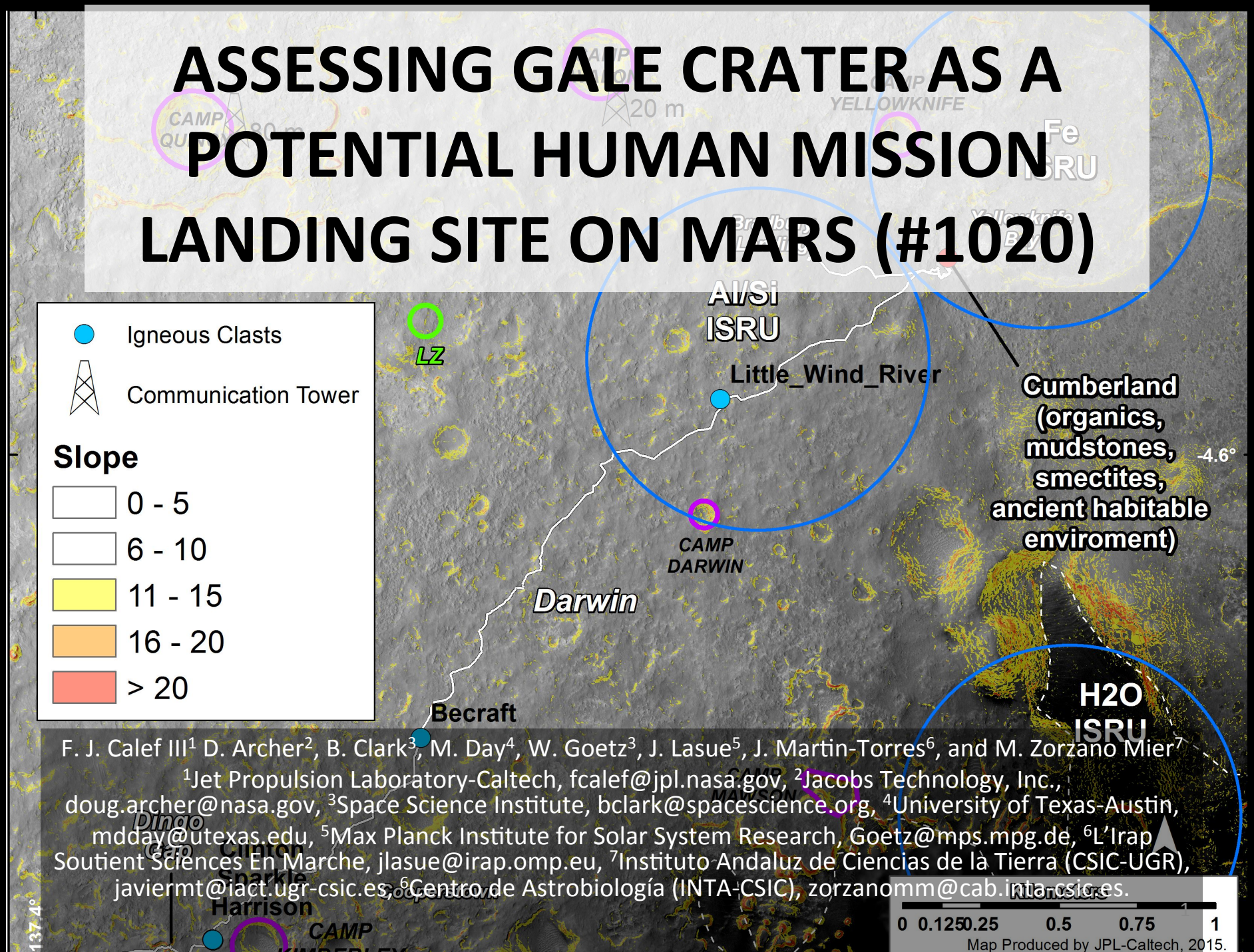
ASSESSING GALE CRATER AS A POTENTIAL HUMAN MISSION LANDING SITE ON MARS (#1020)



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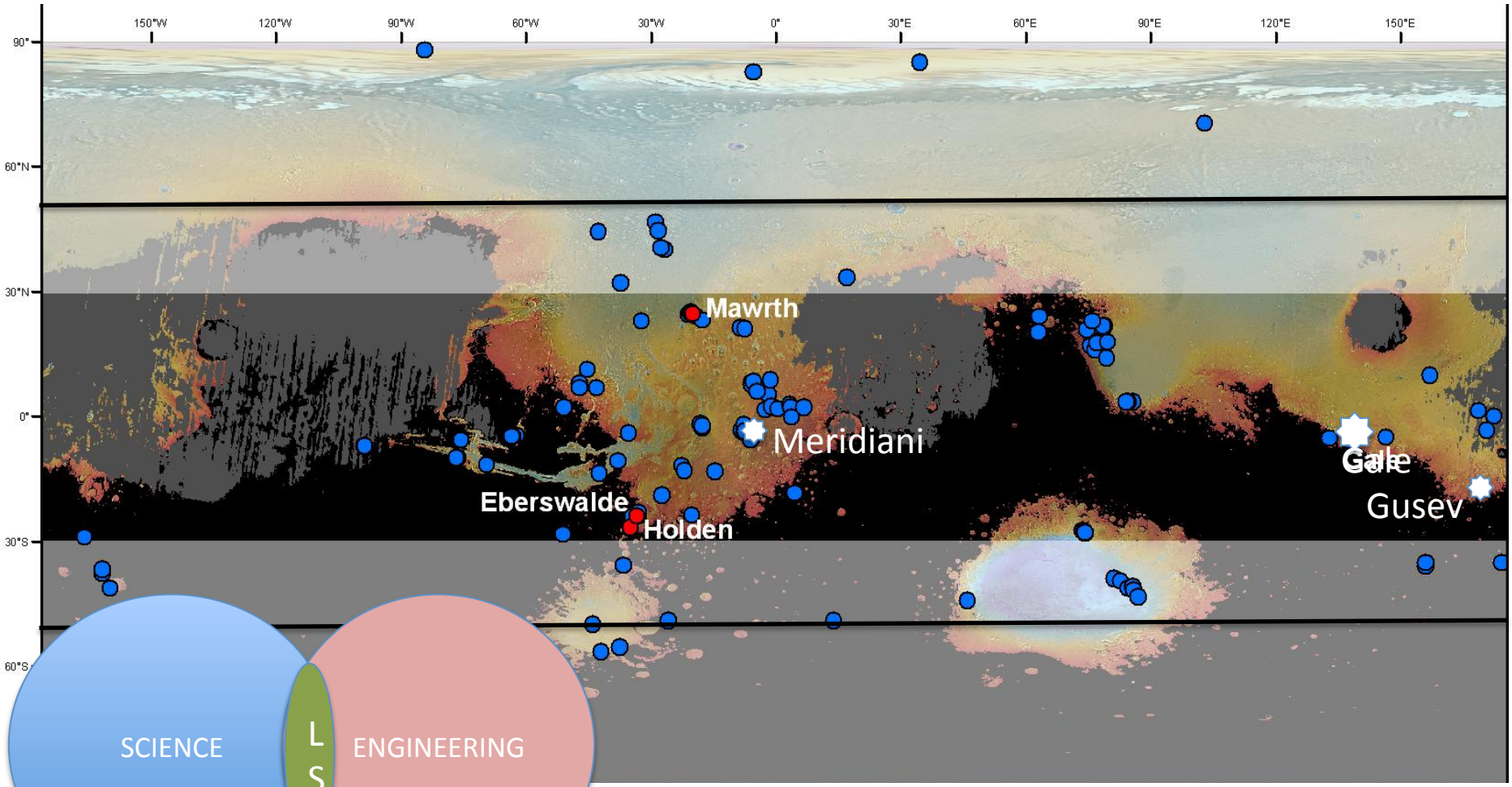
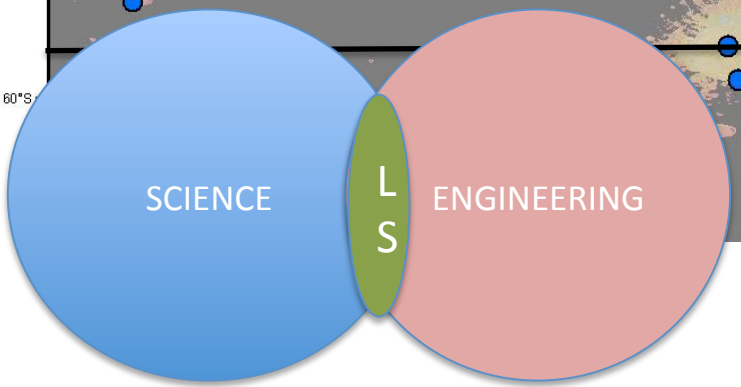
"Go Where You Know"

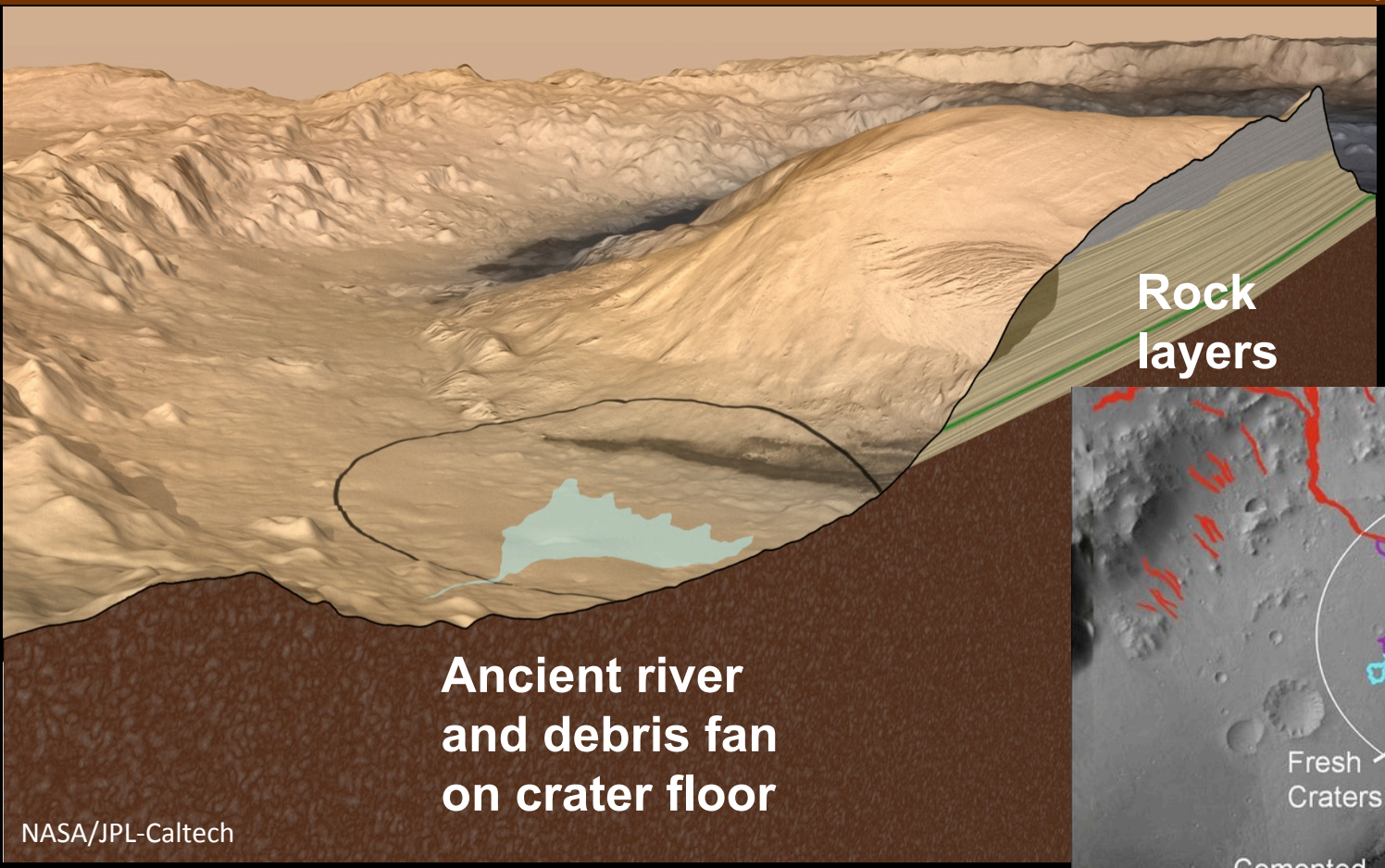




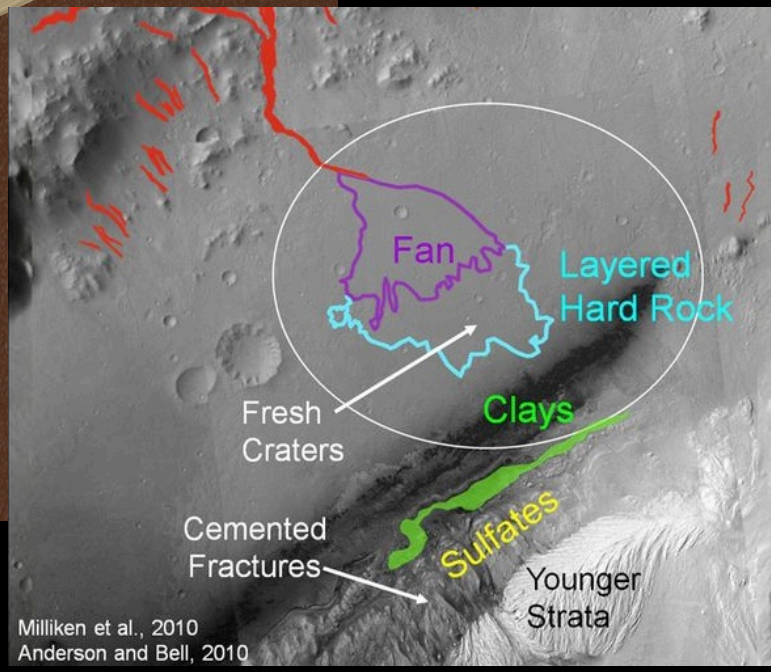
155-km Gale Crater contains a 5-km high mound of stratified rock. Strata in the lower section of the mound are composed of clays and sulfates, while the upper mound is dry, suggesting transition from 'wet' Mars to 'dry' Mars (Late Noachian to Early Hesperian?).

