The Composition of Mars

Michelle Wenz

Curiosity Image NASA

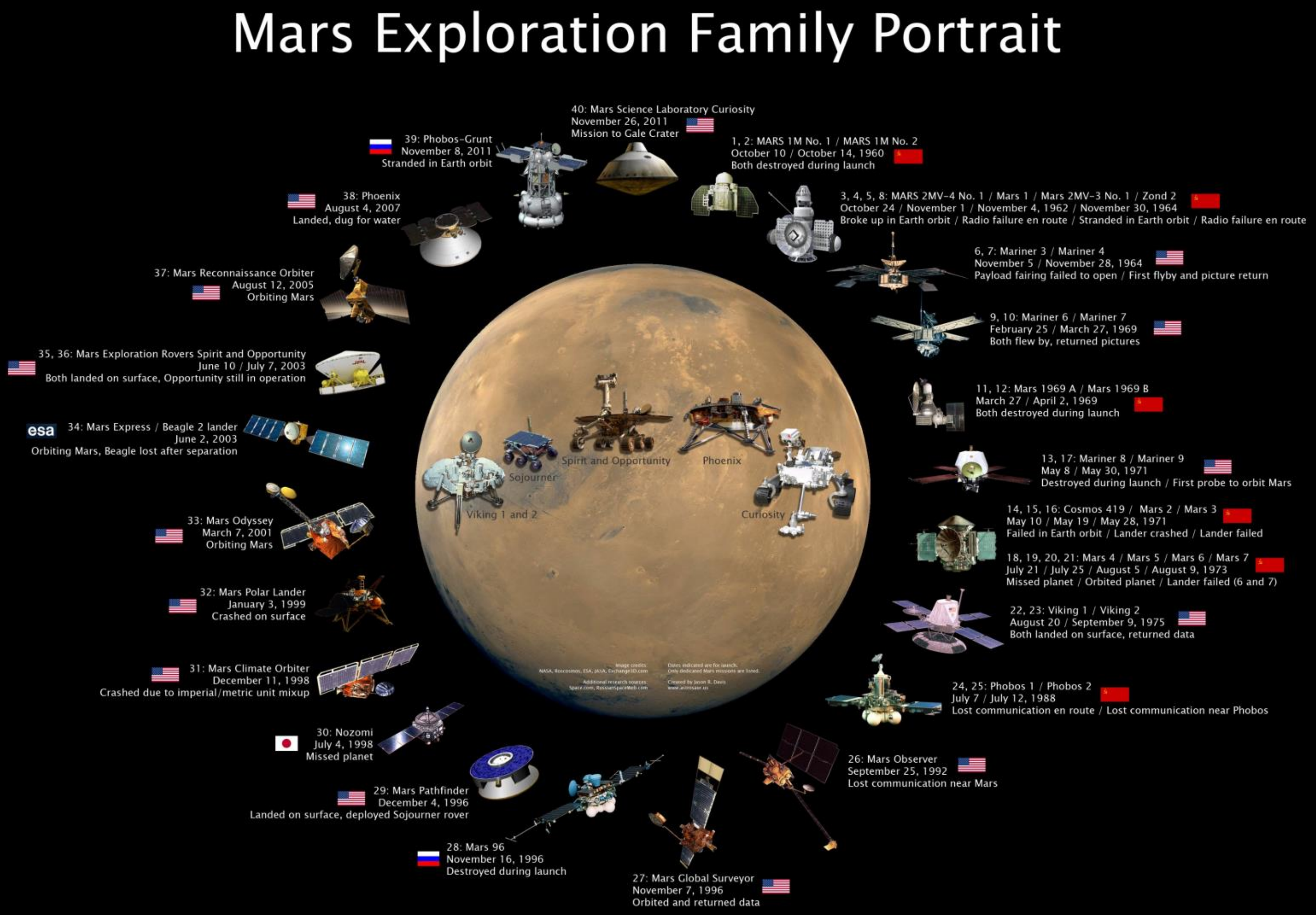
Importance of minerals

- Role in transport and storage of volatiles
  - Ex. Water (adsorbed or structurally bound)
  - Control climatic behavior
- Past conditions of mars
  - specific pressure and temperature formation conditions
- Constrains formation and habitability

Curiosity Rover at Mount Sharp drilling site, NASA image

Missions to Mars

- 44 missions to Mars (all not successful)
  - 21 NASA
  - 18 Russia
  - 1 ESA
  - 1 India
  - 1 Japan
  - 1 joint China/Russia
  - 1 joint ESA/Russia
- First successful mission was Mariner 4 in 1964



Credit: Jason Davis / astrosaur.us, http://utprosim.com/?p=808

First Successful Mission: Mariner 4

Mariner 4, NASA image

- First image of Mars
- Took 21 images
- No evidence of canals
- Not much can be said about composition

Mariner 4 first image of Mars, NASA image

Viking Lander

Viking Planning, NASA image

- First lander on Mars
- Multispectral measurements

Viking Anniversary Image, NASA image

Viking Lander

- Measured dust particles
  - Believed to be global representation
- Computer generated mixtures of minerals
  - quartz, feldspar, pyroxenes, hematite, ilmenite

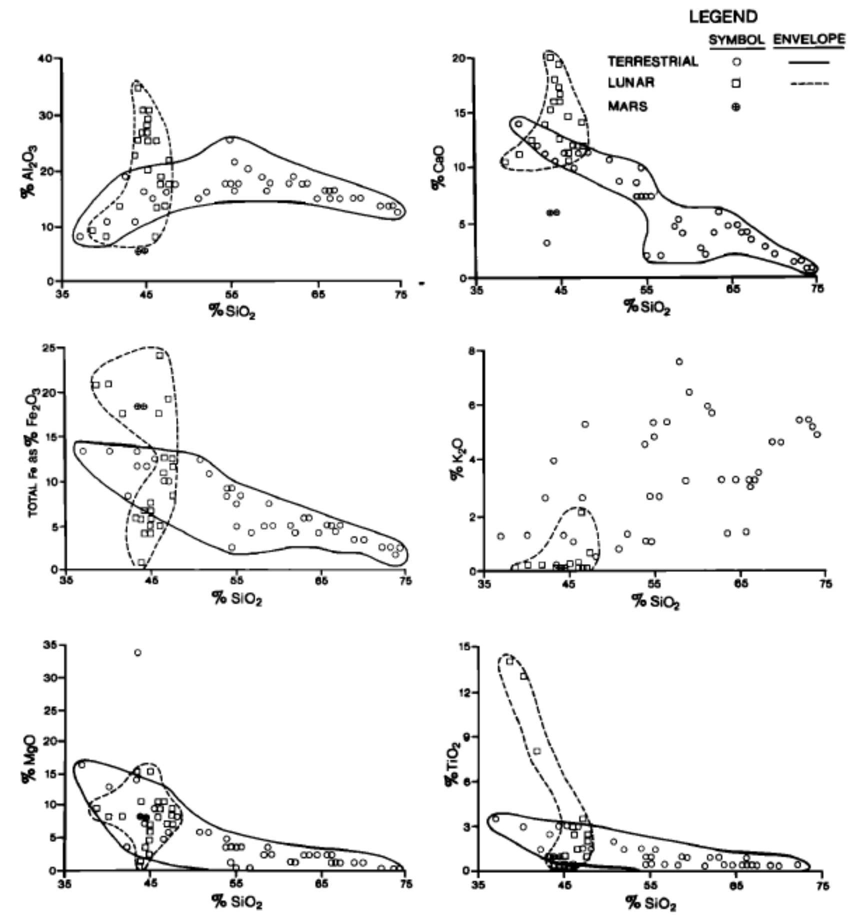


Fig. 1. Harker variation diagrams for terrestrial and lunar igneous rocks and Martian fines. Lunar rocks are basaltic and anorthositic rocks and breccias from the Apollo 11, 12, 14, 15, 16, and 17 missions [*Rose et al.*, 1973, 1975; *Taylor*, 1975]. Terrestrial igneous rocks are averages of common rock types [*Wedepohl*, 1969]. Fields enclosing the vast majority of the two groups have been delineated subjectively.

