

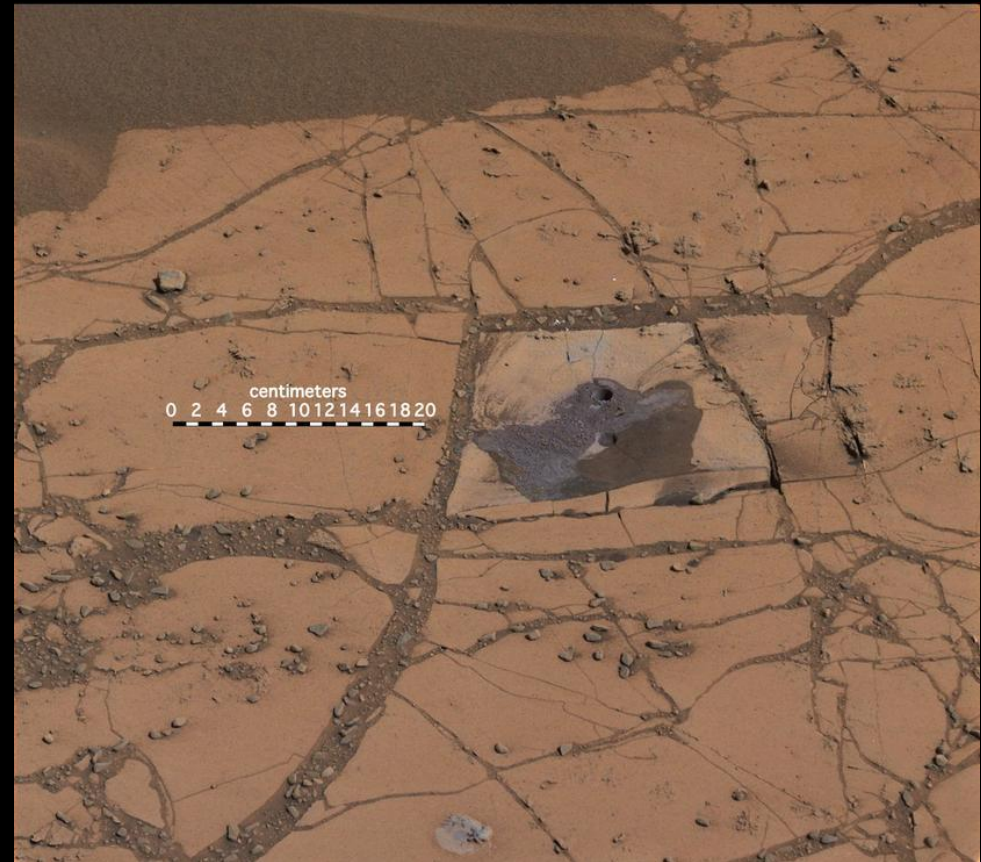
A wide-angle photograph of a Martian landscape. The scene shows rolling hills and a valley with a winding path or stream bed. The terrain is reddish-brown and appears to be composed of layered rock and soil. The sky is a clear, pale blue. The overall atmosphere is bright and clear.