CURIOSITY

Water-Related Geology and Minerals around Mount Sharp

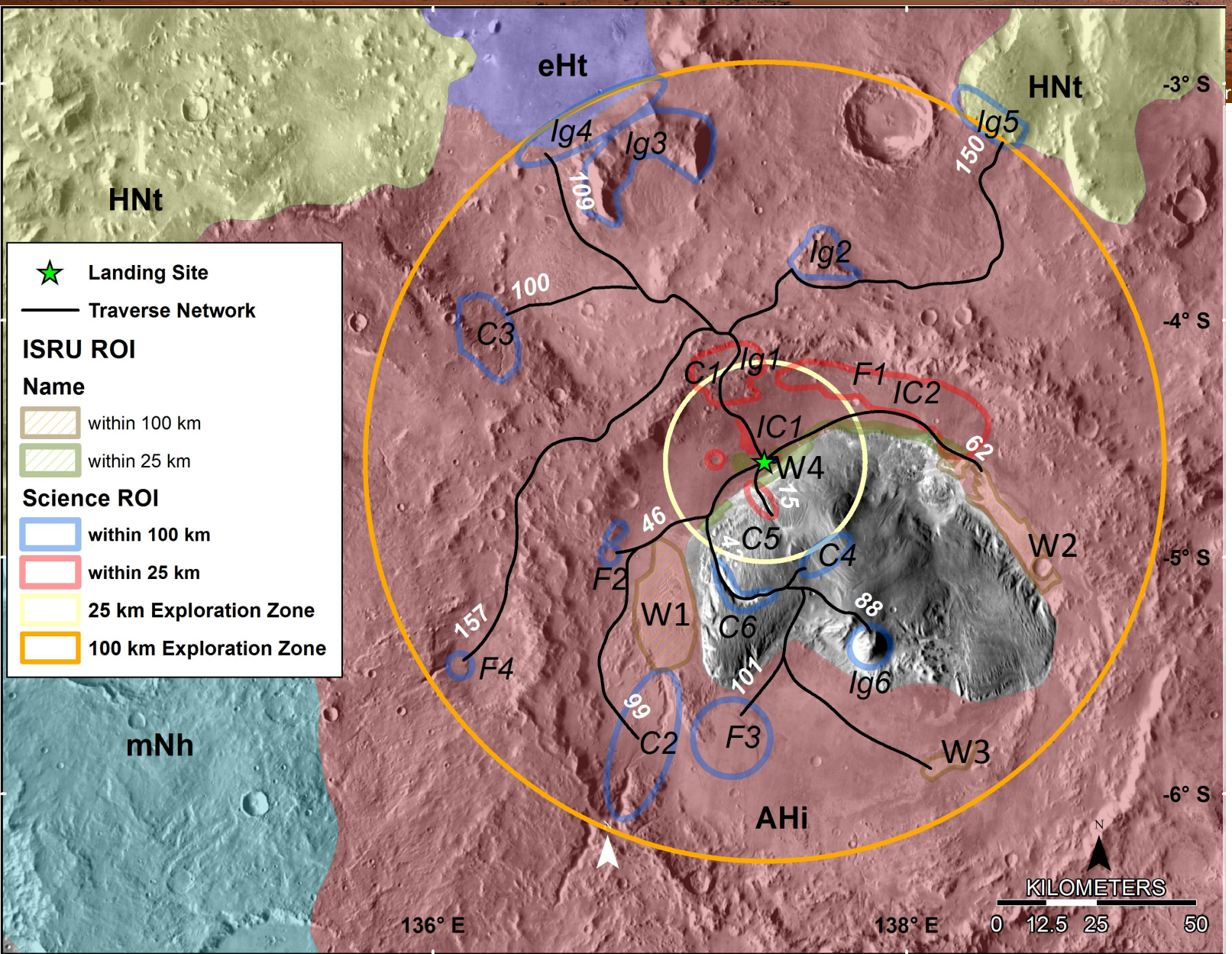


NASA/JPL-Caltech



Milliken et al., 2010
Anderson and Bell, 2010

Gale Crater Exploration Zone



LZ Coordinates

Longitude (E)

137.42009295°

Latitude (S)

4.59310427°

Elevation (MOLA)

-4497.77

Easting

8145534.27 m

Northing

-272254.70 m

Science ROI

C = Channel

F = Fan

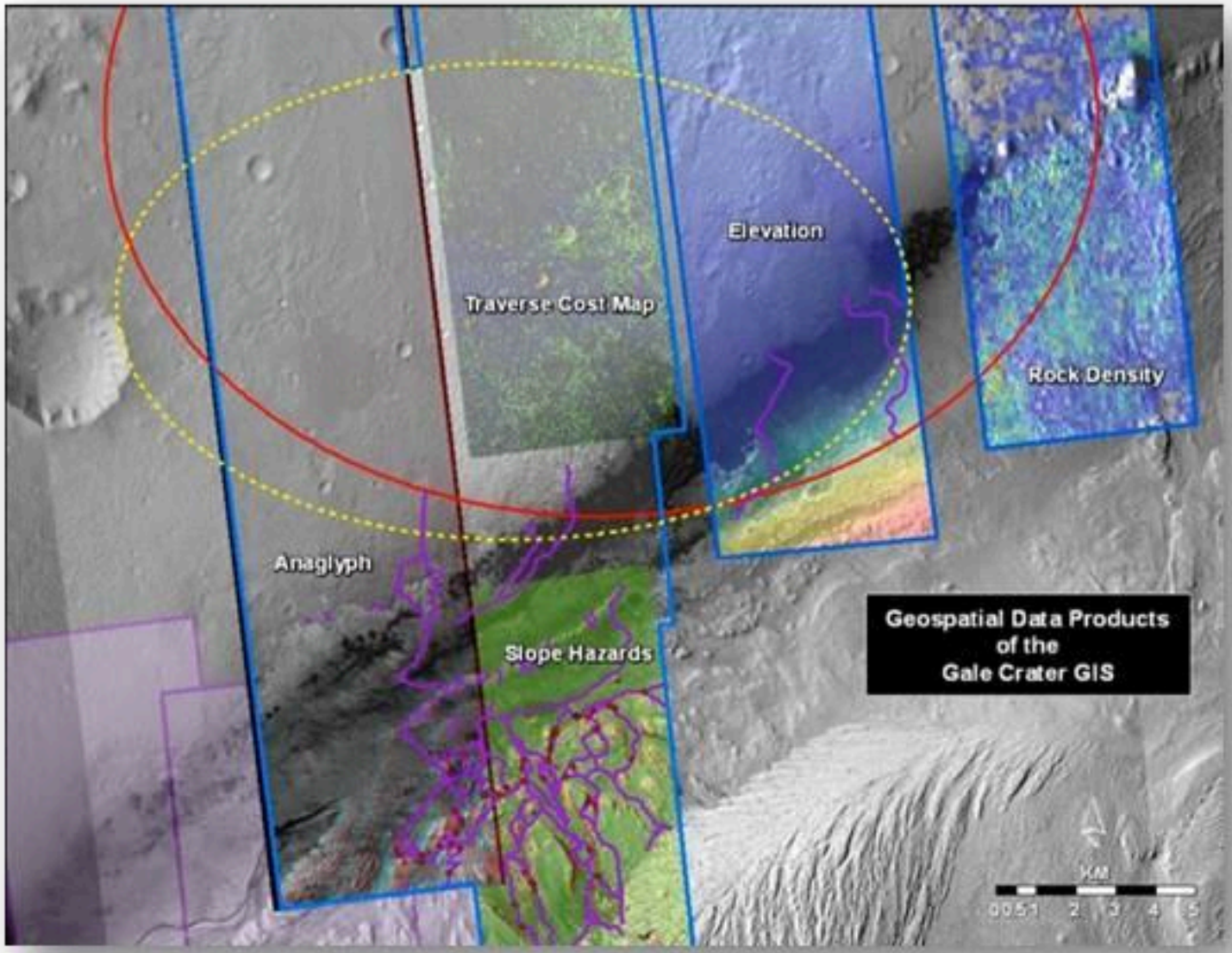
Ig = Igneous

IC = Inverted Channels

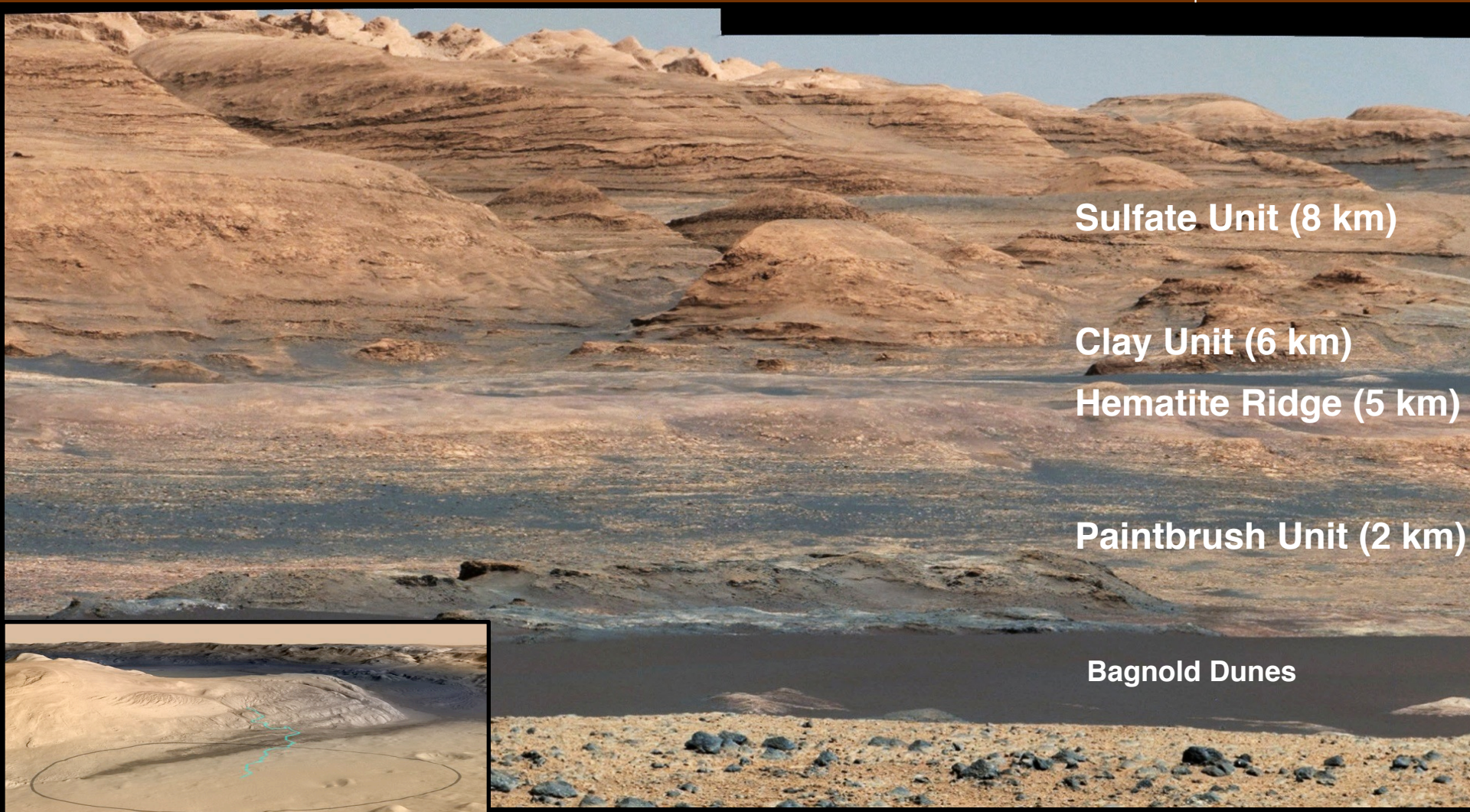
ISRU ROI

W = Water ROI

Multiple Co-Registered Datasets: Slope, Rock Abundance, Hazards

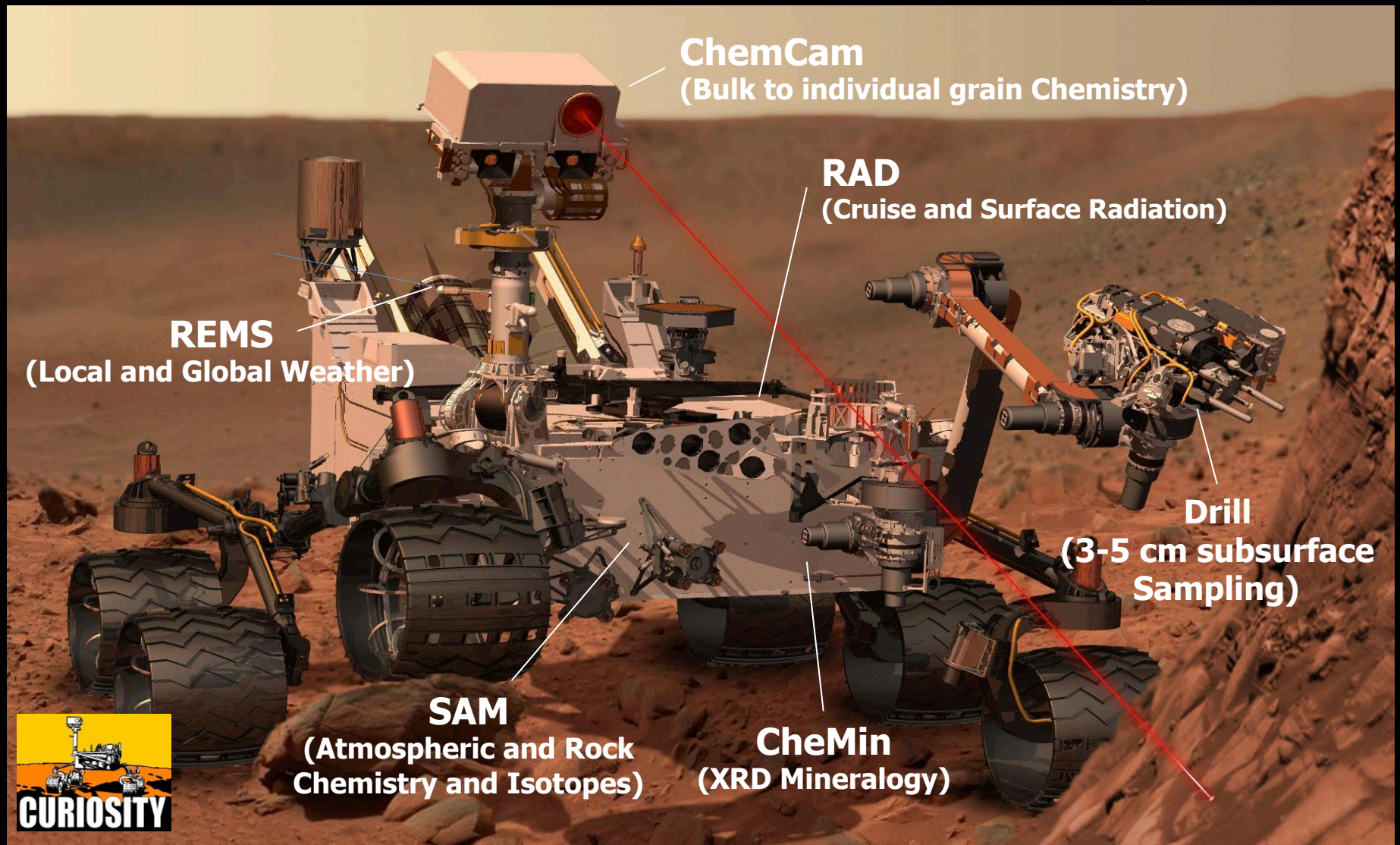


Aeolis Mons (Mt. Sharp) Geology Insitu



NASA/JPL-Caltech/MSSS

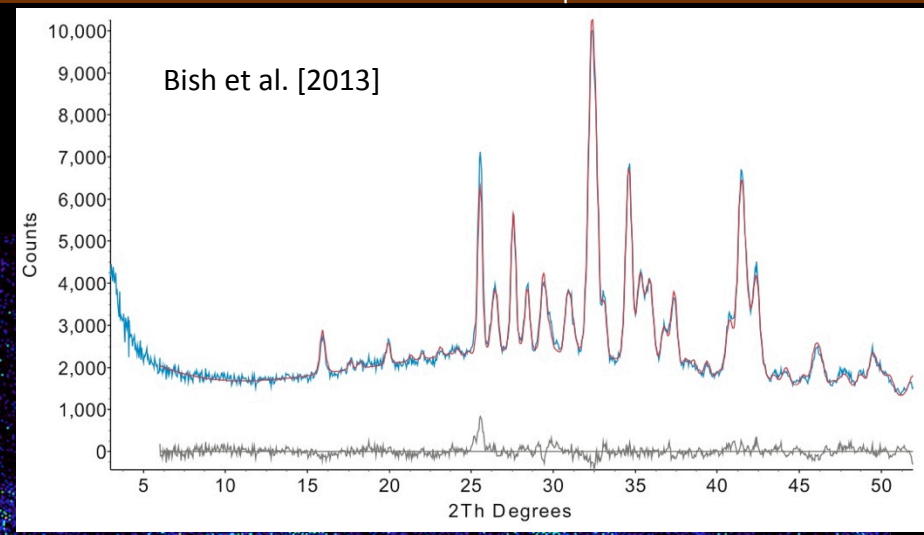
Curiosity's Science Payload Allows Unique Science & ISRU ROI Characterization

