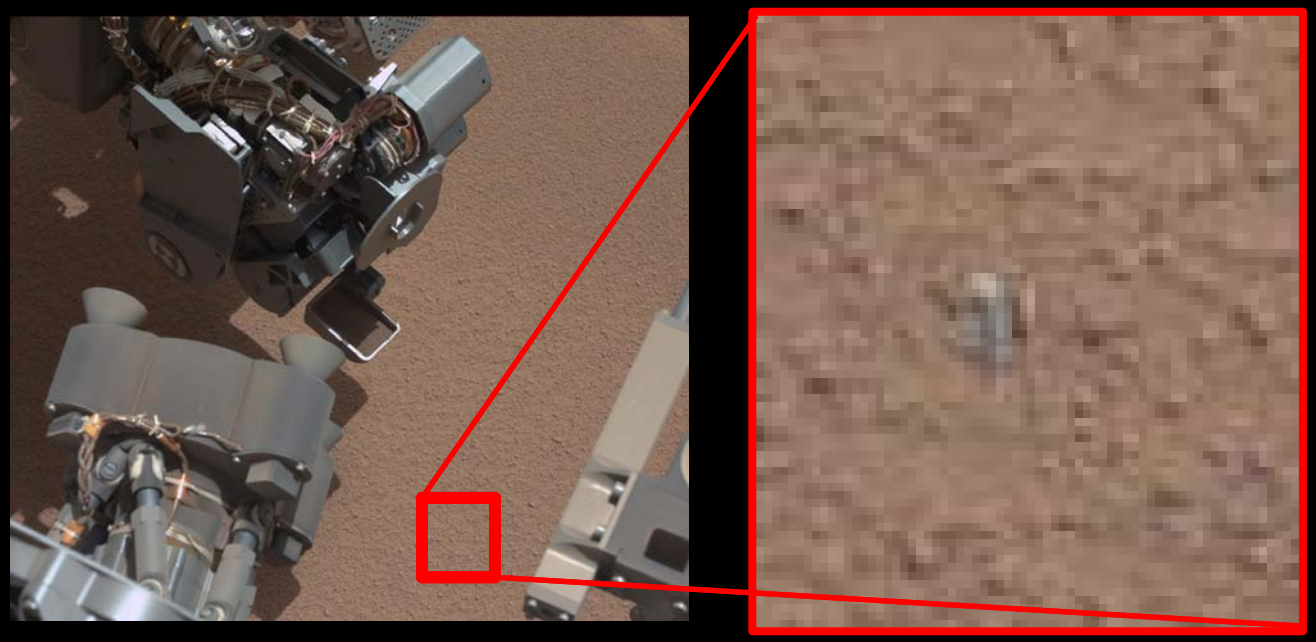
Wheel scuff to confirm depth of sand, for safe scooping

NASA/JPL-Caltech

CURIOSITY

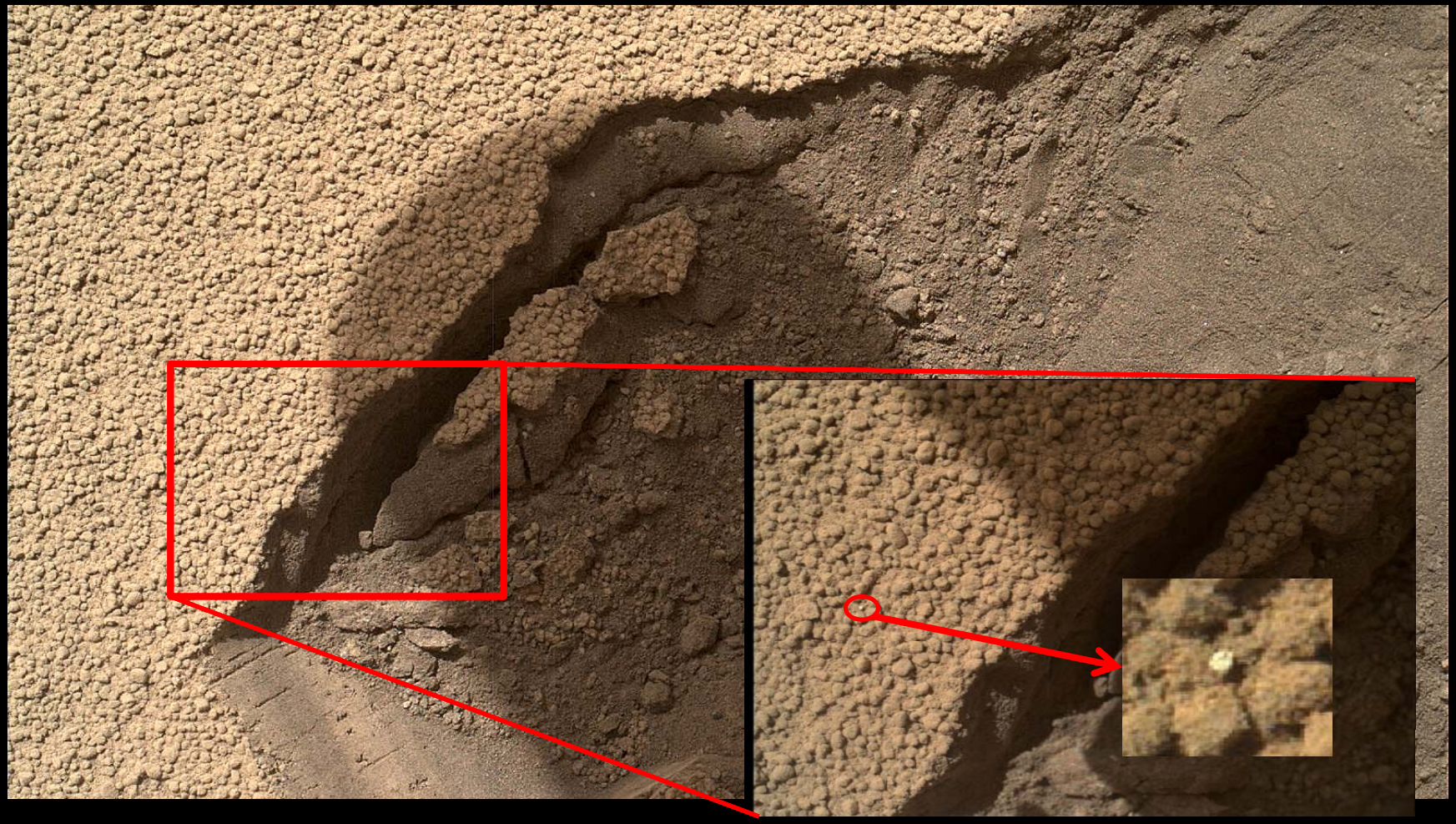
Scooping Campaign at Rocknest: sol 62

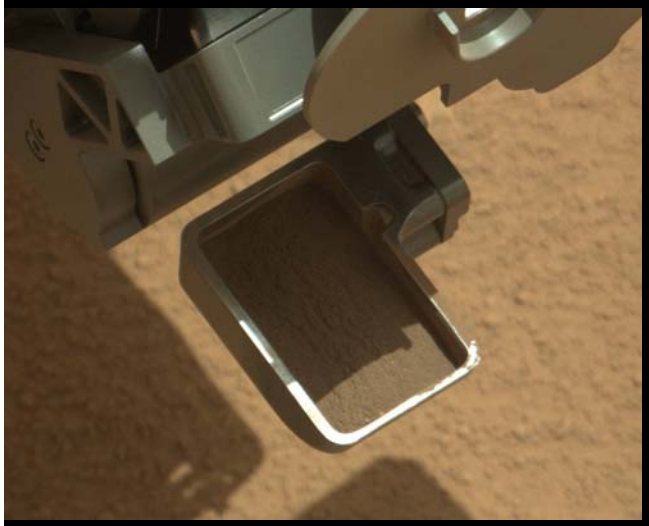
Sol 60 image



Sol 67 image

FOD?

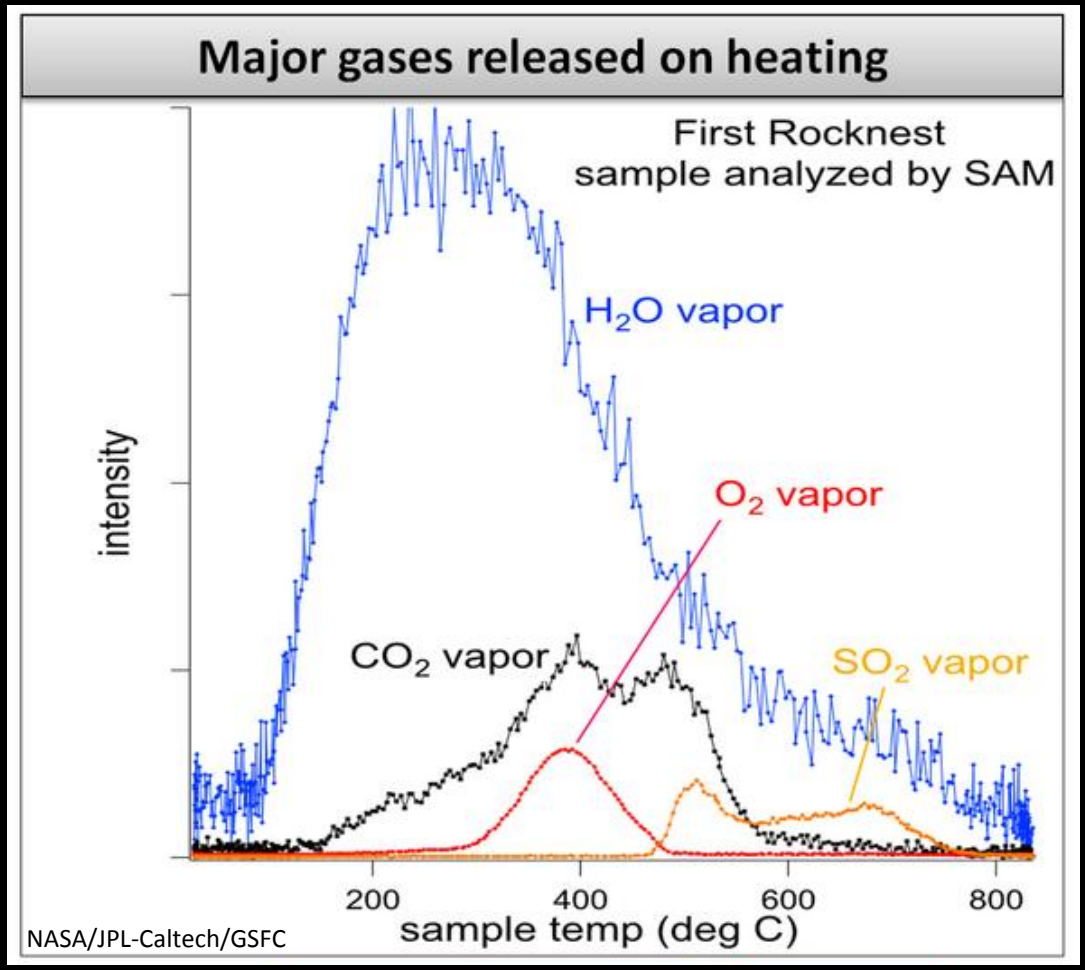




NASA/JPL-Caltech/MSSS

CURIOSITY

MAHLI view of coarse (0.5 to 1.5 mm) sand from the ripple's surface, and fine (< 0.25 mm) sand on wall and floor of trench



Water

Oxygen

Sulfate

Hot → Hotter

SAM found evidence for water, sulfate minerals, Fe/Mg carbonates, and chlorate/perchlorate compounds