Toulmin III et al., 1977

Hubble Space Telescope

- Better resolution than Mariner 6 and 7
- Viking limited to three bands between 450 and 590 nm
- UV- near IR
  - Optimized for iron bearing minerals and silicates

Hubble Space Telescope NASA/ESA Image featured in Astronomy Magazine

Hubble Spectroscopy Results

- 1994-1995
- Ferric oxide absorption band 860 nm
  - hematite
- Pyroxene 953 nm absorption band
- Looked for olivine contributions
  - 1042 nm band
  - No significant olivine contributions

Hubble Space Telescope 1995, NASA

Composition by Hubble

- Measure of the strength of the absorption band
- Ratio vs. radiance factor
- Low albedo flat spectra
- 5% variation in dark regions
- 953 nm pyroxene absorption
  - Stronger in craters and calderas
- Ferric mineral content increase in darker regions

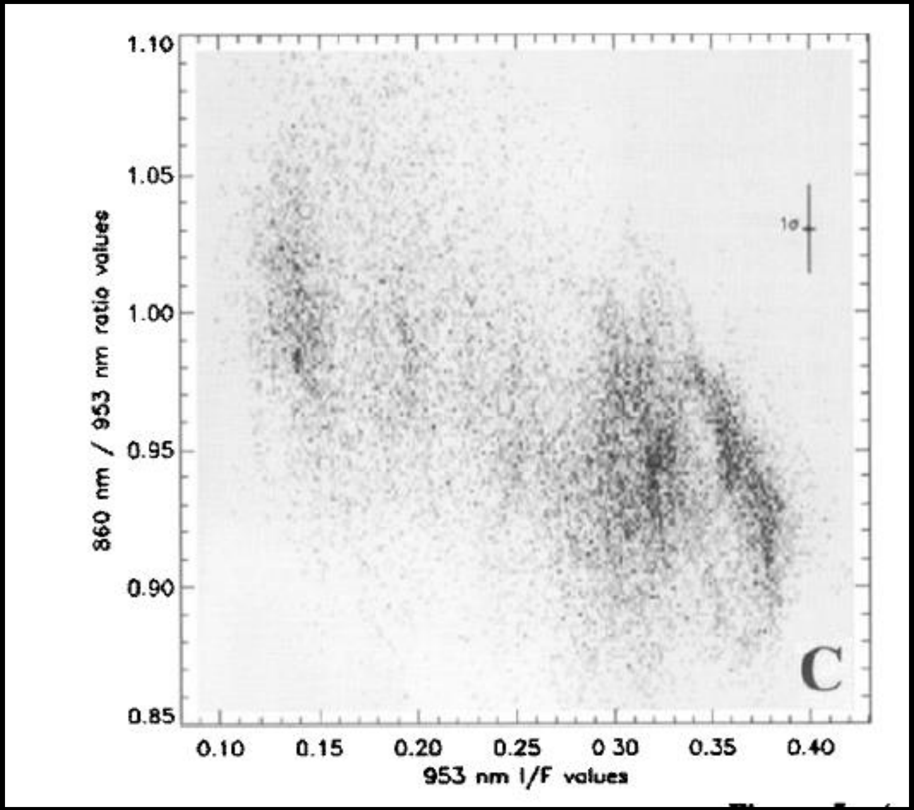
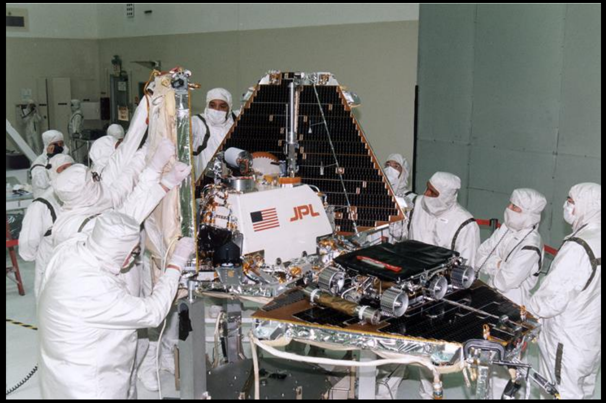
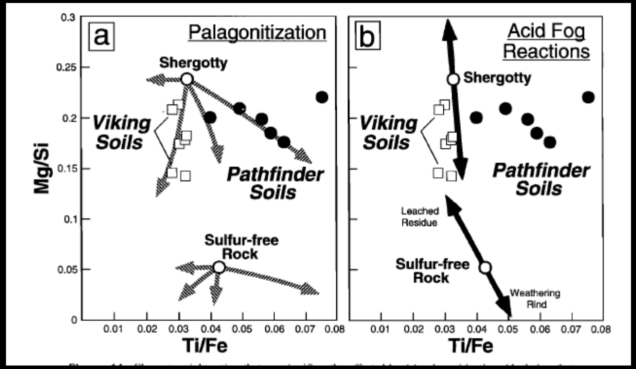


Figure 5 from Bell III et al., 1997

Pathfinder (1997) Mineralogy

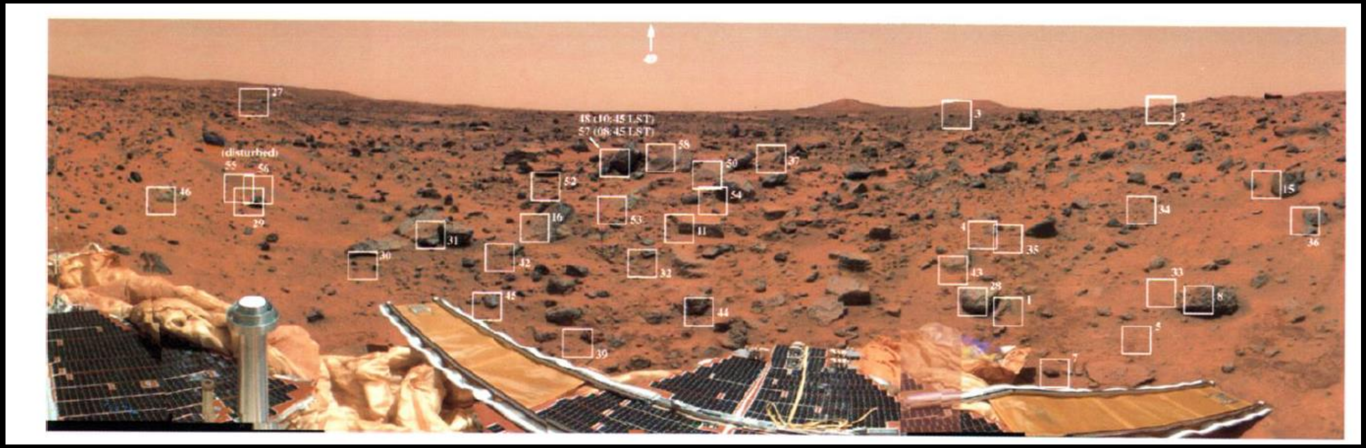


Pathfinder, NASA Image



Comparison with Viking, Bell et al., 2000

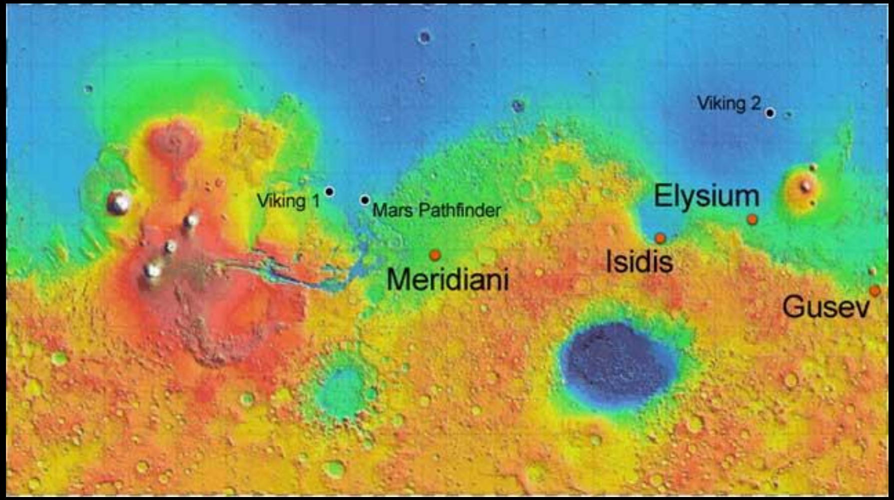
- Ferric Oxides
- Goethite
- Differs from Viking
  - Had significantly higher S and Cl abundances
  - Lower Si abundances
- Tried computer calculations of mixtures of minerals
  - smectite, silicate and oxides didn't yield acceptable solutions



Multispectral spot locations, Bell et al., 2000

Spirit (2003) Mineralogy

- First color image from surface Mars
- Had Mössbauer spectrometer
  - Measured the oxidation state of Fe
  - ID of Fe bearing phases
  - Relative abundance of phases
- Gusev Crater