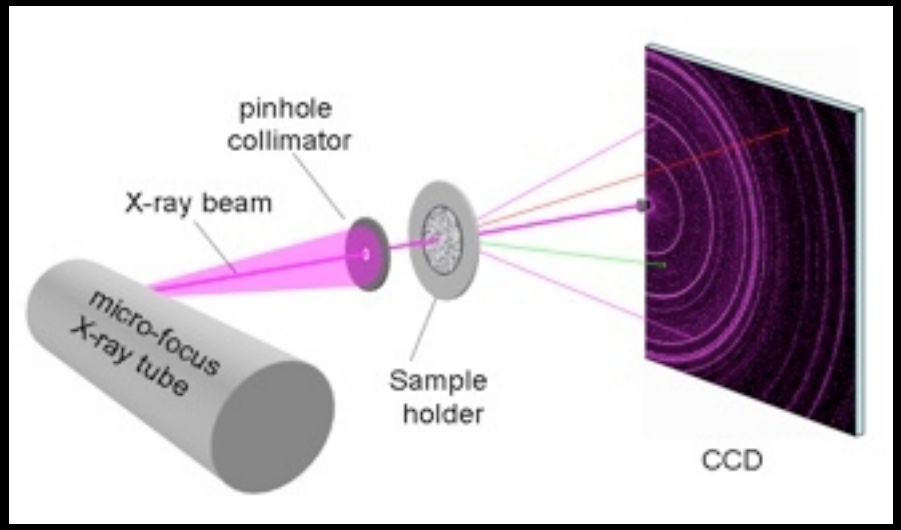


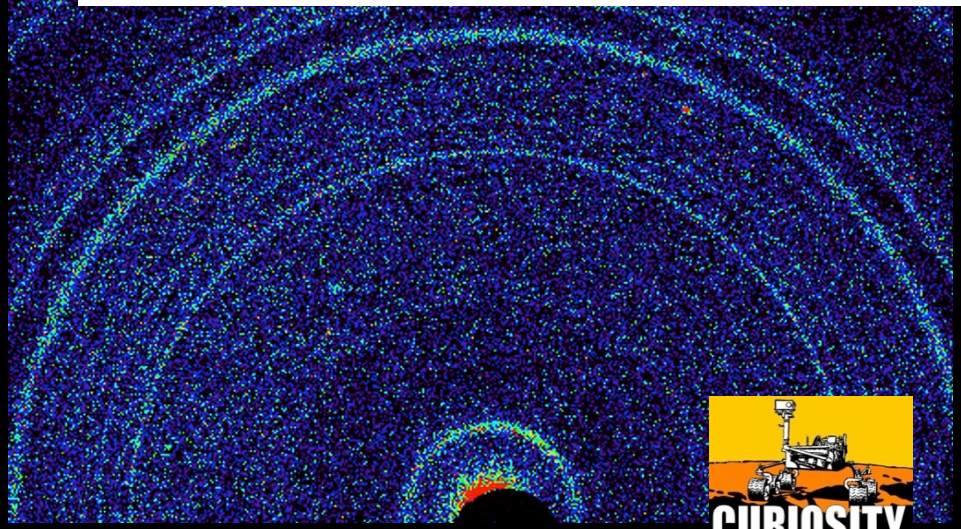
Rocknest sand has a typical Mars basalt composition, but also 1.5-3% bound water. Both a water and food growth medium.

Rocknest sand is composed of unaltered basaltic minerals, typical of rocks and soils on Mars

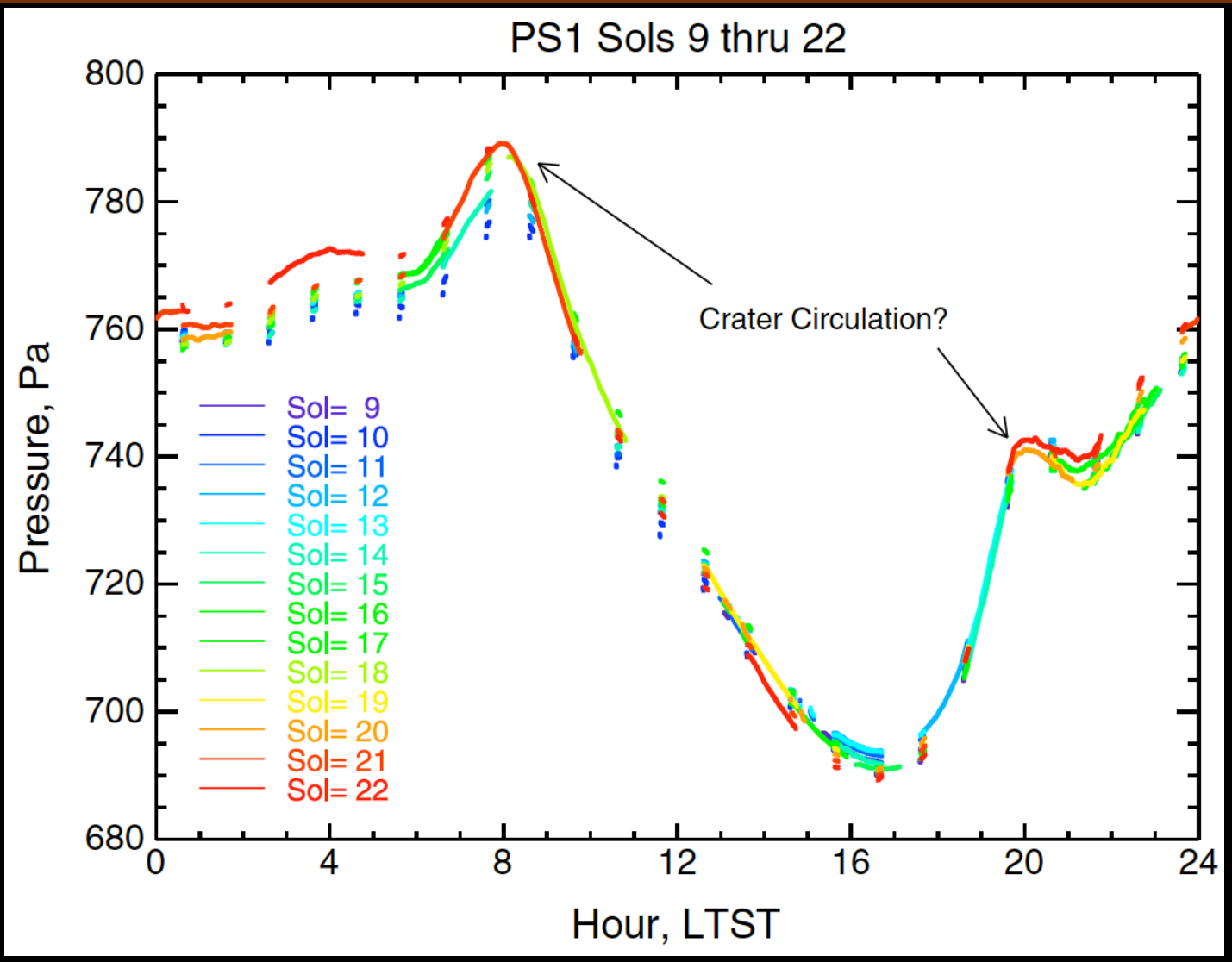
Samples also contained 30-45% non-crystalline material, containing volatiles, sulfur, calcium, and perhaps nanophase ferric oxide.







REMS pressure measurements reveal local, mesoscale, and planetary phenomena



REMS takes hourly measurements with occasional 1-Hz extended sessions

Daytime convective vortices are present, but no dust devils have been observed

Diurnal thermal tides (left) are amplified and modified by the crater topography

The CO_2 pressure cycle at Gale also has components due to elevation and planetary circulations

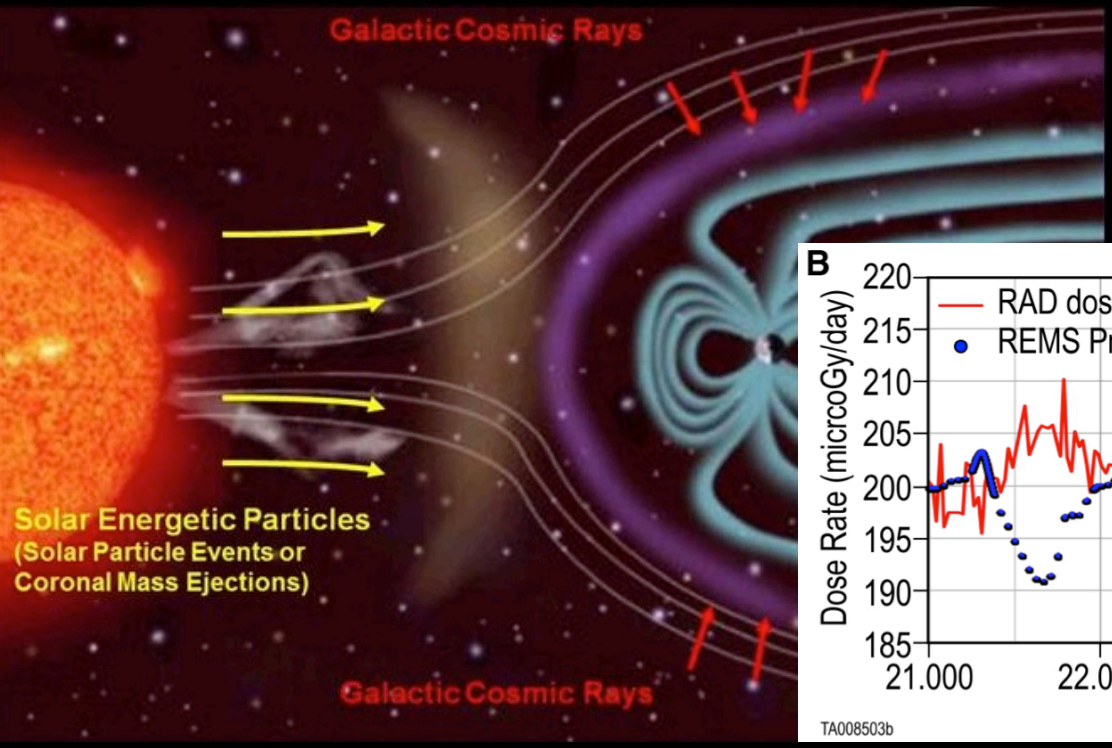
CURIOSITY

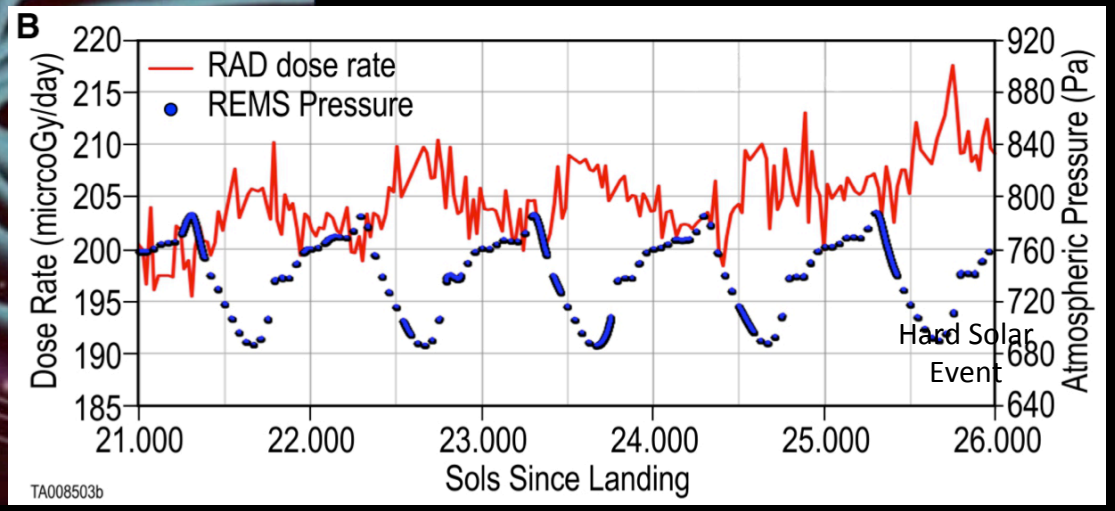
The RAD instrument measured the radiation flux from both galactic cosmic rays and solar energetic particles, in cruise and at Mars' surface.

The surface dose rate is about half that measured in cruise

A crewed mission would receive ~1 Sievert of exposure in a trip to Mars with 500 sols on the surface

[Hassler et al., 2014]





Curiosity's Radiation Assessment Detector measures high-energy radiation

Atmospheric Gas Abundances Measured by SAM

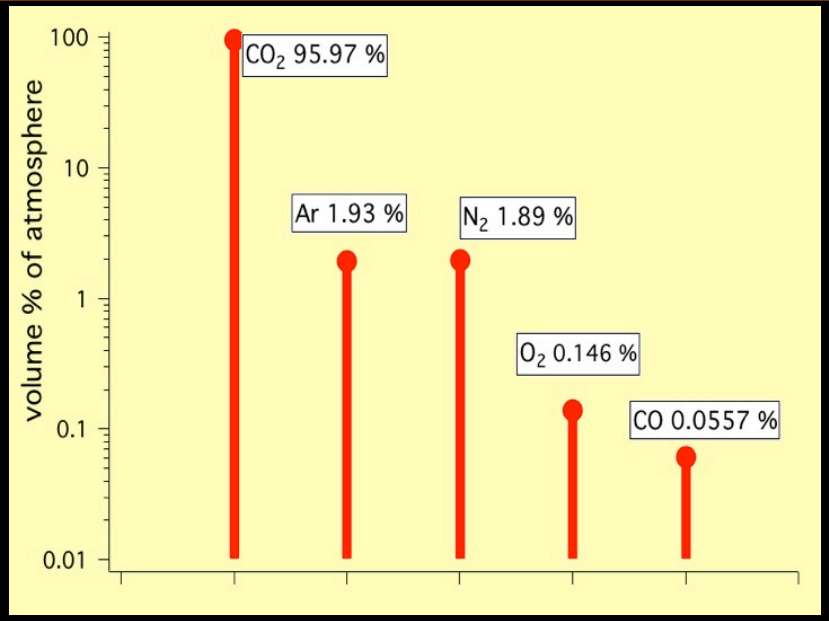
SAM also found that Mars' atmosphere is enriched in the heavy versions of isotopes, indicating massive atmospheric loss to space

