Lunar and Planetary Science Conference, March 18th, 2015

COMMUNITY USER WORKSHOP ON PLANETARY LIBS (CHEMCAM) DATA

Past and Current ChemCam Results

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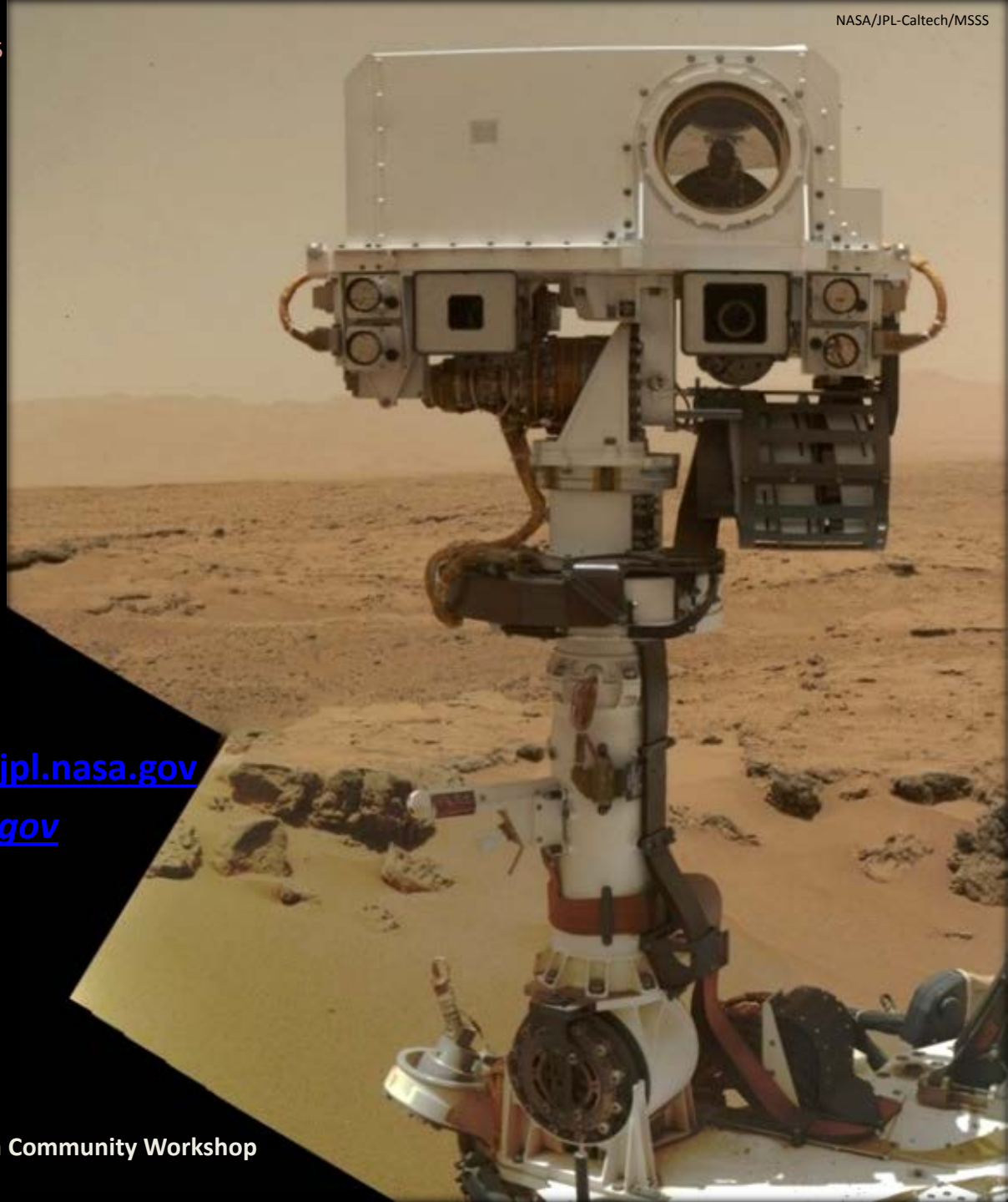
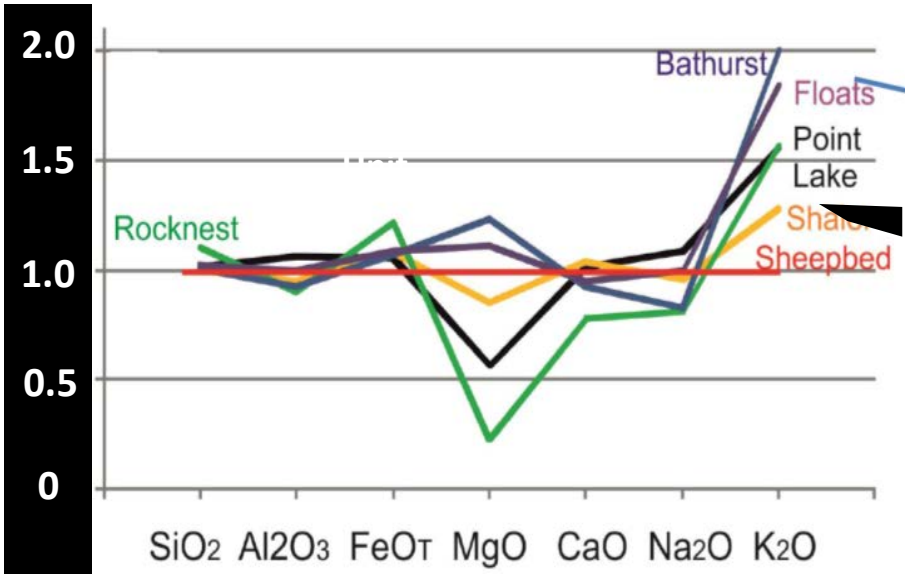
and the entire ChemCam Team



Chemostratigraphy of Yellowknife Bay sediments

ChemCam used > 30,000 shots and > 100 of super-high resolution images to characterize the Yellowknife Bay sediments far more comprehensively than with any other instrument. Using large aggregates of observations provides high confidence in the relative differences in these units. In the Shaler outcrop alone, only ChemCam was able to cover the whole area, as the rover was not allowed to drive up the outcrop for arm-deployed sampling. ChemCam has been doing similar studies at other outcrops.

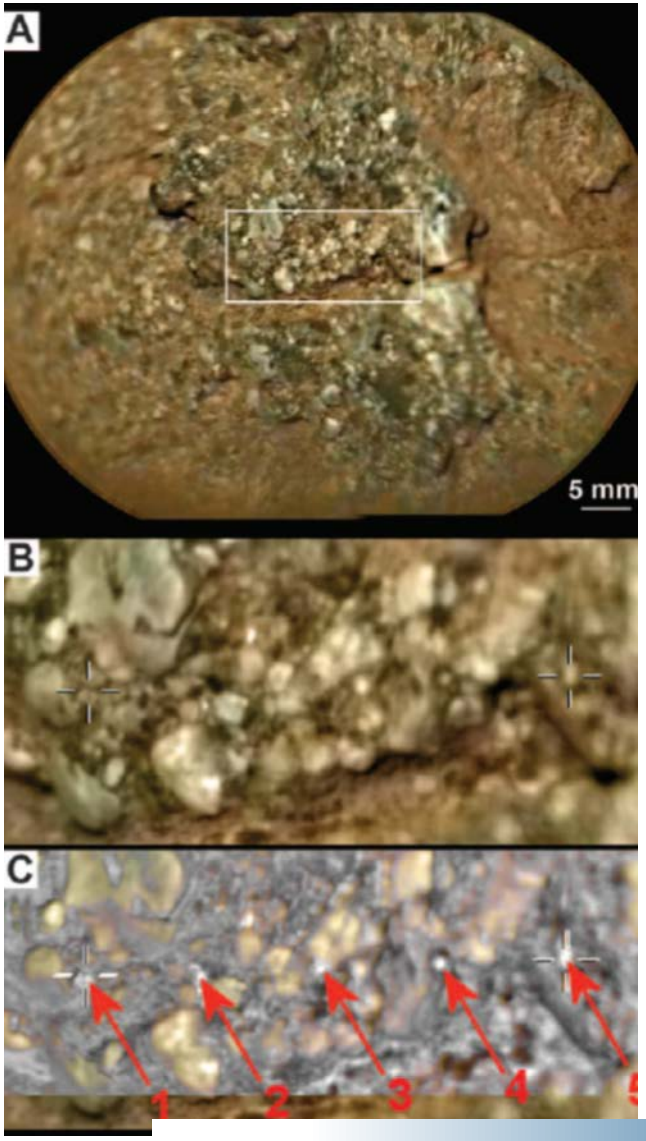


RMI LIBS

Stratigraphy	Texture	Chemistry	Interpretation
Glenelg member Bathurst	Faint layering, mm thick lamination. Sandstone to siltstone.	High alkali, distinct strong K/Na ratio. Similar to floats found in hummocky plains.	Eolian or volcaniclastic. Unknown cementation. May not be part of YKB sediments.
Glenelg member Rocknest	Layered sandstone or massive texture with flow features.	High Fe and alkali. Mg depleted. Similar composition of both textures.	Unknown depositional origin. Cement with Fe-oxides. Disturbance by late event may explain the massive textures.
Glenelg member Shaler	Laminated sandstone with cross-bedding, locally siltstone. Lateral variations with pitted texture.	Close to Sheepbed and Gillespie Lake composition except higher K. Locally low Mg in pitted texture.	Fluvial sediments. Local alteration during diagenesis forming pitted texture.
Glenelg member Point Lake	Pitted texture locally large vugs with glassy texture. Layering not obvious. Many cracks.	High alkali. Low Mg. Glassy texture contains points with high K, Na (feldspar-like)	Diagenetically modified sediments with enhanced alkali content and dissolution features.
Gillespie Lake member	Fine-grained to pebbly sandstone. Strong induration, poor layering. Many cracks and filled veins.	Similar to Sheepbed. Unidentified hydrated phases.	Fluvial sediments. Cementation by aqueous fluids.
Sheepbed member	Local layering visible. Mudstone to siltstone. Many filled veins and open cracks	Homogeneous mafic composition except diagenetic features.	Lacustrine sediments. Early in situ diagenetic alteration. Late diagenetic episode with calcium sulfate veins.