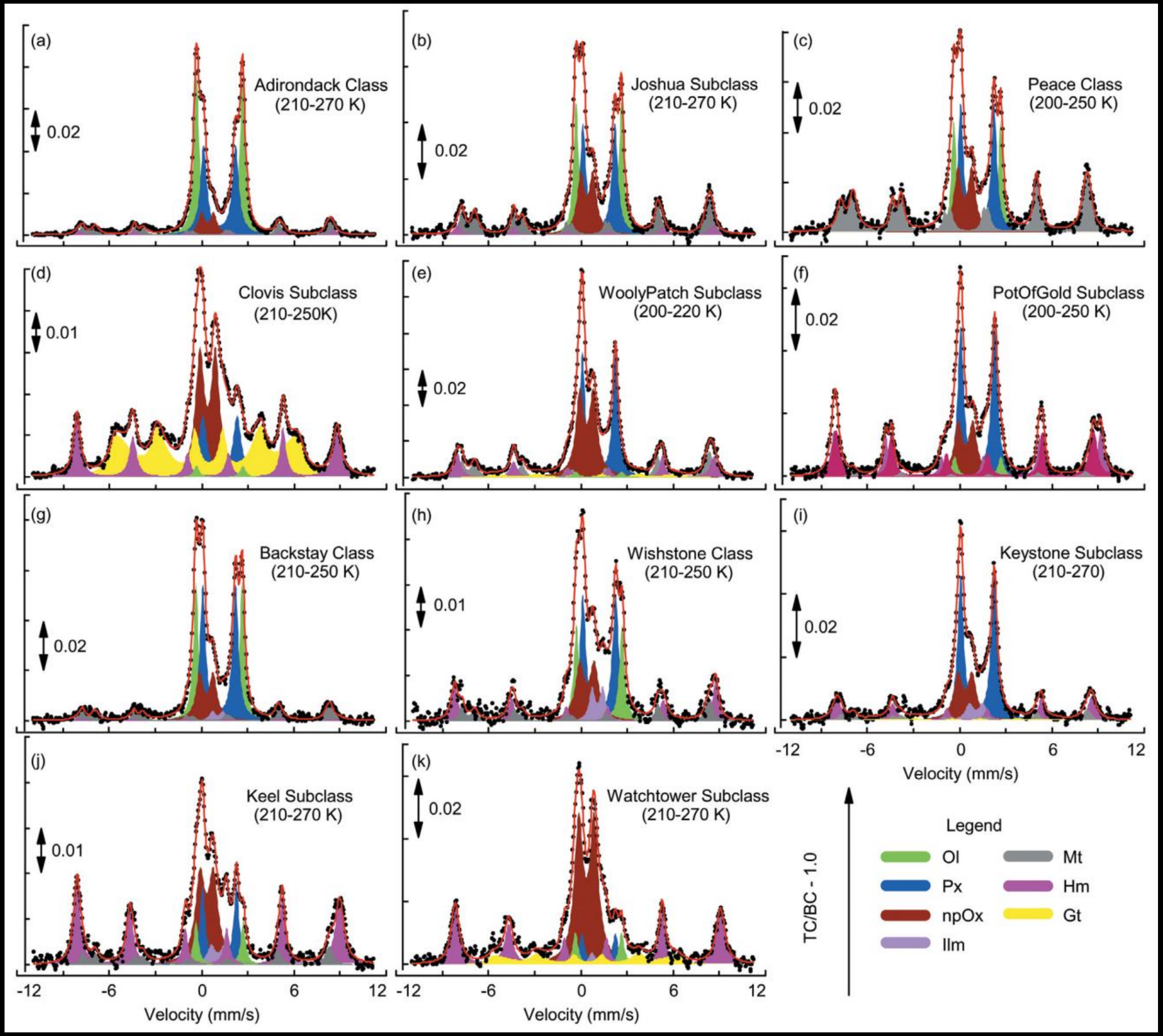


NASA Image from MER "Opportunity" Page

Spirit 2003, NASA

Mineralogy as determined by Spirit

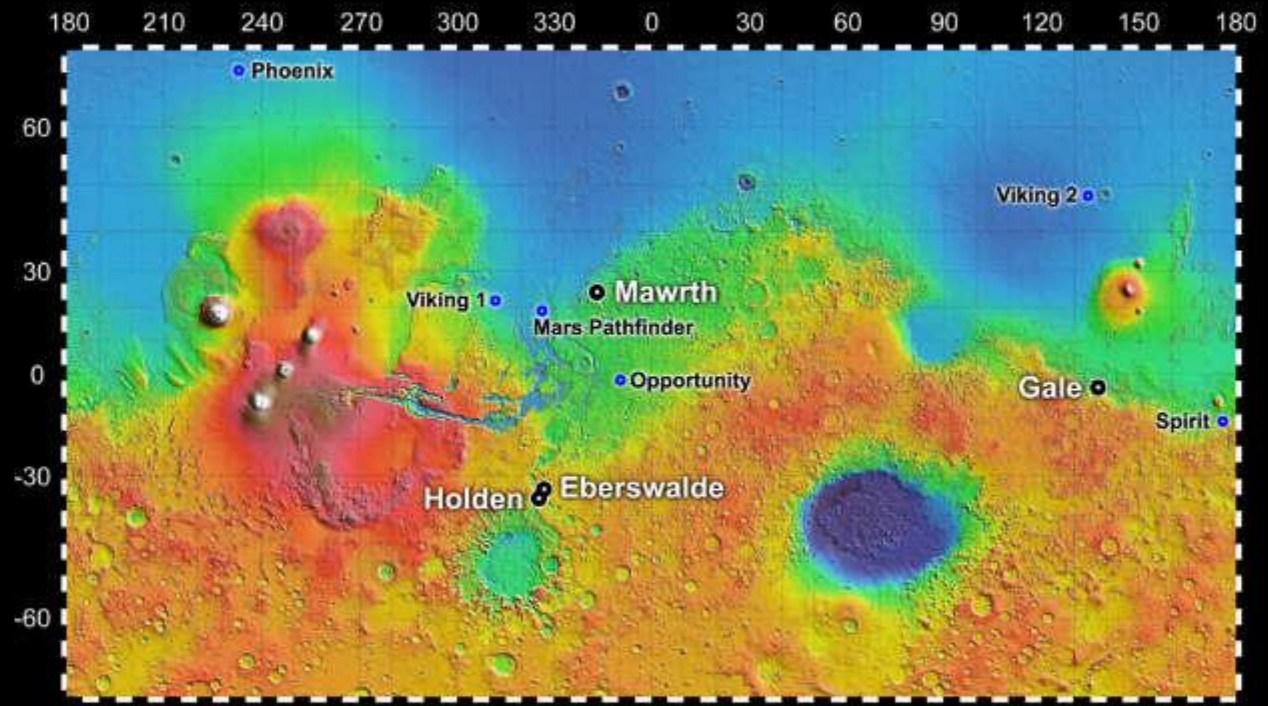
- Minerals
  - olivine
  - pyroxene
  - ilmenite
  - magnetite
  - hematite
  - goethite
  - nanophase ferric oxide
  - Fe sulfate



Morris et al., 2006

Opportunity (2003) Mineralogy

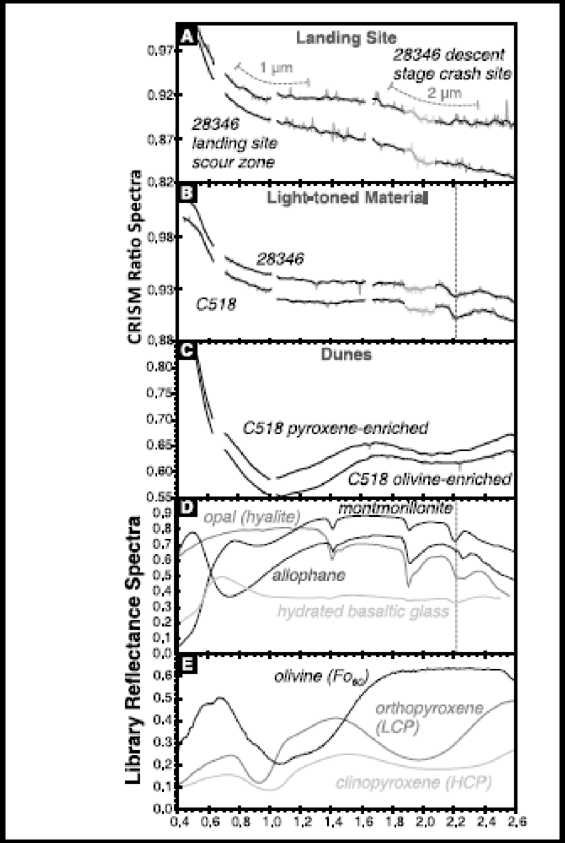
- Eagle Crater
- Minerals they found
  - olivine
  - pyroxene
  - magnetite
  - nanophase ferric oxide
  - jerosite
  - hematite
  - kamacite



NASA Image from MER "Opportunity" Page

Mars Reconnaissance Orbiter (2005)

- Gale Crater
- Compact Reconnaissance Imaging Spectrometer for Mars (CRISM)
- Minerals
  - iron bearing minerals
  - hydrated sulfates
  - silica
  - phyllosilicates
  - carbonates