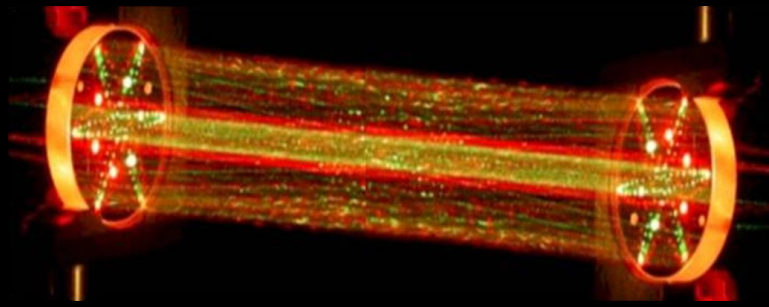
$\delta^{13}C = 46 \pm 4$ per mil

$\delta D = 4950 \pm 1080$ per mil

$^{40}Ar/^{36}Ar = 1900 \pm 300$

Methane HAS been definitively detected
Upper limit = ~7 ppb

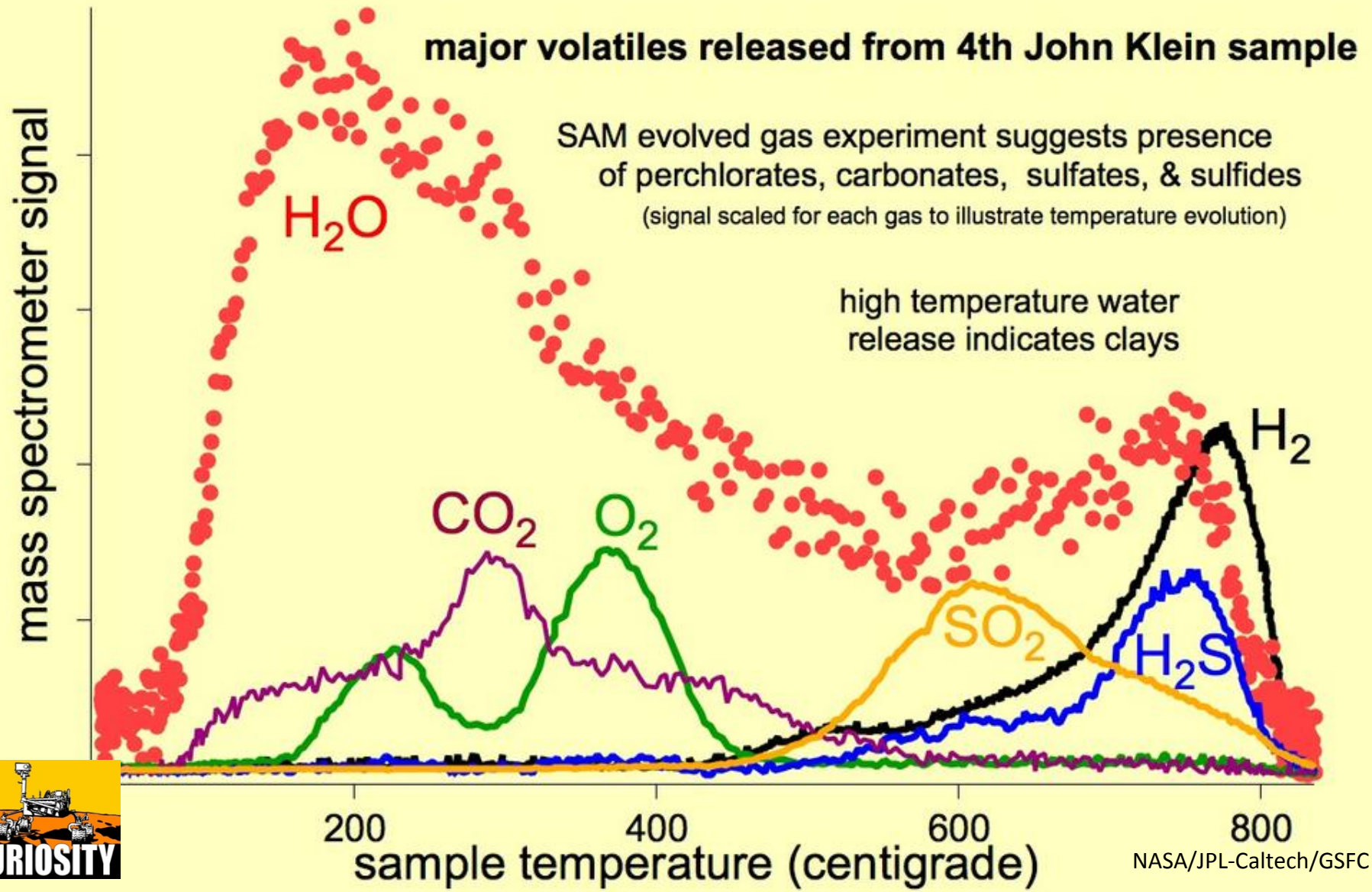




SAM found that argon, rather than nitrogen is the second most abundant gas

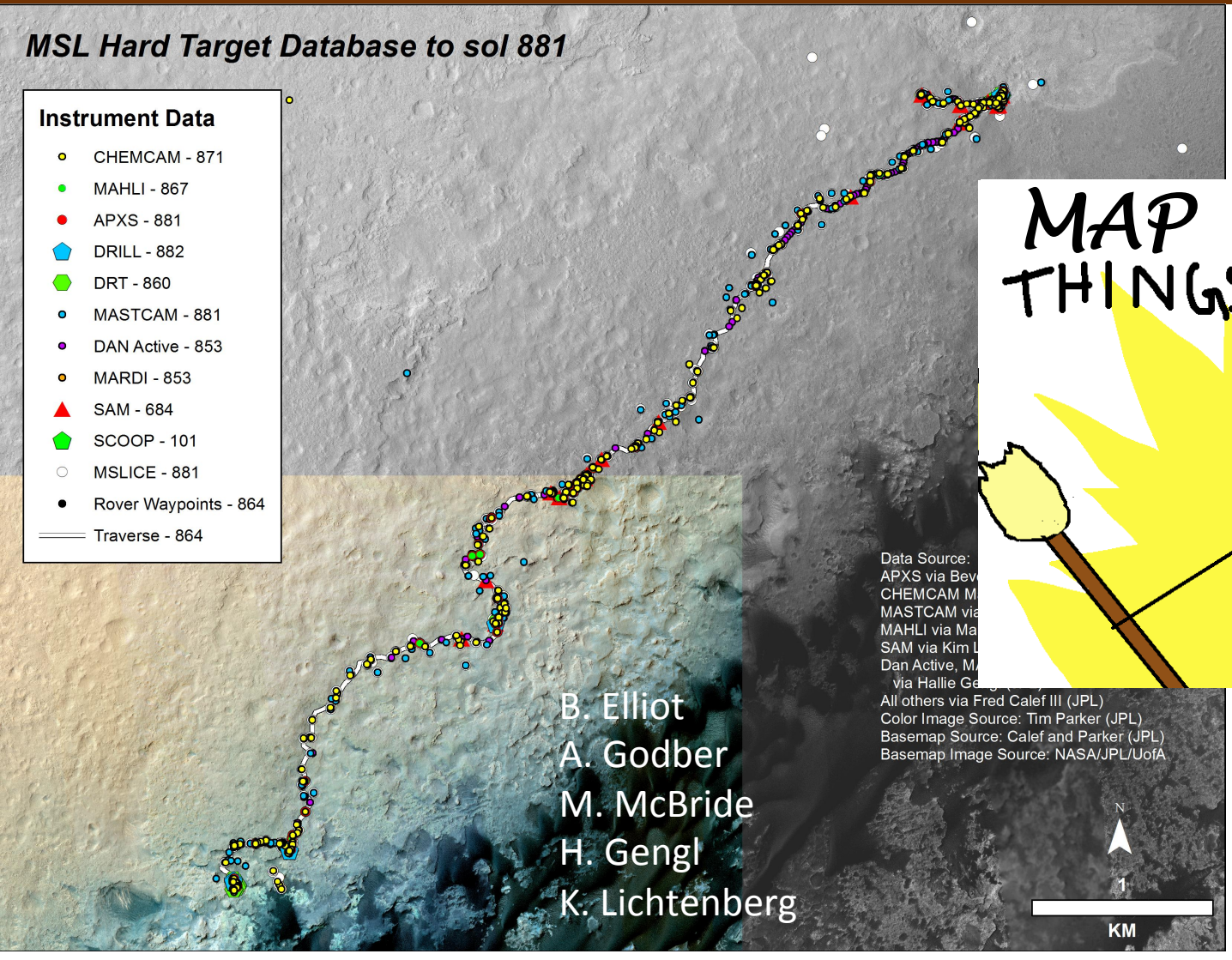
CURIOSITY

Major gases released from John Klein sample and analyzed by SAM



NASA/JPL-Caltech/GSFC

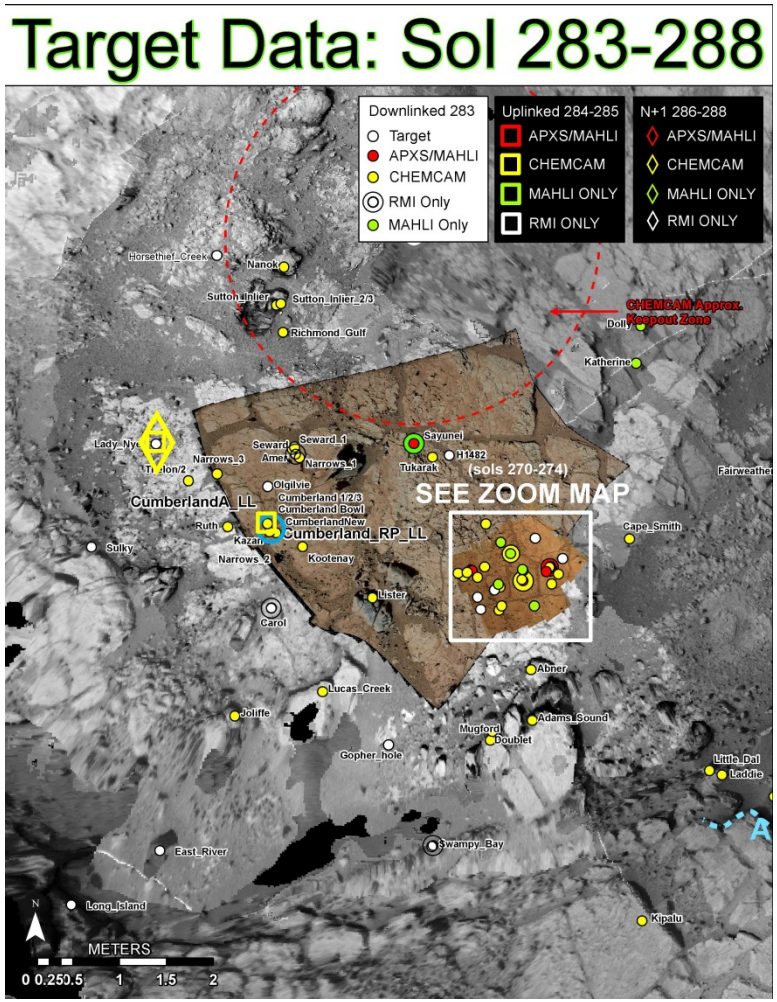
Tracking Science Observations

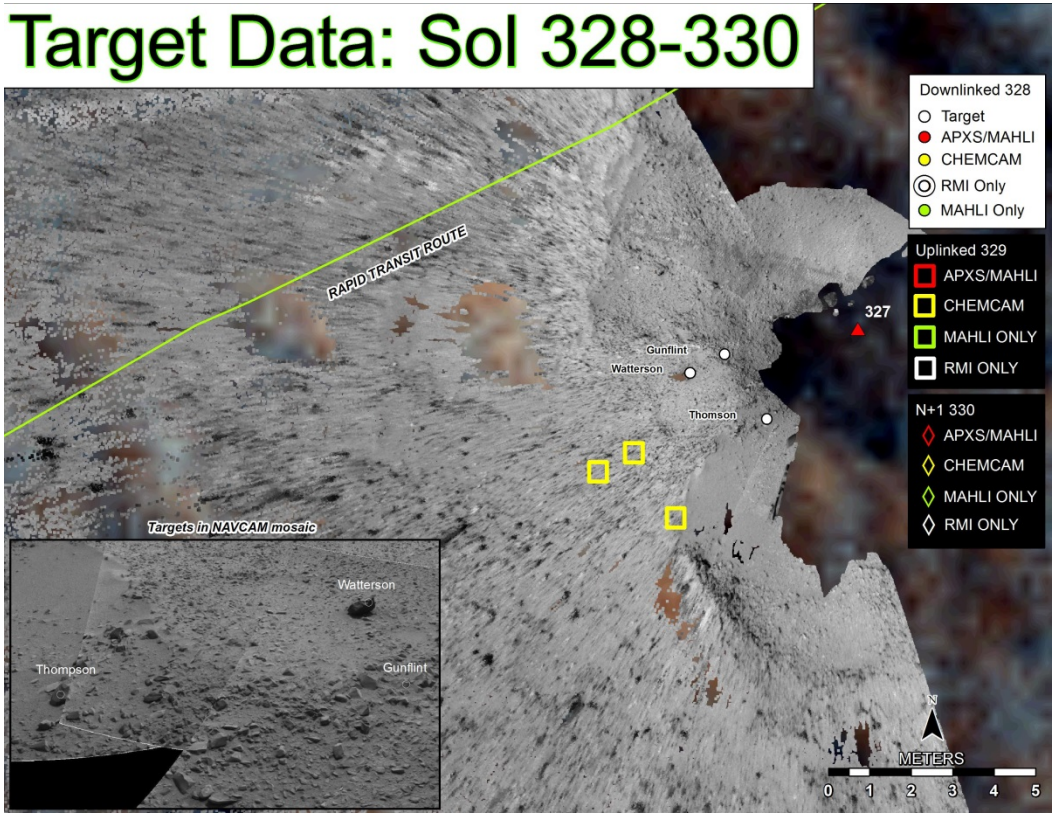


B. Elliot
A. Godber
M. McBride
H. Gengl
K. Lichtenberg

http://hyperboleandahalf.blogspot.com/2010/06/this-is-why-ill-never-be-adult.html

Example Target Map from MSL Operations

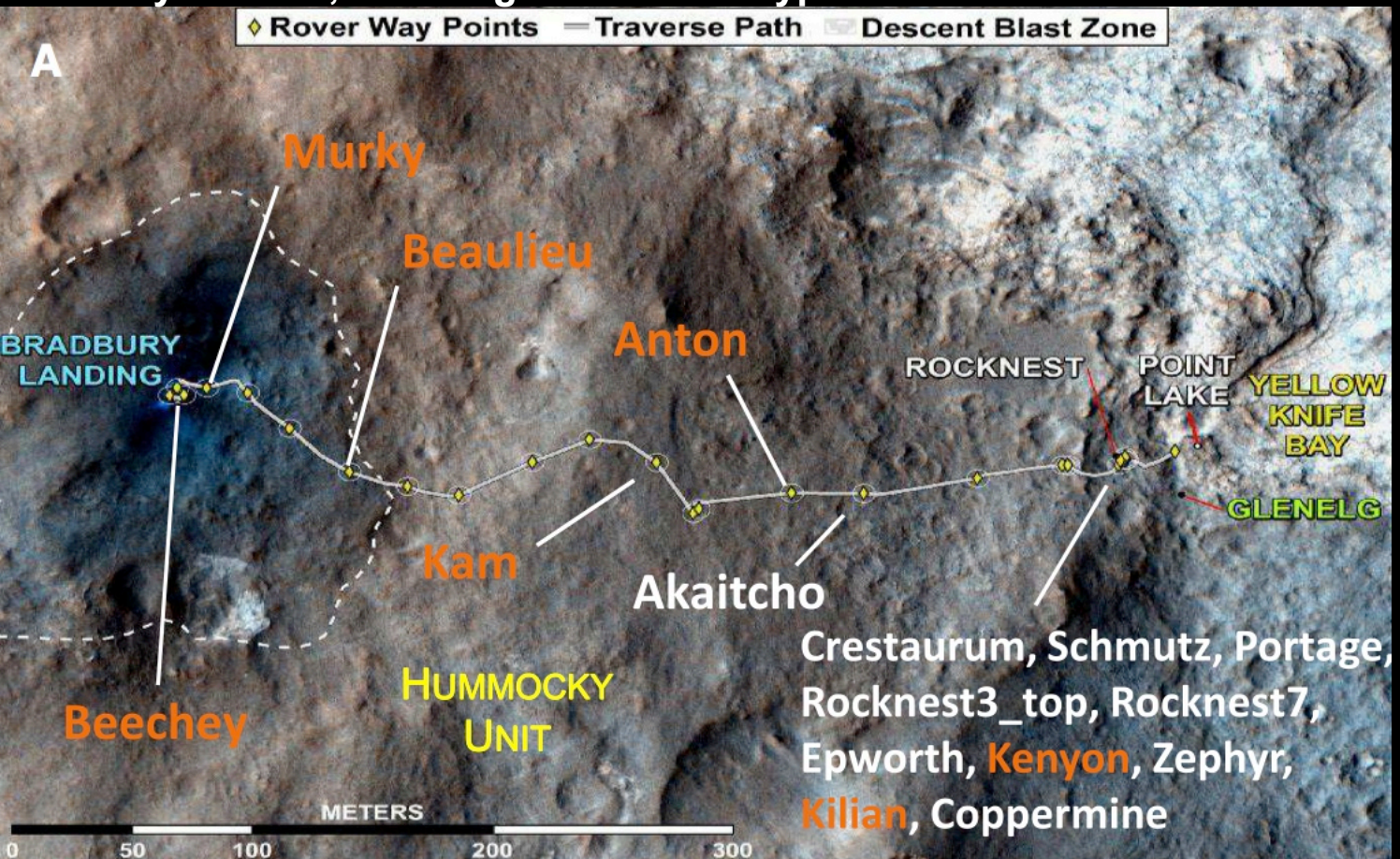




Felsic vs. Mafic ISRU Source Areas

ChemCam identified two principal soil types along the traverse to Yellowknife Bay: a fine-grained, mafic type similar to other soils, and a locally derived, coarse-grained felsic type.