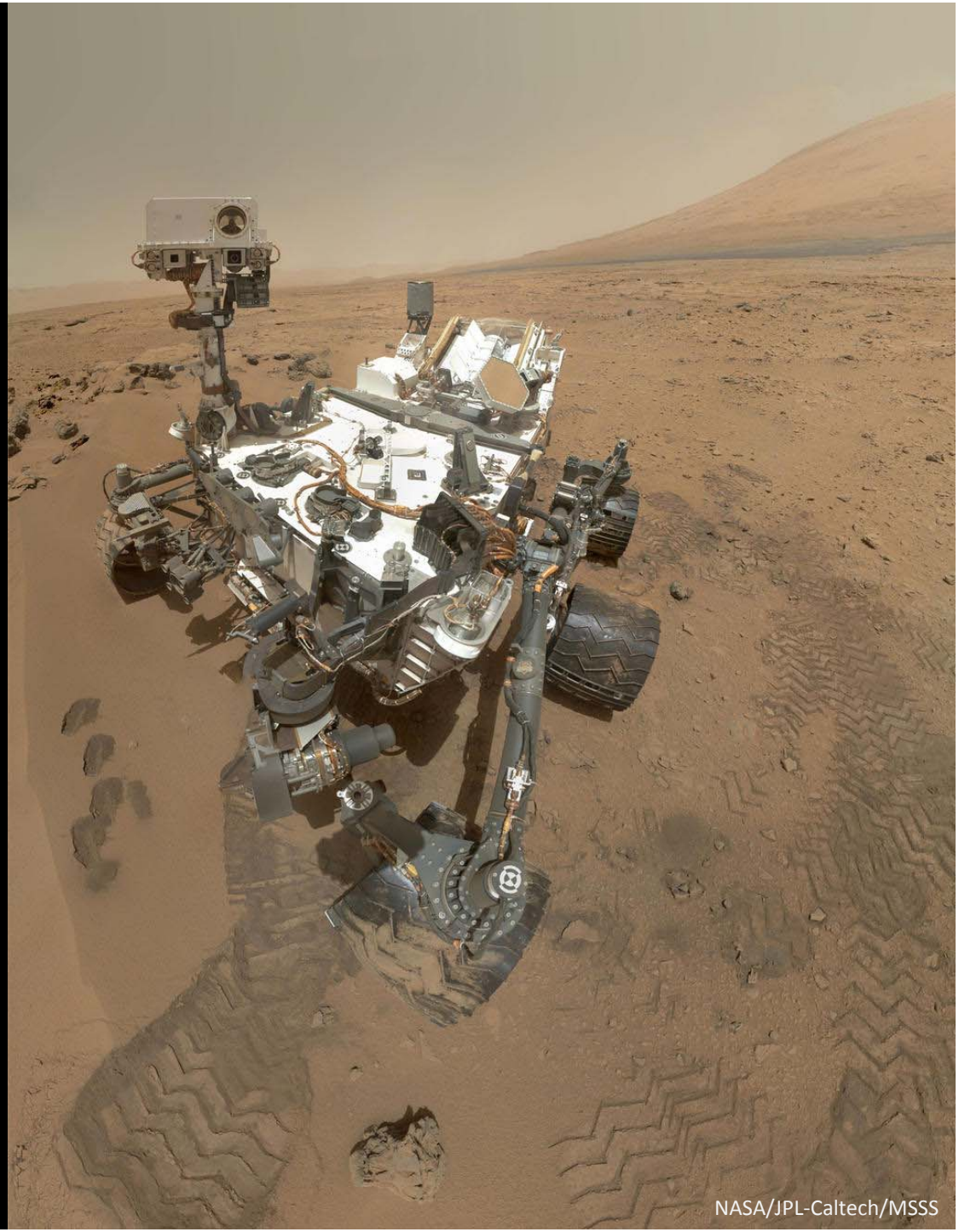
CURIOSITY

Gases released during SAM experiments

Curiosity self-portrait at Rocknest

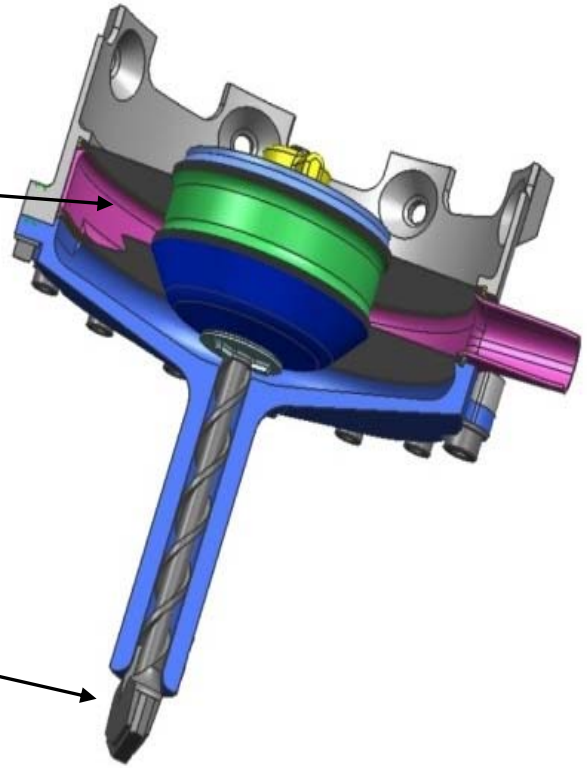
Assembled from 55 MAHLI images

Shows four scoop trenches and wheel scuff



Exploration of Yellowknife Bay

the Drill

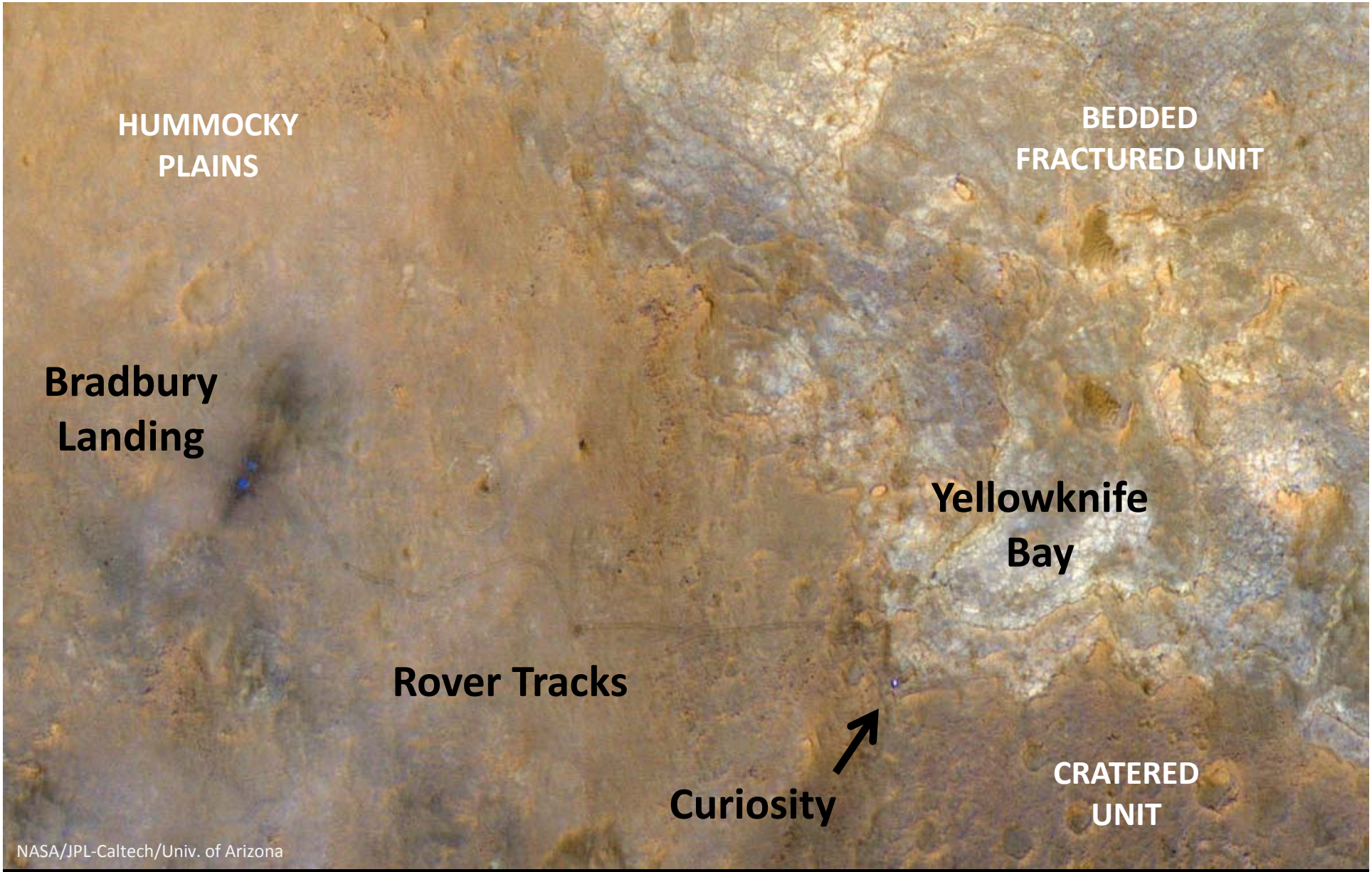

Sample chamber
inside the Bit
Powder exits
Drilled Powder enters

Target Assessment Meetings (TAM)

- Scientific rational behind the campaign
- Understanding the surroundings
  - Sample is accessible from the arm
  - Relatively flat surface
  - Big enough target to pre-load
  - Slip Risk
  - Tip/Tilt
- Bulk Properties
  - Have we drilled something like it in the past?
  - If not how concerned are we?
  - Will the material act like fines?

Example activities for drilling campaign

- **Activities:**
  - Mini Start Hole (3-4mm depth)
  - Mini-Drill Hole (2 cm depth)
    - Mainly to observe the material properties
  - Single full depth drill hole (5-6cm depth)
  - Sample processing: Sieve sample to 150 micron
  - Delivery to CheMin, followed by delivery to SAM (if requested)
  - Sample caching



CURIOSITY

Curiosity and its tracks captured by HiRISE on the Mars Reconnaissance Orbiter

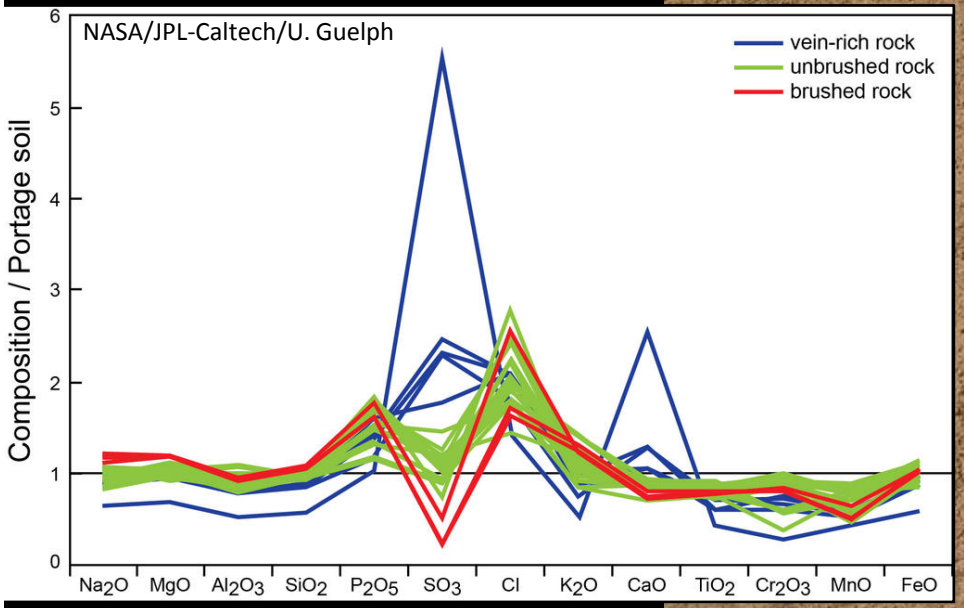
NASA/JPL-Caltech/MSSS

CURIOSITY

“Shaler” rocks just outside Yellowknife Bay show inclined, fine layers that indicate sediment transport