# The Composition of Mars

Michelle Wenz

# 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



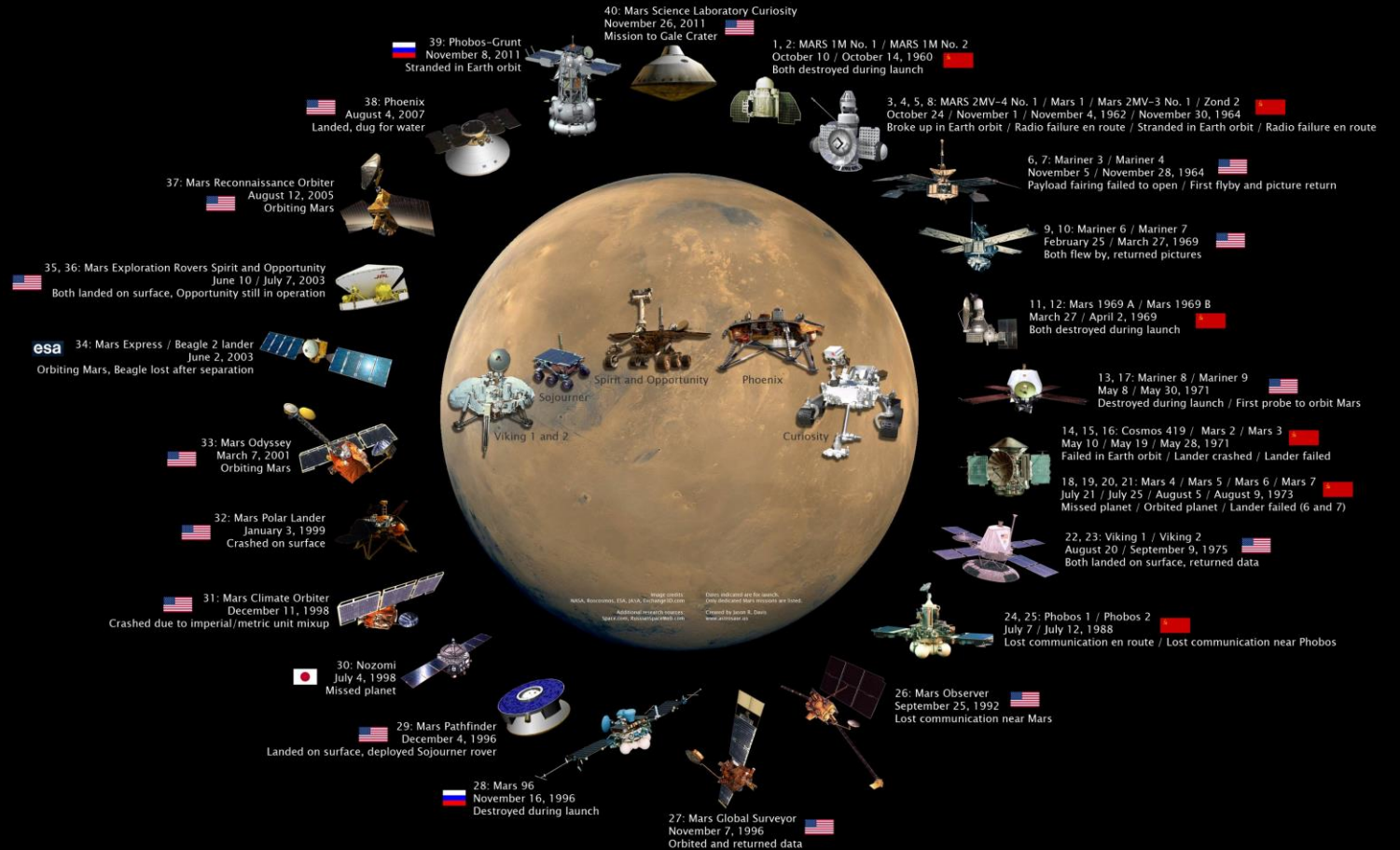
# Missions to Mars

- 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

## Mars Exploration Family Portrait

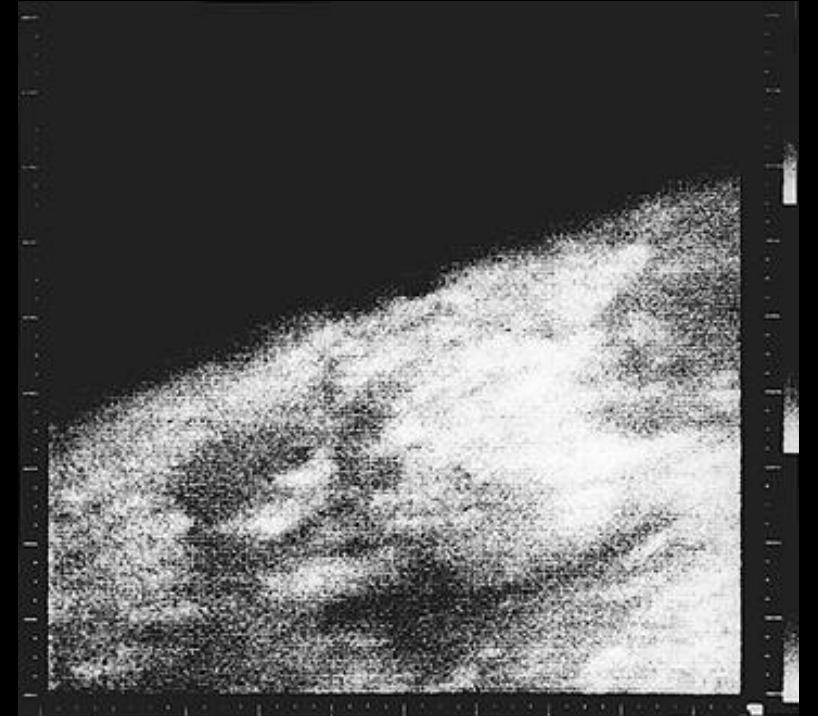


# First Successful Mission: Mariner 4



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

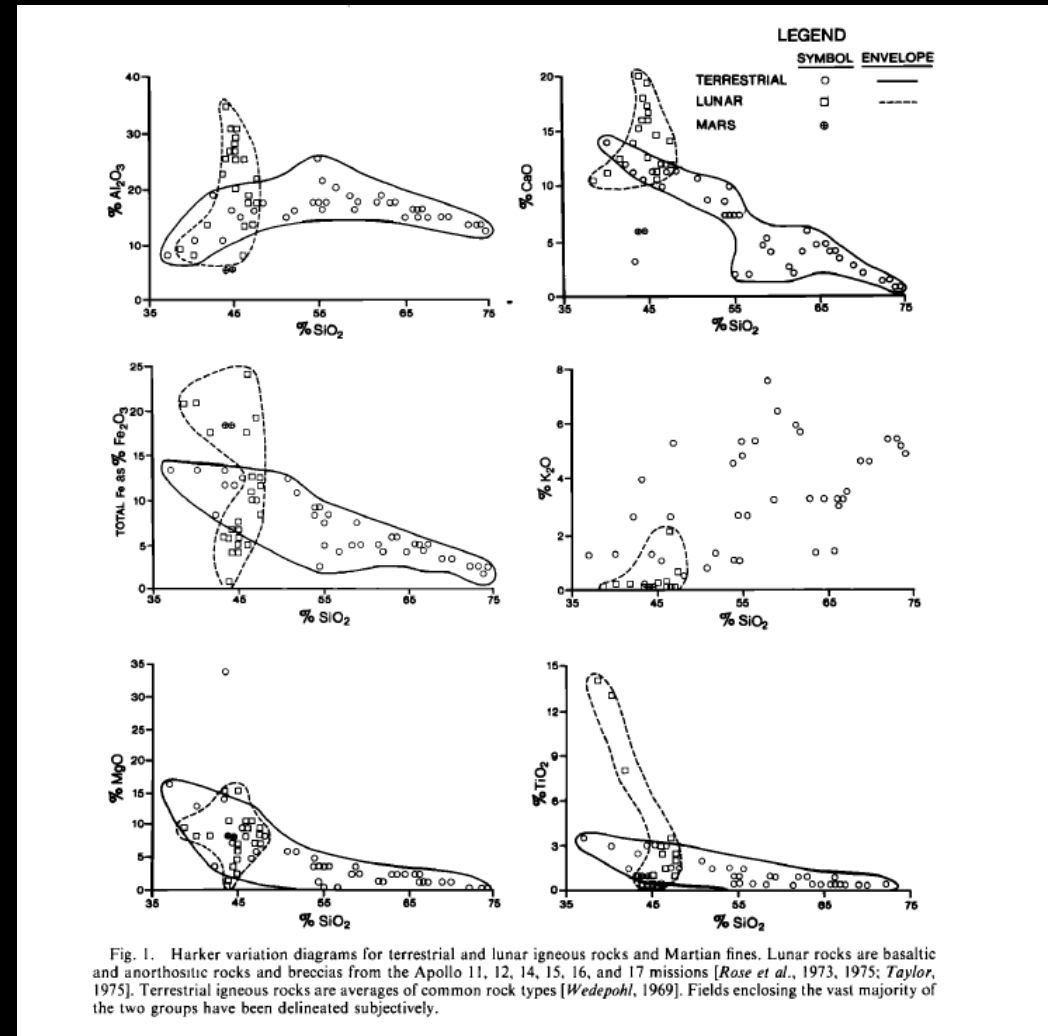
- First lander on Mars
- Multispectral measurements



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





# 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

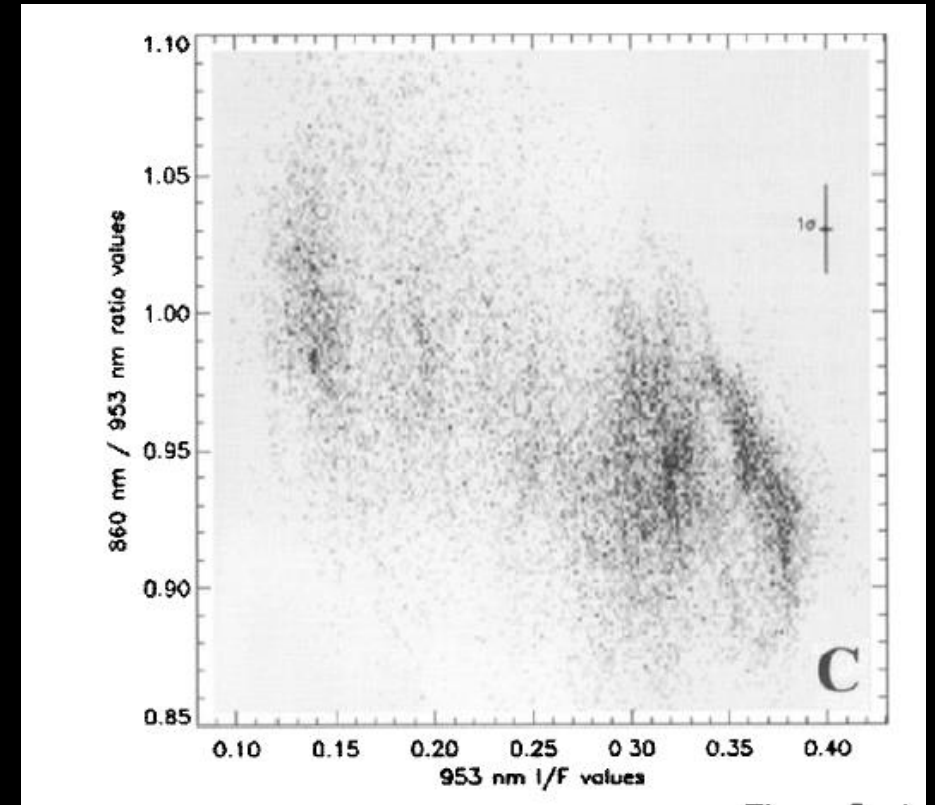
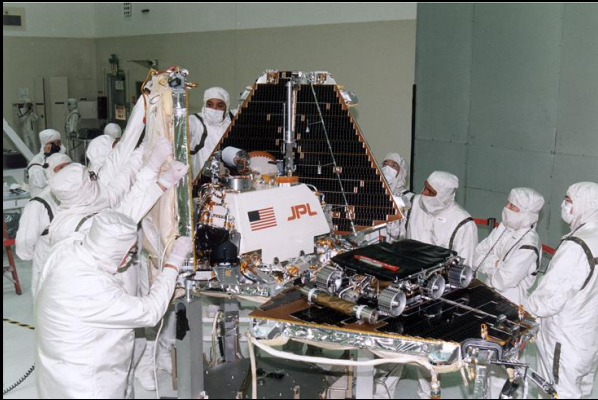
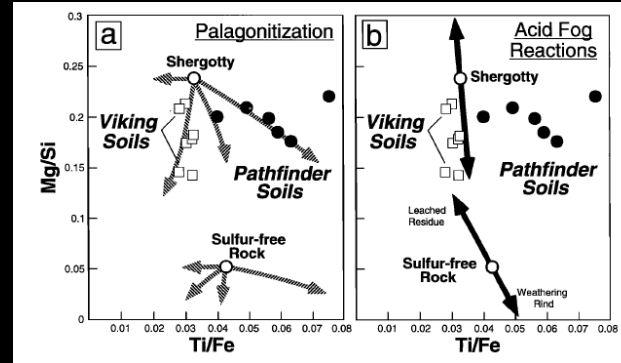