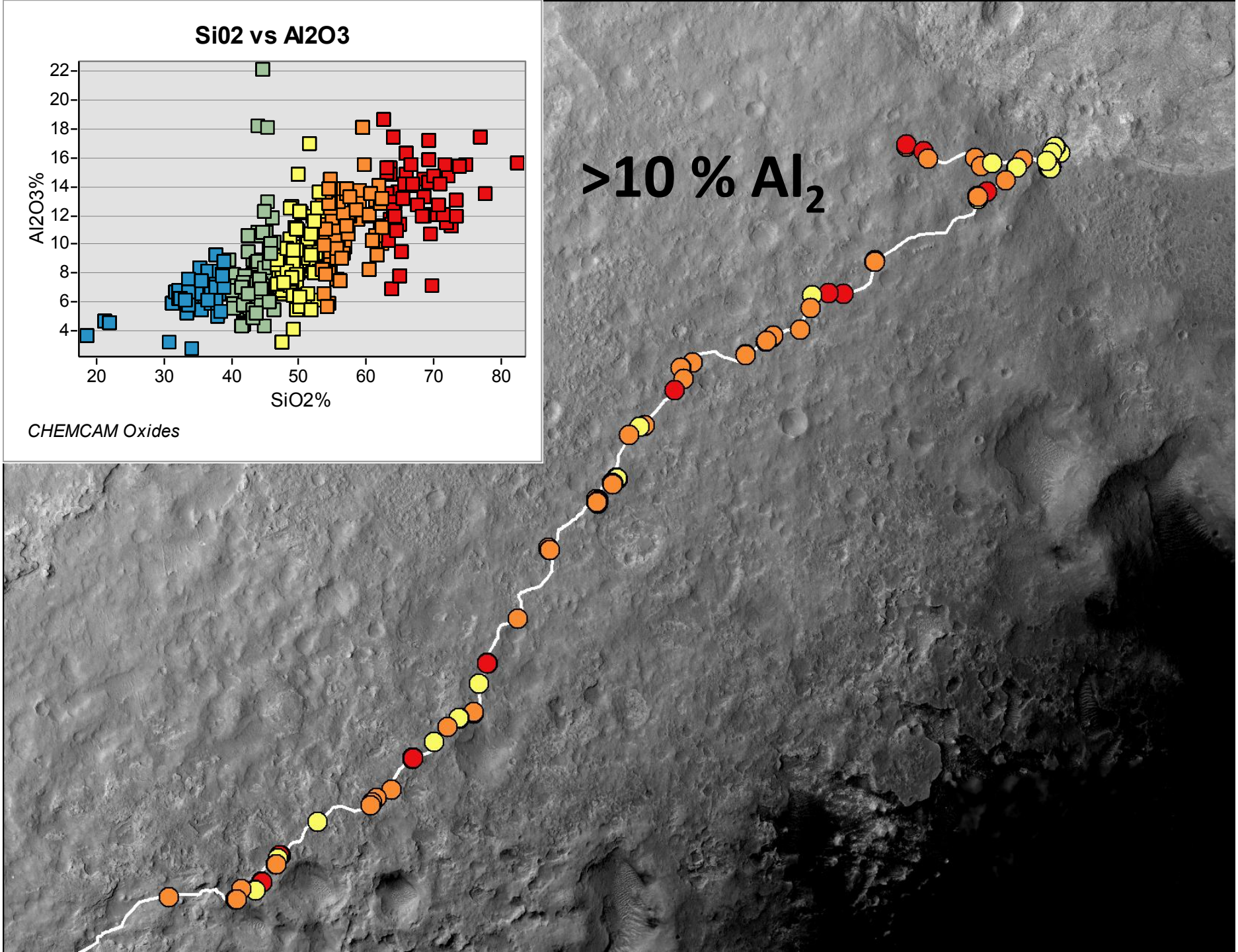
Mafic soil component has hydration signature, corresponding to the X-ray amorphous component sampled by CheMin and SAM.

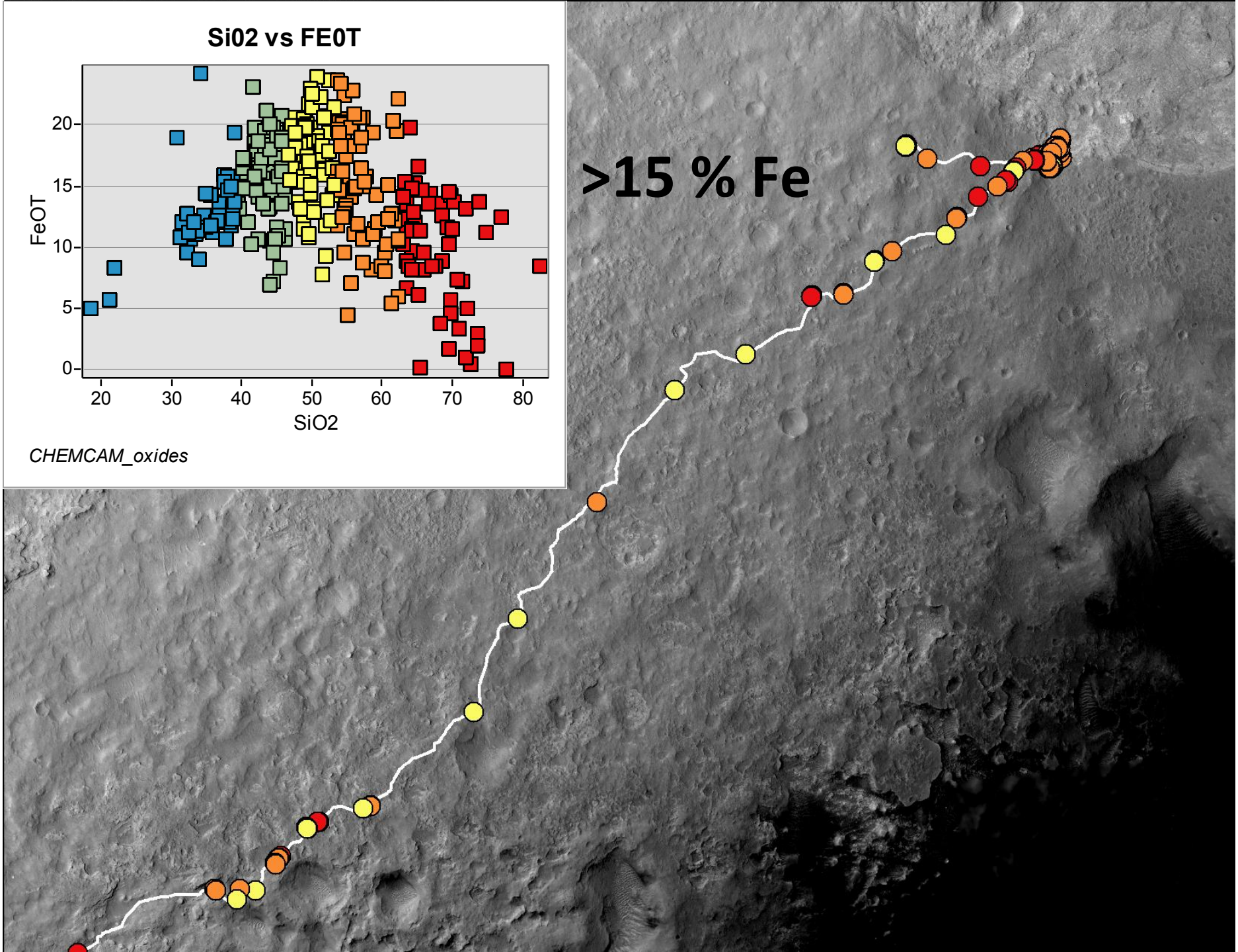


Meslin et al. [2013]

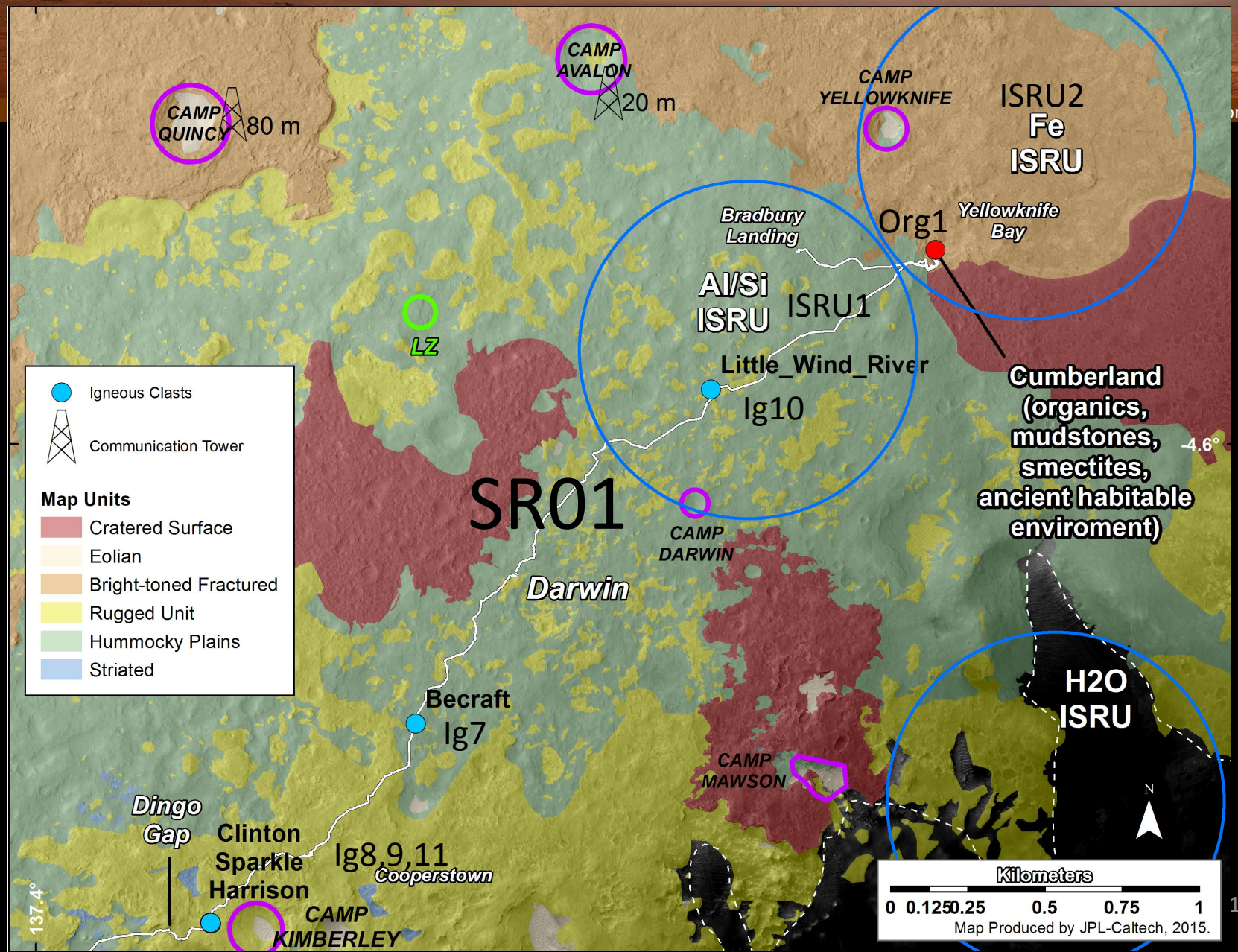
Mafic

Felsic

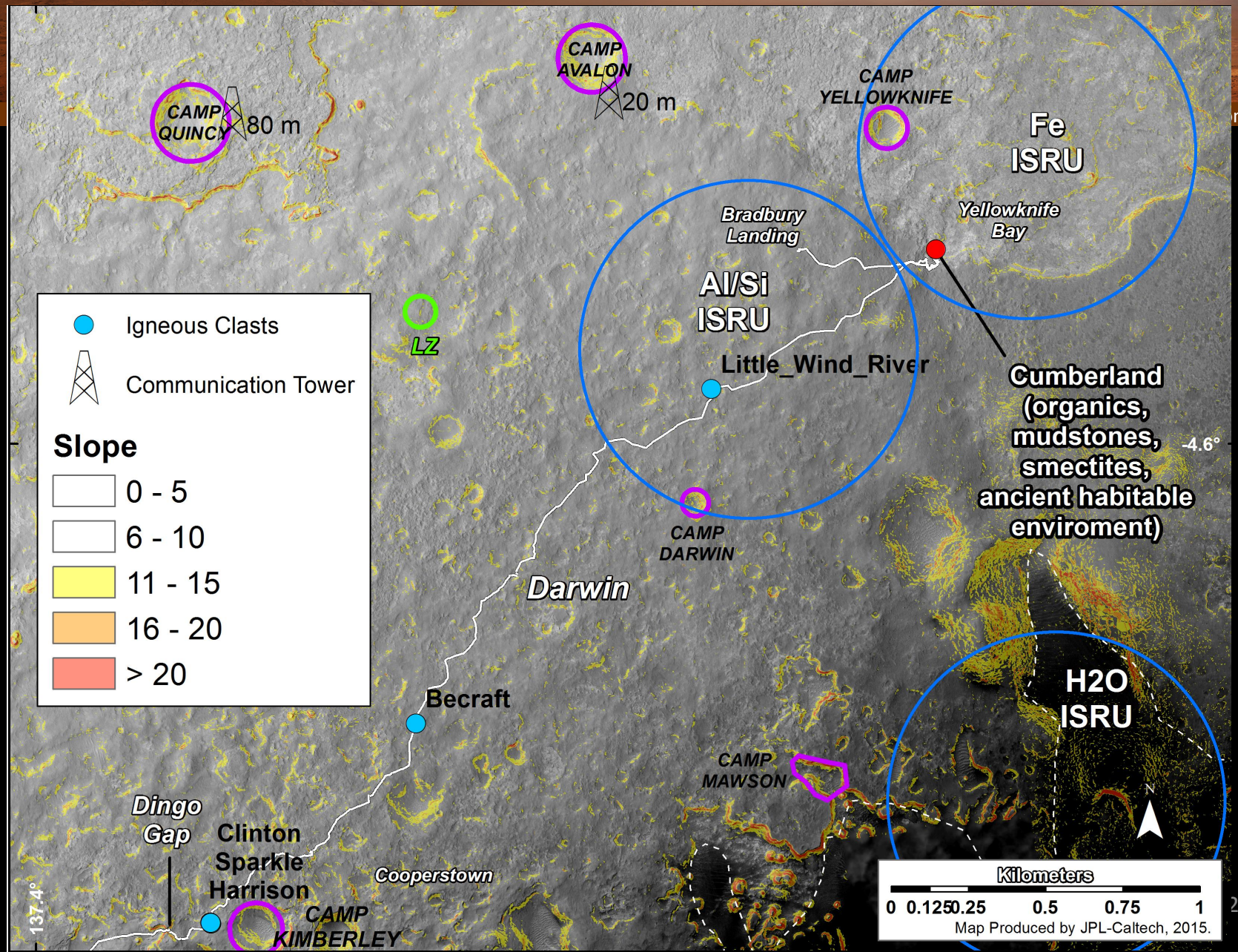

Si02 vs Al2O3
Al2O3%
SiO2%
22
20
18
16
14
12
10
8
6
4
20
30
40
50
60
70
80
CHEMCAM Oxides
>10 % Al2