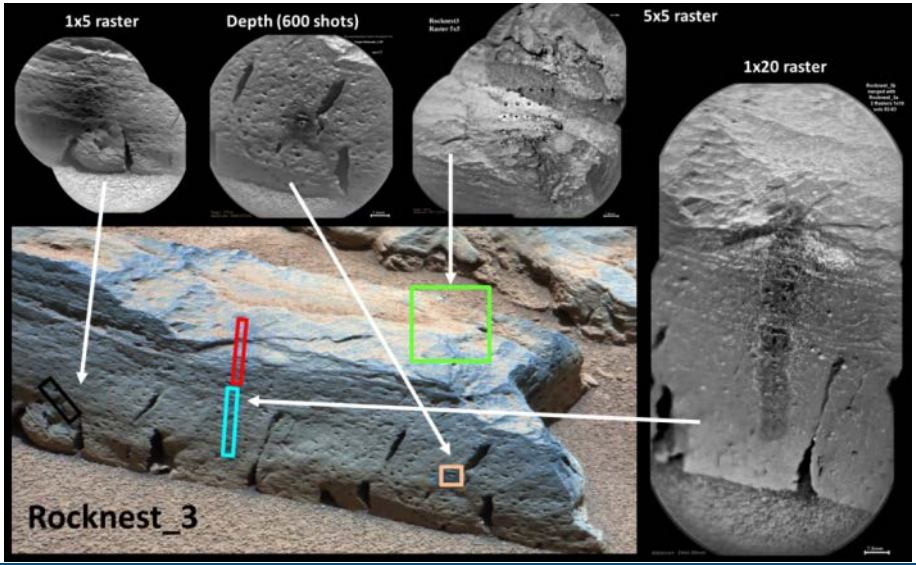
- Mangold et al. **Chemical variations in Yellowknife Bay formation sedimentary rocks analyzed by ChemCam onboard the Curiosity rover on Mars**, *Journal of Geophysical Research Planets*, doi:10.1002/2014JE004681, in press.
- Anderson et al. **ChemCam results from the Shaler outcrop in Gale Crater, Mars**, *Icarus*, 249:2-21, doi:10.1016/j.icarus.2014.07.025, 2015.
- Wiens et al. ChemCam: Chemostratigraphy by the first Mars microprobe, Elements, 11(1):33-38, doi:10.2113/gselements.11.1.33, 2015

Fe-rich cements in sediments



The micro-beam LIBS technique allows us to probe small areas, looking for interstitial material. In the first Science paper on conglomerates we reported that one observation point showed the beam profiling through a Fe-rich hydrated phase which we interpret to be an iron-rich cement binding the conglomerate clasts.

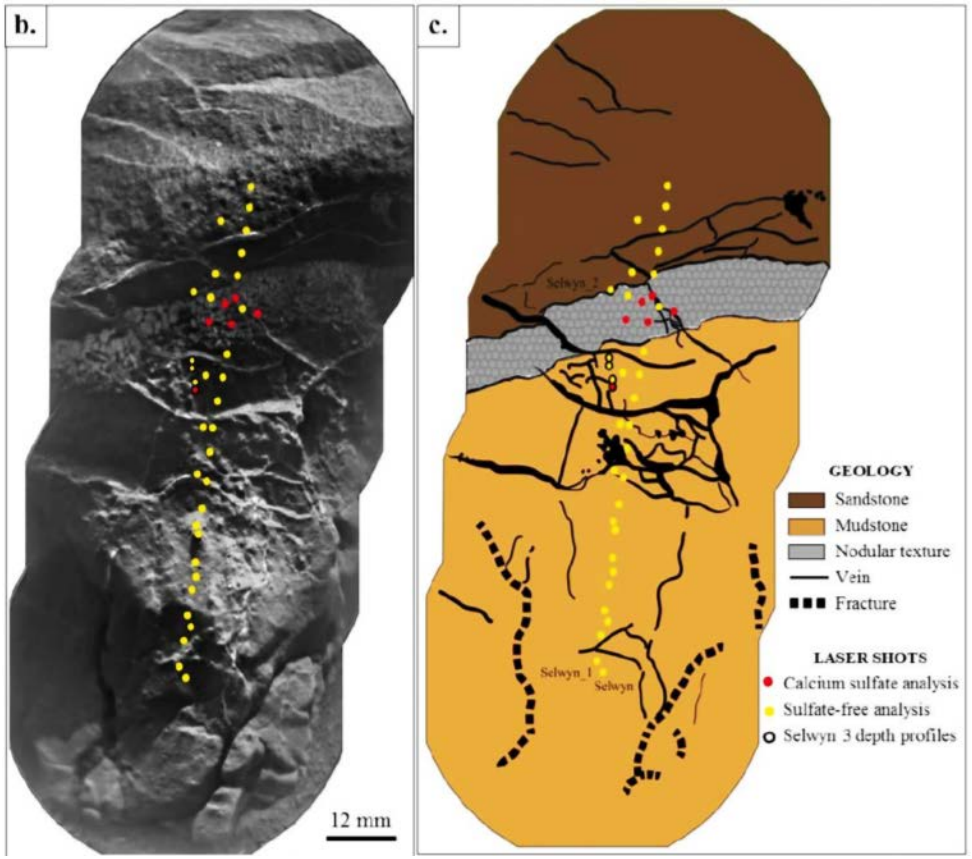
We have evidence for this cement in the Rocknest rocks as well and in other outcrops at Gale Crater.



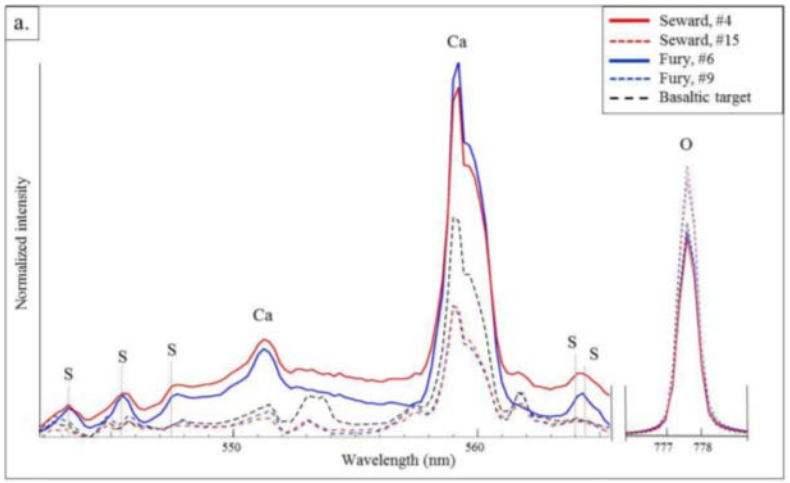
- Williams R. et al. (2013) Martian fluvial conglomerates at Gale Crater. Science 340, 1068-1072, DOI: 10.1126/science.1237317.
- Blaney et al. Chemistry and texture of the rocks at Rocknest, Gale Crater: Evidence for sedimentary origin and diagenetic alteration, Journal of Geophysical Research Planets, 119 (9):2109-2131, doi:10.1002/2013JE004590, 2014.

Ca-sulfate veins, variable hydration

ChemCam was the first to observe and confirm the composition of the calcium sulfate veins in the Yellowknife Bay units. We were also able to show that the veins were variably hydrated, confirmed by the Mastcam 1 micron band. These Ca-sulfate veins are widespread in Gale.



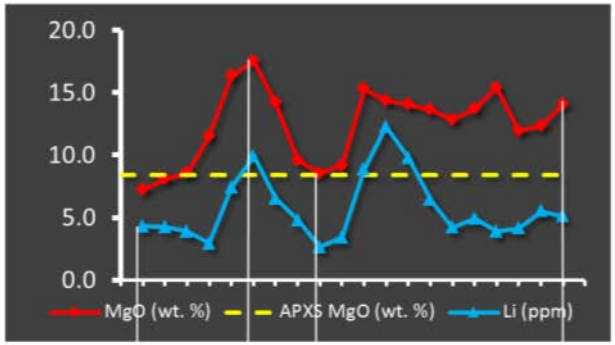
Chemostratigraphy with ChemCam laser

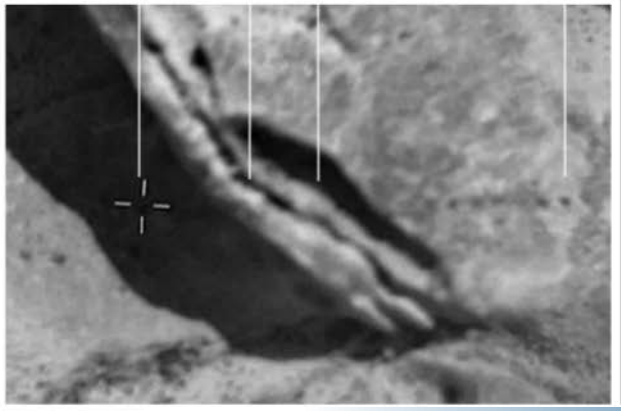


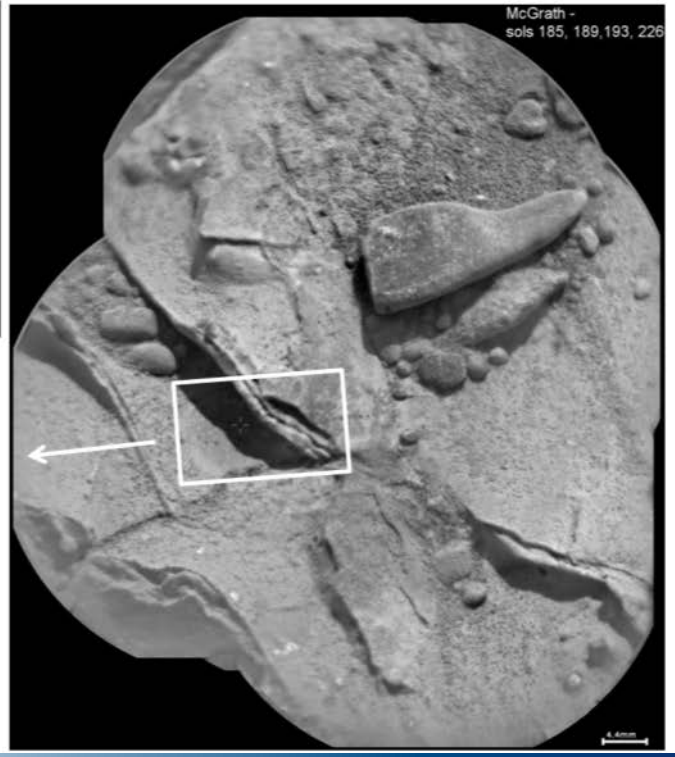
- Nachon et al. **Calcium sulfate veins characterized by ChemCam/Curiosity at Gale Crater, Mars**, *Journal of Geophysical Research Planets*, 119(9):1991-2016, doi:10.1002/2013JE004588, 2014.