Figure 5 from Bell III et al., 1997

# Pathfinder (1997) Mineralogy

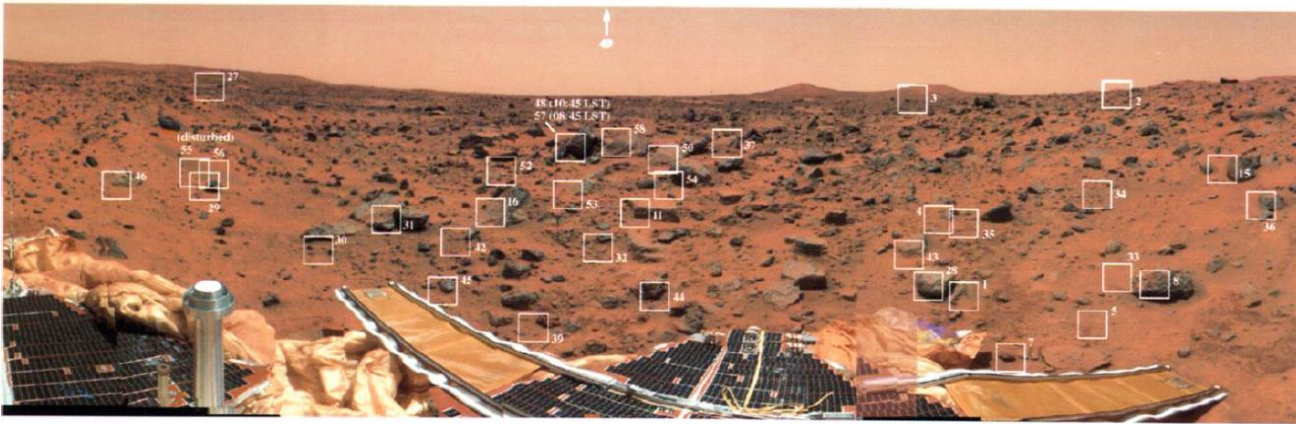


Pathfinder, NASA Image



Comparison with Viking, Bell et al., 2000

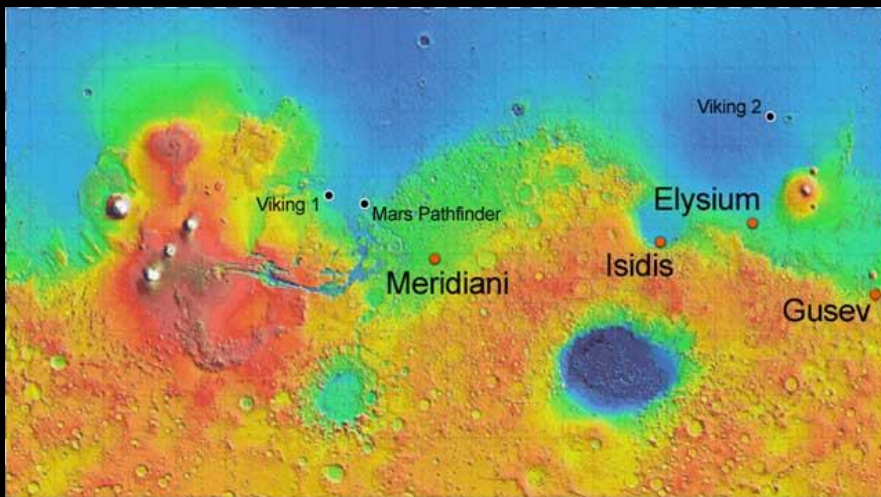
- Ferric Oxides
- Goethite
- Differs from Viking
  - Had significantly higher S and Cl abundances
  - Lower Si abundances
- Tried computer calculations of mixtures of minerals
  - smectite, silicate and oxides didn't yield acceptable solutions