Si02 vs FE0T
FeOT
SiO2
0
5
10
15
20
20
30
40
50
60
70
80
CHEMCAM_oxides
>15 % Fe

1st Mission Exploration Zone



1st Mission Exploration Zone



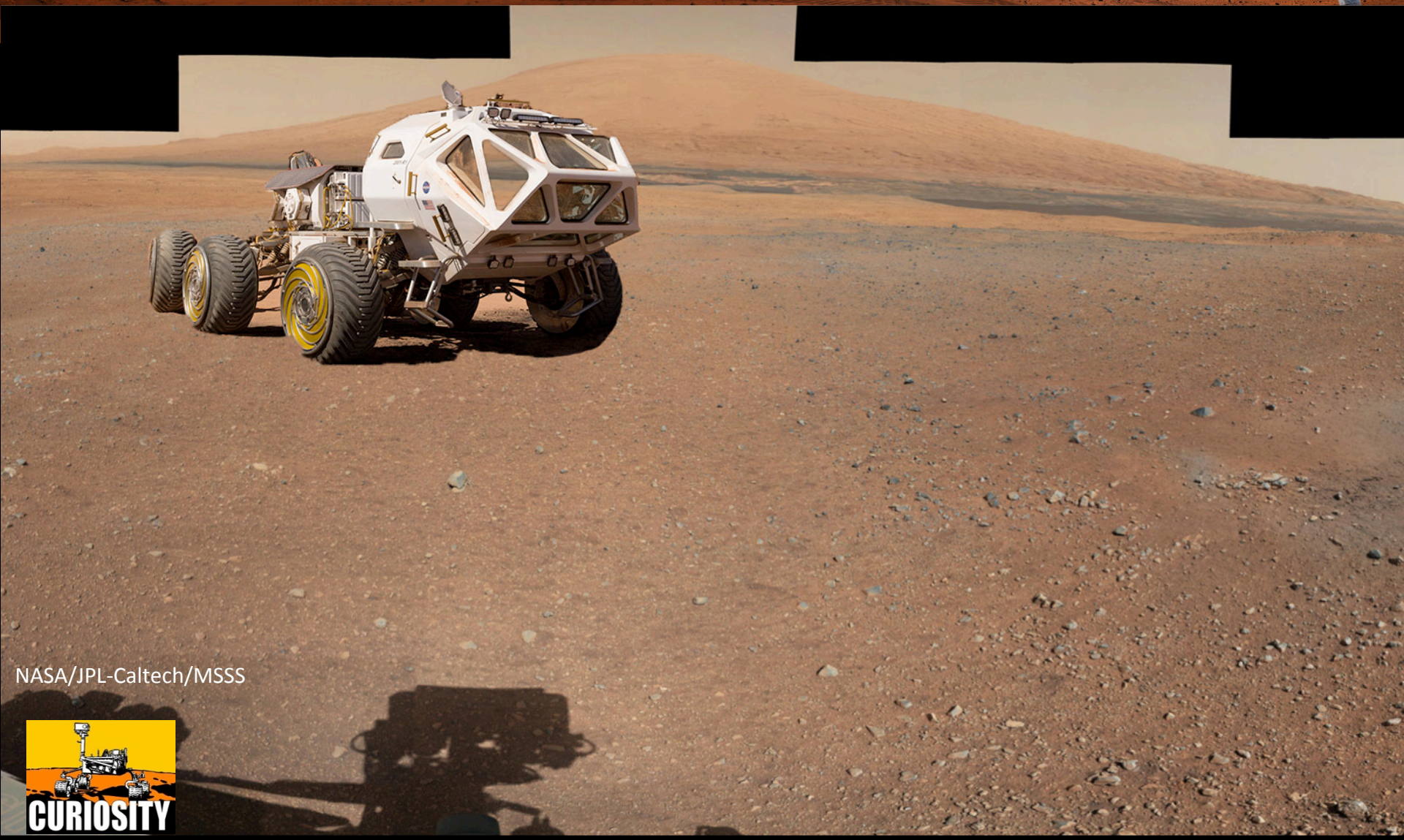
ISRU Resource Numbers: Water

- Water
  - Based on Leshin et al. (2013), Rocknest sands contained up to 3 wt% H_2O via SAM, Bagnold Dune field contains 10^4-10^6 MT **adsorbed** water.
  - Easy to process. Potentially 'reuseable'.

ISRU Resource Numbers: Metals

- Aluminum and Silicon
  - ISRU01 rocks on average have ~12 wt% Al and ~55-60 wt% Si. ISRU02 rocks, ~18 wt% Fe.
  - Assuming rock density ~2.5 gm/cc:
    - 300 kg/m^3 Al (ISRU01)
    - 1375-1500 kg/m^3 Si (ISRU01)
    - 450 kg/m^3 Fe (ISRU02)

What it looks like at the (human) landing site…



Building material and ISRU Al/Si Resource
Rounded pebbles and sand in the conglomerate
"Link"

NASA/JPL-Caltech/MSSS

CURIOSITY

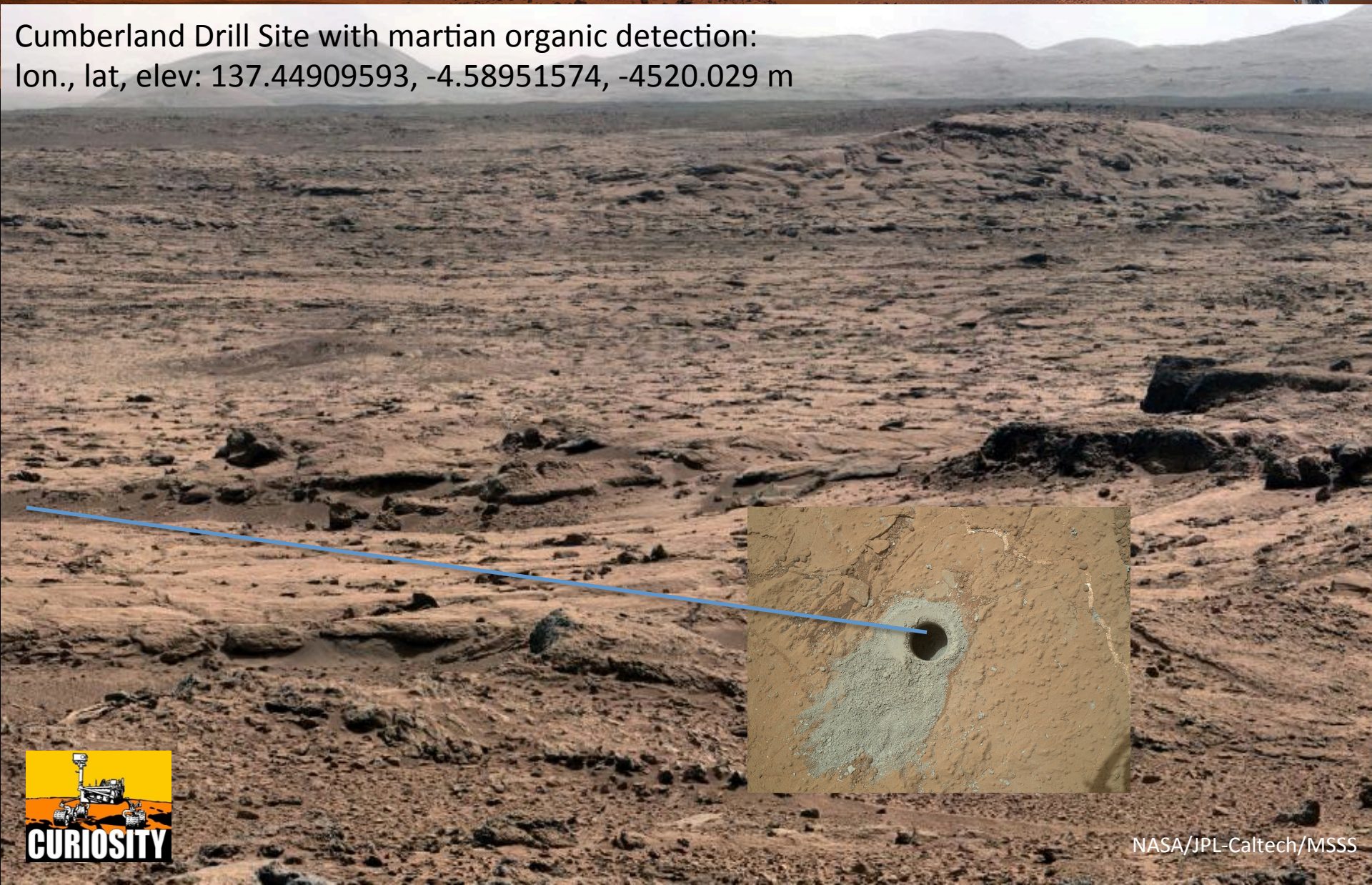
Large feldspar-rich crystals (phenocrysts) in an igneous clast (Harrison)

SRIg09 Harrison (lat, lon, elev)
-4.62617745, 137.40955945, -4489.114 m

S

CURIOSITY

Science ROI: Yellowknife Bay for Organics and Lake sediments (Sheepbed Mudstones)



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

NASA/JPL-Caltech/MSSS

How Close are Distal Science ROIs

RUBRICS

Science ROI(s) Rubric

Site Factors					SRIg01-06	SRIg07-11	SRIC01-02	SROrg1	SRF01-04	SRC01-06	SR01	EZ SUM
Science Site Criteria	Astrobio	Threshold	AND/OR	Potential for past habitability			○	●	●			5,1
				Potential for present habitability/refugia							○	0,1
		Qualifying		Potential for organic matter, w/ surface exposure			○	●	○	○		1,11
	Atmospheric Science	Threshold		Noachian/Hesperian rocks w/ trapped atmospheric gases				●	●		●	6,0
		Qualifying		Meteorological diversity in space and time							●	1,0
				High likelihood of surface-atmosphere exchange							●	1,0
				Amazonian subsurface or high-latitude ice or sediment								
				High likelihood of active trace gas sources							○	0,1
	Geoscience	Threshold		Range of martian geologic time; datable surfaces	●	●			●	●		21, 0
				Evidence of aqueous processes			●	●	●	●		13, 0
				Potential for interpreting relative ages	●	●	●	●	●	●		20, 0
		Qualifying		Igneous Rocks tied to 1+ provinces or different times	●	●						11, 0
				Near-surface ice, glacial or permafrost								
				Noachian or pre-Noachian bedrock units	●	●	?					11, 0
				Outcrops with remnant magnetization	○	○						0, 11
				Primary, secondary, and basin-forming impact deposits							●	1, 0
				Structural features with regional or global context	●	●		●			●	13, 0
				Diversity of aeolian sediments and/or landforms							●	1, 0