Mg ridge transect

ChemCam is providing fine-scale geochemical constraints within the Yellowknife Bay formation: Mg and Li variations are correlated at the site of the raised ridge. Elevated Mg (but not Li) likely represents the outer layer of the cement, exposed on the dipping surface. ChemCam analyses of isopachous cements within early diagenetic raised ridges indicate the presence of a Mg-Fe-Cl rich phase (or assemblage). Mg-rich diagentic features are seen at multiple locations at Gale.



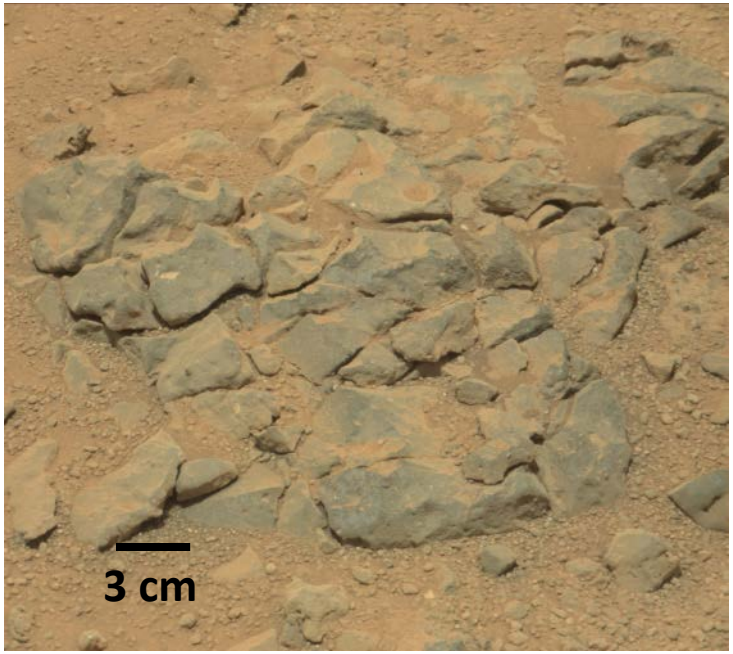




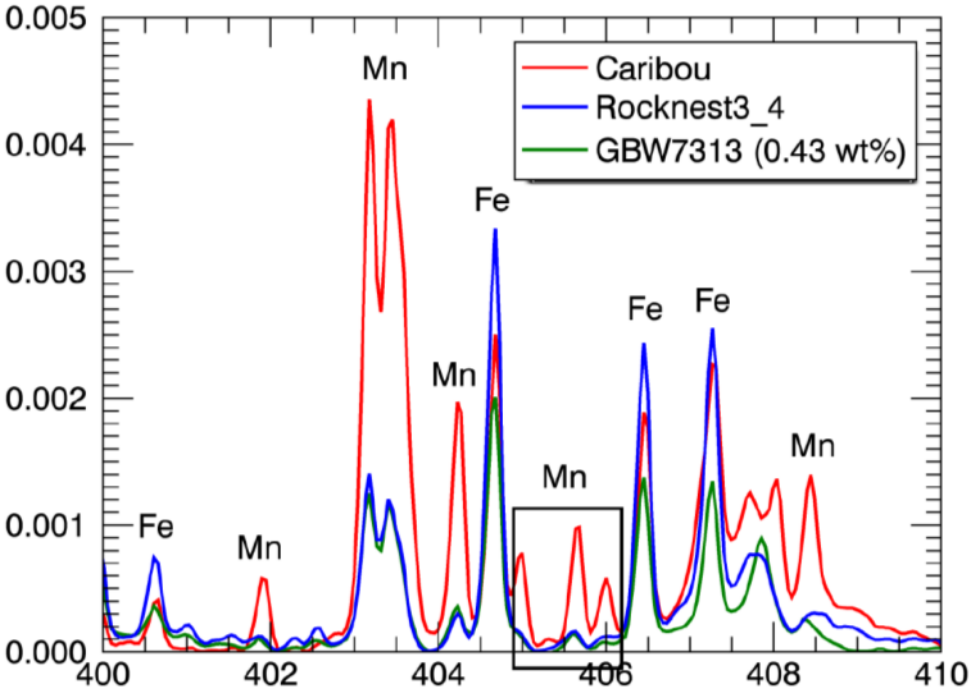
- McLennan S.M. et al. (2013) Elemental geochemistry of sedimentary rocks in Yellowknife Bay, Gale Crater, Mars. Sciencexpress, 9 December, DOI:10.1126/science.124473.
- Léveillé et al. **Chemistry of fracture-filling raised ridges in Yellowknife Bay, Gale Crater: Window into past aqueous activity and habitability on Mars**, *Journal of Geophysical Research Planets*, 119 (11):2398-2415, doi:10.1002/2014JE004620, 2014.

First manganese-rich minerals

The production of manganese-rich minerals requires a highly oxidizing environment. The discovery by ChemCam of a number of Mn-rich minerals has powerful implications for their formation environment.



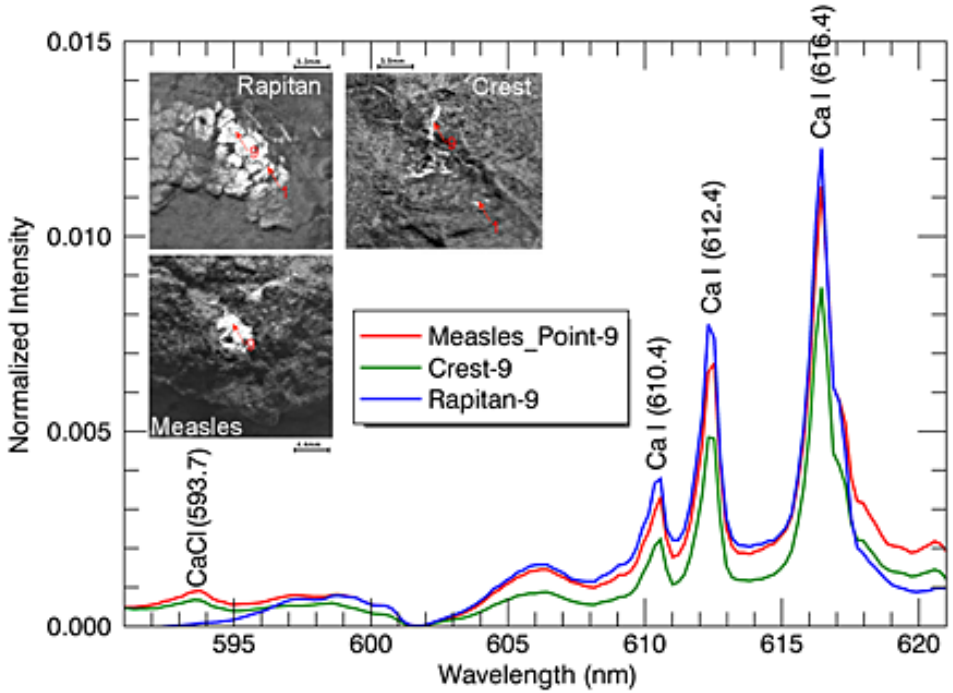
Caribou Sandstone with High-Mn Mineral

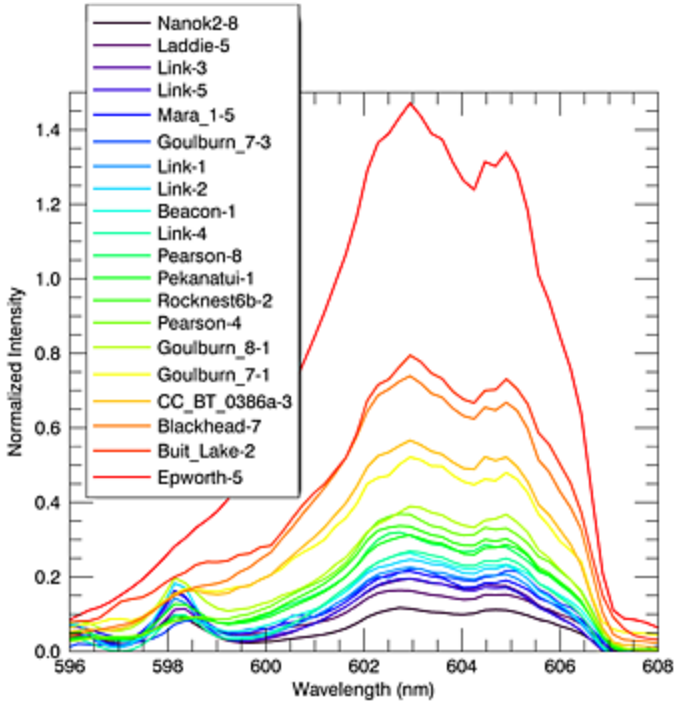


- Lanza, et al. **High manganese concentrations in rocks at Gale crater, Mars,** *Geophysical Research Letters*, 41(16):5755-5763, doi:10.1002/2014GL060329, 2014.
- Lanza et al. **Understanding the signature of rock coatings in laser-induced breakdown spectroscopy data**, *Icarus*, 249:62-73, doi:10.1016/j.icarus.2014.05.038, 2015.

First Mars fluorine chemistry

Fluorine could not be previously analyzed on Mars, as XRF-type instruments cannot observe elements with atomic masses lighter than sodium. ChemCam has now made multiple observations of fluorine, which is relatively abundant in SNC meteorites. Its presence implies lower magma melting temperatures, and it is often present as an element within alteration minerals.