Seelos et al., 2014

Dust devil, HiRise, NASA

Most recent mineralogy on Mars

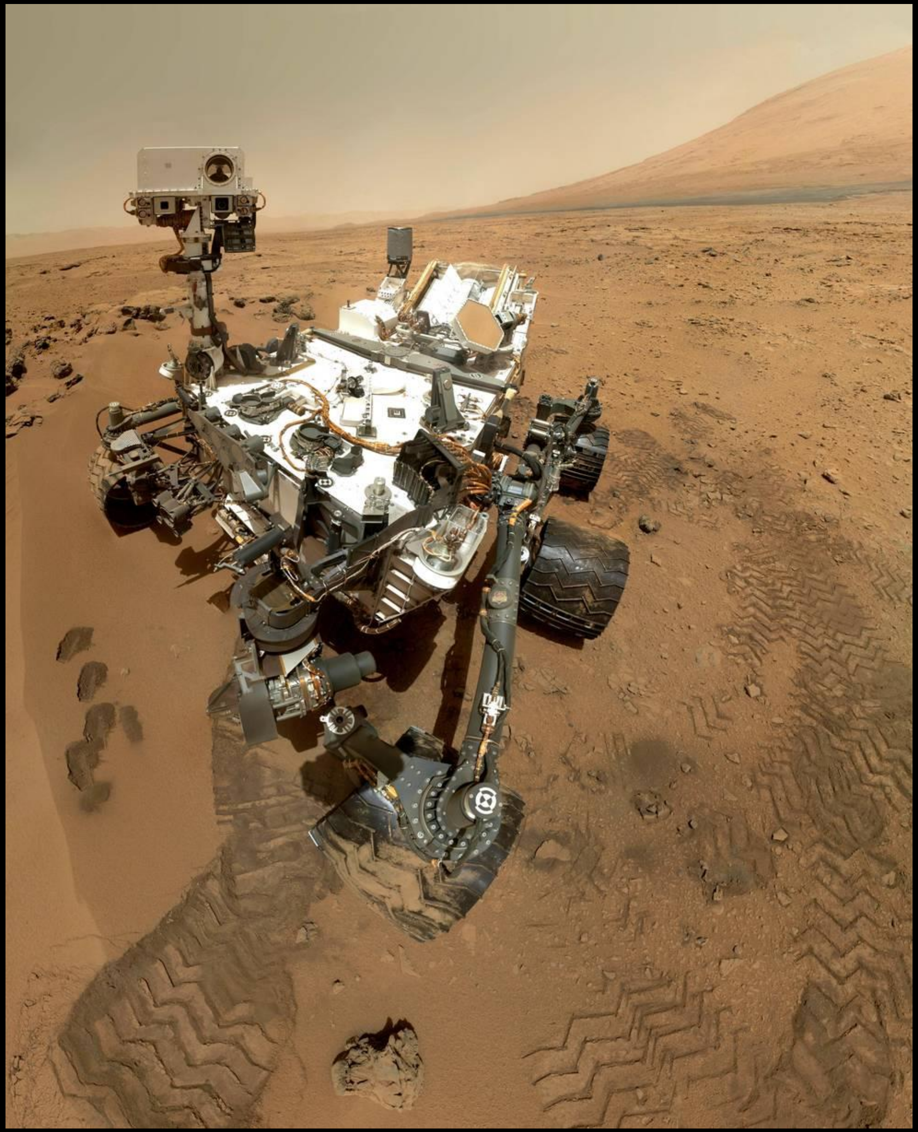
Curiosity by Mars Hand Lens Imager, NASA

Drill hole Curiosity, NASA

Possible Iron Meteorite Curiosity, NASA

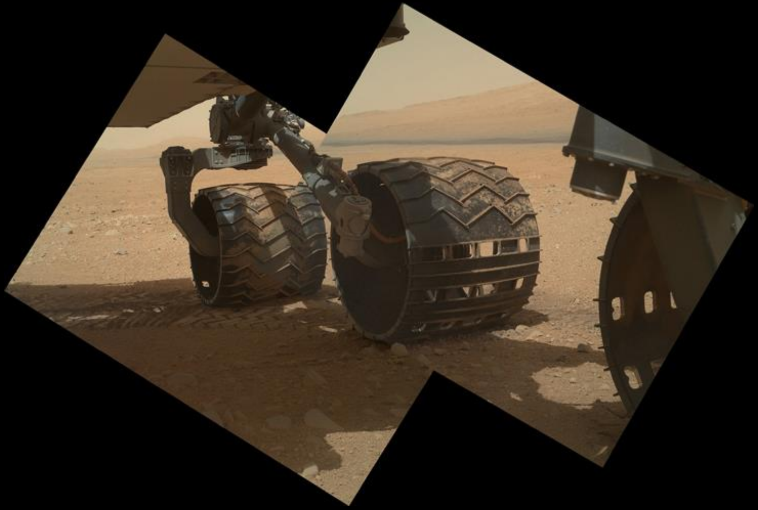
Curiosity, NASA

Mars Curiosity Rover (2012)

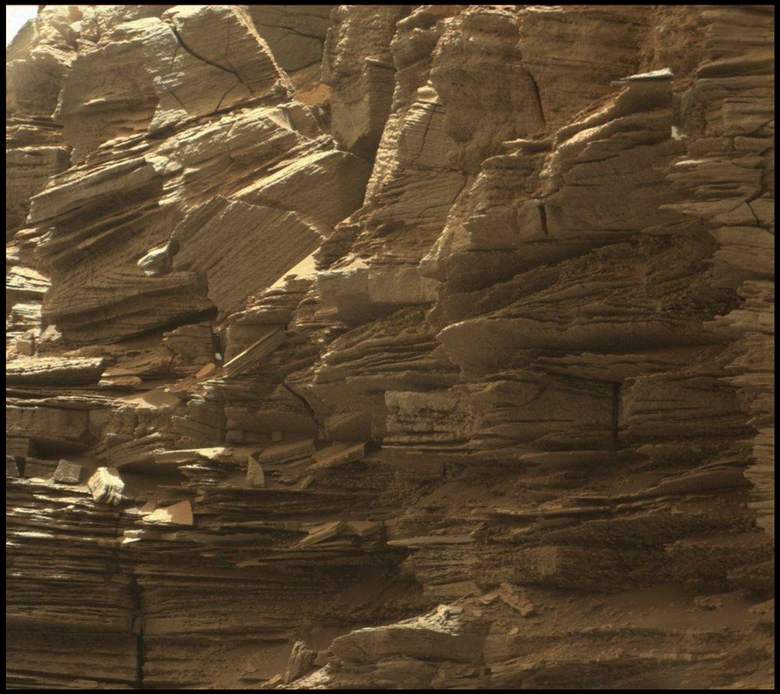


Curiosity rover image taken by using the Mars Hand Lens Imager taken, NASA

Shaunna Morrison, photo featured in UA news article, Photo credit: Thomas Bristow/NASA