Key	
●	Yes
○	Partial Support or Debated
	No
?	Indeterminate

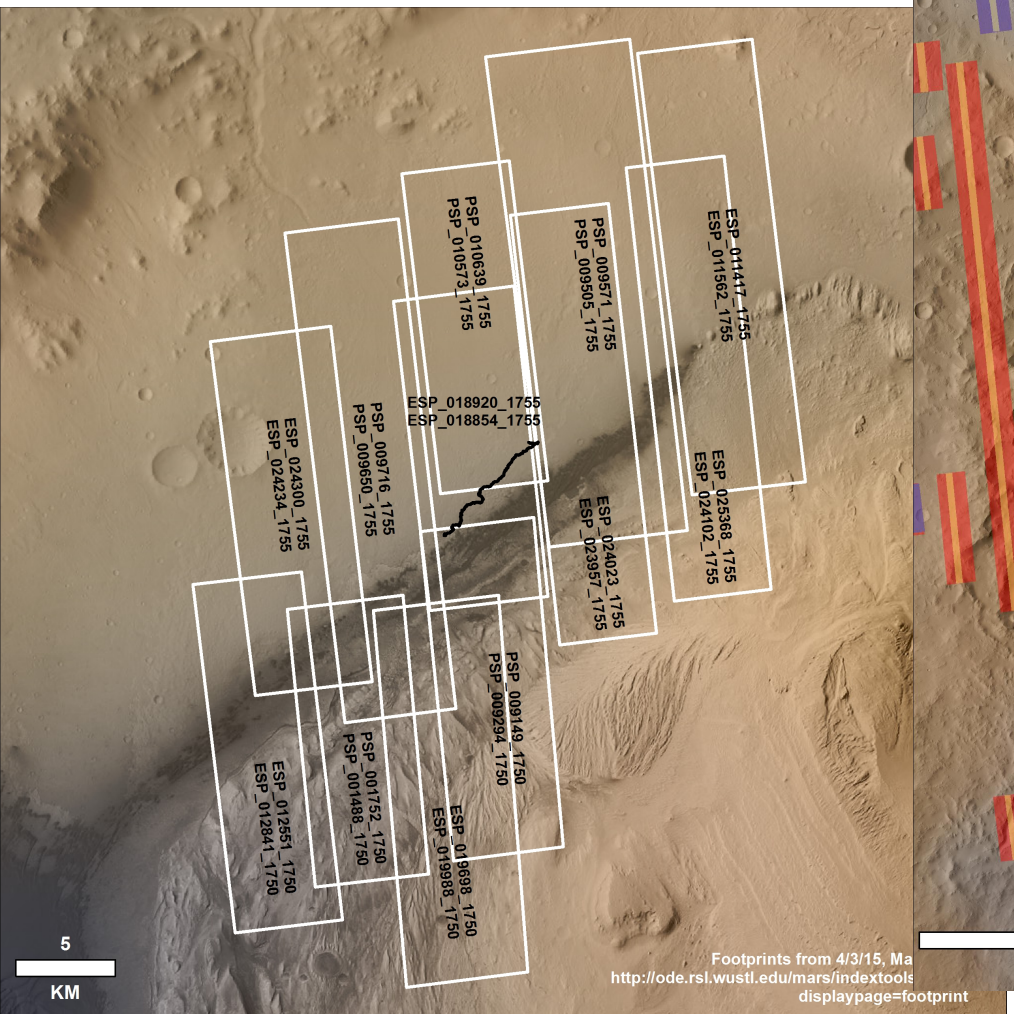
Resource ROI(s) Rubric

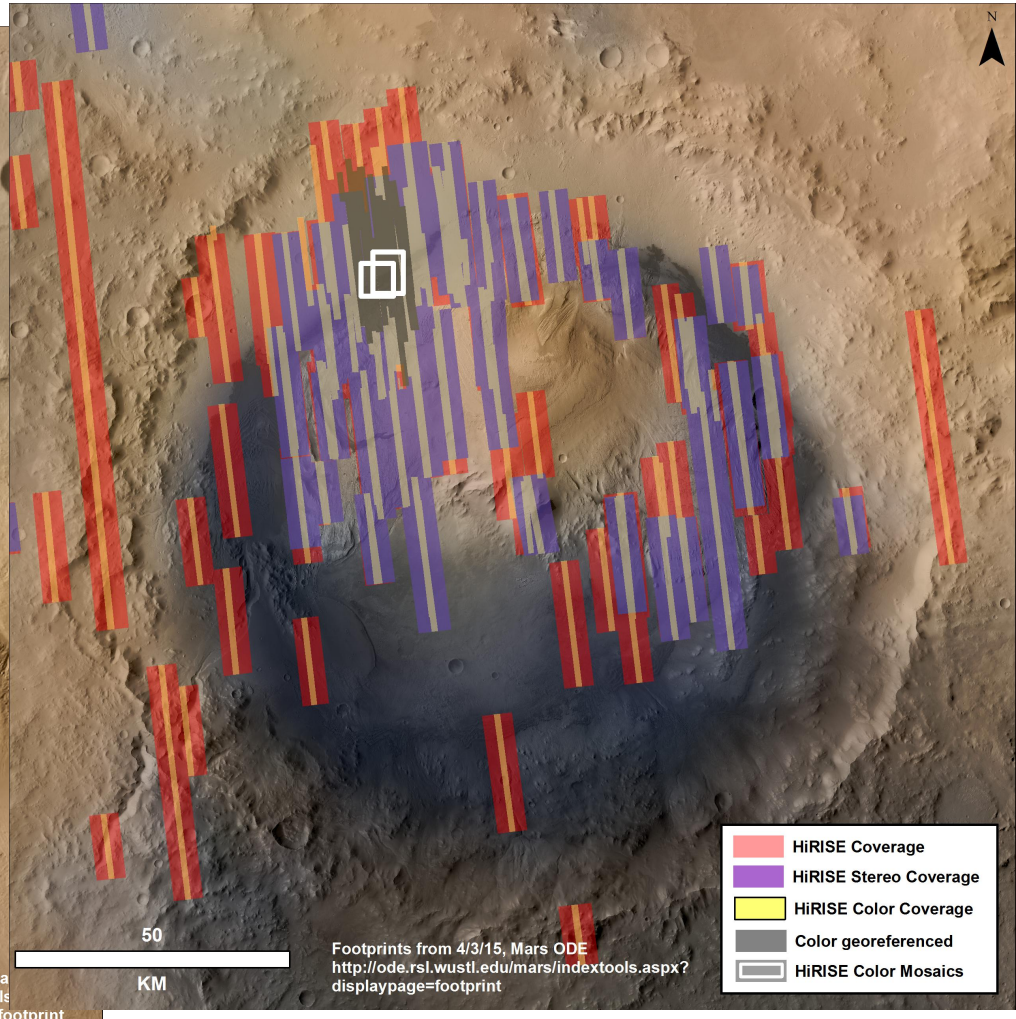
ISRU and Civil Engineering Criteria			Site Factors	RW01-04	RISUR1	LZ01	ISRU2					EZ SUM
	Engineering		Meets First Order Criteria (Latitude, Elevation, Thermal Inertia)			●						1
	Water Resource	Threshold	AND/OR **Potential for ice or ice/regolith mix**									
			Potential for hydrated minerals	●								4
			Quantity for substantial production	●								4
			Potential to be minable by highly automated systems	●								4
			Located less than 3 km from processing equipment site	●								1
			Located no more than 3 meters below the surface	●								4
			Accessible by automated systems	●								4
		Qualifying	Potential for multiple sources of ice, ice/regolith mix **and** hydrated minerals									
			Distance to resource location can be >5 km	●								3
			Route to resource location must be (plausibly) traversable	●								3
	Civil Engineering	Threshold	**~50 sq km region of flat and stable terrain with sparse rock distribution**			●						1
			1–10 km length scale: <10°			●						1
			Located within 5 km of landing site location			●						1
		Qualifying	Located in the northern hemisphere			○						0, 1
			Evidence of abundant cobble sized or smaller rocks and bulk, loose regolith			●						1
			Utilitarian terrain features			●						1
	Food Production	Qualifying	Low latitude			●						1
			No local terrain feature(s) that could shadow light collection facilities			●						1
			Access to water			●						1
			Access to dark, minimally altered basaltic sands			●						1
	Metal/Silicon Resource	Threshold	**Potential for metal/silicon**		●		●					2
			Potential to be minable by highly automated systems		●		●					2
			Located less than 3 km from processing equipment site		●		●					2
			Located no more than 3 meters below the surface		●		●					2
			Accessible by automated systems									
		Qualifying	Potential for multiple sources of metals/silicon		●		●					2
			Distance to resource location can be >5 km		●		●					2
			Route to resource location must be (plausibly) traversable		●		●					2

Key	
●	**Yes**
○	**Partial Support or Debated**
	No
?	**Indeterminate**

DATA NEEDS

Gale HiRISE Coverage





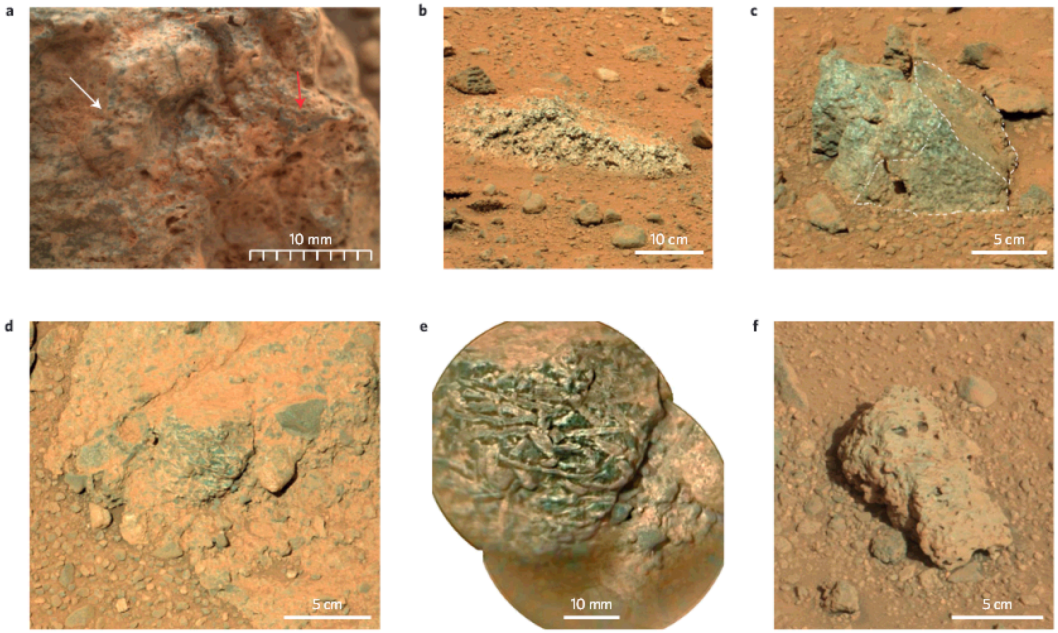
Highest Priority EZ Data Needs

- HiRISE Stereo of traverse exiting Gale crater to the north via Peace Vallis.
- CTX and/or HiRISE Stereo along traverse route outside Gale crater to potential volcanic unit.

[in order of priority: addressing threshold first, then qualifying]

SCIENCE ROIs

Science ROI: Dateable Rocks SRIg07-11



- SRIg07 Becraft (lat,lon)

-4.6152702, 137.42078452, -4498.119 m

- SRIg08 Clinton (lat,lon)

-4.62615916, 137.40954931, -4489.232 m

- SRIg09 Harrison (lat,lon)

-4.62617745, 137.40955945, -4489.114 m

- SRIg10 Little Wind River (lat,lon)

-4.59700021, 137.4369205, -4500.566 m

- SRIg11 Sparkle (lat,lon)

-4.62620416, 137.40957441, -4489.030 m

- Dateable Crustal (?) Rocks

[in order of priority: addressing threshold first, then qualifying]

RESOURCE ROIs

Resource ROI 1

TBD

- Latitude, longitude, altitude and current imaging available
- Describe characteristics of RROI 2 relevant to addressing the potential for acquiring resources required to support human missions

BACKUP SLIDES

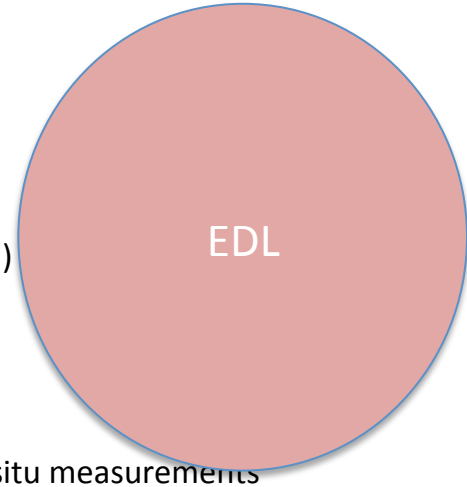
Prioritization List of EZ Data Needs

- Provide a prioritized list of orbiter data to be collected to assess the (A) science potential and (B) resource potential of the EZ. For each request, this list should include:
  - Instrument name
  - Latitude and Longitude of center of image
  - A short justification/rationale for this request
- See following slide for detailed information about available datasets

- The HLS^2 Steering Committee will examine the requests and priorities
- All requests will be made through a central/specified POC

EDL/ISRU Requirements

- Meets all EDL Requirements
  - Between +/- 50 degree latitude (near equator)
  - <2 km MOLA altitude (well below) (~6 km below)
  - Area ~25 km^2 with < 10 degree slopes (MSL qualified)
  - Low dust (MSL qualified)
- ISRU Resource Requirements
  - Access to water in dune sands with >>100 MT capability. (Calculated from SAM/CHEMCAM)
  - Region for infrastructure and small cobble-sized rocks/loose regolith for construction
  - Raw material for feedstock: Fe, Al, Si. (CHEMCAM insitu measurements)
- EDL
  - Increased atmospheric density provides margin for parachute and powered descent.
  - Atmospheric environment (temperature, pressure, wind) characterized by min. 2 years in-situ measurements (REMS onboard MSL, as well as NAVCAM Tau)
  - Thick atmosphere provides additional radiation shielding: ~25-32 gm/cm^2 at 90-degree (overhead); 6-8 gm/cm^2 better than other rover sites.
  - Radiation hazard has been characterized by in-situ measurements (RAD onboard MSL) at ~1.01 Sv for a Mars mission.
  - Terrain: ~10 km of stereo NAVCAM data (~1 cm/pixel or better). (MER Oppy has 42+ km. MER Spirit ~7.7 km)
  - Low dust, low slope



Science Requirements

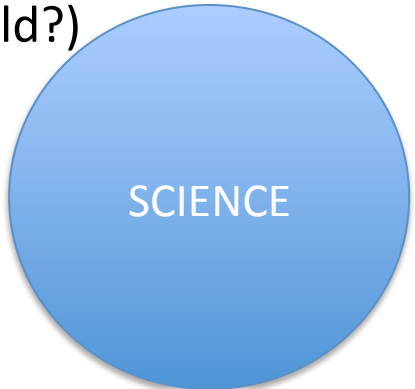
- Science Requirements
  - Access high preservation potential for organics and habitability (Yellowknife Bay lake sediments containing Martian organics)
  - Noachian and/or Hesperian rocks in stratigraphic context (Crater rim (Noachian) and lower mound (Hesperian)
  - Exposure of at least 2 crustal units for radiometric dating (Nearby Noachian crust and Hesperian units to north)
  - Outcrops indicative of aqueous environments/groundwater interaction (Yellowknife Bay mudstones, Bradbury Rise conglomerates, Gypsum veins at Pahrump)
  - Identifiable stratigraphic contacts and cross-cutting relationships
  - Other diverse ROIs (Barchan dunes, potential methane release, etc.)

SCIENCE

Why Gale Crater?

- Scientifically Diverse
  - Multiple fluvial environments documented: stream deposited conglomerates to lake mudstones. (e.g. Williams et al., *Science*, 2013. Grotzinger et al., *Science*, 2013.)
  - Detection of methane above background. (Webster et al., *Science*, 2014)
  - Indigenous Carbon sources, NASA/JPL press release,http://mars.nasa.gov/msl/news/whatsnew/index.cfm?FuseAction=ShowNews&NewsID=1767, 2014
  - Indigenous Nitrogen sources
  - Definitive habitable environments
  - Martian highlands and lowlands within 10's km distance from current MSL landing site.
  - Water resources from dune sediments (e.g. Rocknest, Bagnold?)

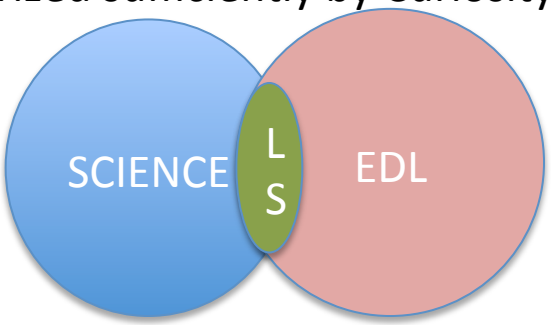
  Leshin et al., *Science*, 2013.

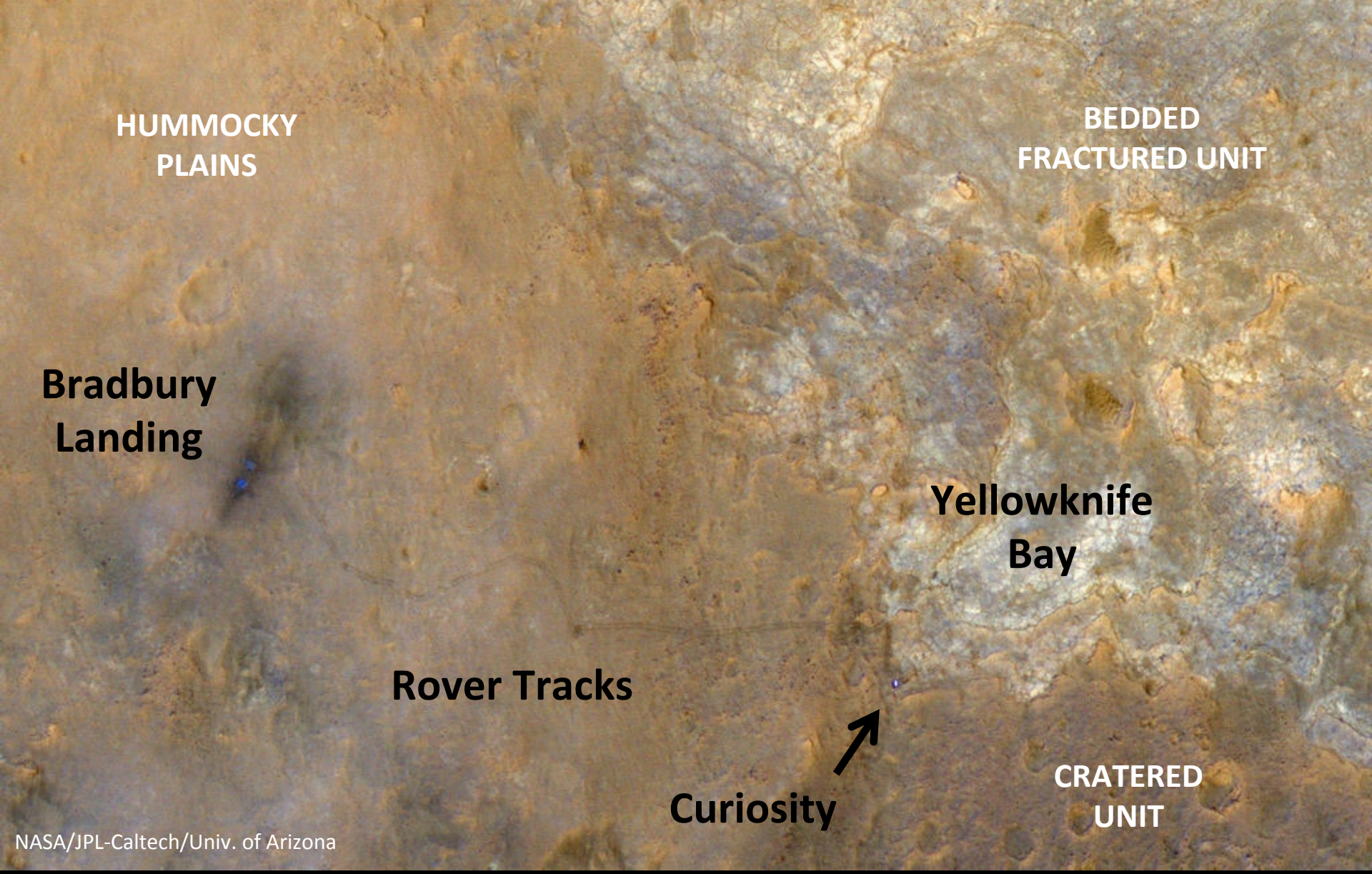


Reference Mission Goals

- In regards to Mars design reference architecture (DRA) 5.0.
  - Gale crater easily meets all the science and engineering goals for the DRA (I-V)
  - two mission types were proposed: "short-stay" with 30-90 days on the surface (500-650 days total) and "long-stay" with 500+ days on Mars (~900 days total).
  - "Short-stay" missions were ruled out partially because of insufficient time for assessing and collecting diverse samples.
  - Gale crater offers crustal material within ~20 km at the rim, Aeolis Mons (Mt. Sharp) clay to sulfate transition within ~15 km, primary alluvial fan material <5 km and fluvially derived conglomerates and clays, some lacustrine, upon landing in many areas of the current MSL ellipse.
  - The Isidis/Syrtis reference landing site in DRA 5.0 had most scientific features well beyond the safe 'walk-back' distance of ~20 km from a centrally located habitat.
  - Many known scientific outcrops at Gale crater are well within this distance if the human habitat where placed within the current MSL landing ellipse.
  - Outcrops would be close, safe, and pre-characterized sufficiently by Curiosity to allow short or long-stay missions.