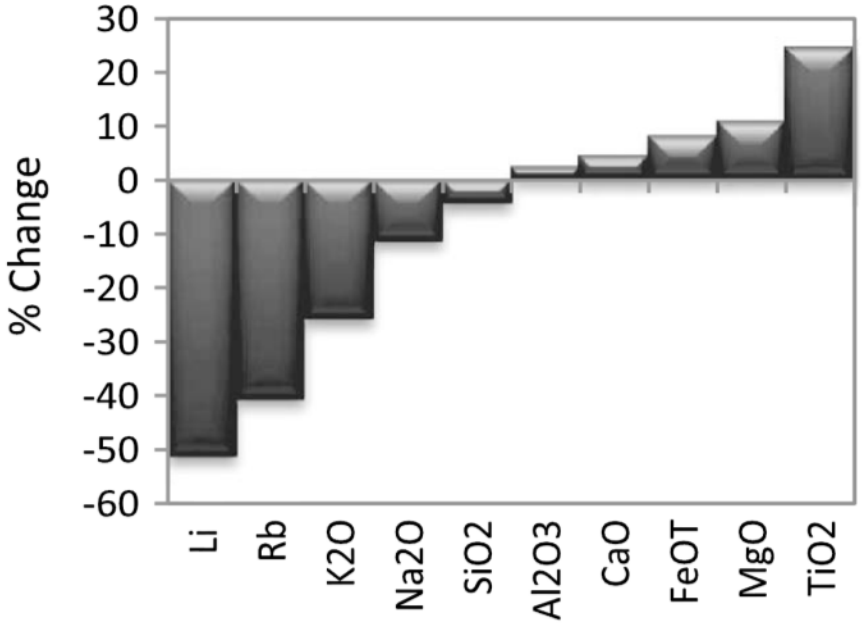


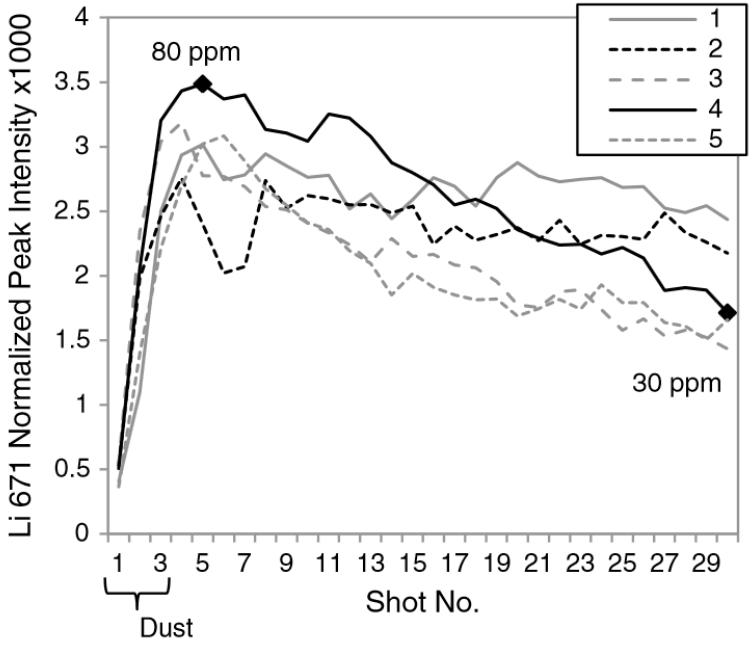


- Forni O. et al., First detection of fluorine on Mars: implications for Gale crater's geochemistry, Geophys Res. Let., 2015, DOI:10.1002/2014GL05742.

Rock surface alteration of mobile elements

On the Bathurst_Inlet sample all five ChemCam observations showed surface depletions in mobile elements, grading from the most mobile element (Li) to the less mobile elements (e.g., Si, Ti). The gradient was consistent among all observed elements, definitively showing relatively recent rock surface alteration.



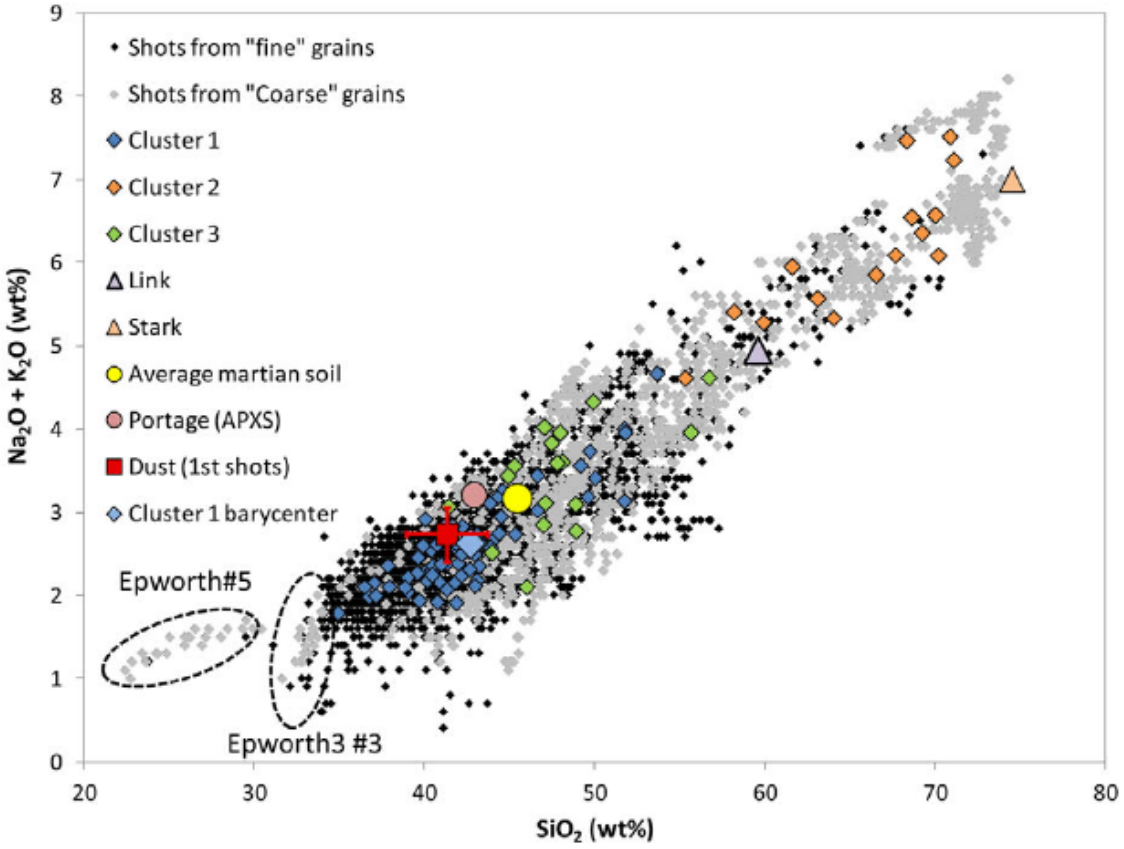


- Ollila et al. **Trace element geochemistry (Li, Ba, Sr, and Rb) using *Curiosity*'s ChemCam: Early results for Gale Crater from Bradbury Landing Site to Rocknest**, *Journal of Geophysical Research Planets*, 119(1):255-285, doi:10.1002/2013JE004517, 2014.

Li trends with depth for 5 points on Bathurst_Inlet

Multiple components in soils

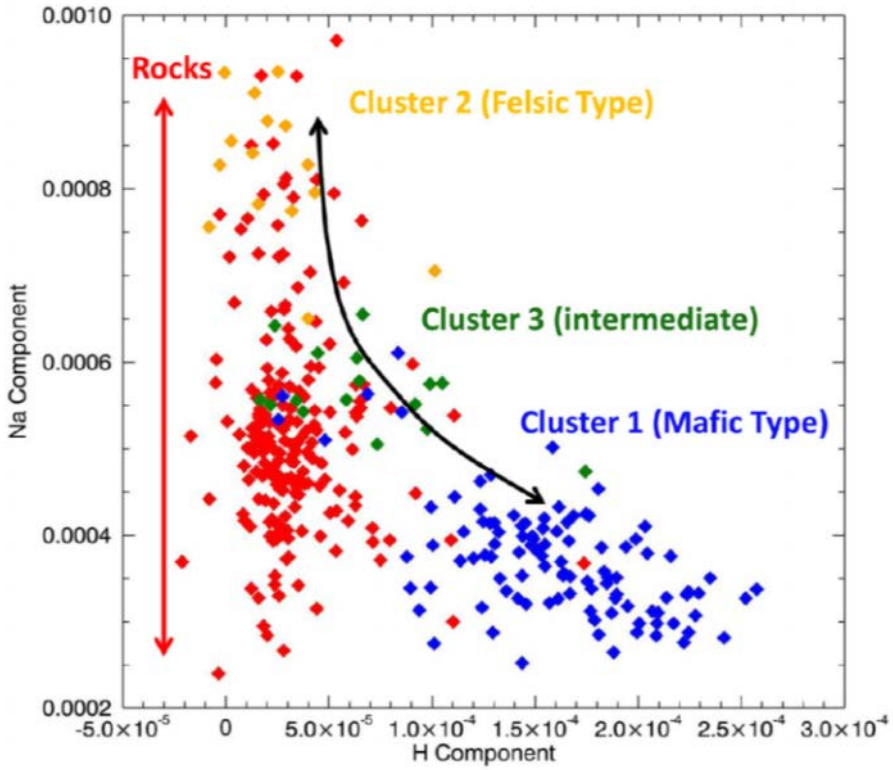
ChemCam provides the first microbeam analysis of soils, showing for the first time that all soils we have analyzed so far consist of multiple components including contributions from the local rock types. We can correlate these components with characteristic grain sizes.