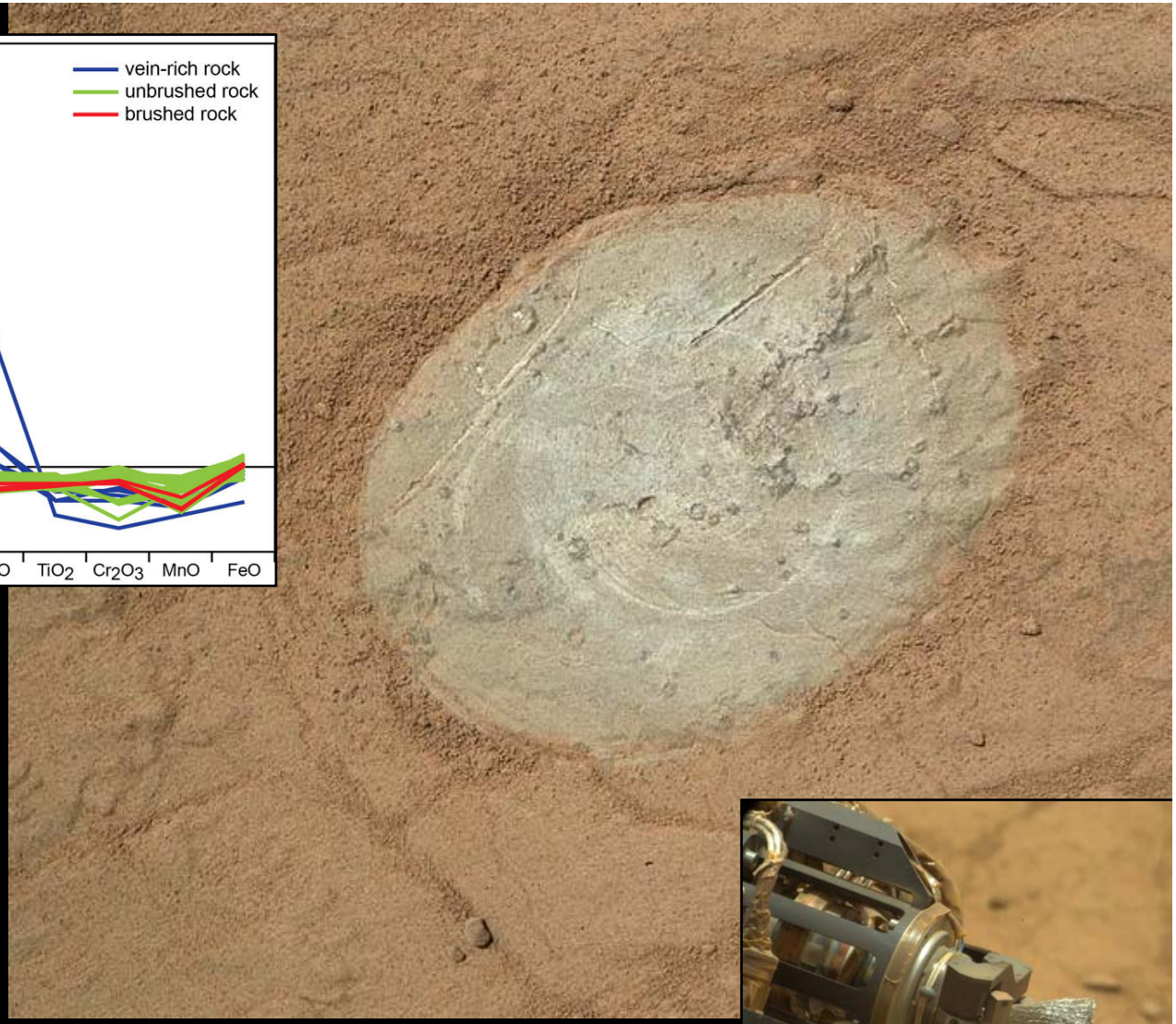
CURIOSITY

John Klein drill site showing fractured bedrock and ridge-forming veins



APXS sees sulfur and calcium in vein-rich rock

Removing the dust results in slightly lower sulfur



NASA/JPL-Caltech/MSSS

CURIOSITY

APXS and the dust-removing brush

NASA/JPL-Caltech/D. Bouic

Arm deployed at Yellowknife Bay

NASA/JPL-Caltech/LANL/CNES/IRAP/IAS/LPGN

NASA/JPL-Caltech/MSSS

NASA/JPL-Caltech/MSSS

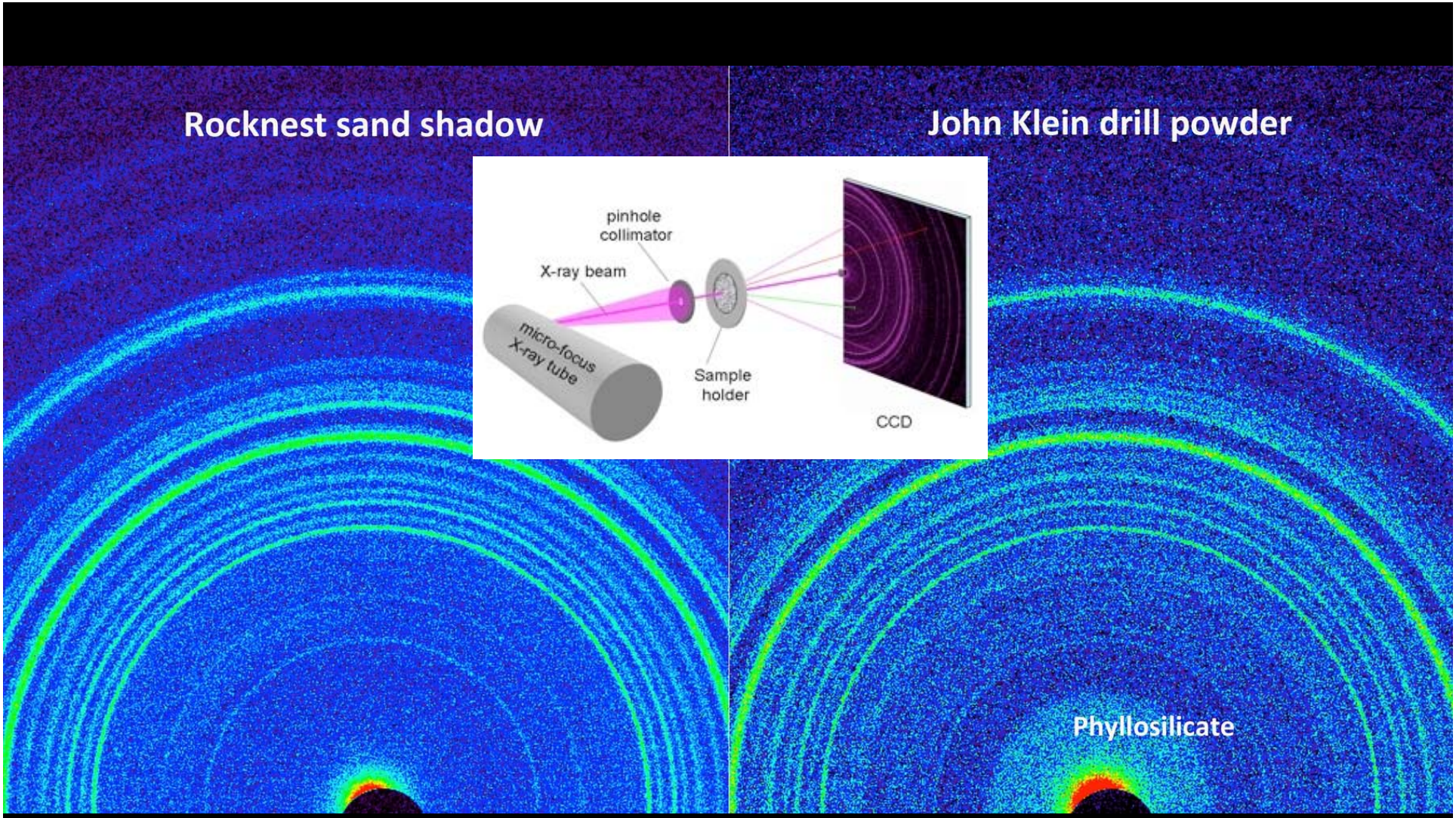
CURIOSITY

Curiosity's 1.6-cm drill bit, drill and test holes, and scoop full of acquired sample

NASA/JPL-Caltech/MSSS

CURIOSITY

John Klein dime-sized drill hole with light-toned veins and ChemCam profile



NASA/JPL-Caltech/Ames

The Sheepbed mudstone at Yellowknife Bay contains ~ 20% clay minerals that formed in place. The bulk composition is similar to that of unaltered basaltic materials.

An Ancient Habitable Environment at Yellowknife Bay

- The regional geology and fine-grained rock suggest that the John Klein site was at the end of an ancient river system or within an intermittently wet lake bed
- The mineralogy indicates sustained interaction with liquid water that was not too acidic or alkaline, and low salinity. Furthermore, conditions were not strongly oxidizing.
- Key chemical ingredients for life are present, such as carbon, hydrogen, nitrogen, oxygen, phosphorus, and sulfur
- The presence of minerals in various states of oxidation would provide a source of energy for primitive organisms