- **Conclusion:** Gale crater provides excellent EDL and science opportunities for a human-rated mission





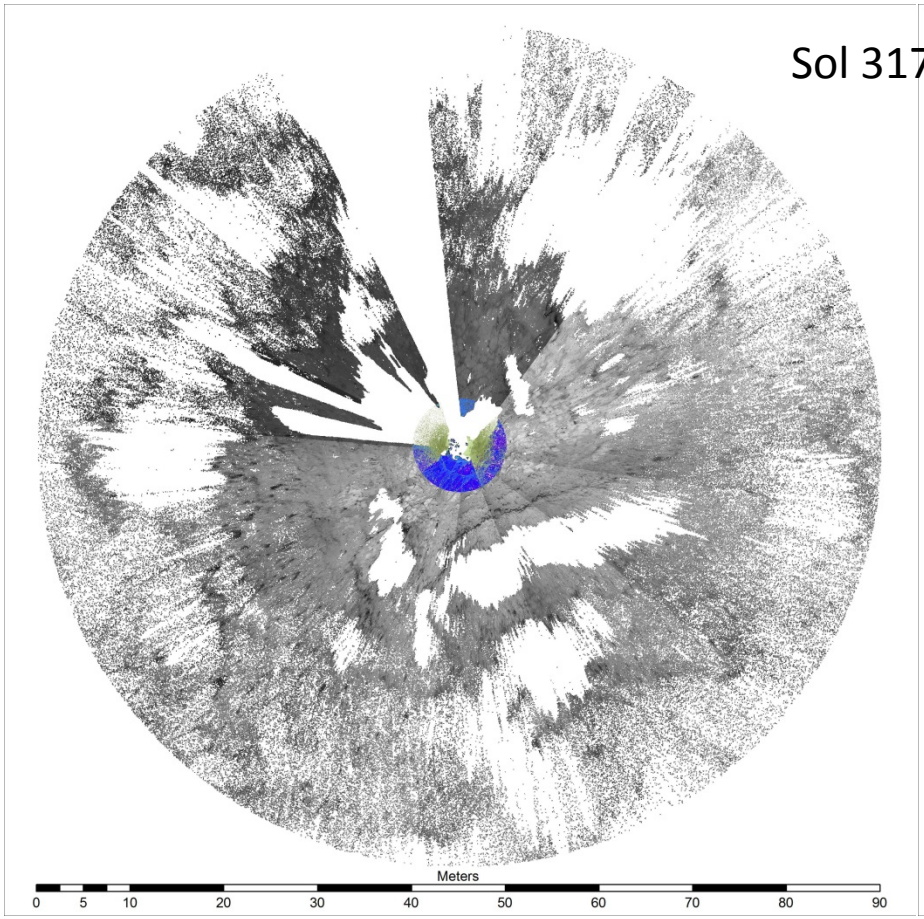
CURIOSITY

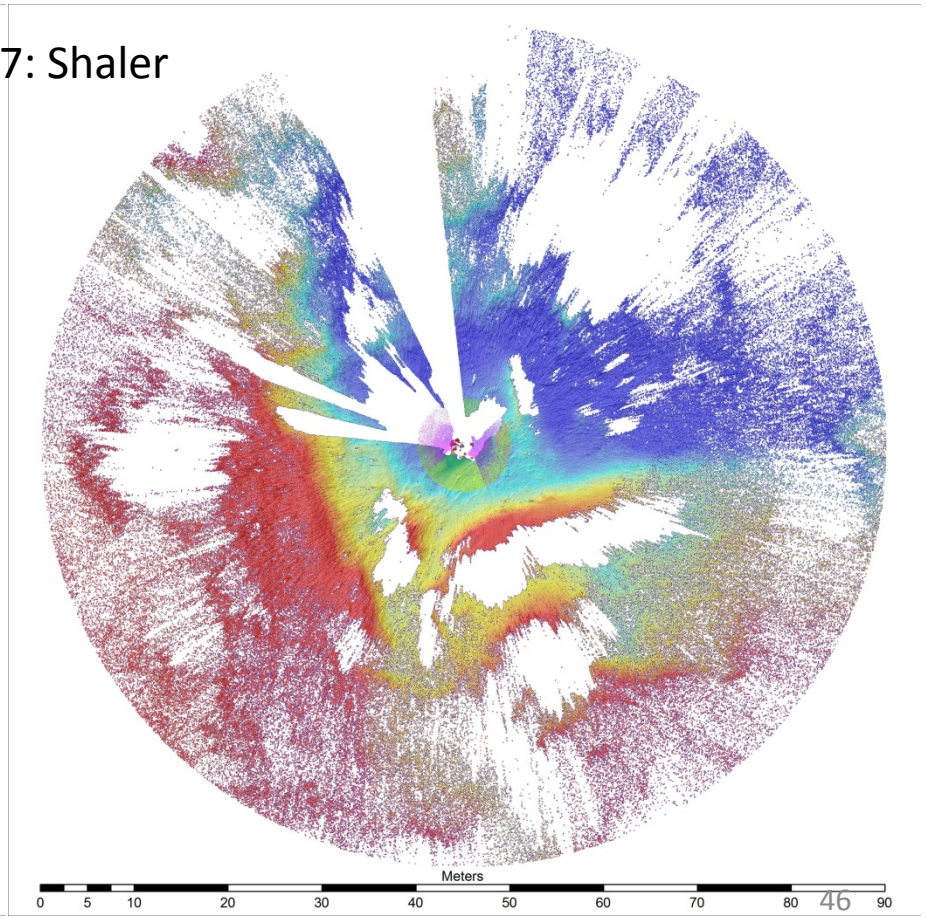
Science and ISRU ROIs
Color HiRISE of Bradbury Rise and Yellowknife bay

Insitu Data Products Provide Unparalleled Surface Details

NAVCAM 45m radius @ 1cm/p, 5m radius @ 1mm/p, HAZCAM front & rear 5m radius @1mm/p

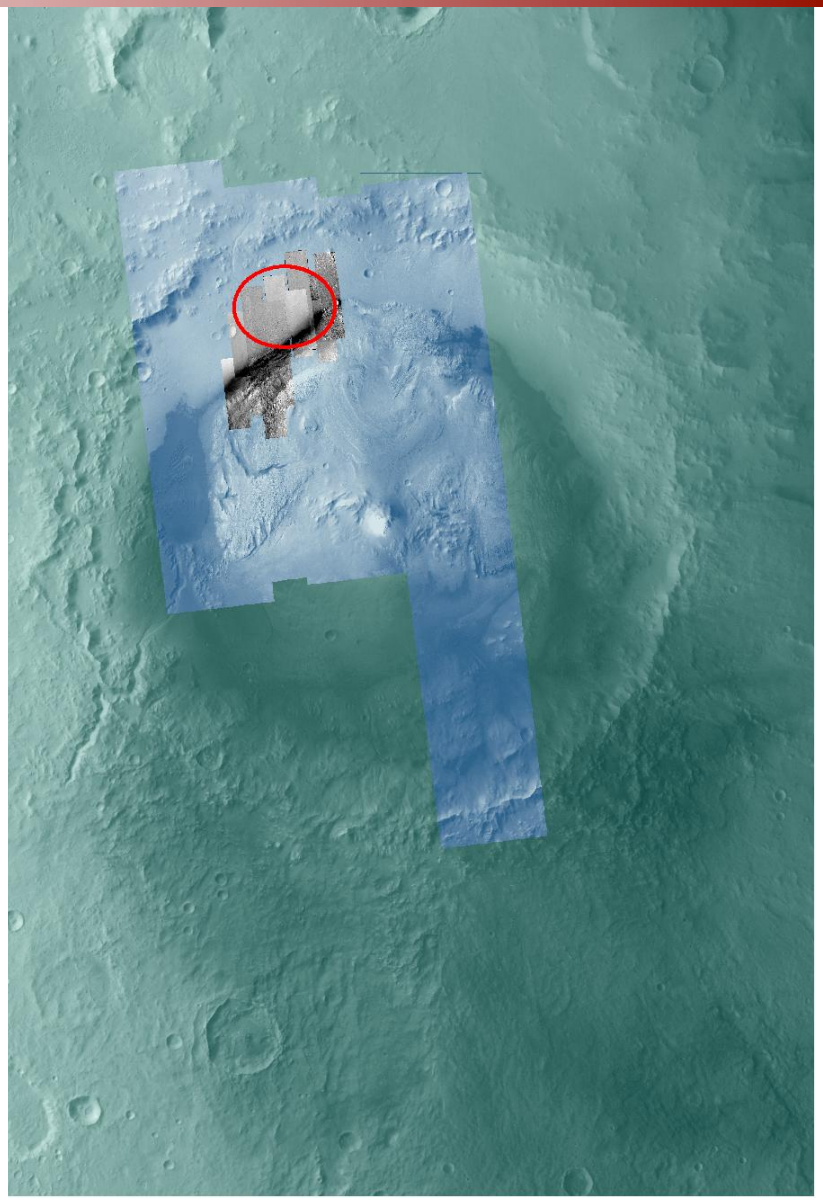
Sol 317: Shaler



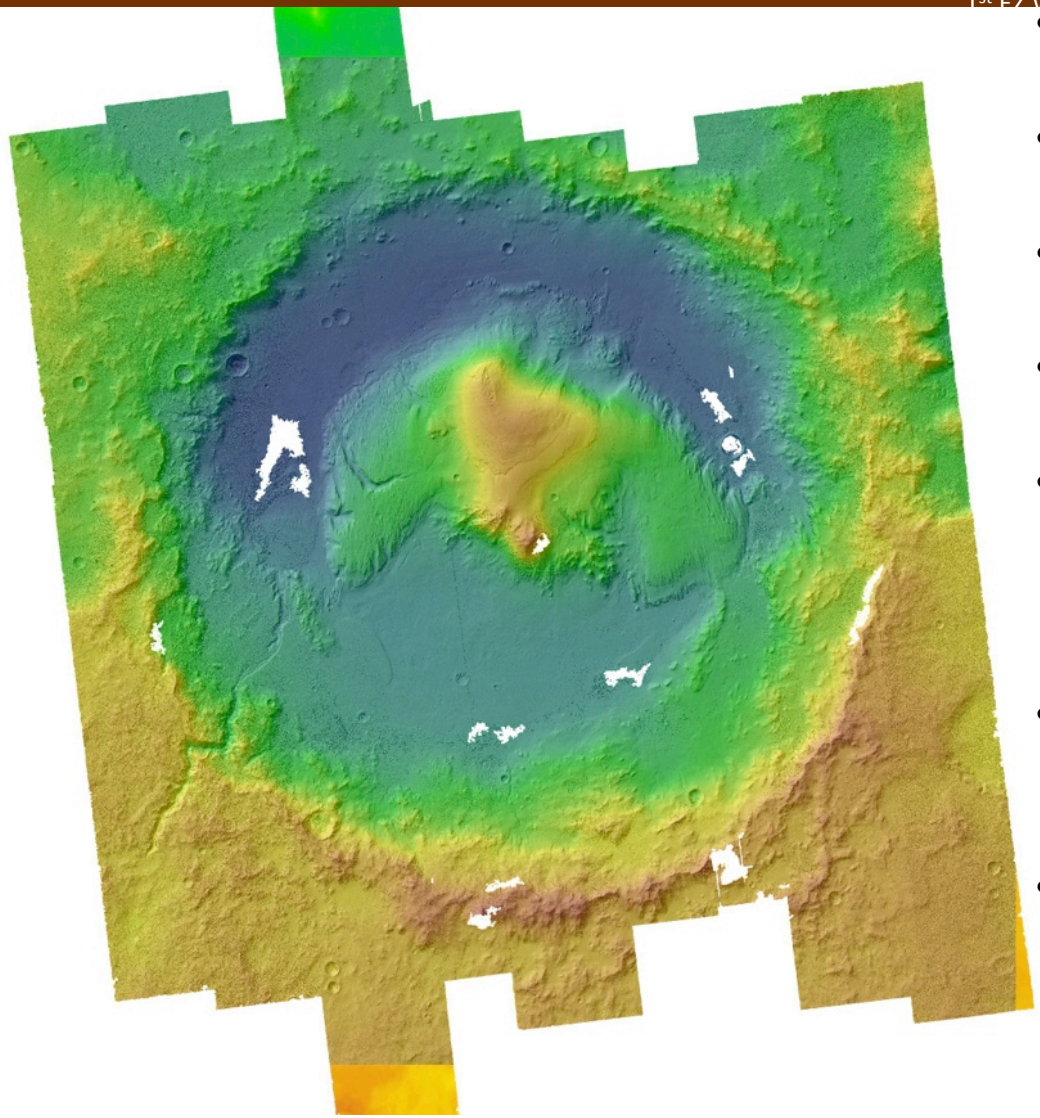


Building the Resolution Pyramid

- MOLA->HRSC->CTX->HiRISE
- Visible imagery coverage down to 0.25 m/pixel over entire ellipse and nominal science 'go to' area for the next 5 years or so.
- DEM mosaic at all levels (HRSC=50 m/p, CTX=25m/p, HiRISE=1m/p)
- Equirectangular Projection
- Sphere radius 3396190 m
- positive East, -180/+180
- clon=0
- Meters
- GeoTIFF (BIG) -> File Geodatabase



Gale Crater CTX DEM Mosaïc



- 12 CTX Stereo Pairs
- DEM Vertical *resolution* ~20 m
- DEM Horizontal pixel size: 20 m
- CTX Orthophoto 6 m/pixel
- Western and Eastern most DEMs noisy (see hillshade data)
- DEM mosaic leveled to HRSC & MOLA
- Seams between DEMs from 0-40 m offset