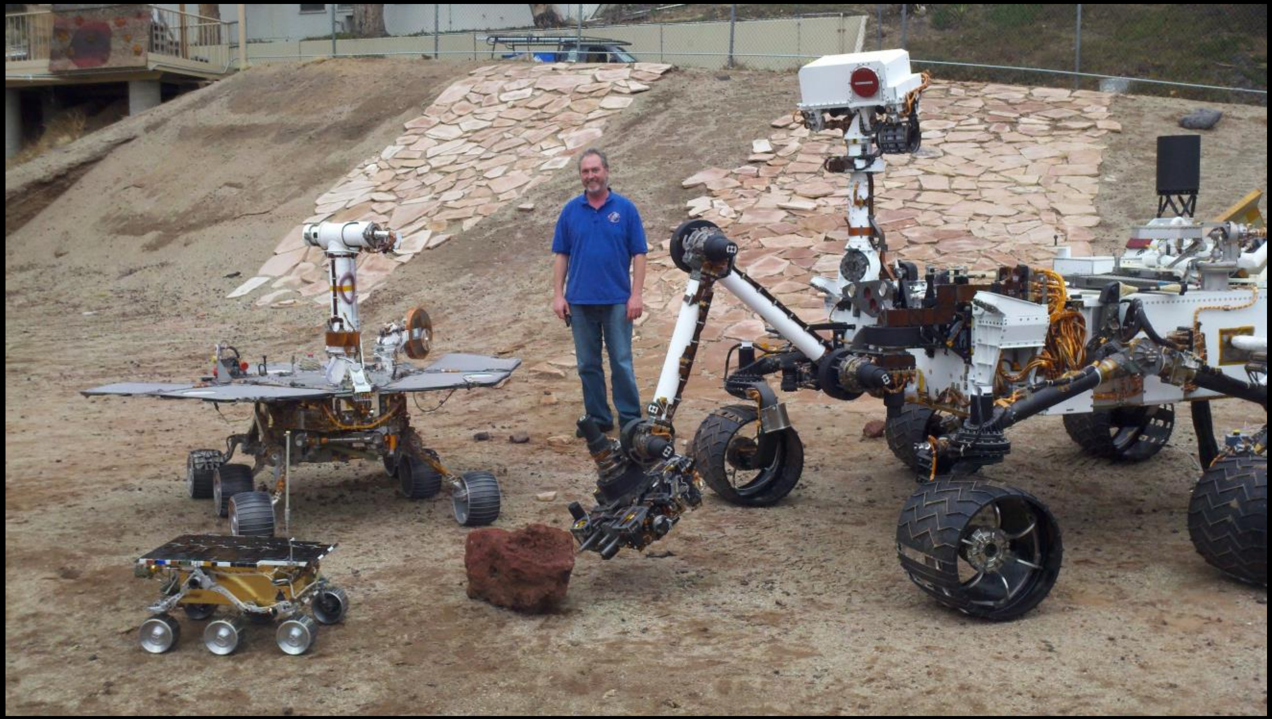
Wheels Curiosity, NASA



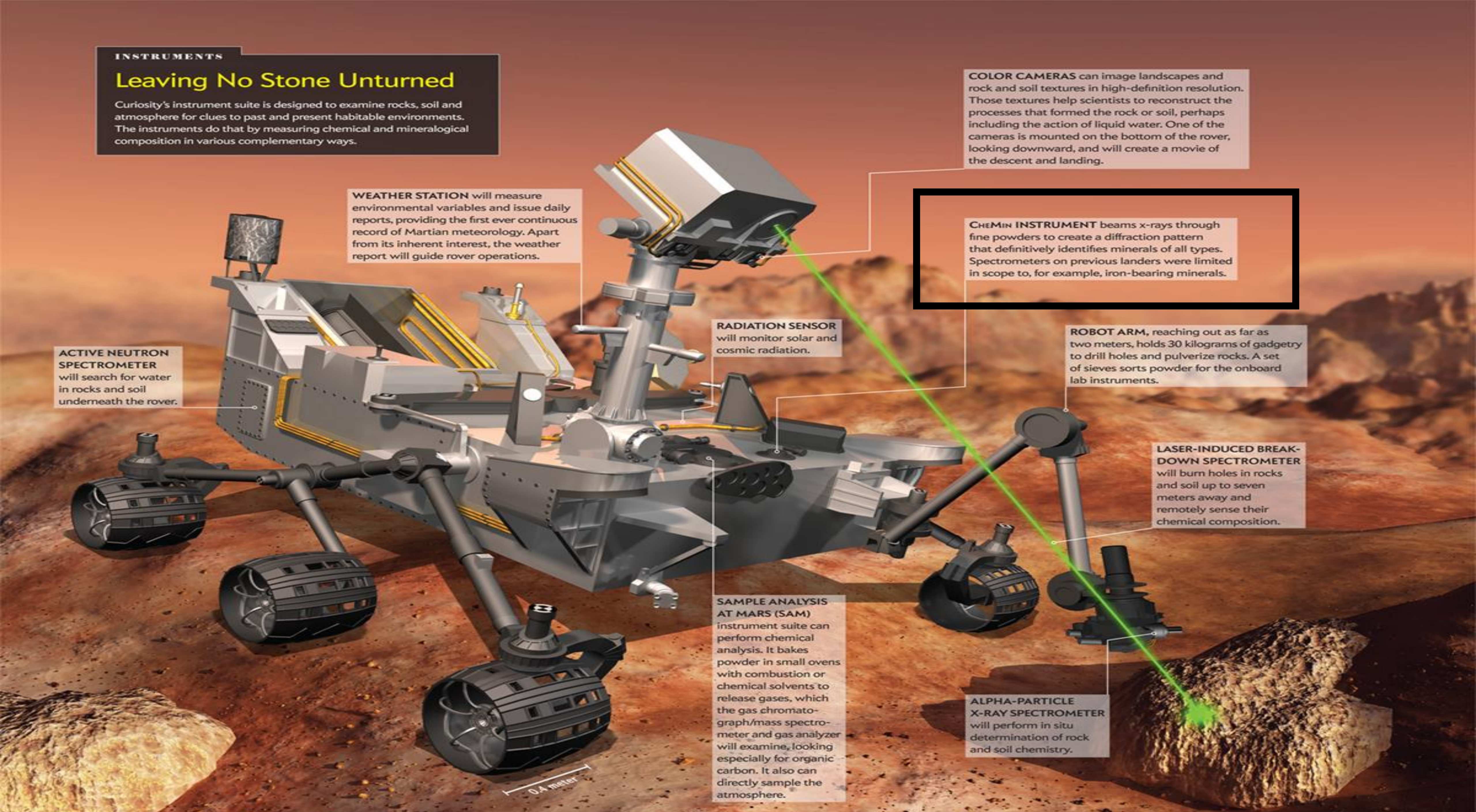
Murray Buttes at Mount Sharp Curiosity, NASA

Obama calling to congratulate MSL team for Curiosity landing, NASA

How is Curiosity Different



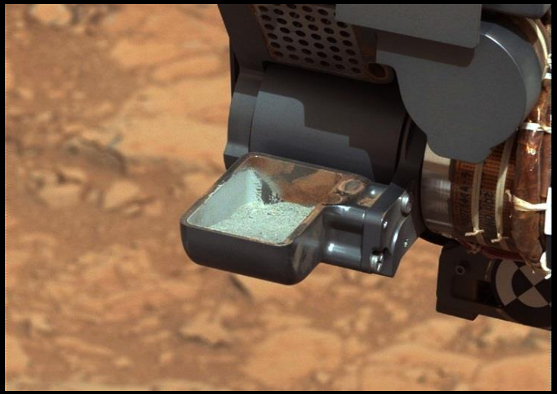
Left to right: Sojourner, Spirit and Opportunity, Curiosity, in Pasadena, CA JPL Image



Grotinger and Vasavada, Reading the Red Planet, Scientific American 2012

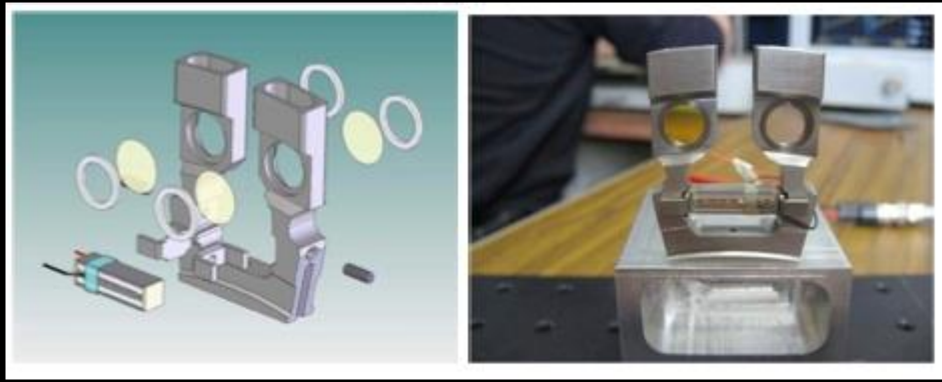
CheMin

- X-Ray diffractometer
- Can detect individual minerals in complex mixtures at the 3% and above
- 27 reusable sample chambers
- Sample wheel



CheMin, NASA Image

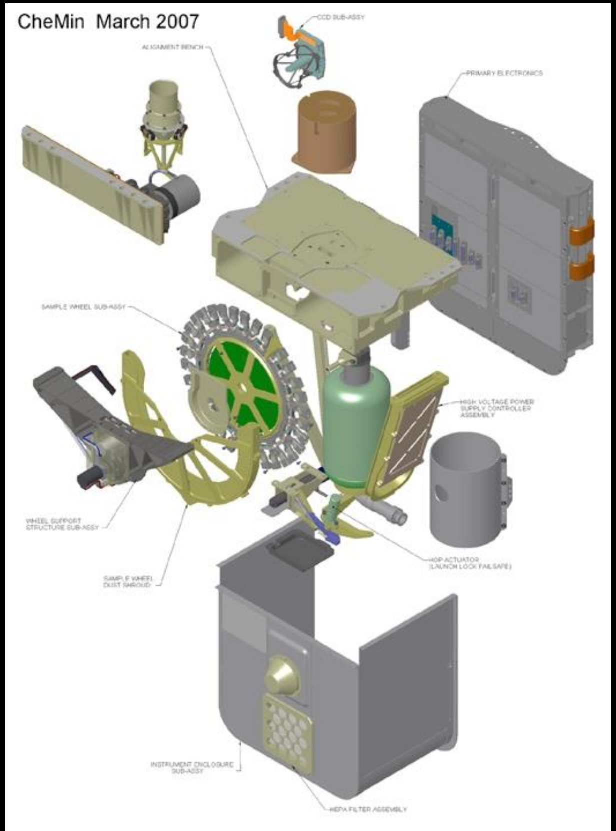
CheMin, NASA Image



CheMin, JPL Image

CheMin

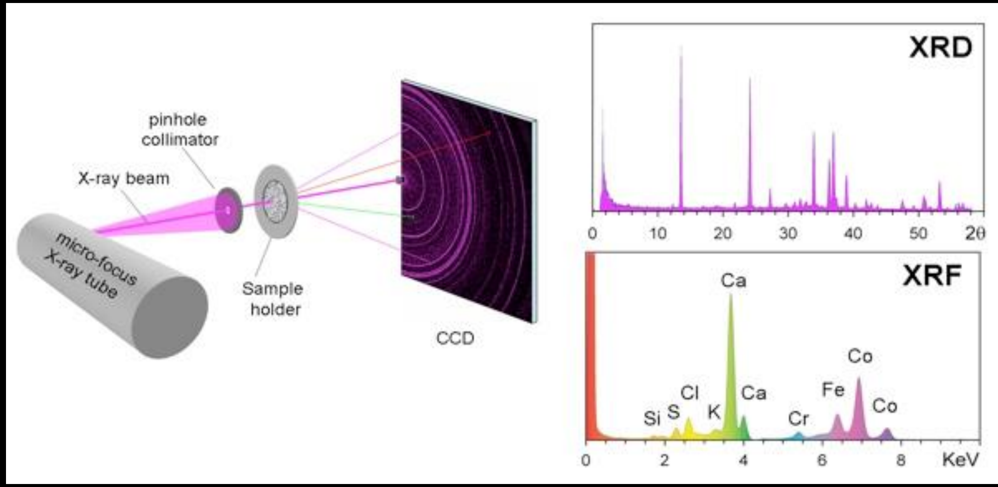
- Won awards for its design
  - Research and development magazine
  - Pittcon gold medal
  - 2010 NASA commercial invention of the Year
  - …..
  - Can now purchase through Olympus instruments