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



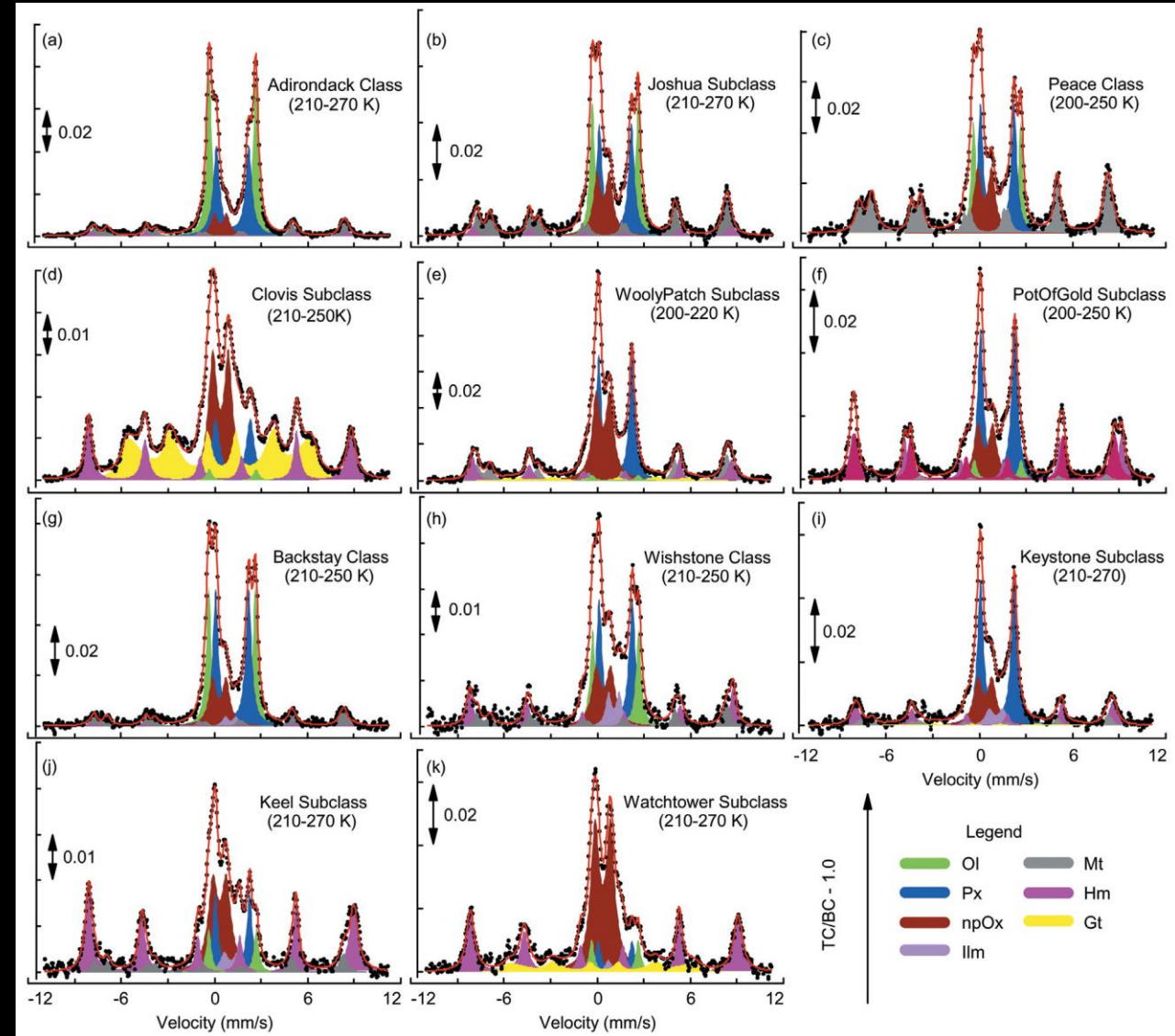
Spirit 2003, NASA



# Mineralogy as determined by Spirit

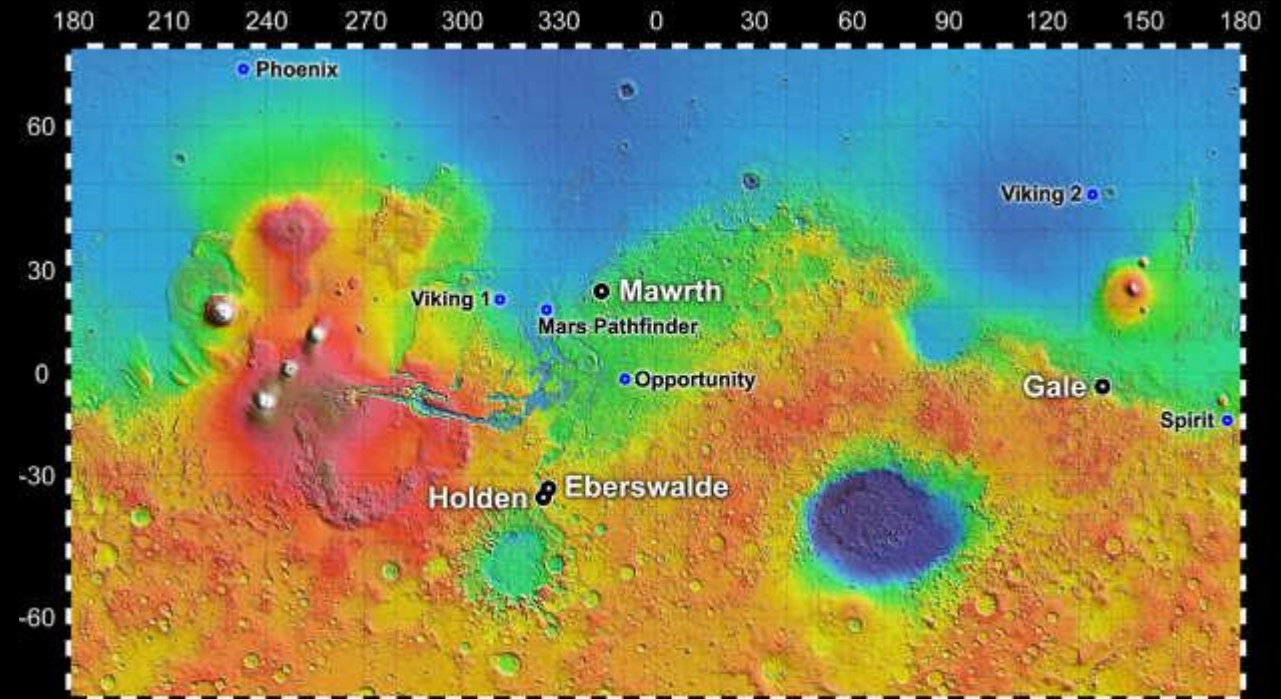
## ■ Minerals

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



# Opportunity (2003) Mineralogy

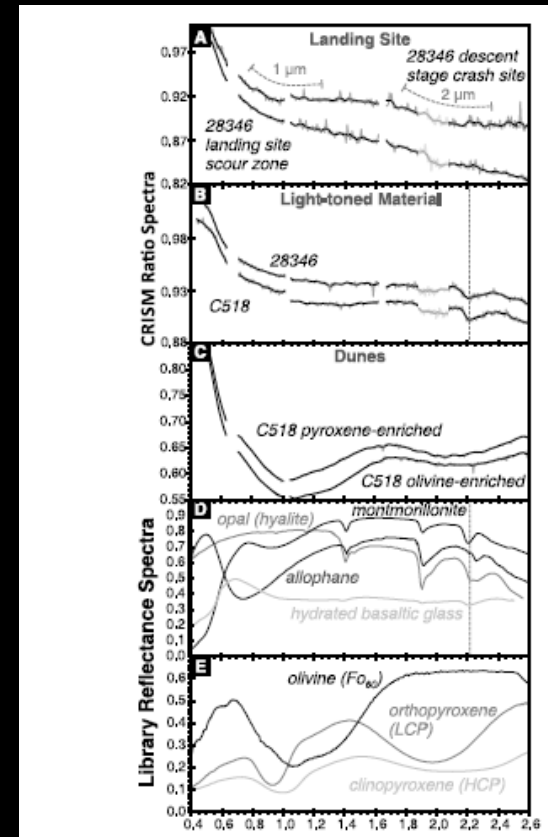
- Eagle Crater
- Minerals they found
  - olivine
  - pyroxene
  - magnetite
  - nanophase ferric oxide
  - jerosite
  - hematite
  - kamacite



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



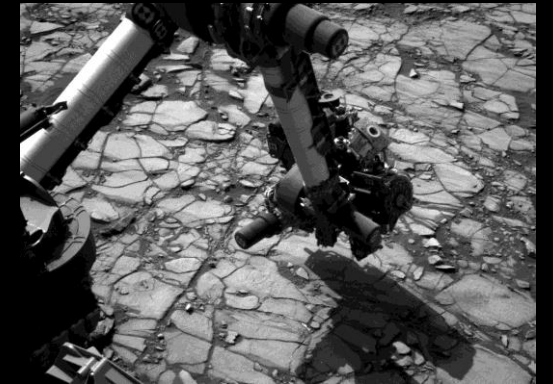
Curiosity by Mars Hand Lens Imager, NASA



Drill hole Curiosity, NASA



Possible Iron Meteorite Curiosity, NASA



Curiosity, NASA



# Mars Curiosity Rover (2012)



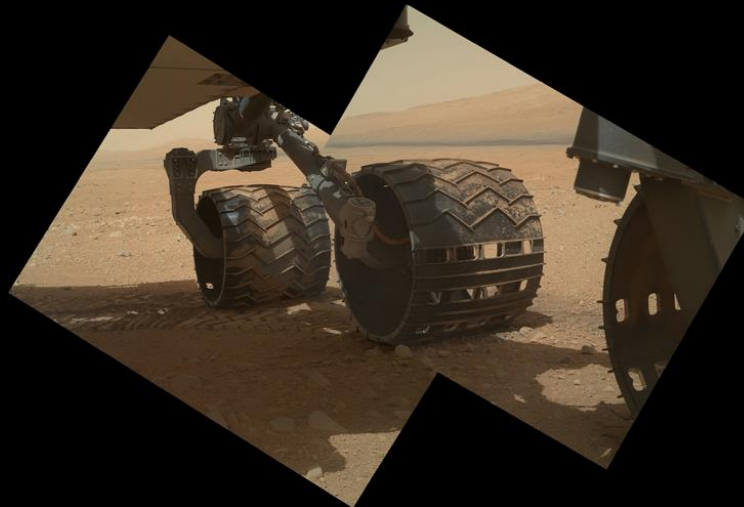
Curiosity rover image taken by using the Mars Hand Lens Imager taken, NASA