Imaging of hardware after sol 1202

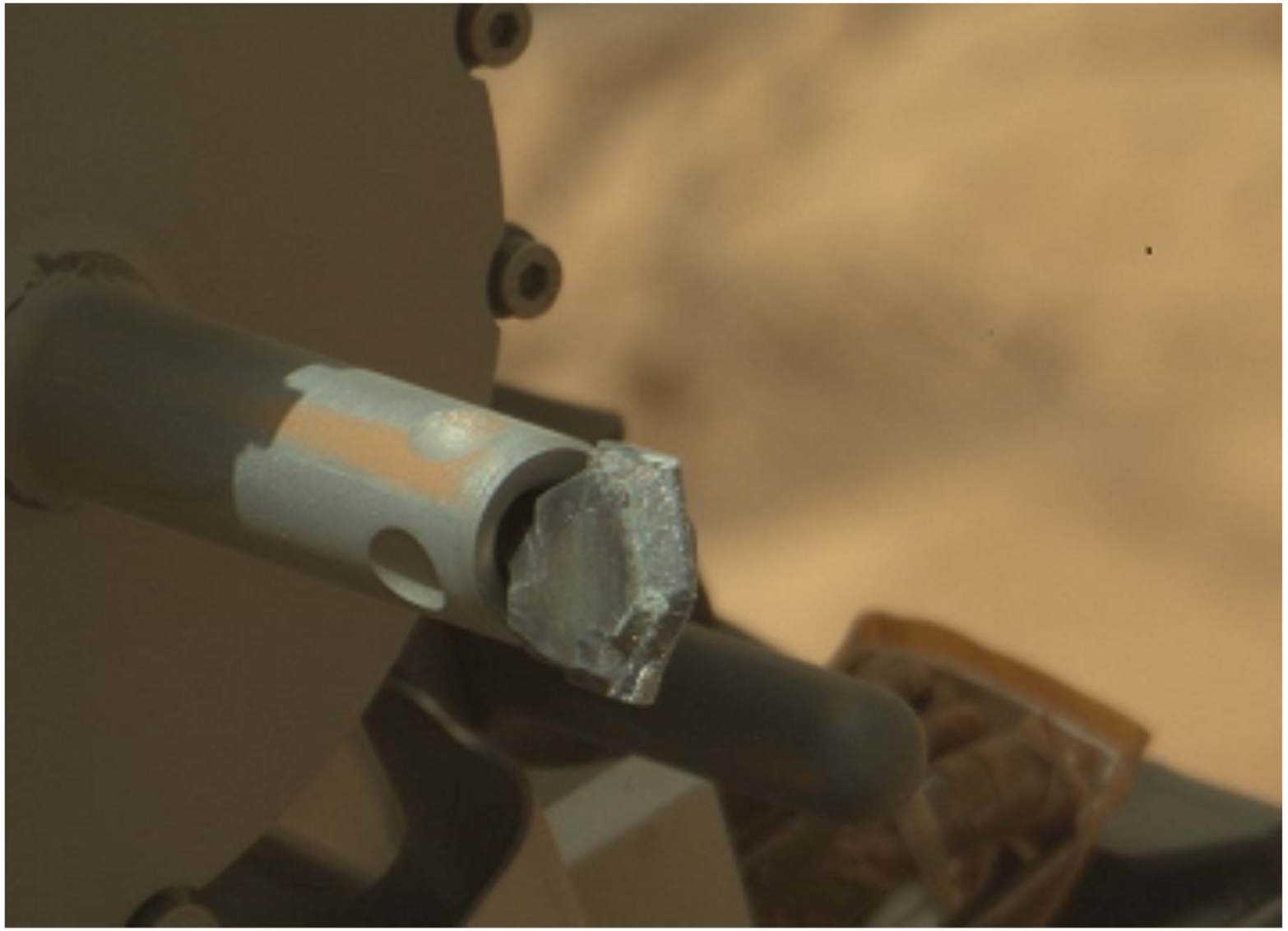
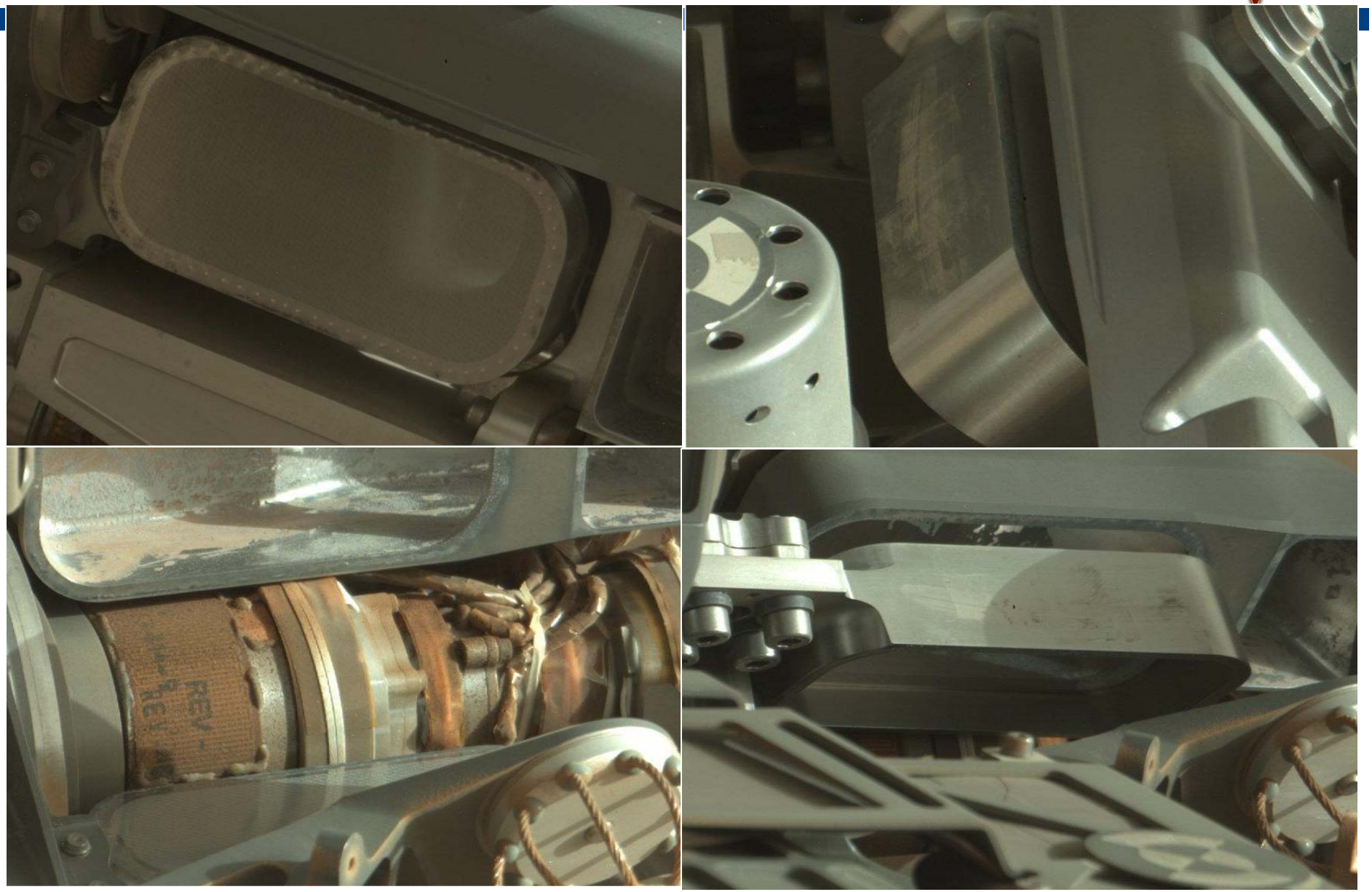


Image of 150u sieve as of 1202



ChemCam RMI of 150u sieve as of 1202

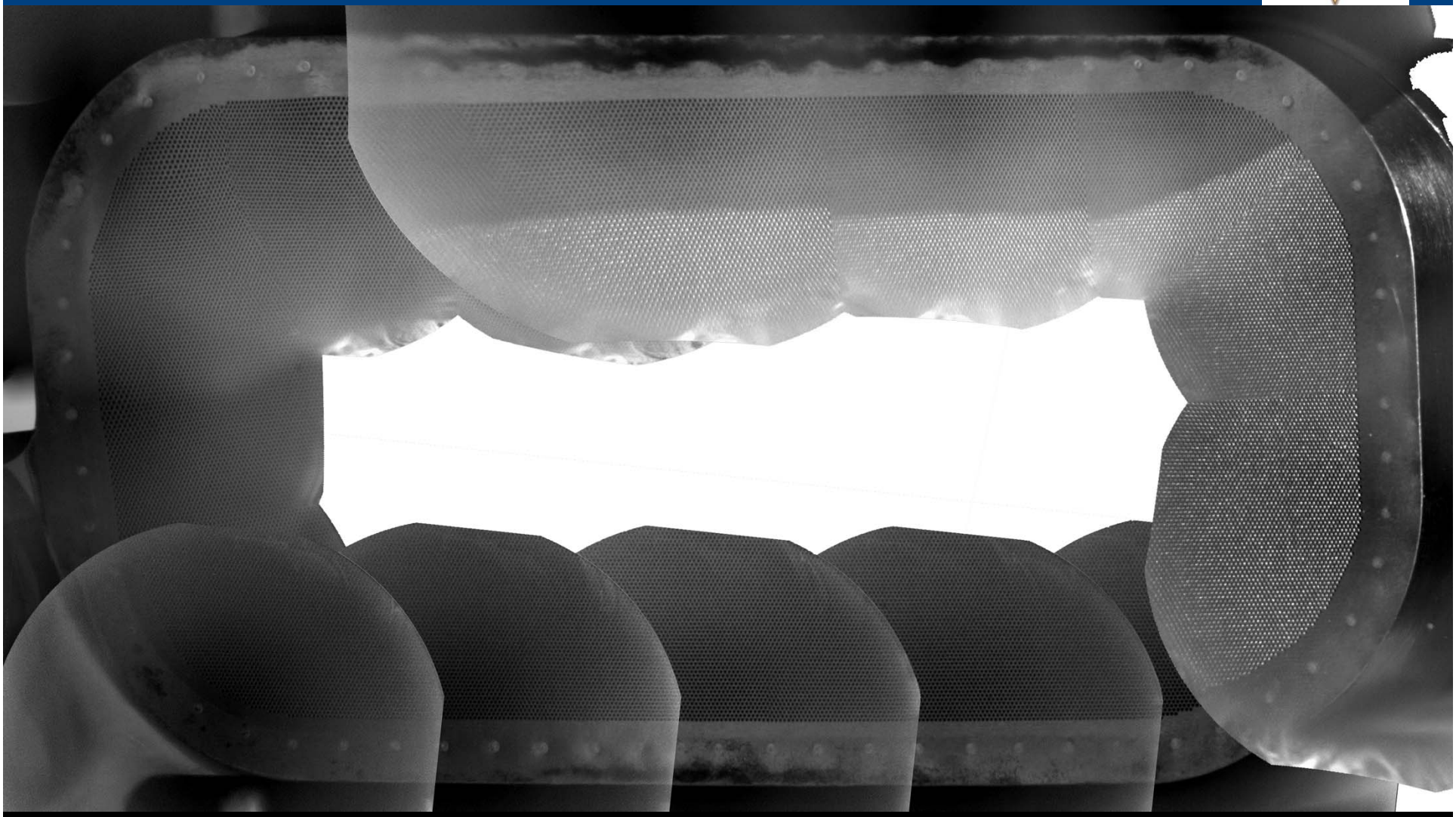
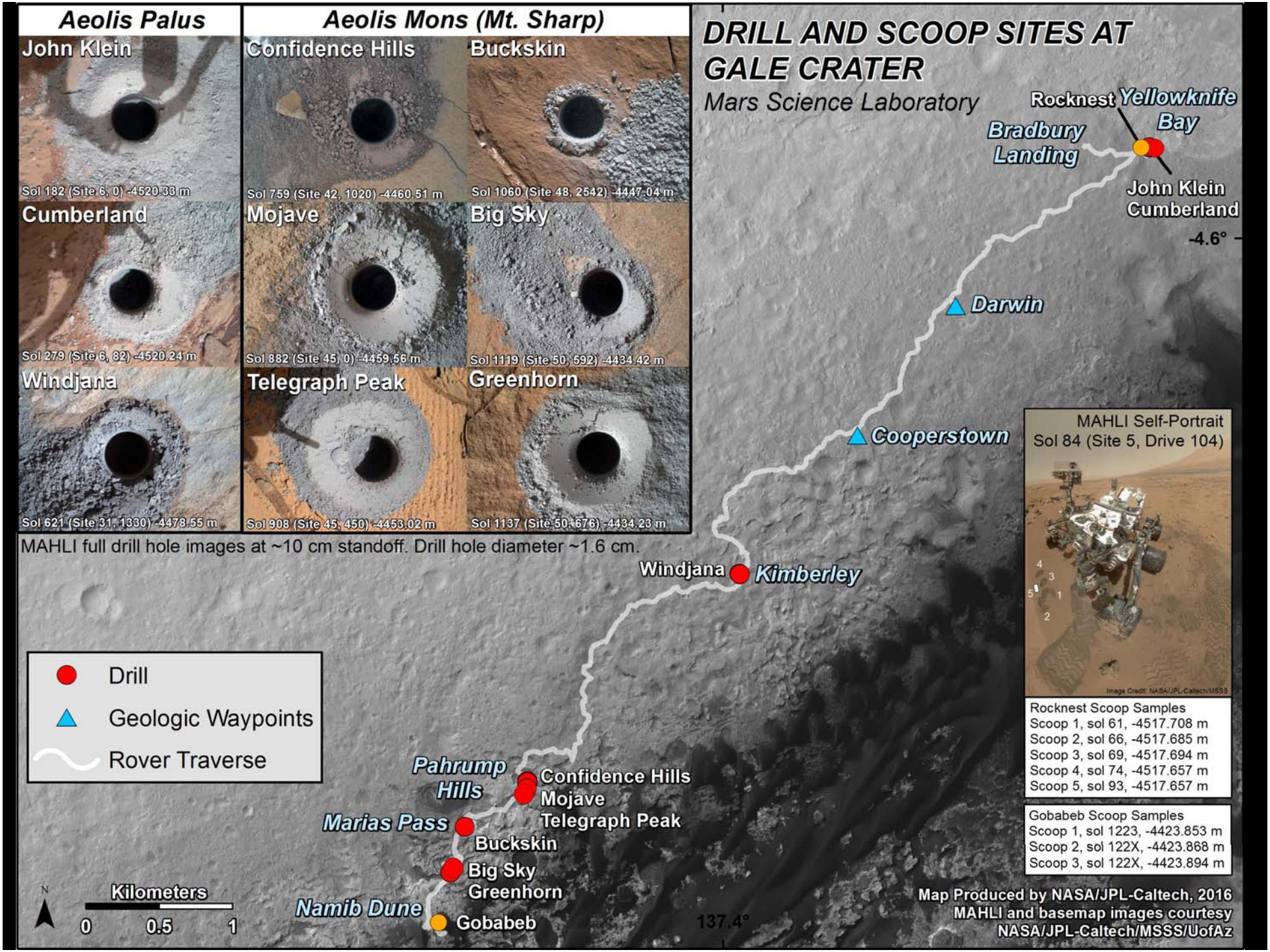