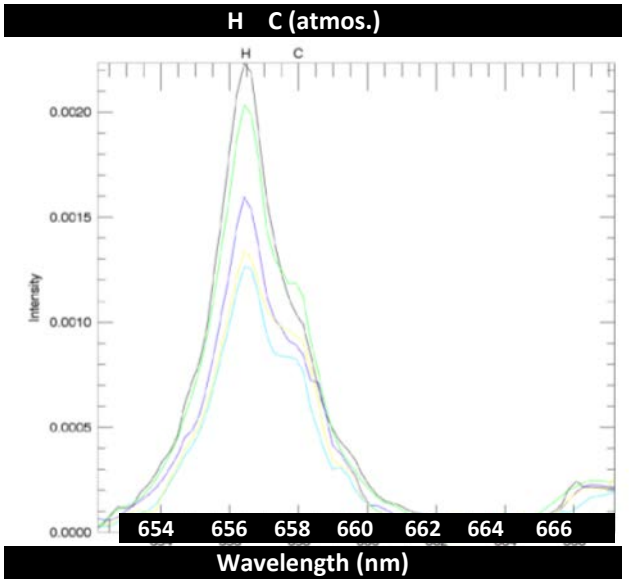


- Meslin P.-Y. et al. (2013) Soil diversity and hydration as observed by ChemCam at Gale crater, Mars. Science 341, DOI: 10.1126/science.1238670.
- Cousin et al. **Compositions of coarse and fine particles in martian soils at Gale: A window into the production of soils**, *Icarus*, 249:22-42, doi:10.1016/j.icarus.2014.04.052, 2015.

Hydrated soil and dust

With the very first laser shot on Mars we discovered that the soil and even the wind-blown dust is hydrated. The SAM instrument quantified the amounts, but ChemCam has shown the ubiquity of water in the soils and has helped constrain the mineral component in the soil containing the water.





- Schröder et al. Hydrogen detection with ChemCam at Gale crater, Icarus, 249:43-61, doi:10.1016/j.icarus.2014.08.029, 2015.

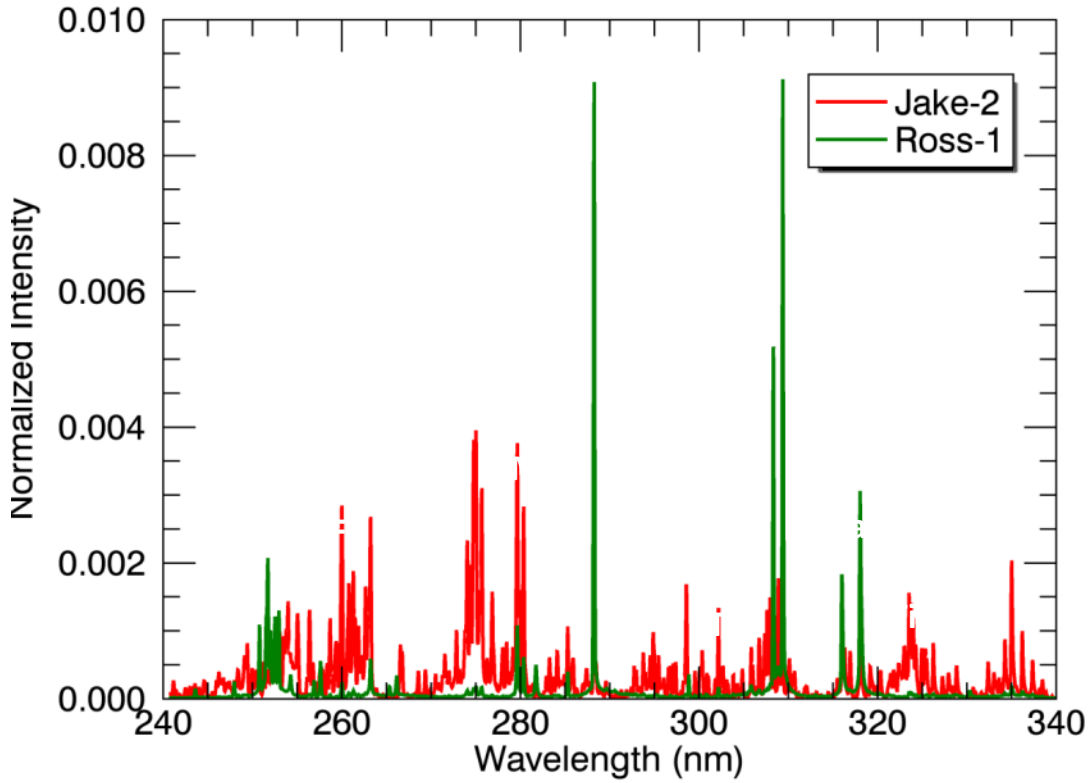
- Meslin P.-Y. et al. (2013) Soil diversity and hydration as observed by ChemCam at Gale crater, Mars. Science 341, DOI: 10.1126/science.1238670.

Felsic rock and pebble compositions

- Meslin P.-Y. et al. (2013) Soil diversity and hydration as observed by ChemCam at Gale crater, Mars. Science 341, DOI: 10.1126/science.1238670.
- Williams R. et al. (2013) Martian fluvial conglomerates at Gale Crater. Science 340, 1068-1072, DOI: 10.1126/science.1237317.
- Sautter et al. **Igneous mineralogy at Bradbury Rise: The first ChemCam campaign at Gale crater**, *Journal of Geophysical Research Planets*, 119(1): 30-46, doi:10.1002/2013JE004472, 2014.

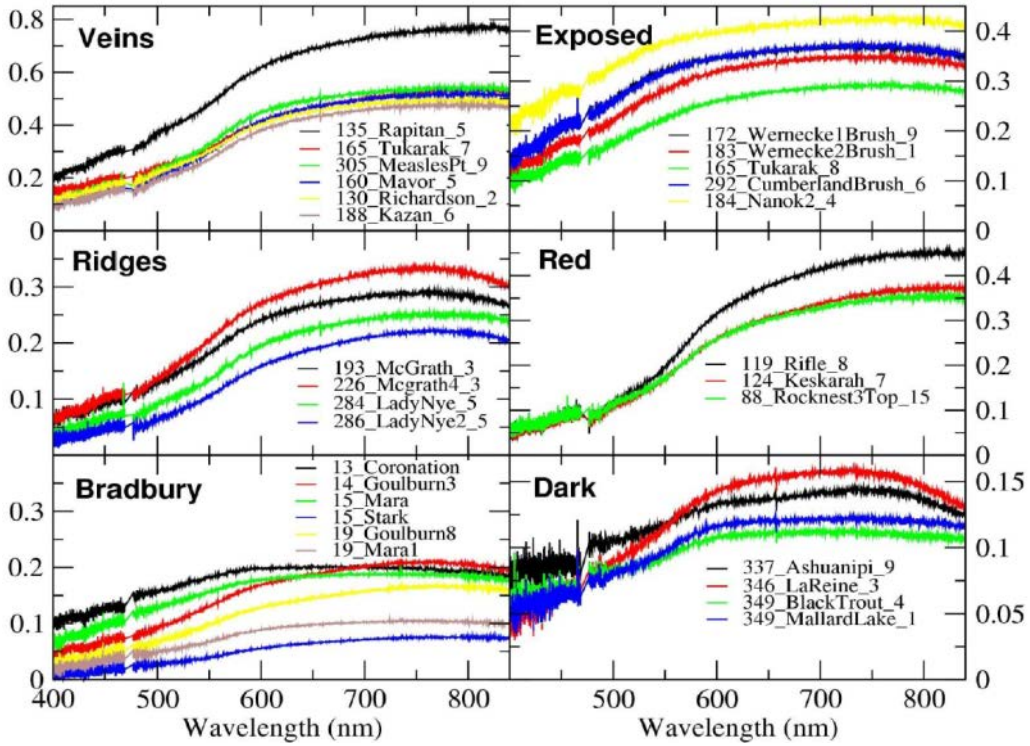
In the very first week ChemCam yielded the first high-silicon rock compositions. These compositions have been found not only in float rocks, but in the pebbles comprising the first conglomerates, and in the coarse soil grains. These were reported in the first Science papers and have been discussed in several papers since. The implication is that the igneous volcanism of Mars is much more varied, including much more evolved magmas, than previously thought.

Ross-1 = felsic composition

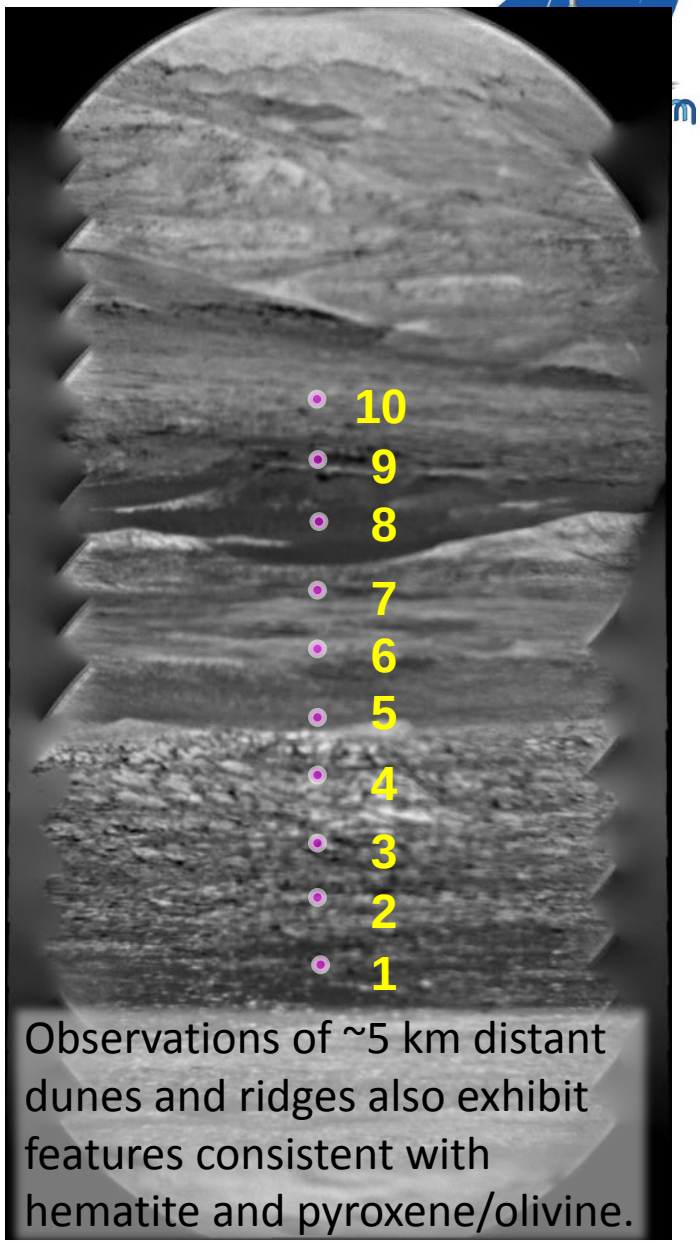


High-resolution reflectance spectroscopy

While the spectral range only covers the 0.4-0.9 micron range, spectral features consistent with hematite, pyroxenes/olivine, and calcium sulfate have been observed.