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



Murray Buttes at Mount Sharp Curiosity, NASA



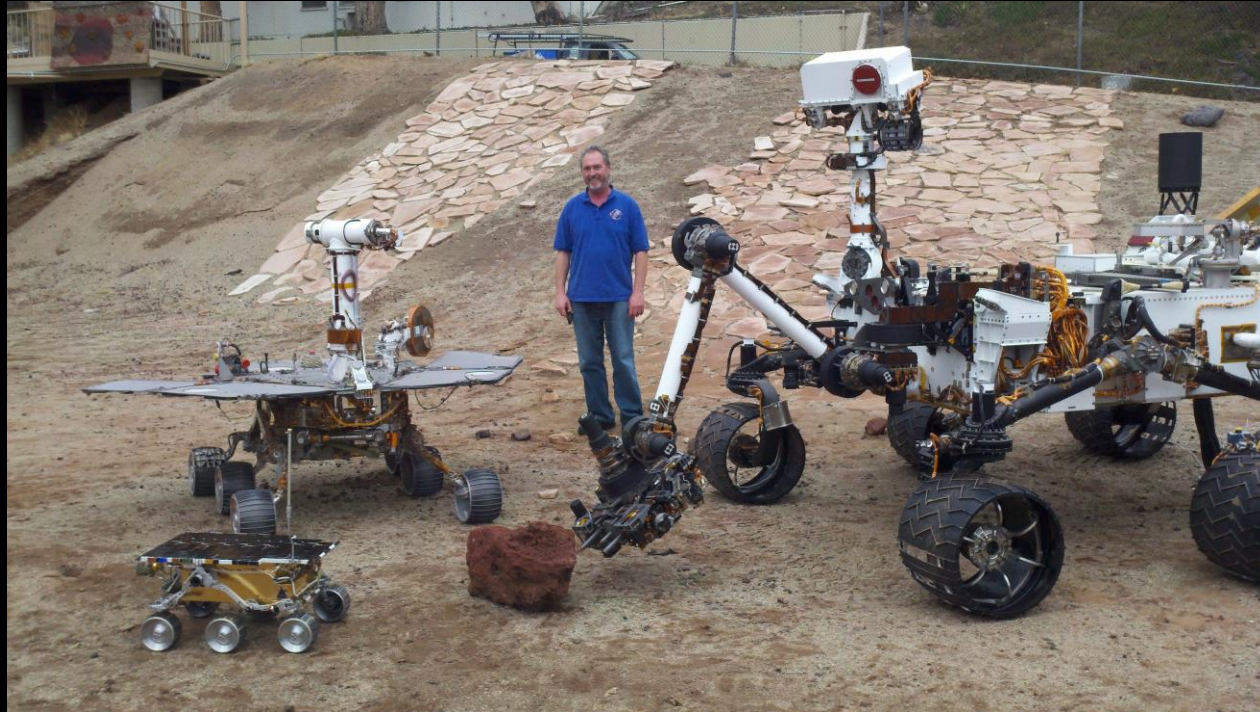
Wheels Curiosity, NASA



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



## INSTRUMENTS

### Leaving No Stone Unturned

Curiosity's instrument suite is designed to examine rocks, soil and atmosphere for clues to past and present habitable environments. The instruments do that by measuring chemical and mineralogical composition in various complementary ways.

**WEATHER STATION** will measure environmental variables and issue daily reports, providing the first ever continuous record of Martian meteorology. Apart from its inherent interest, the weather report will guide rover operations.

**ACTIVE NEUTRON SPECTROMETER** will search for water in rocks and soil underneath the rover.

**RADIATION SENSOR** will monitor solar and cosmic radiation.

**COLOR CAMERAS** can image landscapes and rock and soil textures in high-definition resolution. Those textures help scientists to reconstruct the processes that formed the rock or soil, perhaps including the action of liquid water. One of the cameras is mounted on the bottom of the rover, looking downward, and will create a movie of the descent and landing.

**CHEMIN INSTRUMENT** beams x-rays through fine powders to create a diffraction pattern that definitively identifies minerals of all types. Spectrometers on previous landers were limited in scope to, for example, iron-bearing minerals.

**ROBOT ARM**, reaching out as far as two meters, holds 30 kilograms of gadgetry to drill holes and pulverize rocks. A set of sieves sorts powder for the onboard lab instruments.

**LASER-INDUCED BREAK-DOWN SPECTROMETER** will burn holes in rocks and soil up to seven meters away and remotely sense their chemical composition.

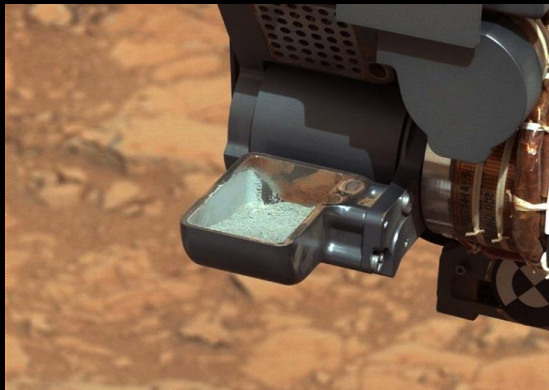
**SAMPLE ANALYSIS AT MARS (SAM)** instrument suite can perform chemical analysis. It bakes powder in small ovens with combustion or chemical solvents to release gases, which the gas chromatograph/mass spectrometer and gas analyzer will examine, looking especially for organic carbon. It also can directly sample the atmosphere.

**ALPHA-PARTICLE X-RAY SPECTROMETER** will perform in situ determination of rock and soil chemistry.



# CheMin

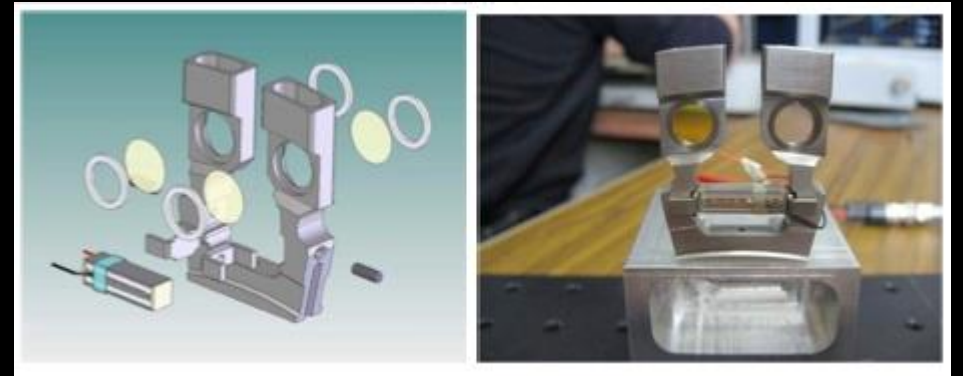
- X-Ray diffractometer
- Can detect individual minerals in complex mixtures at the 3% and above
- 27 reusable sample chambers
- Sample wheel