image curtesy of Olivier Gasnault

Yellowknife Bay
to the Kimberley

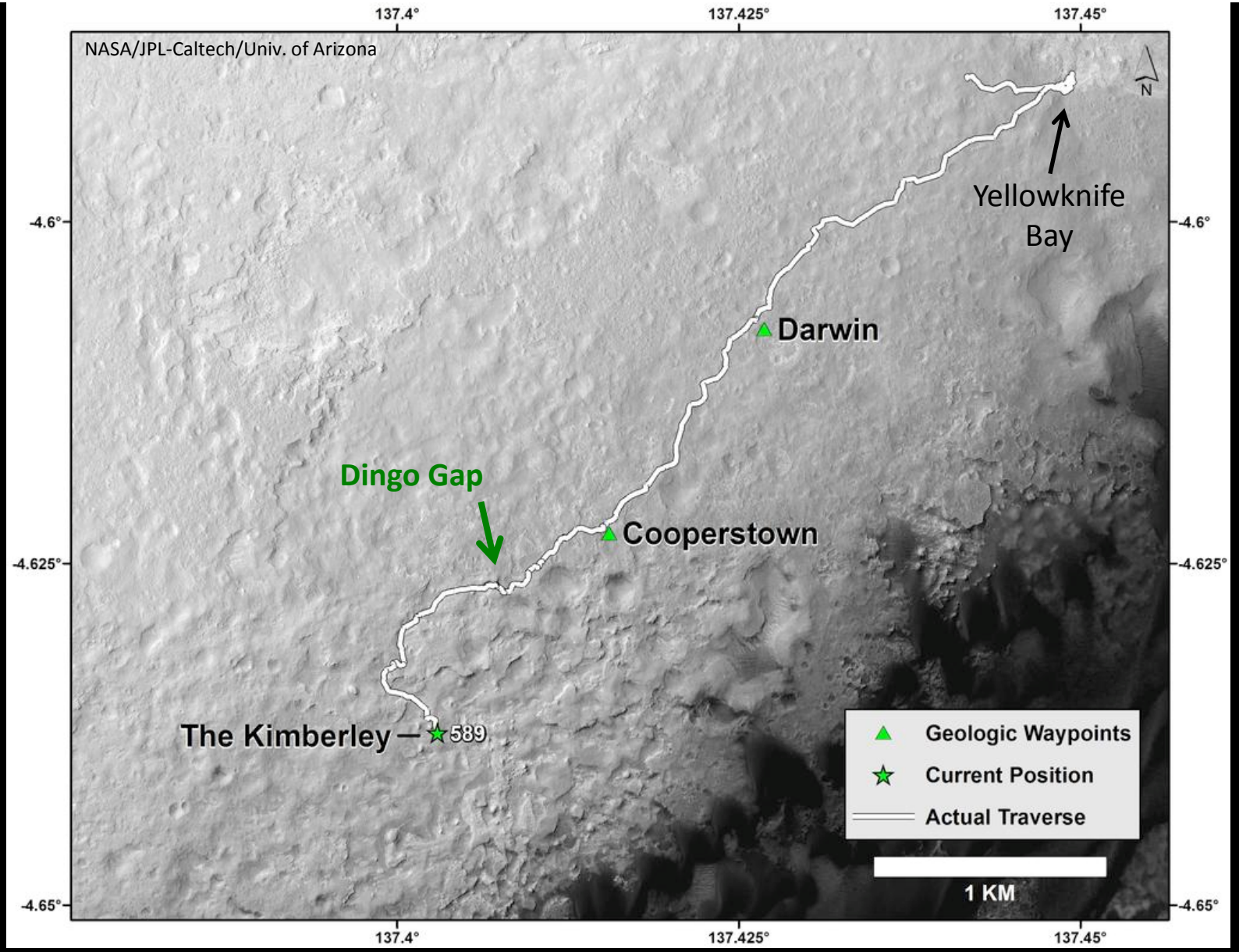

Aeolis Palus
Aeolis Mons (Mt. Sharp)
John Klein
Sol 182 (Site 6, 0) -4520.33 m
Confidence Hills
Sol 759 (Site 42, 1020) -4460.51 m
Buckskin
Sol 1060 (Site 48, 2542) -4447.04 m
Cumberland
Sol 279 (Site 6, 82) -4520.24 m
Mojave
Sol 882 (Site 45, 0) -4459.56 m
Big Sky
Sol 1119 (Site 50, 592) -4434.42 m
Windjana
Sol 621 (Site 31, 1330) -4478.55 m
Telegraph Peak
Sol 908 (Site 45, 450) -4453.02 m
Greenhorn
Sol 1137 (Site 50, 676) -4434.23 m
MAHLI full drill hole images at ~10 cm standoff. Drill hole diameter ~1.6 cm.
DRILL AND SCOOP SITES AT GALE CRATER
Mars Science Laboratory
Rocknest
Yellowknife Bay
Bradbury Landing
John Klein
Cumberland
-4.6°
Darwin
Cooperstown
MAHLI Self-Portrait
Sol 84 (Site 5, Drive 104)
Image Credit: NASA/JPL-Caltech/MSSS
Windjana
Kimberley
Drill
Geologic Waypoints
Rover Traverse
Pahrump Hills
Confidence Hills
Mojave
Telegraph Peak
Marias Pass
Buckskin
Big Sky
Greenhorn
Namib Dune
Gobabeb
137.4°
N
Kilometers
0
0.5
1
Rocknest Scoop Samples
Scoop 1, sol 61, -4517.708 m
Scoop 2, sol 66, -4517.685 m
Scoop 3, sol 69, -4517.694 m
Scoop 4, sol 74, -4517.657 m
Scoop 5, sol 93, -4517.657 m
Gobabeb Scoop Samples
Scoop 1, sol 1223, -4423.853 m
Scoop 2, sol 122X, -4423.868 m
Scoop 3, sol 122X, -4423.894 m
Map Produced by NASA/JPL-Caltech, 2016
MAHLI and basemap images courtesy
NASA/JPL-Caltech/MSSS/UofAz

Bonanza King: A successful failure

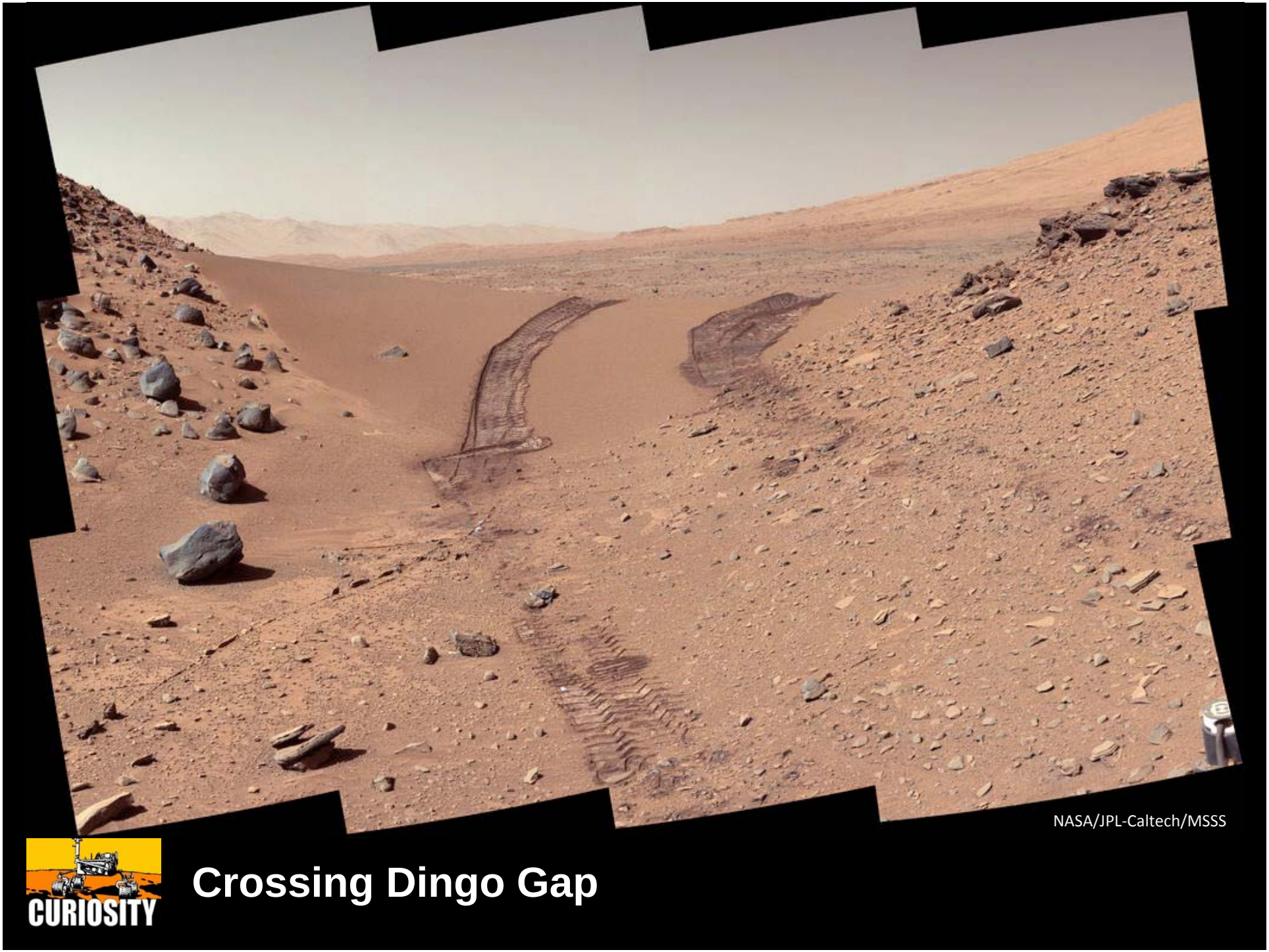
History of CHIMRA at Gale

- **We have utilized Primary Thwack 24 times on Mars**
- **It was used 19 times in testing on the Earth**
- Scoop 1-4 (Sol 61 to 81)
  - Standard Clean All after scooping. This includes multiple Primary Thwacks. Done after scoop 4 on sol 81.
- Scoop 5
  - Clean All occurred on sol 128. No Primary Thwack or Secondary Thwack. Just vibration.
  - A Secondary Thwackless Clean All occurred on sol 173
- John Klein
  - Secondary Thwack Clean All on sol 229.
- Cumberland
  - Thwackless Clean All on sol 486.
- Single Primary Thwack Clean All before Windjana on sol 576
- Single Primary Thwack Clean All after Windjana on sol 704
- Single Primary Thwack Clean All after Confidence Hills on sol 840
- Single Primary Thwack Clean All after Mojave on sol 894
- Single Primary Thwack Clean All after Telegraph Peak on sol 1048
- Single Primary Thwack Clean All after Buckskin on sol 1089
- Single Primary Thwack Clean All after Big Sky on Sol 1133
- Single Primary Thwack Clean All after Greenhorn on Sol 1202