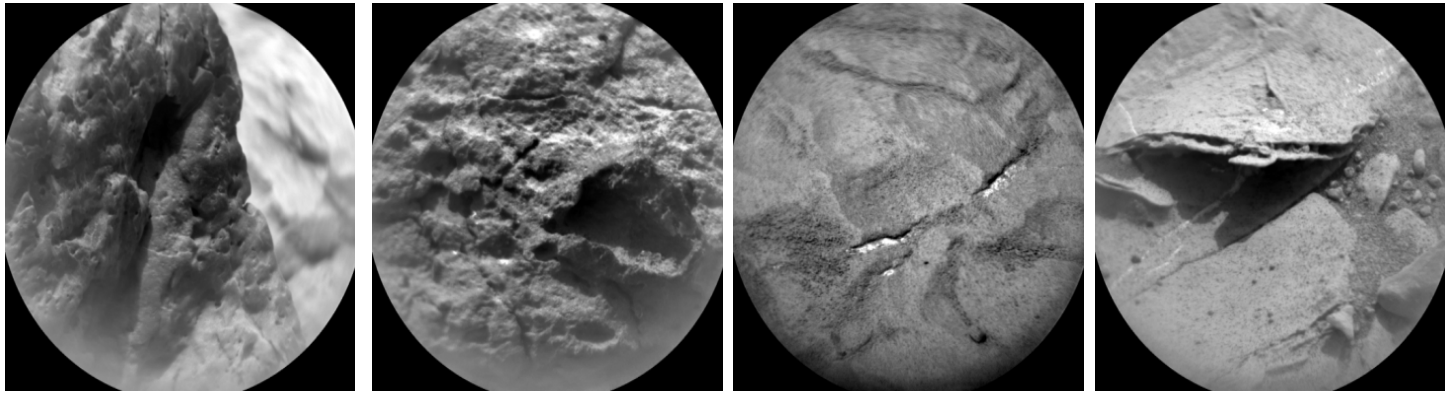
- Johnson et al. **ChemCam passive reflectance spectroscopy of surface materials at the Curiosity landing site, Mars**, *Icarus*, 249:74-92, doi:10.1016/j.icarus.2014.02.028, 2015.



Observations of ~5 km distant dunes and ridges also exhibit features consistent with hematite and pyroxene/olivine.

Variety of fine scale textures

Pointing_test (sol 100) Athole_point (sol 302) Beachrock (sol 126) John_Klein_RP3 (sol 165)



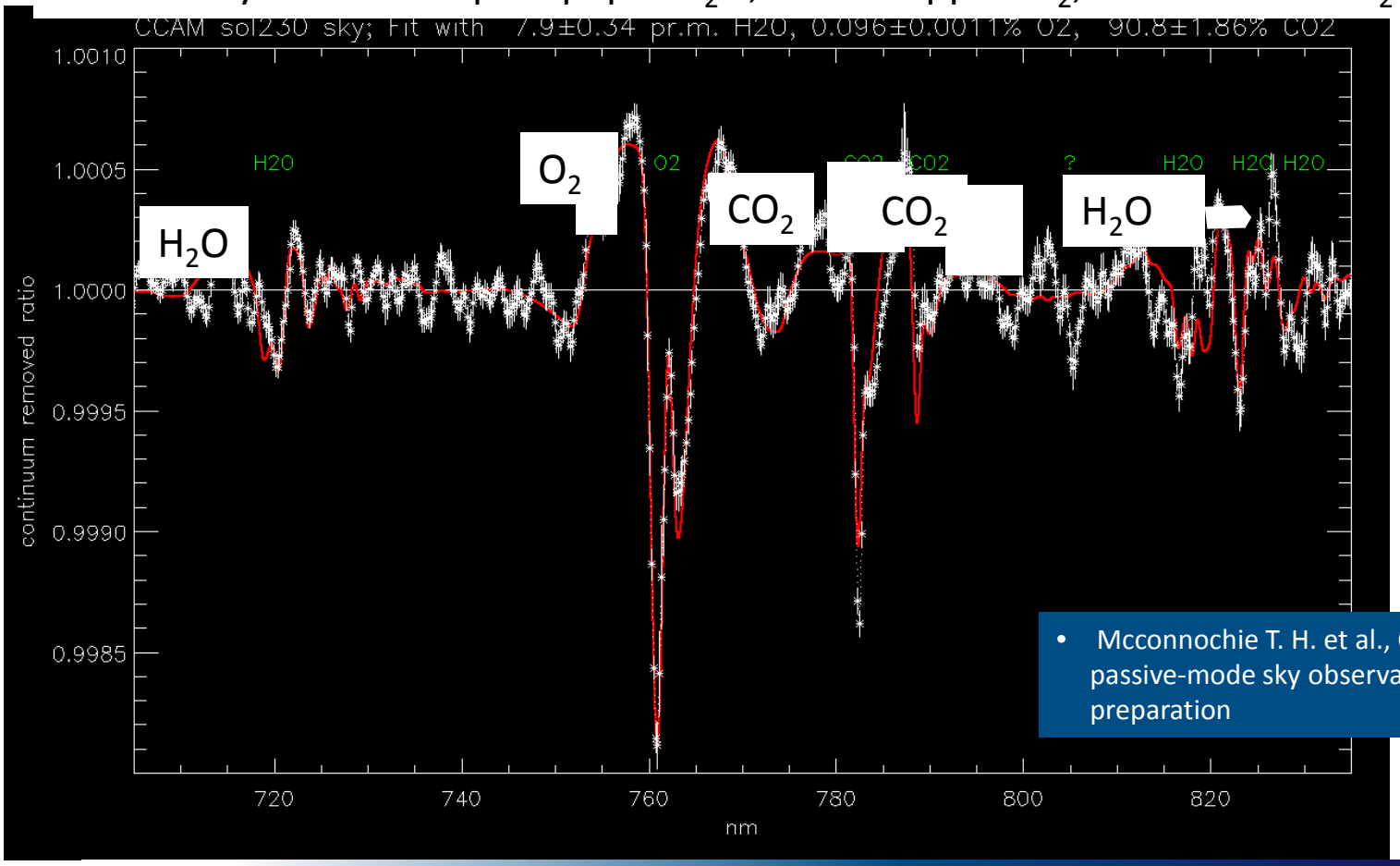
Denham (sol 326) Fabricius_Cliffs (sol 322) Cumberland (sol 187) Selwyn (sol 157)

- Le Mouélic et al. **The ChemCam Remote Micro-Imager at Gale crater: Review of the first year of operations on Mars**, *Icarus*, 249:93-107, doi:10.1016/j.icarus.2014.05.030, 2015.
- Bridges et al., The rock abrasion record at Gale Crater: Mars Science Laboratory results from Bradbury Landing to Rocknest, Journal of Geophysical Research Planets, 119(6):1374-1389, doi:10.1002/2013JE004579, 2014.

Atmospheric H_2O, O_2 abundances

Water and O2 adsorption bands will provide the highest precision local ground-based measurements.

Preliminary fit: 7.9±0.7 precip. µm H_2O; 960±22 ppm O_2; 90.8±3.76% CO_2



Continuum-removed ratio

- Mcconnochie T. H. et al., ChemCam passive-mode sky observations, in preparation

Other published ChemCam related publications

Bridges et al. **Diagenesis and clay mineral formation at Gale Crater, Mars**, *Journal of Geophysical Research Planets*, 120, doi:10.1002/2014JE004757, published online, 2015.

Fabre et al. **In situ calibration using univariate analyses based on the onboard ChemCam targets: First prediction of Martian rock and soil compositions**, *Spectrochimica Acta Part B*, 99:34-51, doi:10.1016/j.sab.2014.03.014, 2014.

Newsom et al. **Gale crater and impact processes - Curiosity's first 364 Sols on Mars**, *Icarus*, 249:108-128, doi:10.1016/j.icarus.2014.10.013, 2015.

Melikechi et al. **Correcting for variable laser-target distances of laser-induced breakdown spectroscopy measurements with ChemCam using emission lines of Martian dust spectra**, *Spectrochimica Acta B*, 96:51-60, doi:10.1016/j.sab.2014.04.004, 2014.

Schmidt et al. **Geochemical diversity in first rocks examined by the Curiosity rover in Gale crater: Evidence for and significance of an alkali and volatile-rich igneous source**, *Journal of Geophysical Research Planets*, 119(1):64-81, doi:10.1002/2013JE004481, 2014.

For More Information

- ChemCam papers, abstracts, and posters can be accessed at: http://www.msl-chemcam.com
  - Go to the ChemCam tab and select Publications