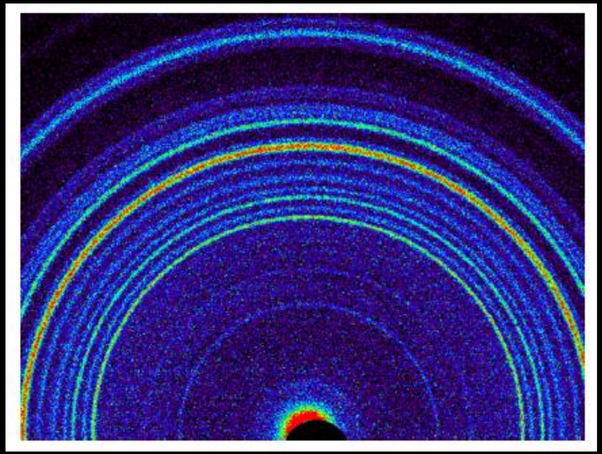
CheMin, JPL image

CheMin

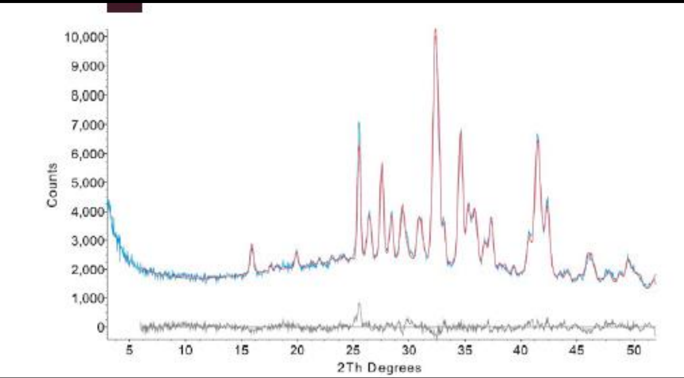
- 2theta 5 to 50 degrees
- 0.35 degree 2theta resolution
- Pizoelelectic actuator vibrate sample
  - Random orientations
- 20 hours collection time
- Co source, 20 KeV and 100 microampere



Downs et al., 2015, Elements and JPL image



Rocknest XRD pattern from Downs et al., 2015, Elements

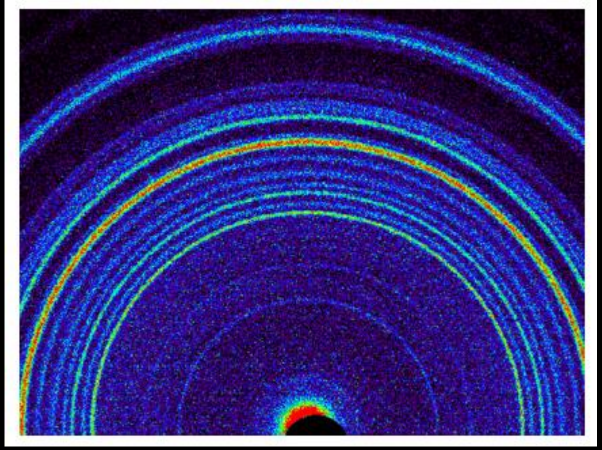


Rocknest XRD pattern from Downs et al., 2015, Elements

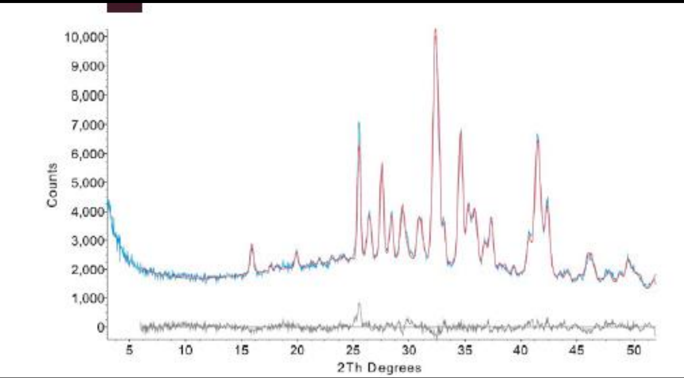
CheMin

- First XRD pattern taken on another planet
  - 41% by weight of crystalline component Feldspar
  - 28 % pyroxene
  - 22% olivine
  - Other minor phases

- The olivine is $(Mg_{1.12}Fe_{0.88})SiO_4$ so Fo56Fa44
(Morrison et al., 2013)
  - San Carlos (Fo91Fa9)
  - This confirms more Fe on surface of Mars then Earth



Rocknest XRD pattern from Downs et al., 2015, Elements



Rocknest XRD pattern from Downs et al., 2015, Elements

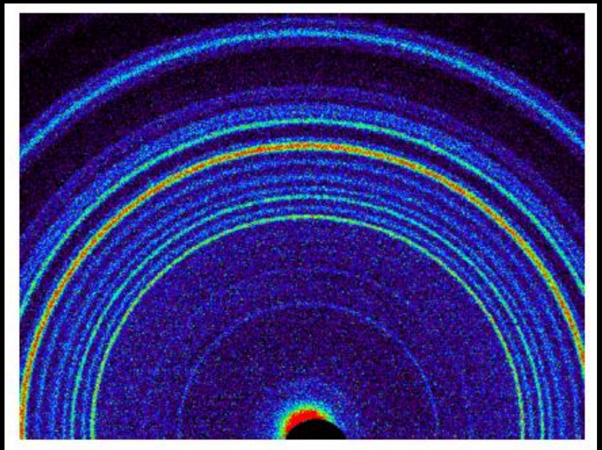
The Red Planet

- Believed to be Iron rich
  - Confirmed by spectroscopy
  - Strong absorption features 400-1200 nm
- Confirmed with X-ray diffraction

Curiosity Rover, NASA image

CheMin

- Pyroxene and olivine have linear trends with composition
- Feldspar is more complex to model
  - $(Ca_{0.52}Na_{0.48})(Al_{1.52}Si_{2.48})O_8$
  - Close to labradorite composition
  - Gem like fragments



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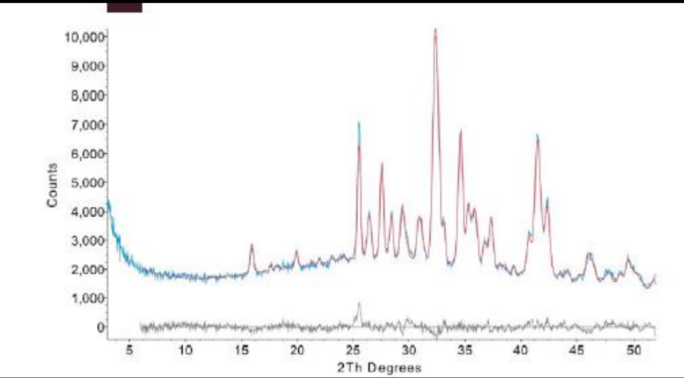
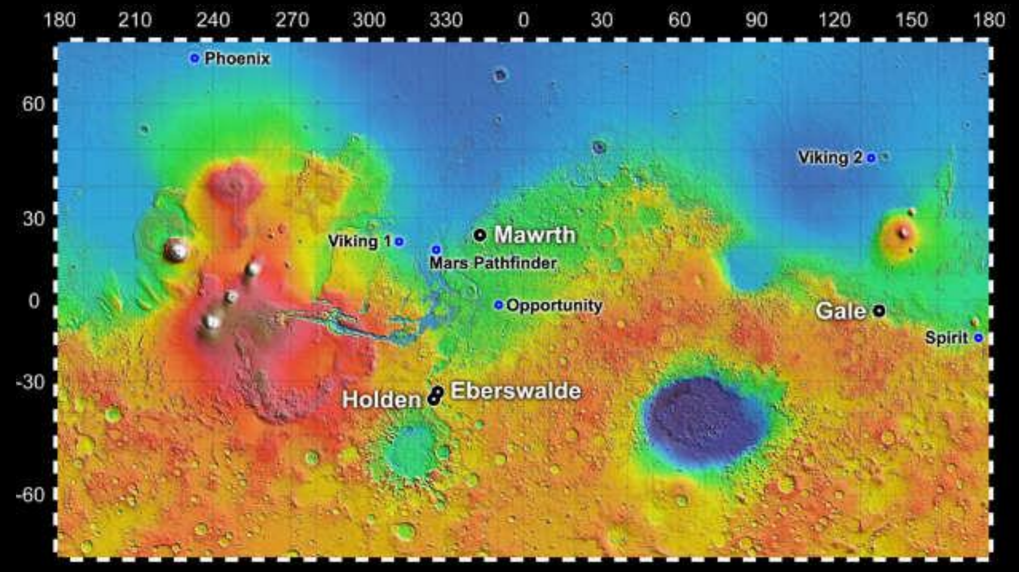