(24x on Mars/43x total)

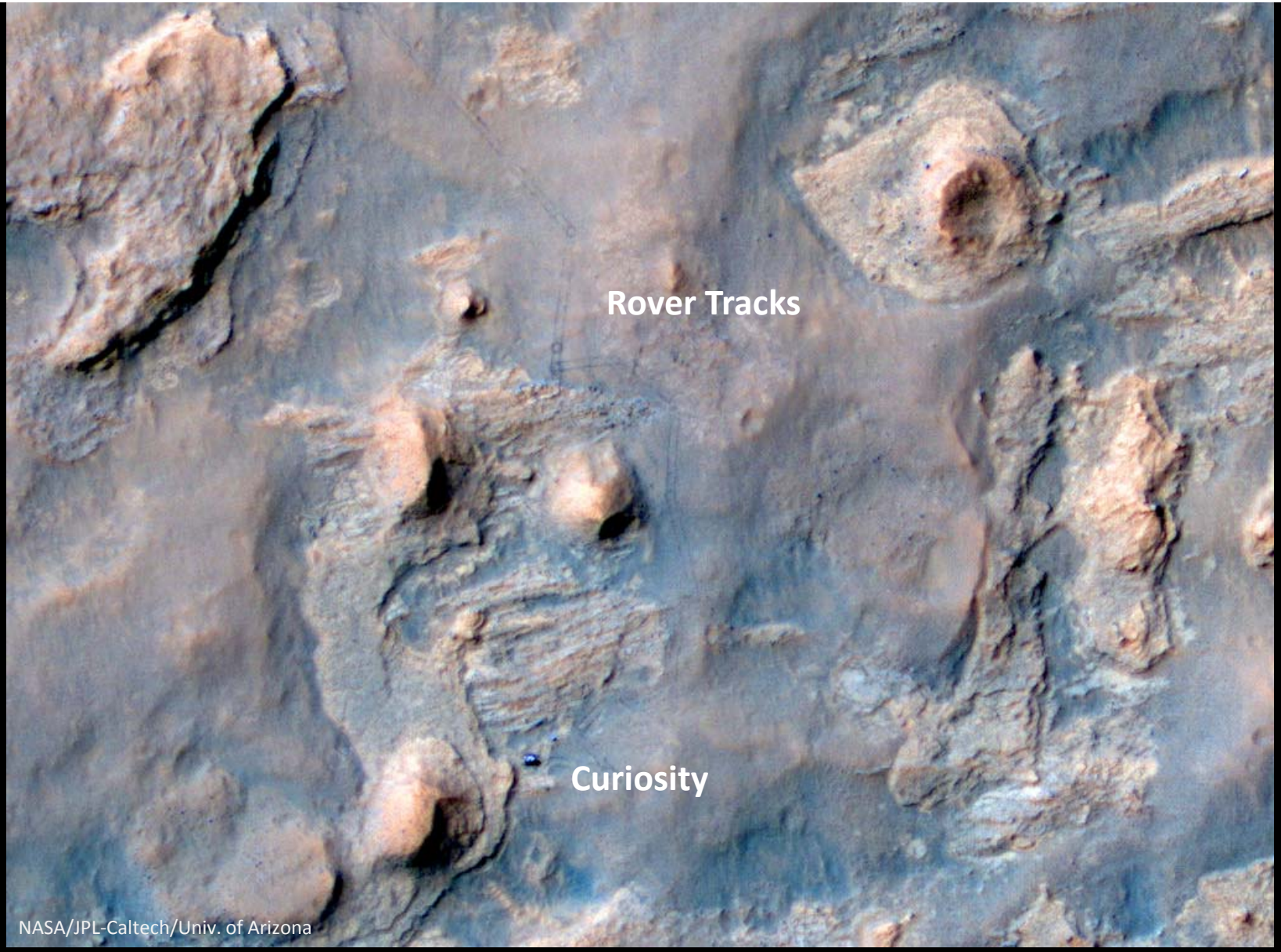


Curiosity's traverse to the Kimberley, via waypoints Darwin and Cooperstown



CURIOSITY

Crossing Dingo Gap



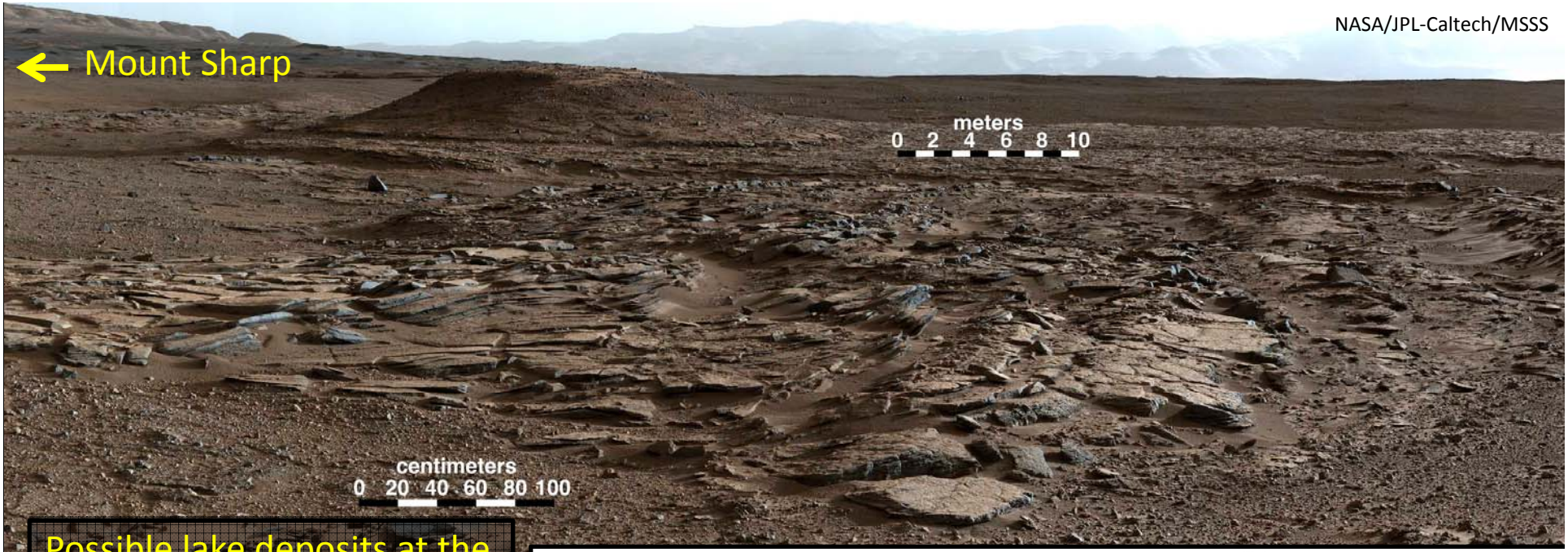
Curiosity at the Kimberley, where four rock types typical of Gale's plains come together

CURIOSITY

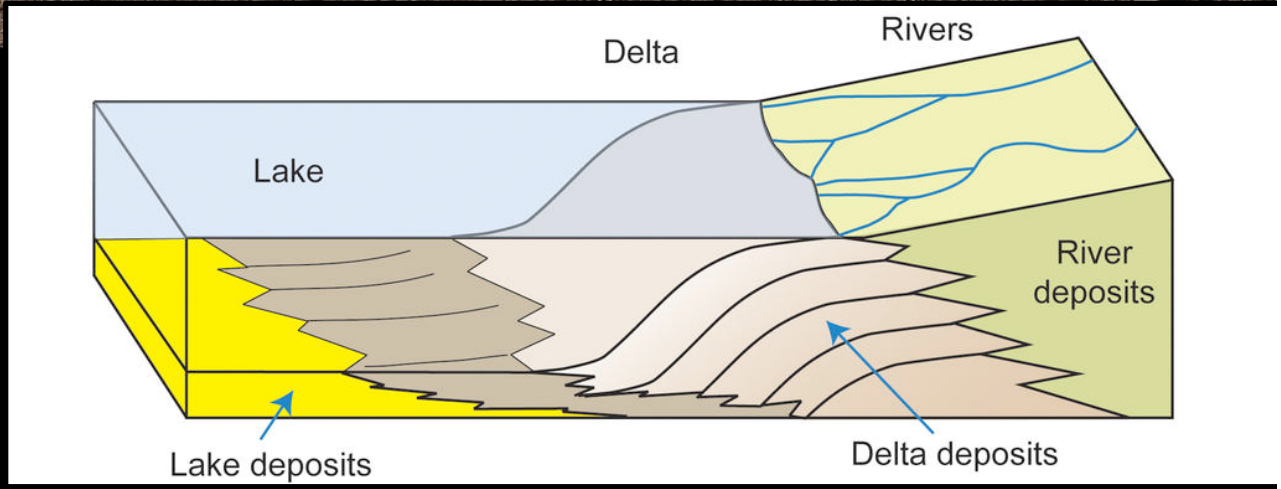
Windjana fluvial sandstone drill target at the Kimberley, showing drilling-induced slumping