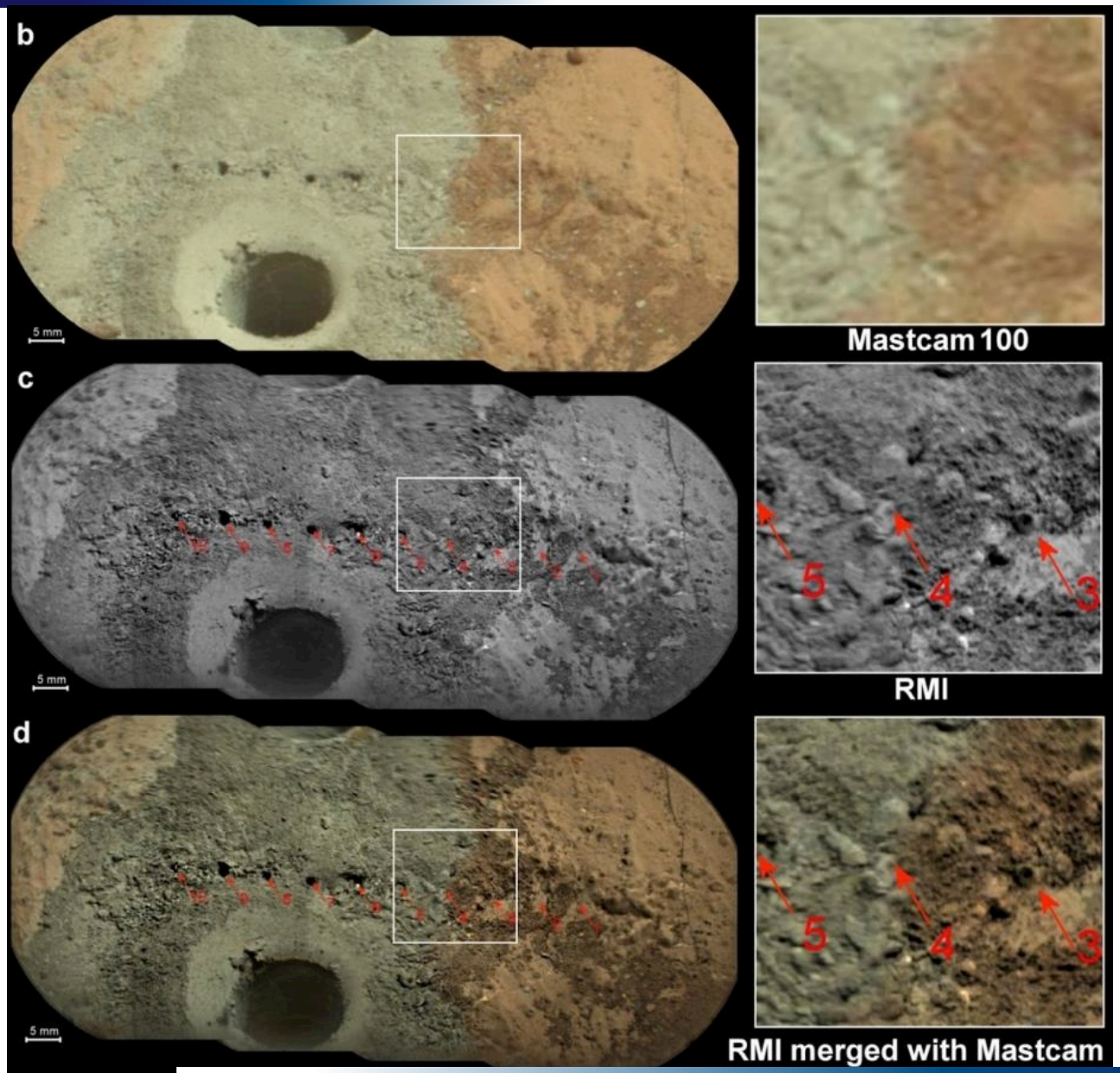
- Today's presentations can be found at:
  - http://pds-geosciences.wustl.edu/workshops/ChemCam_Workshop_Mar15.htm

ChemCam at LPSC

- Many ChemCam team members have posters at LPSC report on the current studies under way.
  - Feel free to stop by and talk to the authors if you want more information.
- The same techniques in the earlier slides are being used on data from various locations in Gale.

CHEMCAM @ LPSC 2015					
TOPIC	AUTHOR	#	DAY	ROOM	TIME
Pahrump	Milliken	2339	Mon	4	9:15
Morphologies	Kah	1901	Mon	4	10:15
Winnipesaukee et al	Wiens	1249	Mon	4	10:30
Lab salt mixtures	Anderson	2724	Tue		Poster
Dyar calib suite	Dyar	1510	Tue		Poster
Grain sizes	Ha	2201	Tue		Poster
Lab H mixtures	Thomas	2119	Tue		Poster
Igneous classification	Cousin	2452	Thu	4	8:30
Igneous	Sautter	1943	Thu	4	8:45
Hematite modeling	Bridges J	1769	Thu	4	11:15
Manganese	Lanza	2893	Thu	4	11:30
Broad overview	Blaney	2093	Thu		Poster
Phosphorous	Blank	2850	Thu		Poster
Rock abrasion	Bridges N	2324	Thu		Poster
Soils @ Pahrump	Cousin	2767	Thu		Poster
F & Li in the Kimberley	Forni	1989	Thu		Poster
Pahrump	Forni	2099	Thu		Poster
Classification	Gasnault	2789	Thu		Poster
LIBS of NWA7034	Gordon	2232	Thu		Poster
Drill tailings	Jackson	2301	Thu		Poster
Zinc	Lasue	1413	Thu		Poster
Potassic rocks	Le Deit	1438	Thu		Poster
LIBS statistics	Lewin	3012	Thu		Poster
Diagenetic	Nachon	1524	Thu		Poster
Hydration in Ca-sulfates	Rapin	2966	Thu		Poster
Soils @ Hidden Valley	Schroeder	2022	Thu		Poster
Fluids, evaporation	Schwenzer	1441	Thu		Poster
Plasma temp effects	Tokar	1369	Thu		Poster
GRS & regional chemistry	Newsom	2284	Fri	4	2:45
Passive Fe-sulfates	Johnson	1433	Fri	4	4:00
Calibration Transfer	Boucher	2773			Print
CCAM pure mineral ID	Dyar	1514			Print

ChemCam capabilities and instrument status

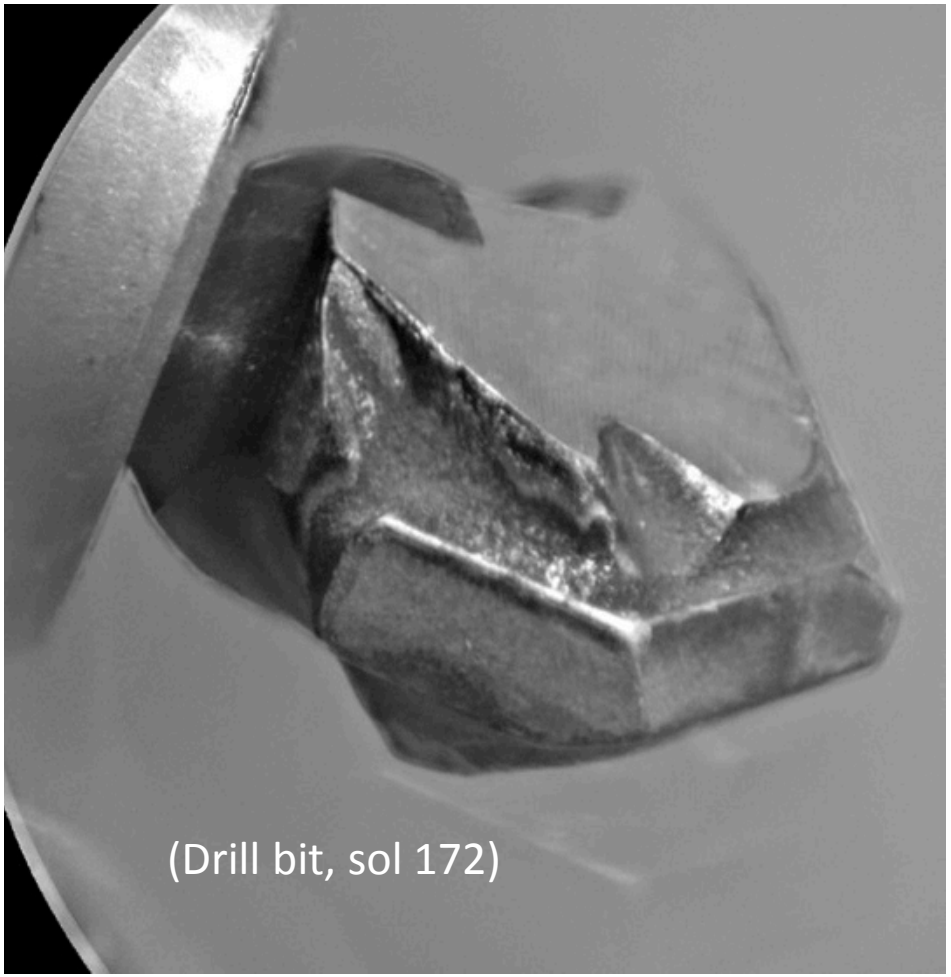


High res. Color images

Drill Tailings sol 183

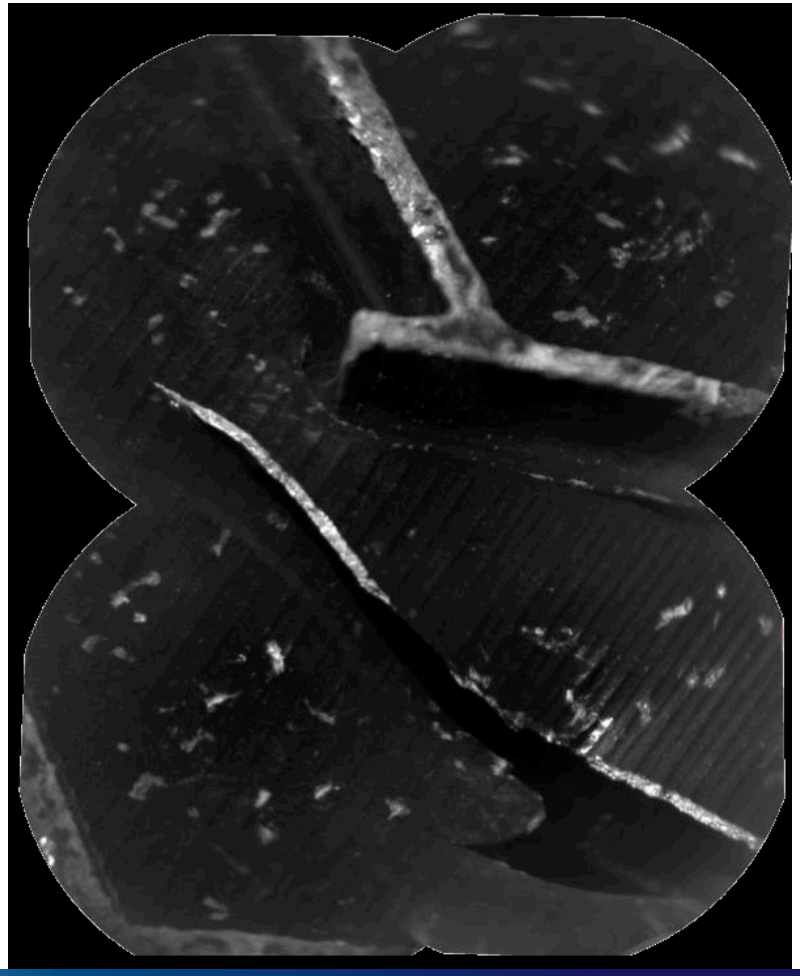
- Le Mouélic et al. **The ChemCam Remote Micro-Imager at Gale crater: Review of the first year of operations on Mars**, *Icarus*, 249:93-107, doi:10.1016/j.icarus.2014.05.030, 2015.