CheMin, NASA Image



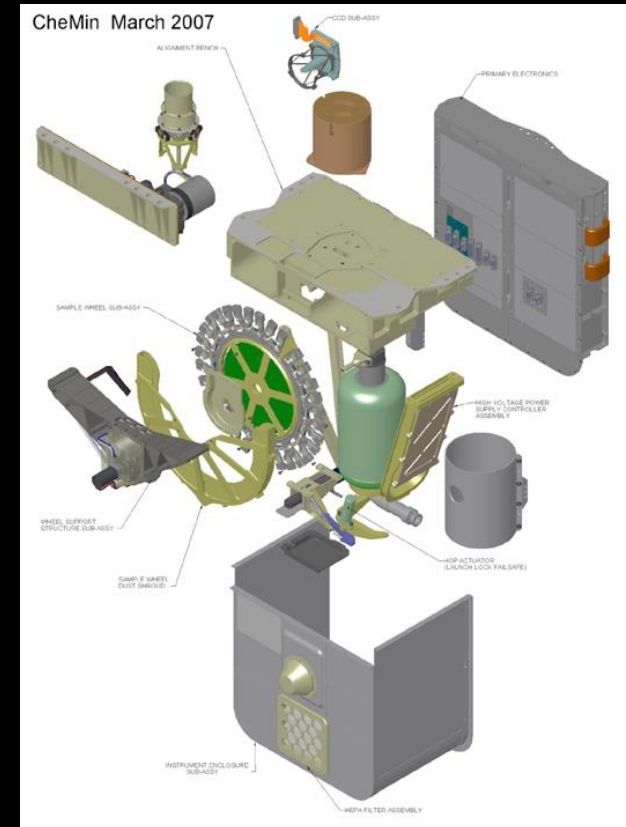
CheMin, NASA Image



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

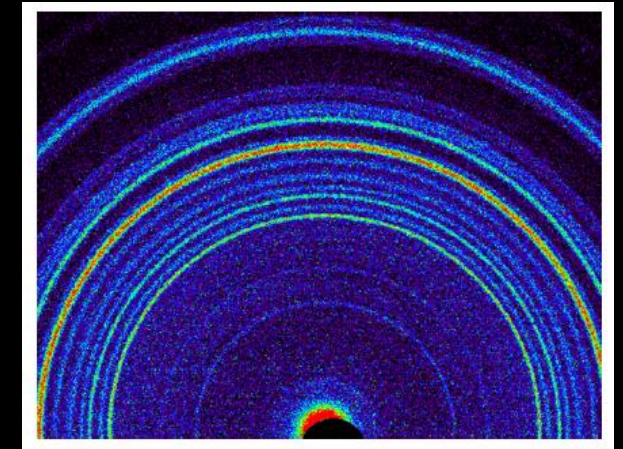


CheMin, JPL image

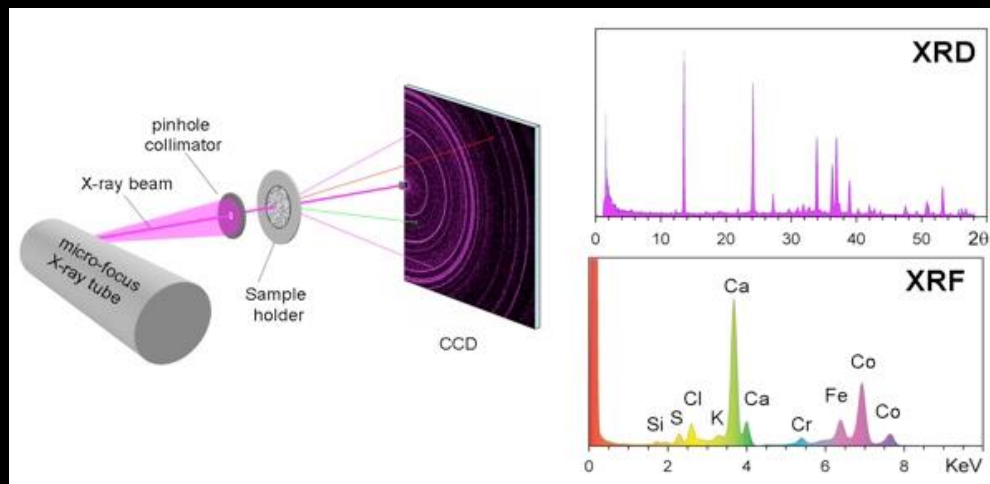


# CheMin

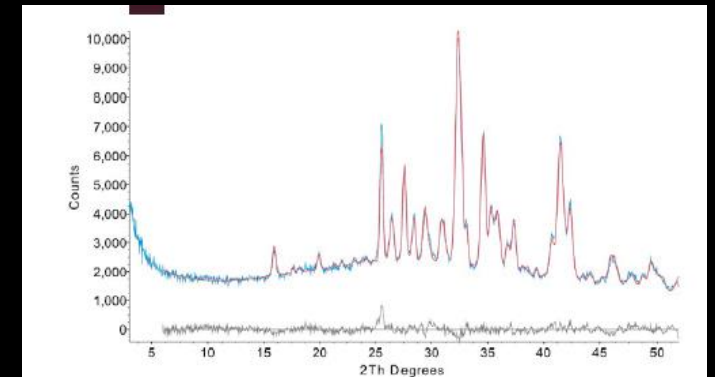
- 2theta 5 to 50 degrees
- 0.35 degree 2theta resolution
- Piezoelectric actuator vibrate sample
  - Random orientations
- 20 hours collection time
- Co source, 20 KeV and 100 microampere



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



Downs et al., 2015, Elements and JPL image



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

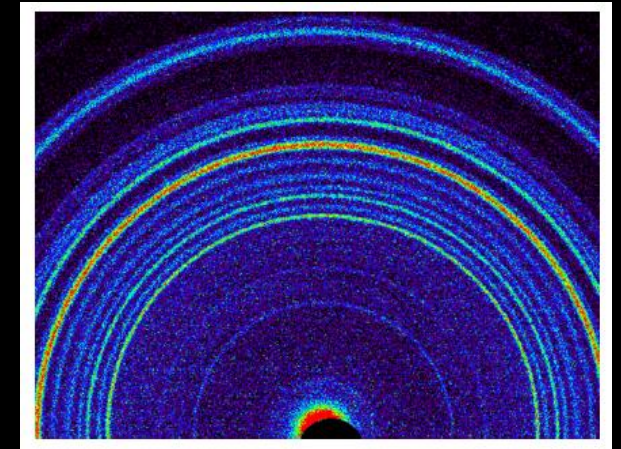
# CheMin

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

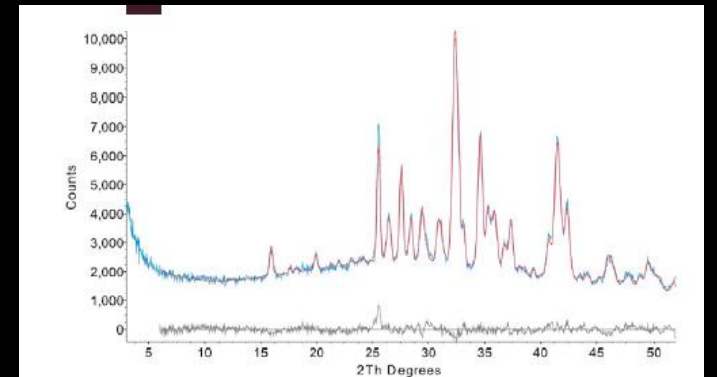
■ The olivine is  $(\text{Mg}_{1.12}\text{Fe}_{0.88})\text{SiO}_4$  so Fo56Fa44

(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

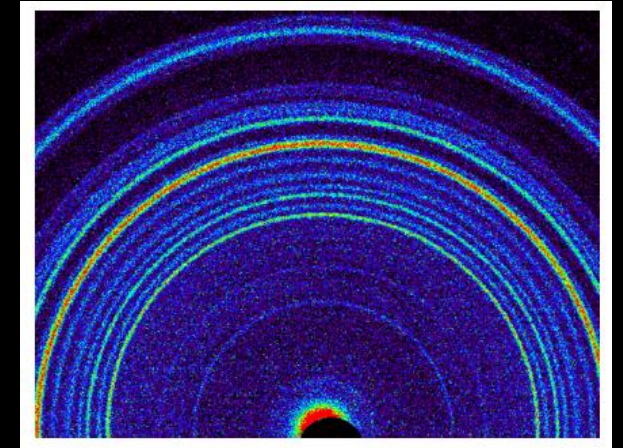


Curiosity Rover, NASA image

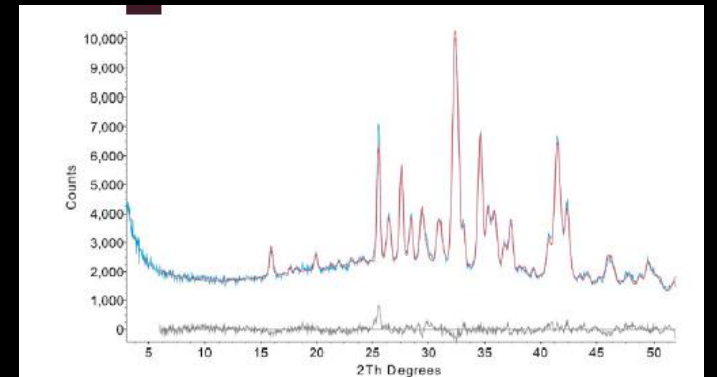


# CheMin

- Pyroxene and olivine have linear trends with composition
- Feldspar is more complex to model
  - $(\text{Ca}_{0.52}\text{Na}_{0.48})(\text{Al}_{1.52}\text{Si}_{2.48})\text{O}_8$
  - Close to labradorite composition
  - Gem like fragments