The Trek to Mt. Sharp,
The Ultimate Destination

NASA/JPL-Caltech/MSSS

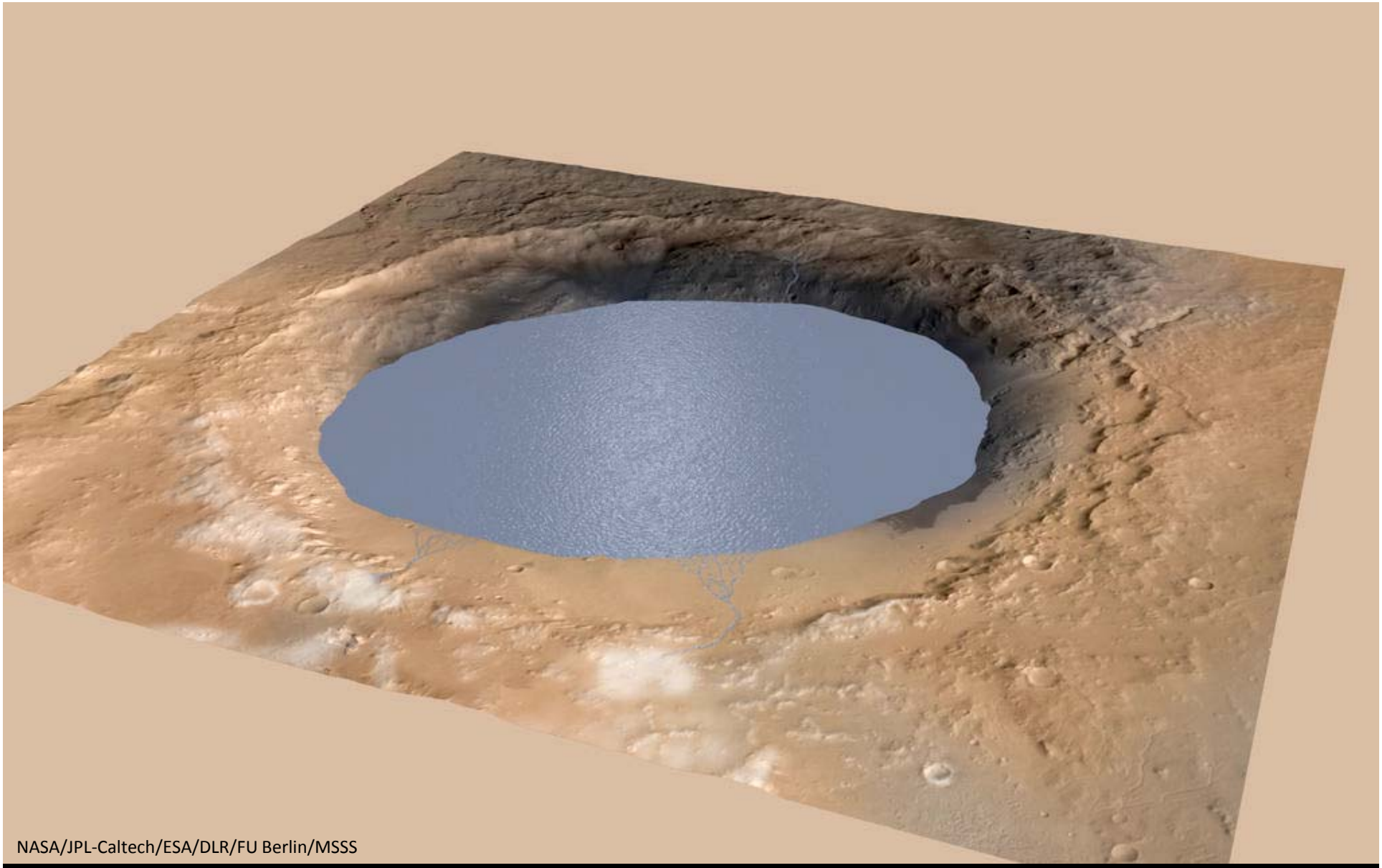


Possible lake deposits at the base of Mount Sharp



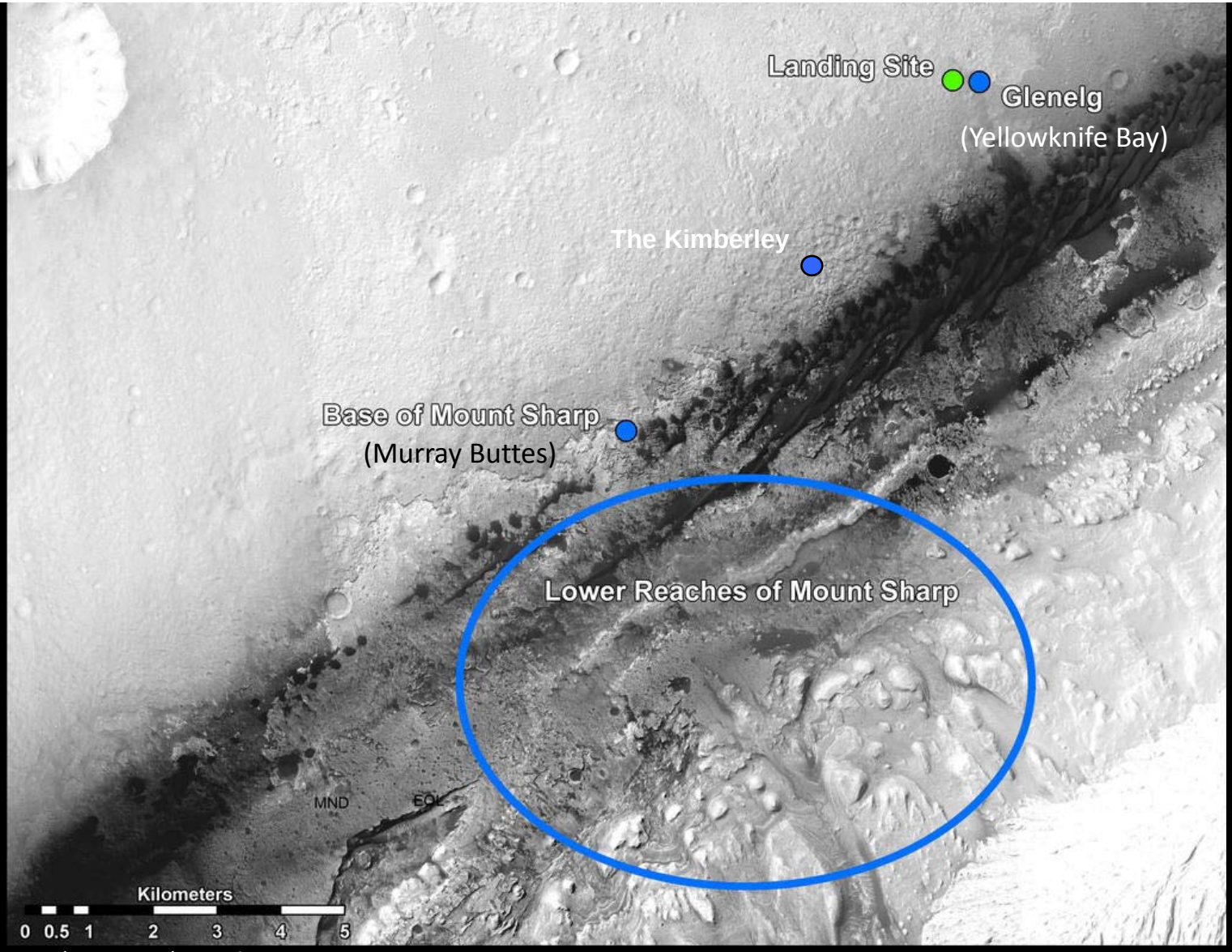
Curiosity is exploring a hypothesis that southward-tilted sandstone beds on Gale Crater's plains indicate fluvial transport of sediment toward Mount Sharp, building up lake deposits there.

CURIOSITY



NASA/JPL-Caltech/ESA/DLR/FU Berlin/MSSS

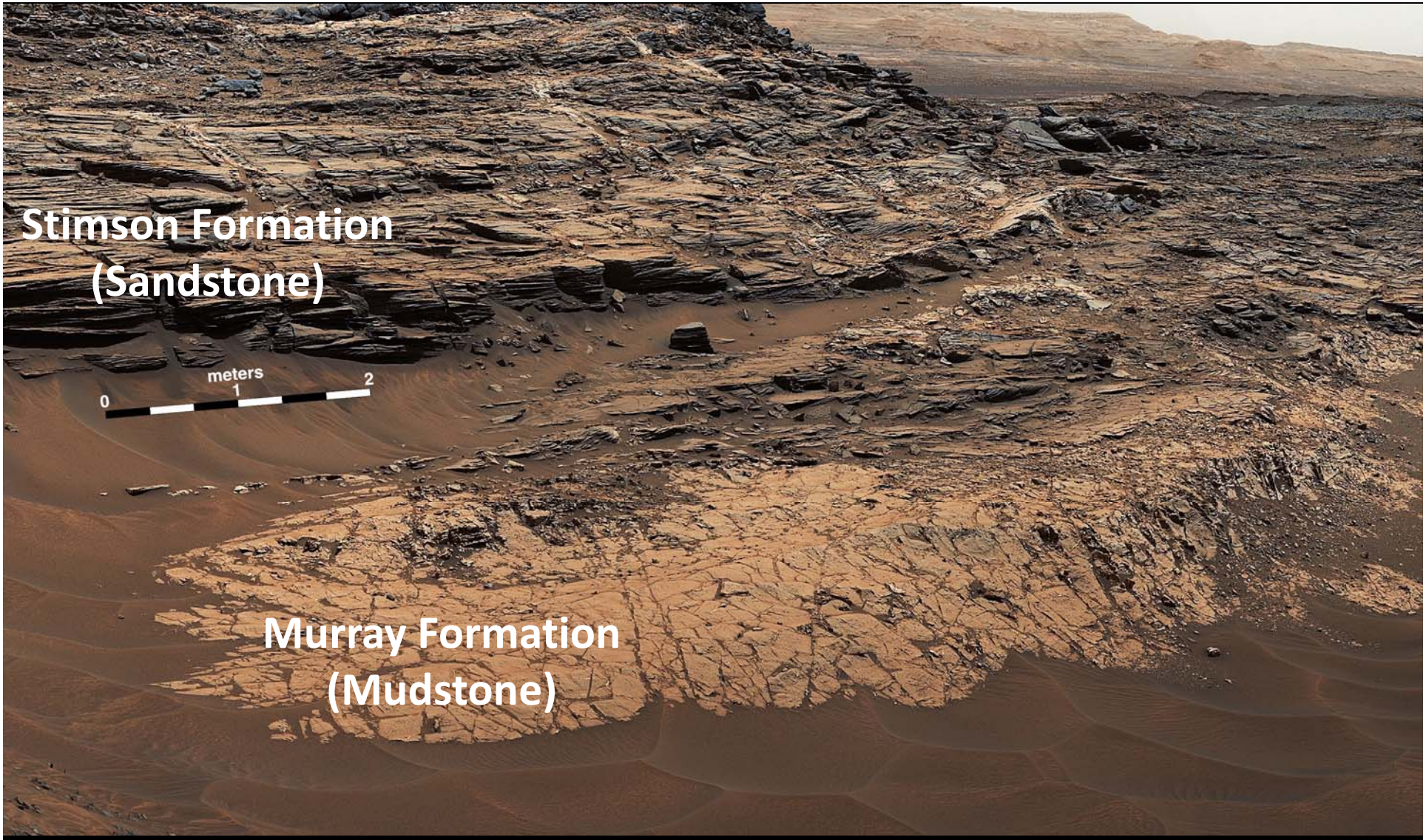
An illustration of lake partially filling Gale Crater. If such a lake existed for millions of years, it would have required a more humid climate and active hydrological cycle.