Assisting rover operations

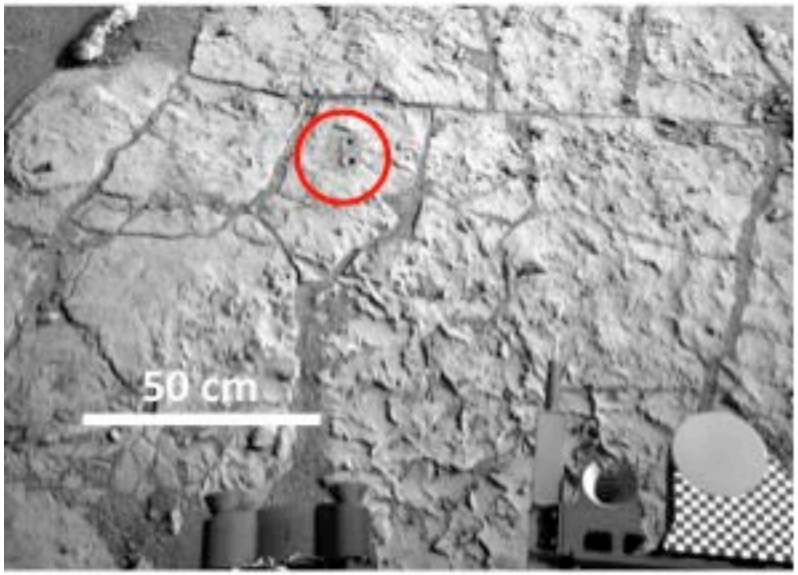


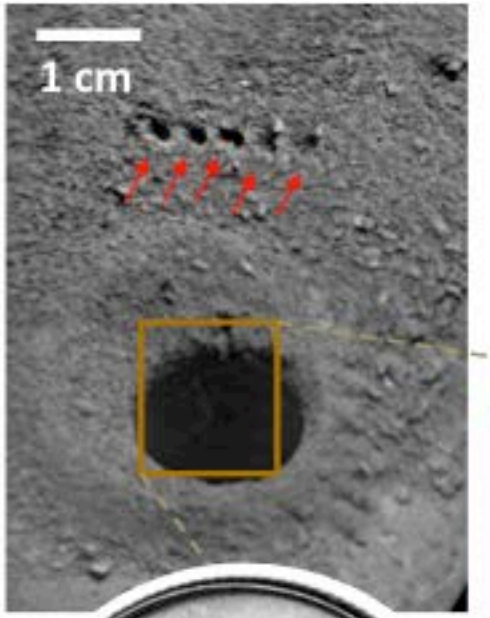
(Drill bit, sol 172)

(Wheel inspection, sol 520)

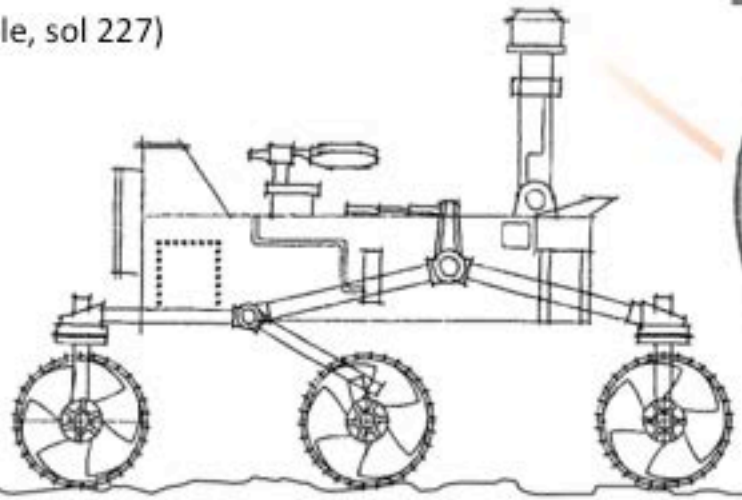


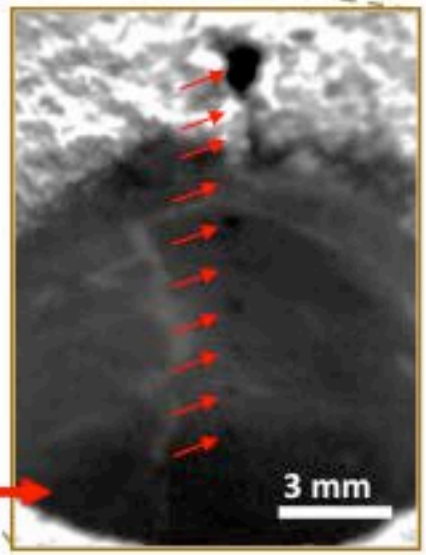
Fine pointing





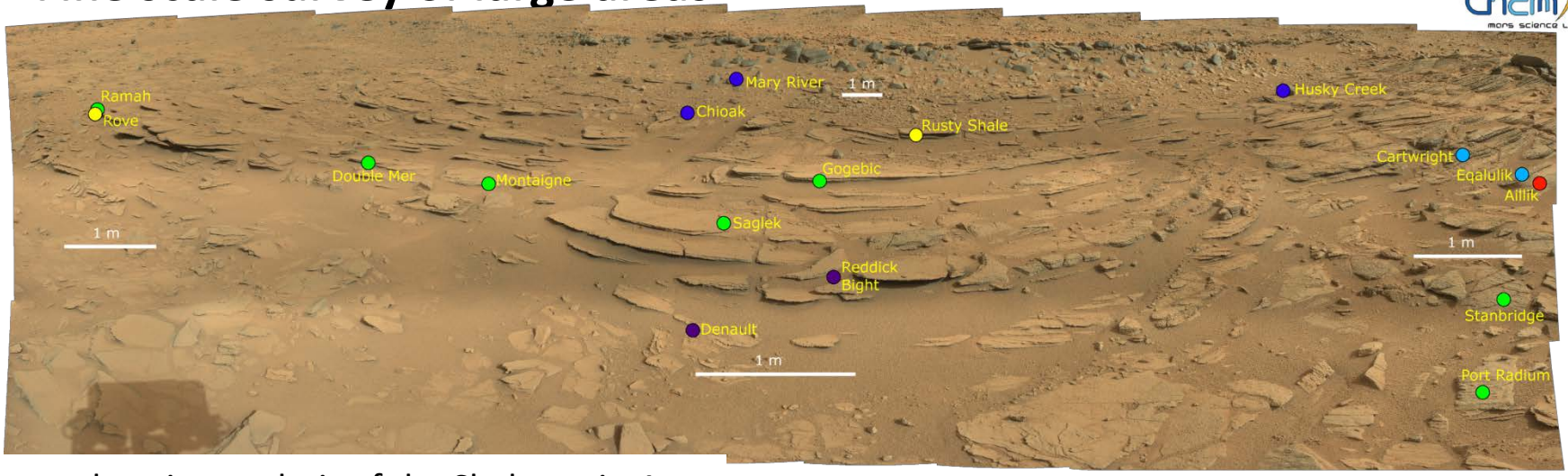
(Drillhole, sol 227)



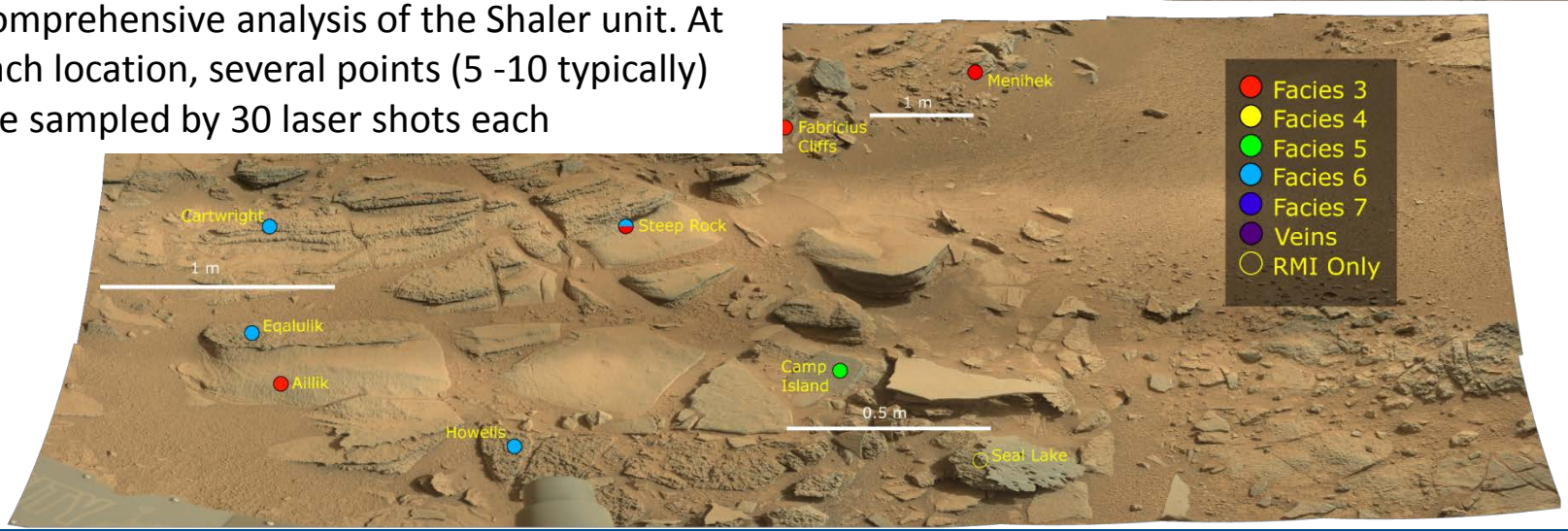


To Scale

Fine scale survey of large areas



Comprehensive analysis of the Shaler unit. At each location, several points (5 -10 typically) are sampled by 30 laser shots each



- Anderson R.B. et al. (2014) ChemCam Results from the Shaler Outcrop in Gale Crater, Mars. Submitted to Icarus.