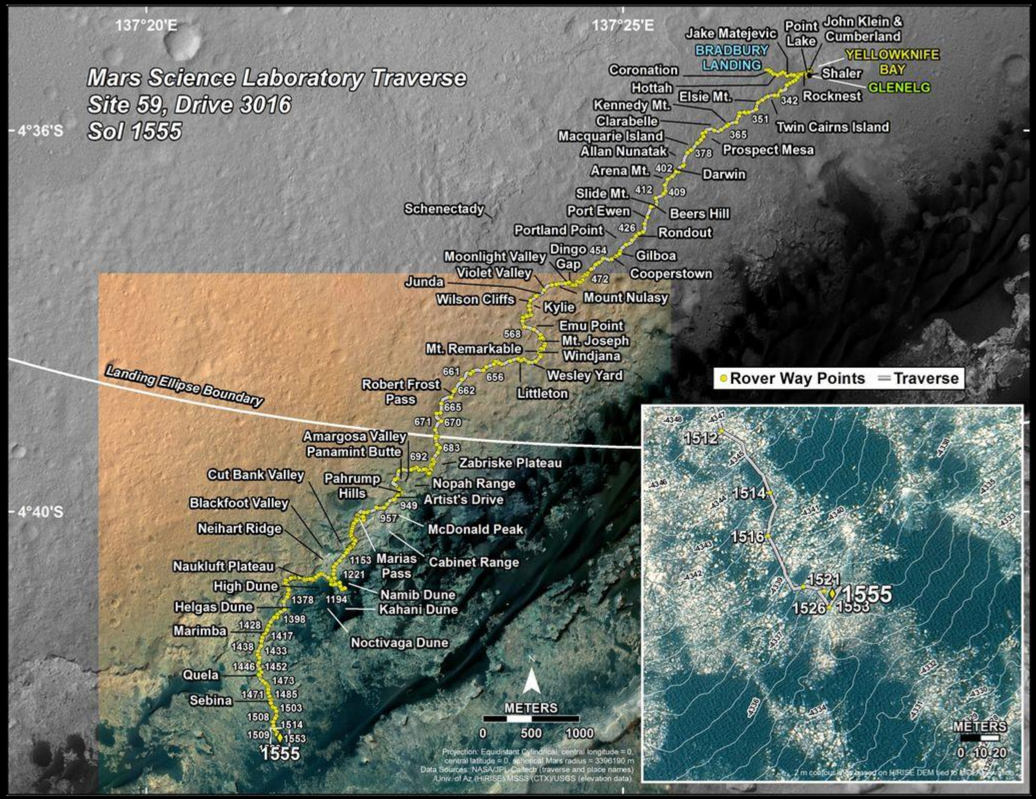
Rocknest XRD pattern from Downs et al., 2015, Elements

Mineralogy as determined by Curiosity

- Gale Crater (just south equator)
  - 4 km deep
  - Evidence for past water flow (MRO)
- Traveled 15 km so far



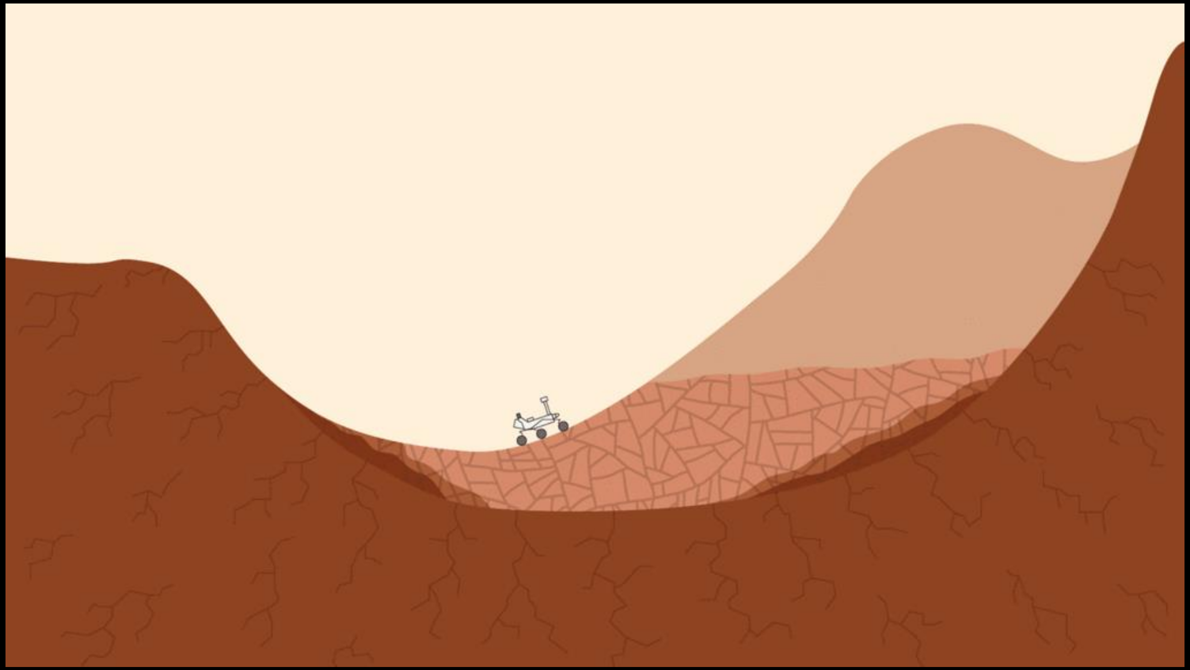
NASA Image from MER "Opportunity" Page



Curiosity Path, NASA Image

Mineralogy as determined by Curiosity

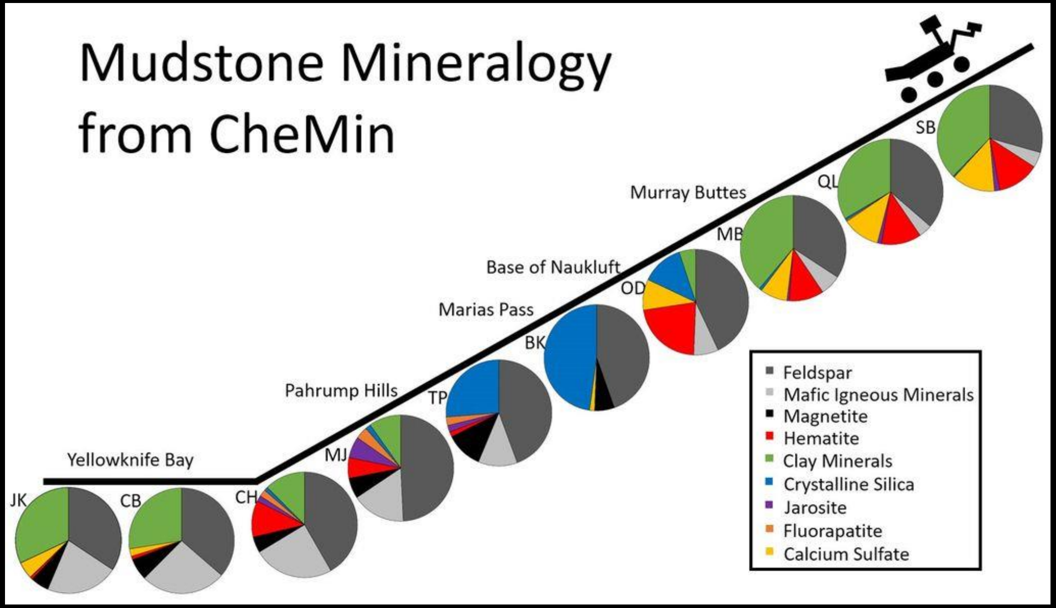
- Gale Crater (just south equator)
  - 4 km deep
  - Evidence for past water flow (MRO)
- Traveled 15 km so far
- Gale Crater is thought to have been a lake



Gale Crater, NASA Figure

Mineralogy as determined by Curiosity

- Basaltic Composition
  - Major constituents
    - Mg-Fe olivines
    - Mg-Fe-Ca pyroxenes
    - Na-C-K Feldspars
  - Minor constituents
    - ilmenite
    - magnetite
- Altered Basalt
  - calcium sulfates (anhydrites and basanite)
    - In agreement with MERS
  - iron oxides (hematite)
  - pyrrhotite
  - clays
  - quartz