NASA/JPL-Caltech/Univ. of Arizona

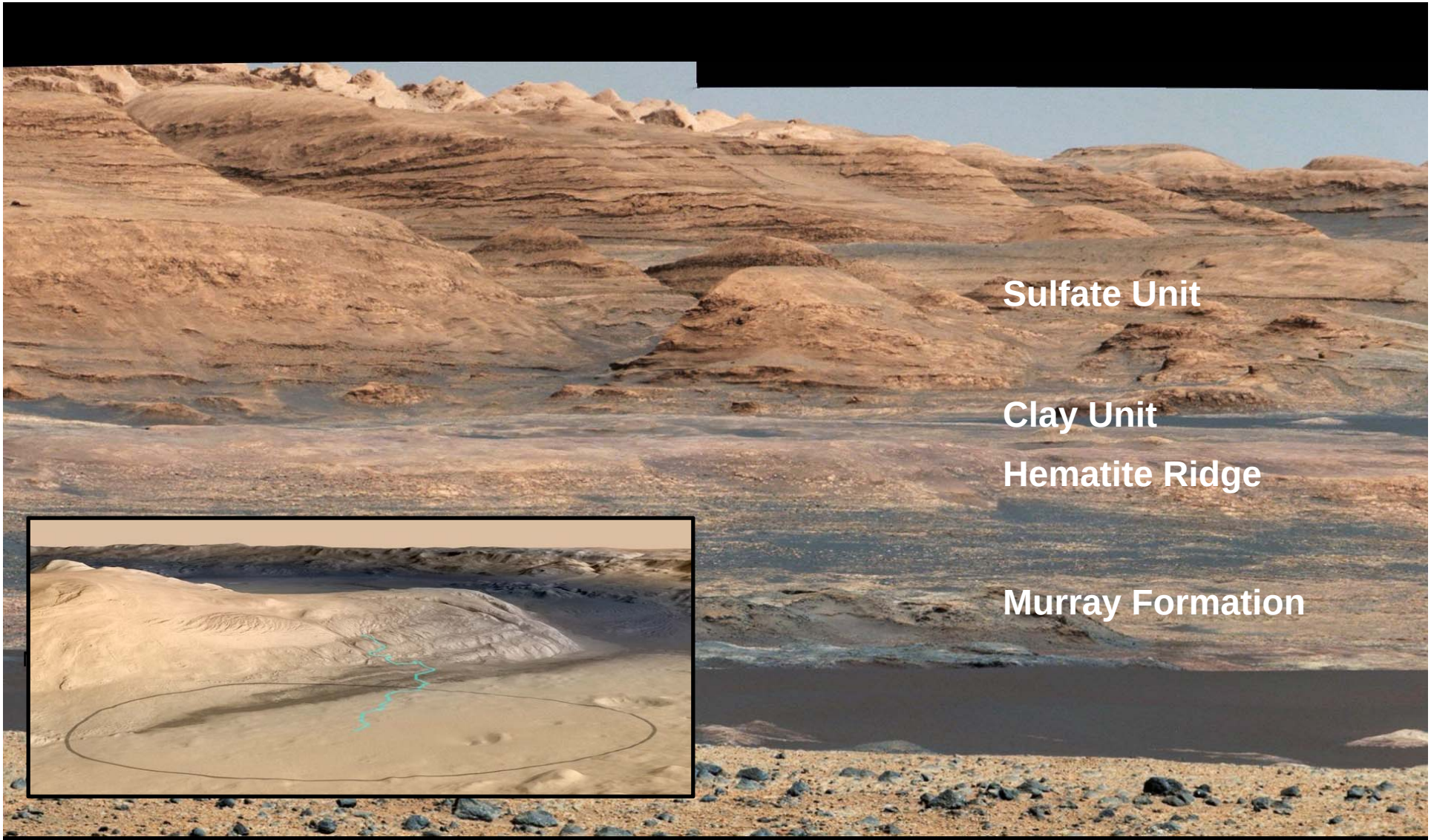
CURIOSITY

Curiosity's ultimate goal is to explore the lower reaches of the 5-km high Mount Sharp



CURIOSITY

At Marias Pass, Curiosity investigated the geological contact between the Murray formation that forms the base of Mount Sharp and a later, but ancient, sand deposit



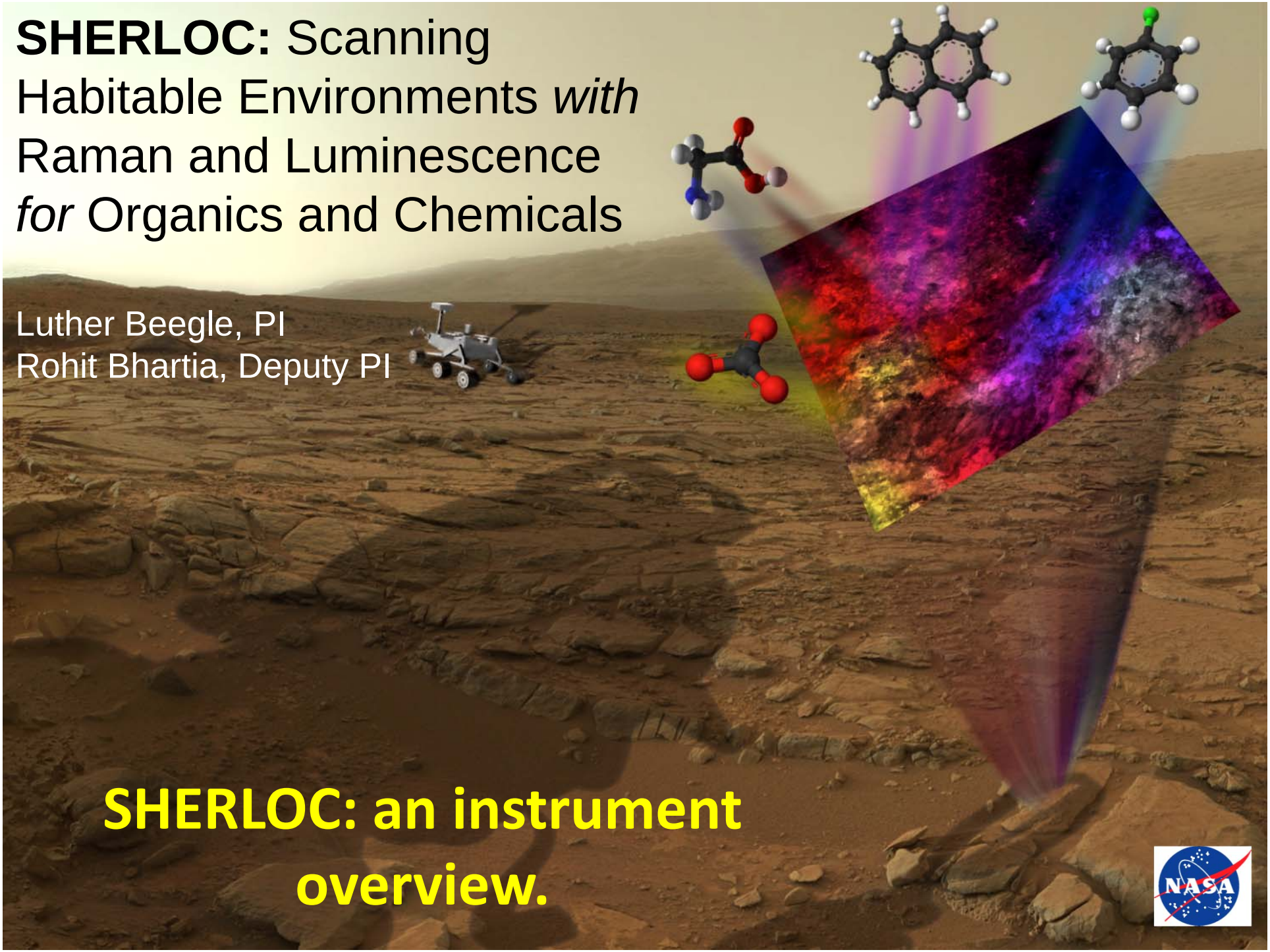
NASA/JPL-Caltech/MSSS

Curiosity's Extended Mission will explore Mt. Sharp, with an emphasis on understanding the subset of habitable environments that preserve organic carbon


NASA/JPL-Caltech/MSSS

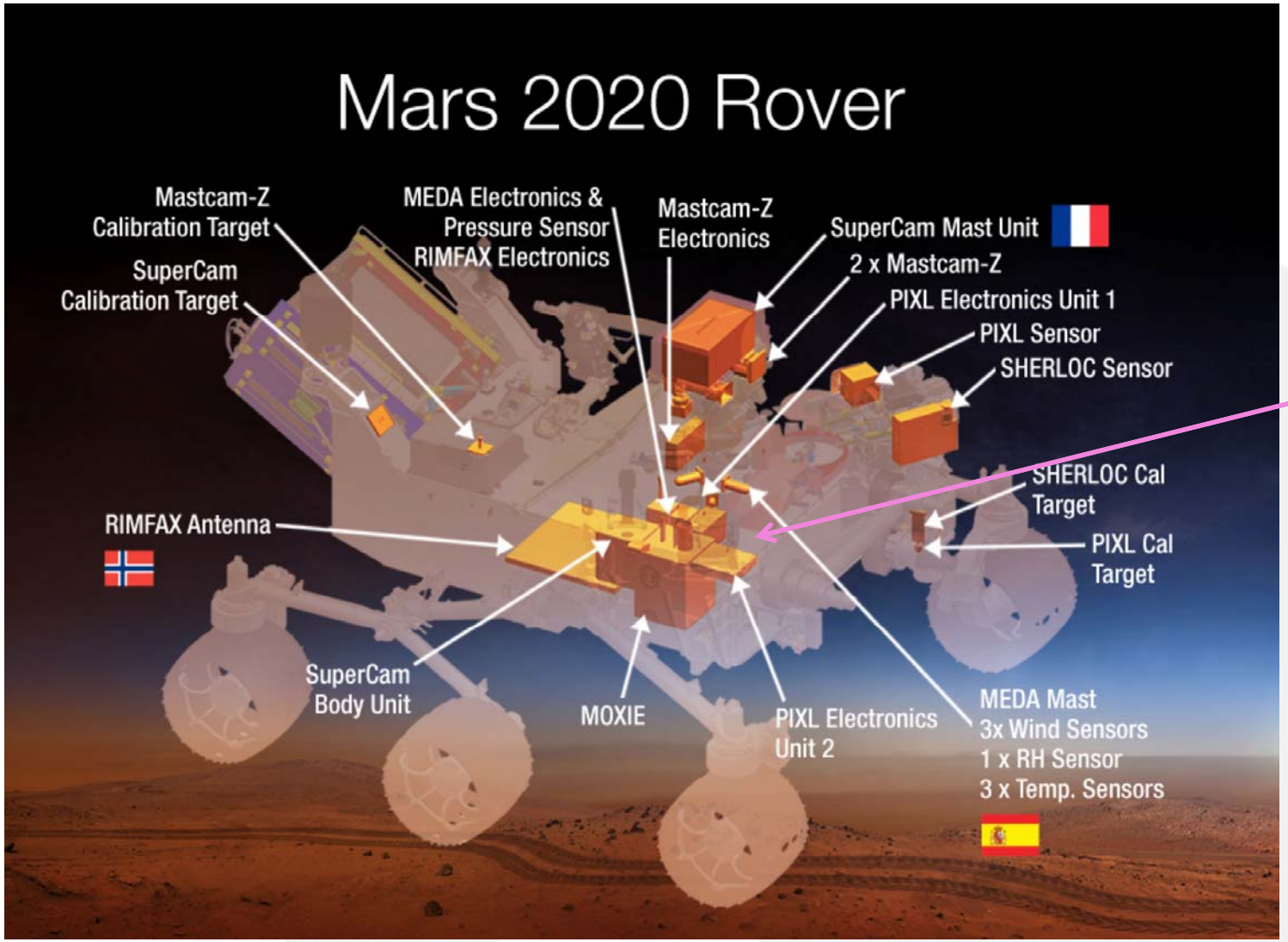
SHERLOC: Scanning Habitable Environments *with* Raman and Luminescence *for* Organics and Chemicals

Luther Beegle, PI
Rohit Bhartia, Deputy PI



SHERLOC: an instrument overview.

The Rover



SHERLOC Electronics Assembly (not identified in NASA press release)

Preparing for future Humans: Space Suite material!

- HEOMD EVA Suit Targets
  - Orthofabric (outer layer of EVA suit outergarment)
  - 3oz. Teflon fabric (outer layer of glove, back of hand, gauntlet)
  - Polycarbonate (helmet visor)
  - RTV silicone (glove palm)
  - Vectran (glove palm)
  - Spectra (EVA suit structural element)
  - 6oz polyester (EVA suit restraints)