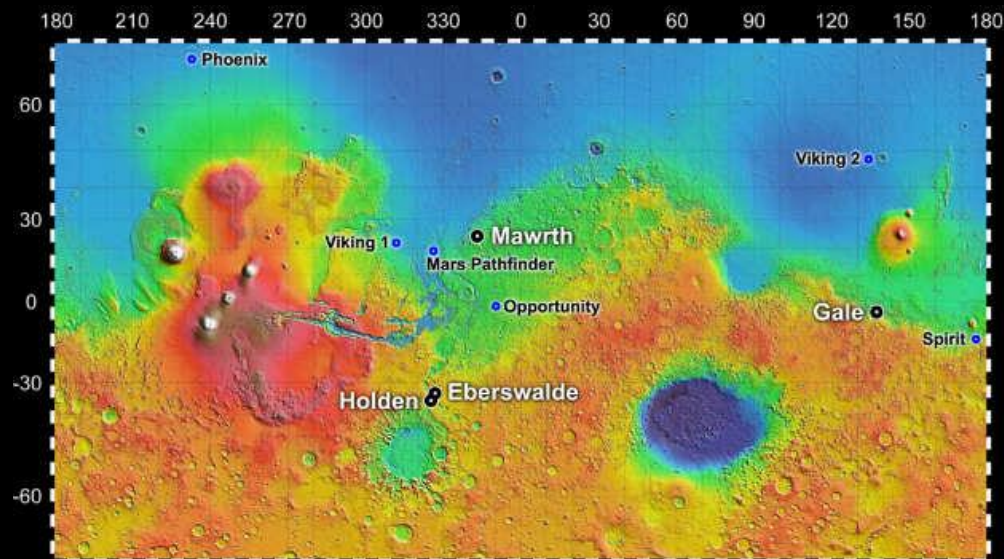
Rocknest XRD pattern from Downs et al., 2015, Elements



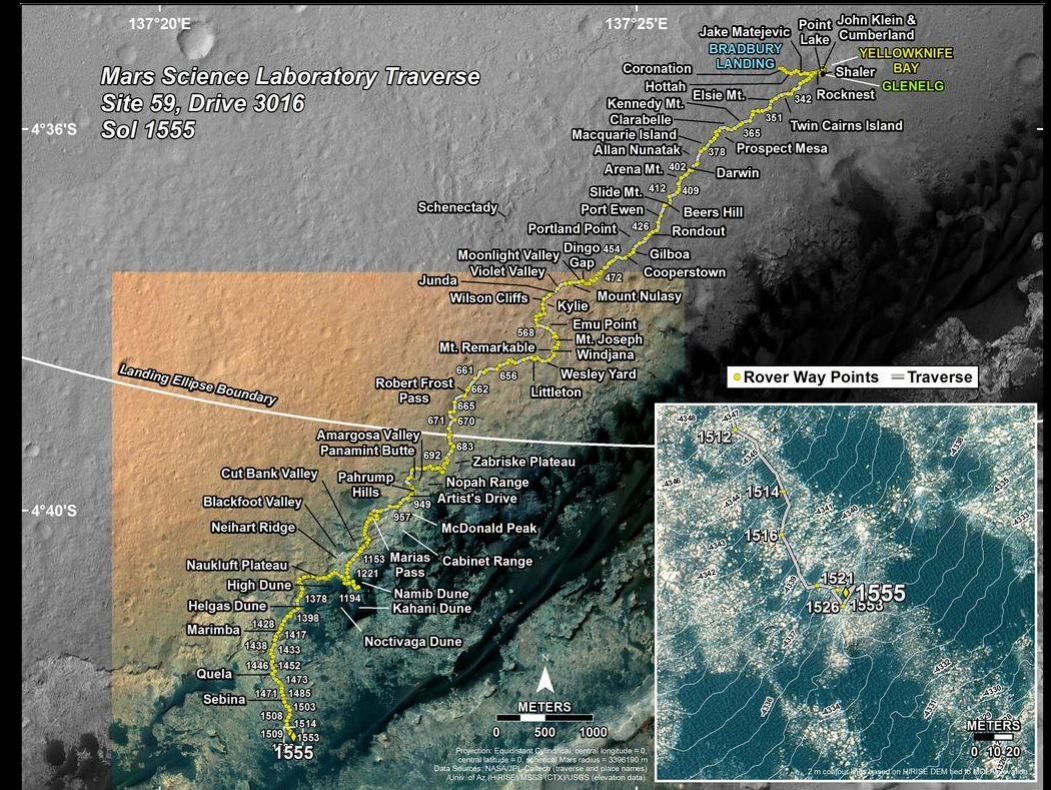
Rocknest XRD pattern from Downs et al., 2015, Elements