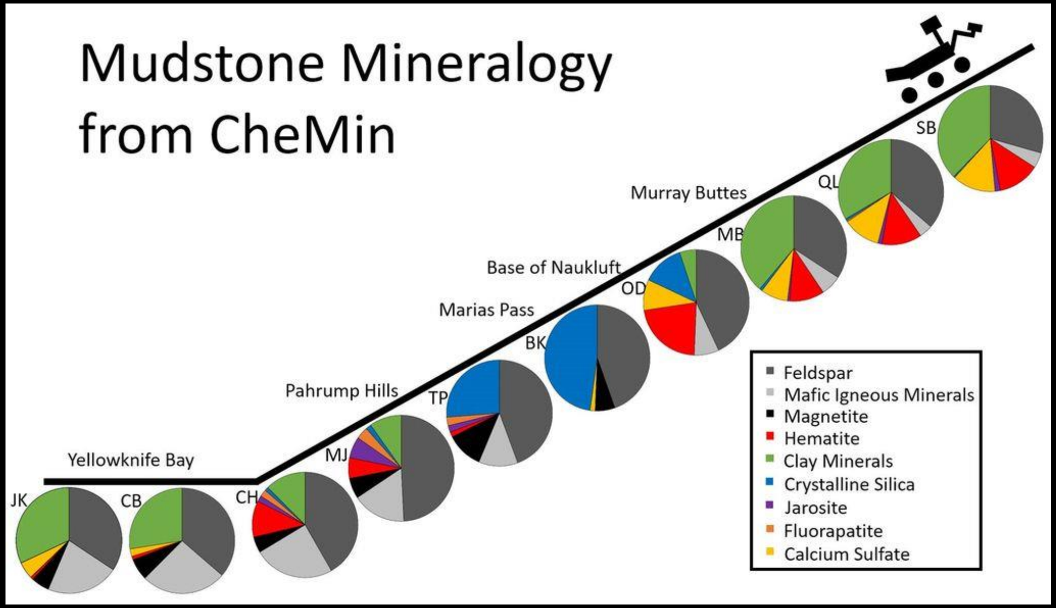


Composition of mudstone drill sites, NASA Figure

MERS, Opportunity, likely Calcium sulfate, NASA

Amorphous Components

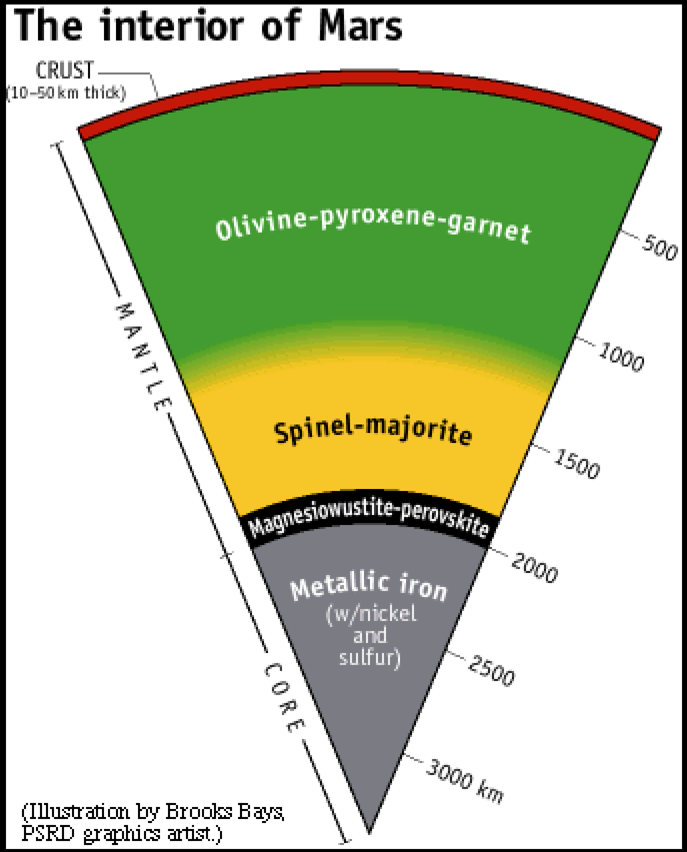
- Likely impact glasses
- Allophane (Al_2O)
- Hisingerite ($Fe_2Si_2O_5(OH)_4\ 2H_2O$)



Composition of mudstone drill sites, NASA Figure

Interior Composition

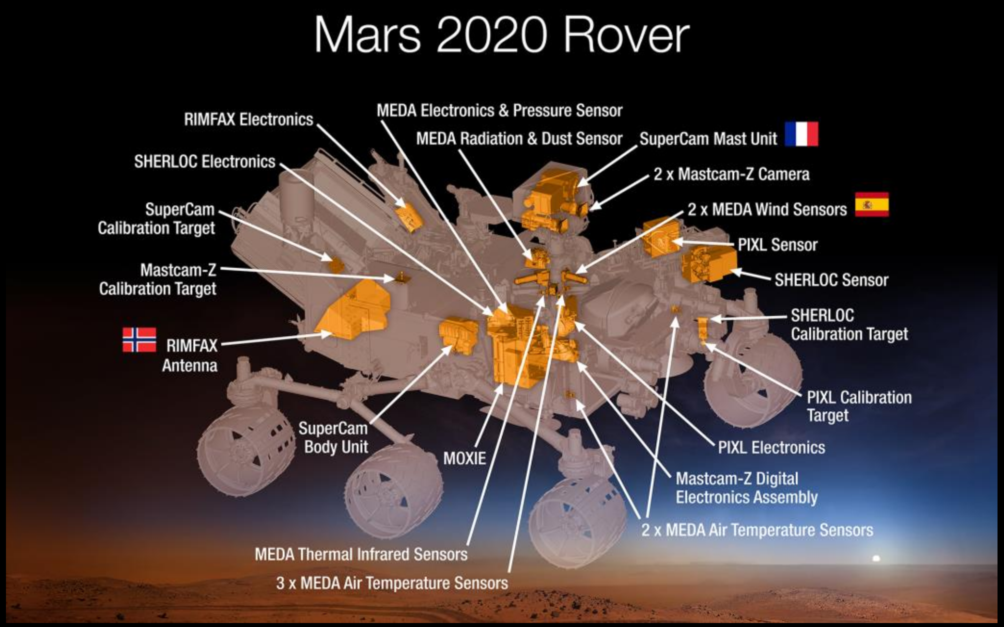
- Mantle is thought to be dominated by olivine
  - Likely Fo75
  - Expect P velocities of 7.64 to 7.80 km/sec (Johnston and Toksoz)
- Fe-FeS core (radius 1500-200 km)
- Need seismic measurements to confirm



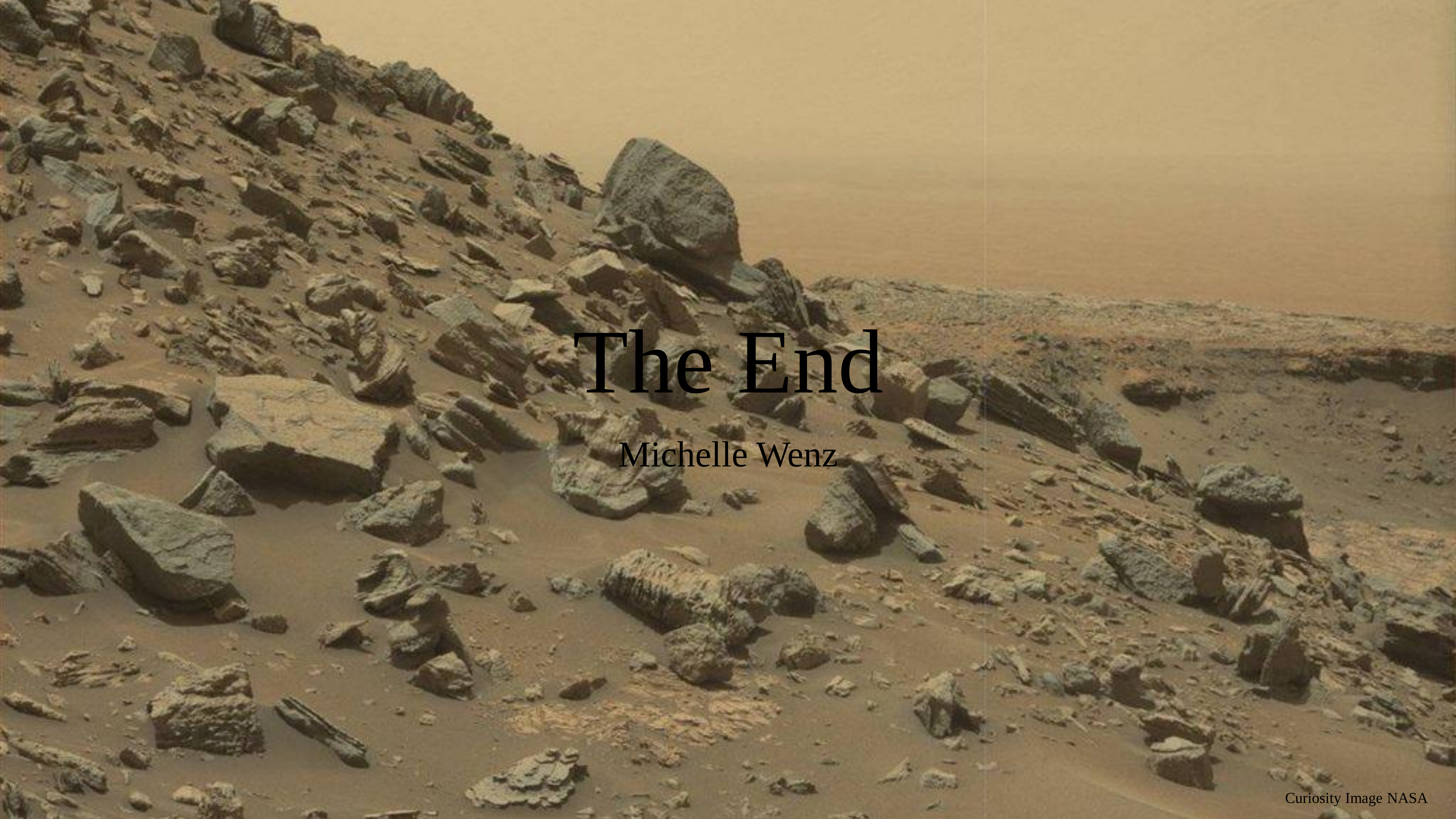
Composition of Mars, http://www.psrd.hawaii.edu

Future Directions

- Need more coverage
- Curiosity hopefully will be renewed in 2018
- People on Mars with hand held Raman spectrometers
  - Was Raman on ExoMars (ESA) but that crashed (no signal) in Oct. 2016



Mars 2020 Rover, NASA Image



The End

Michelle Wenz

Curiosity Image NASA