# Mineralogy as determined by Curiosity

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



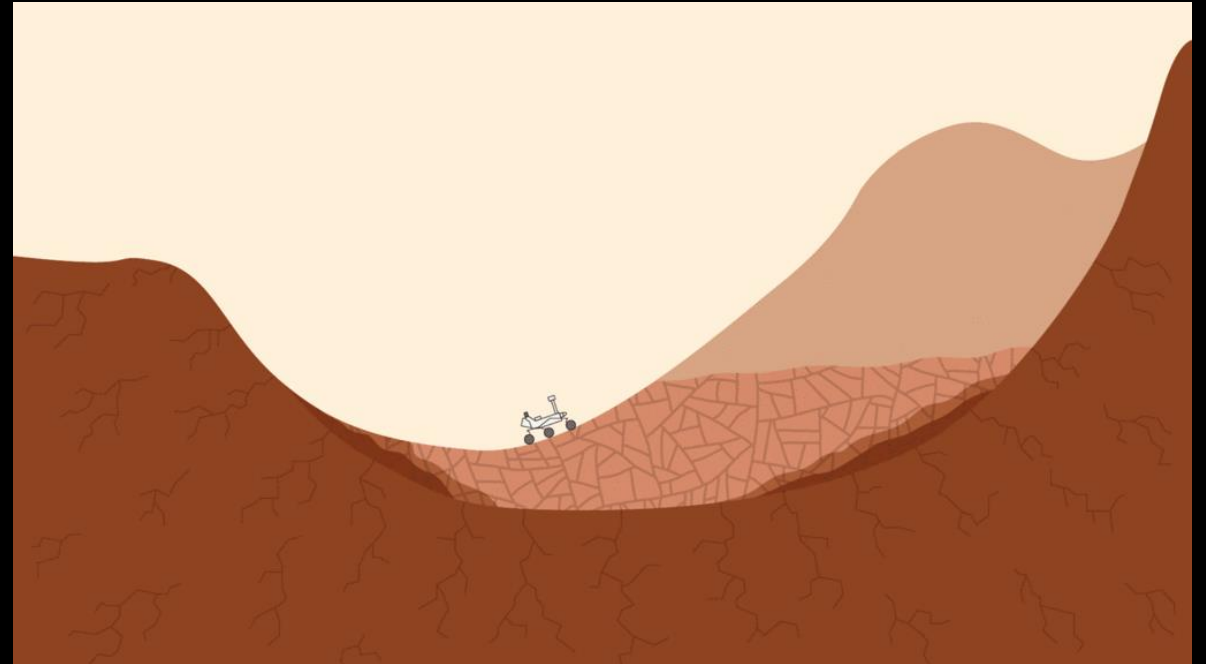
NASA Image from MER "Opportunity" Page



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



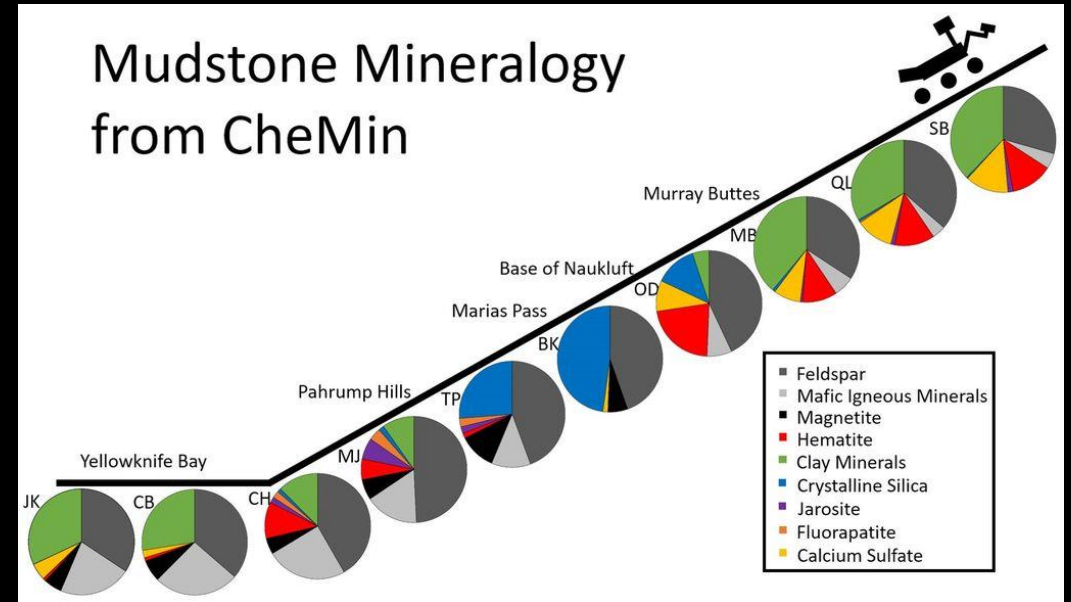
# Mineralogy as determined by Curiosity

- 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



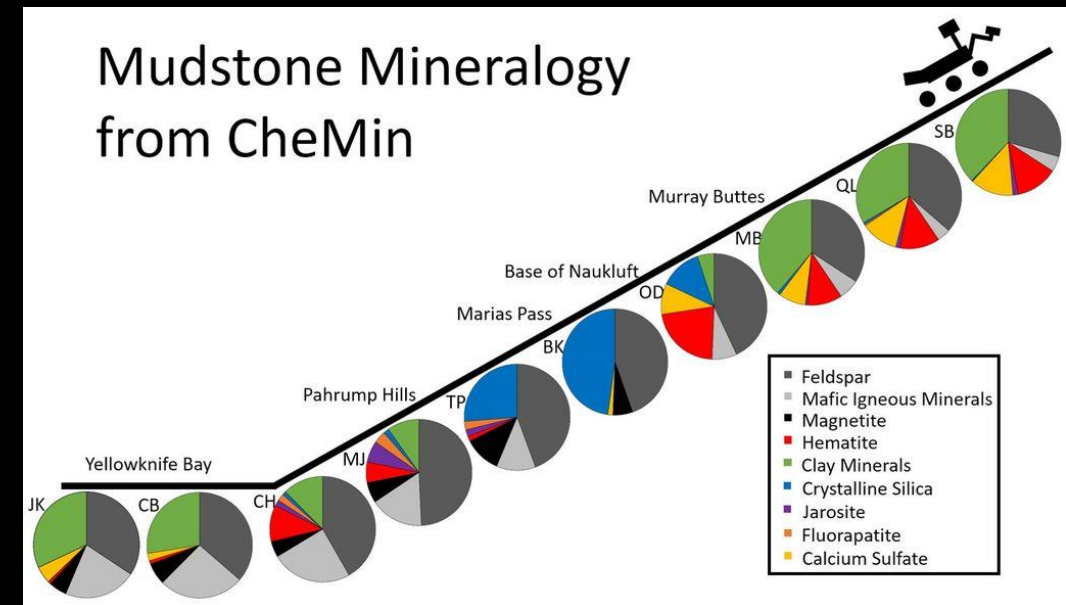
Composition of mudstone drill sites, NASA Figure



MERS, Opportunity, likely Calcium sulfate, NASA

# Amorphous Components

- Likely impact glasses
- Allophane ( $\text{Al}_2\text{O}$ )
- Hisingerite ( $\text{Fe}_2\text{Si}_2\text{O}_5(\text{OH})_4 \cdot 2\text{H}_2\text{O}$ )

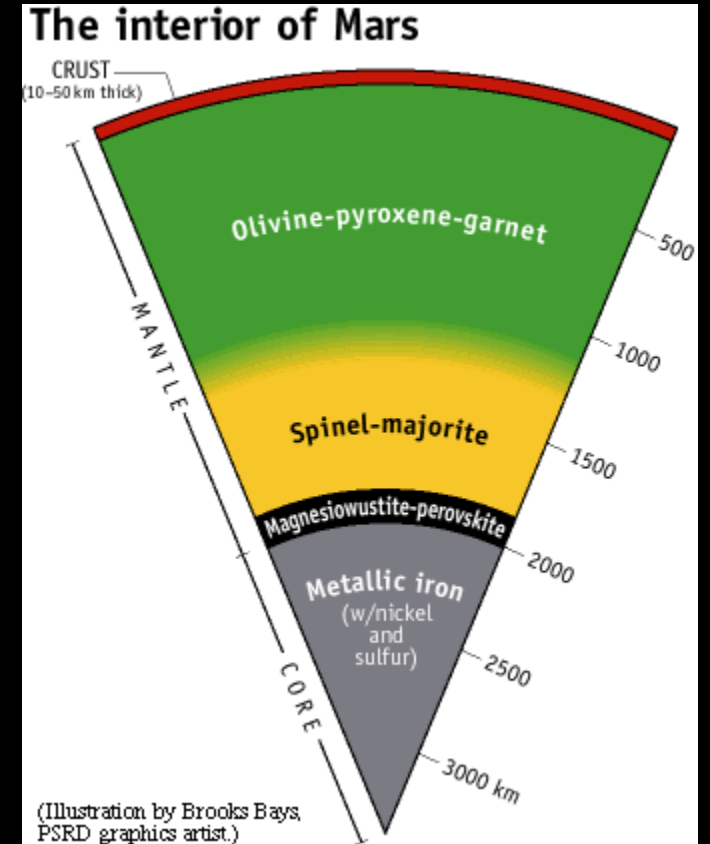


Composition of mudstone drill sites, NASA Figure



# Interior Composition

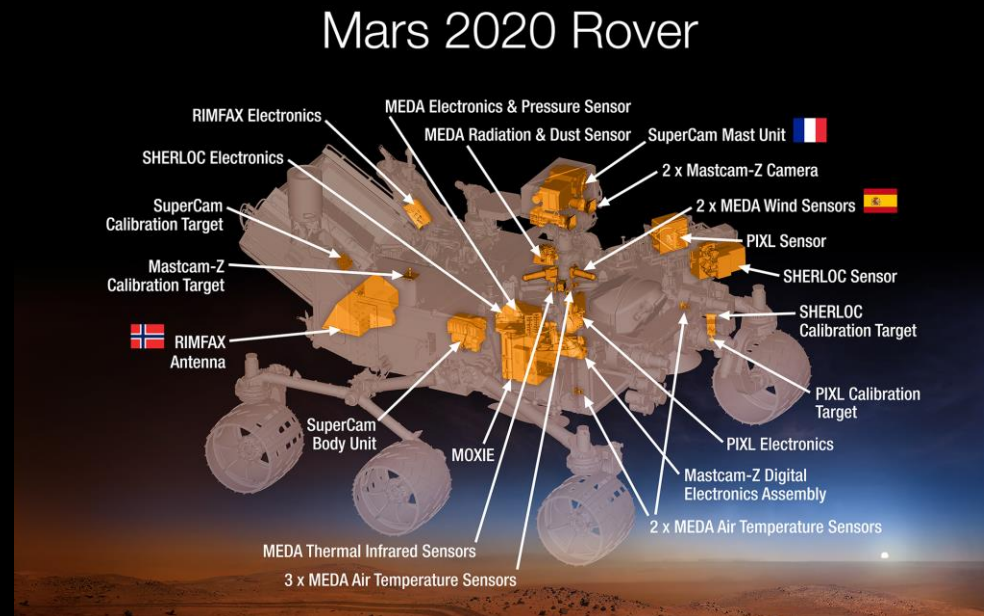
- Mantle is thought to be dominated by olivine
  - Likely Fo75
  - Expect P velocities of 7.64 to 7.80 km/sec (Johnston and Toksoz)
- Fe-FeS core (radius 1500-200 km)
- Need seismic measurements to confirm



Composition of Mars, <http://www.psrh.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



A panoramic view of a rocky, reddish-brown Martian landscape. The foreground is filled with numerous dark, angular rocks of various sizes scattered across a sandy, reddish-brown terrain. In the center, a large, prominent rock formation stands out. The background shows a vast, flat expanse of the same terrain stretching towards a hazy, orange-brown horizon under a clear sky. The overall scene is desolate and arid.

# The End

Michelle Wenz