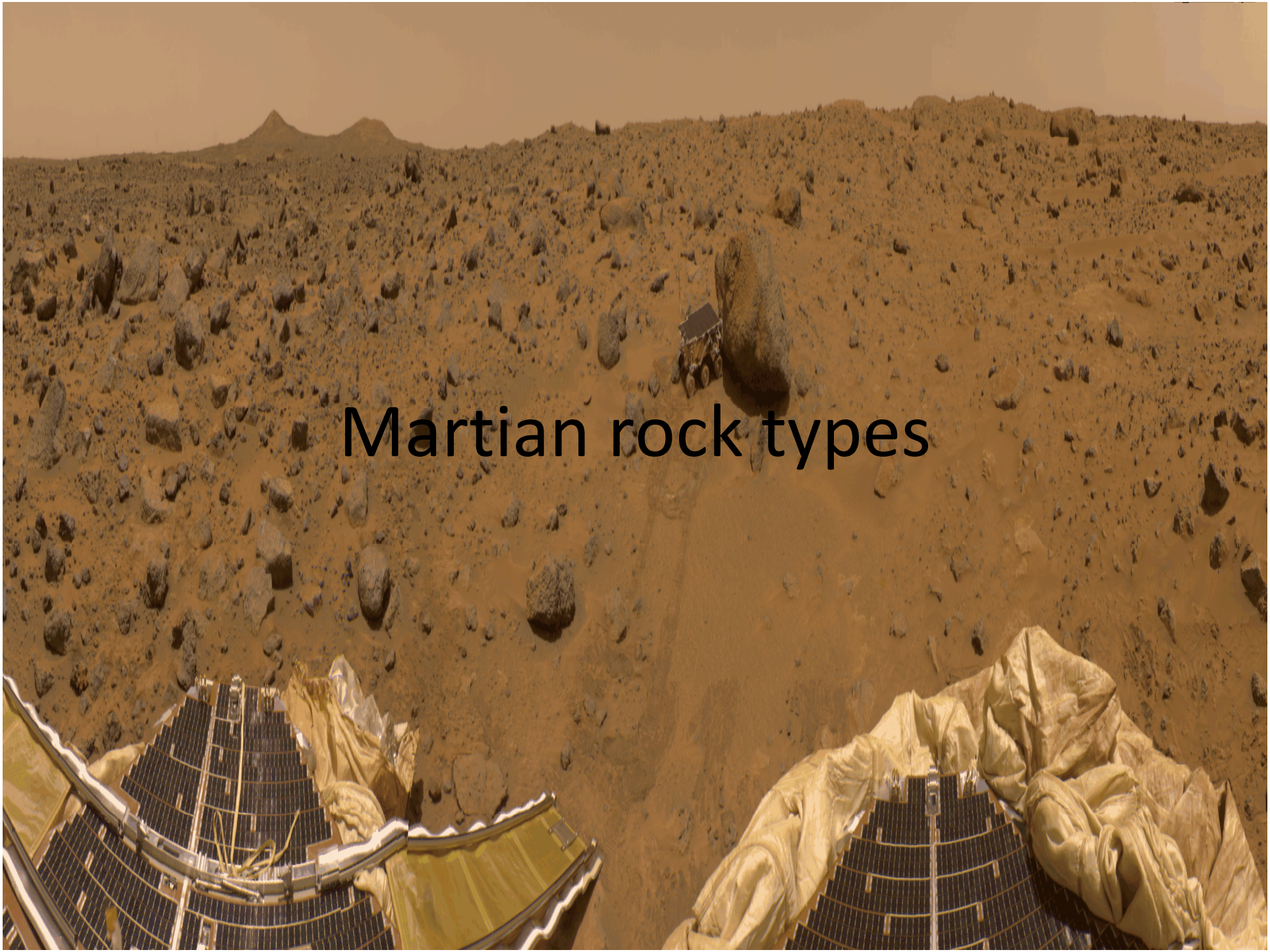
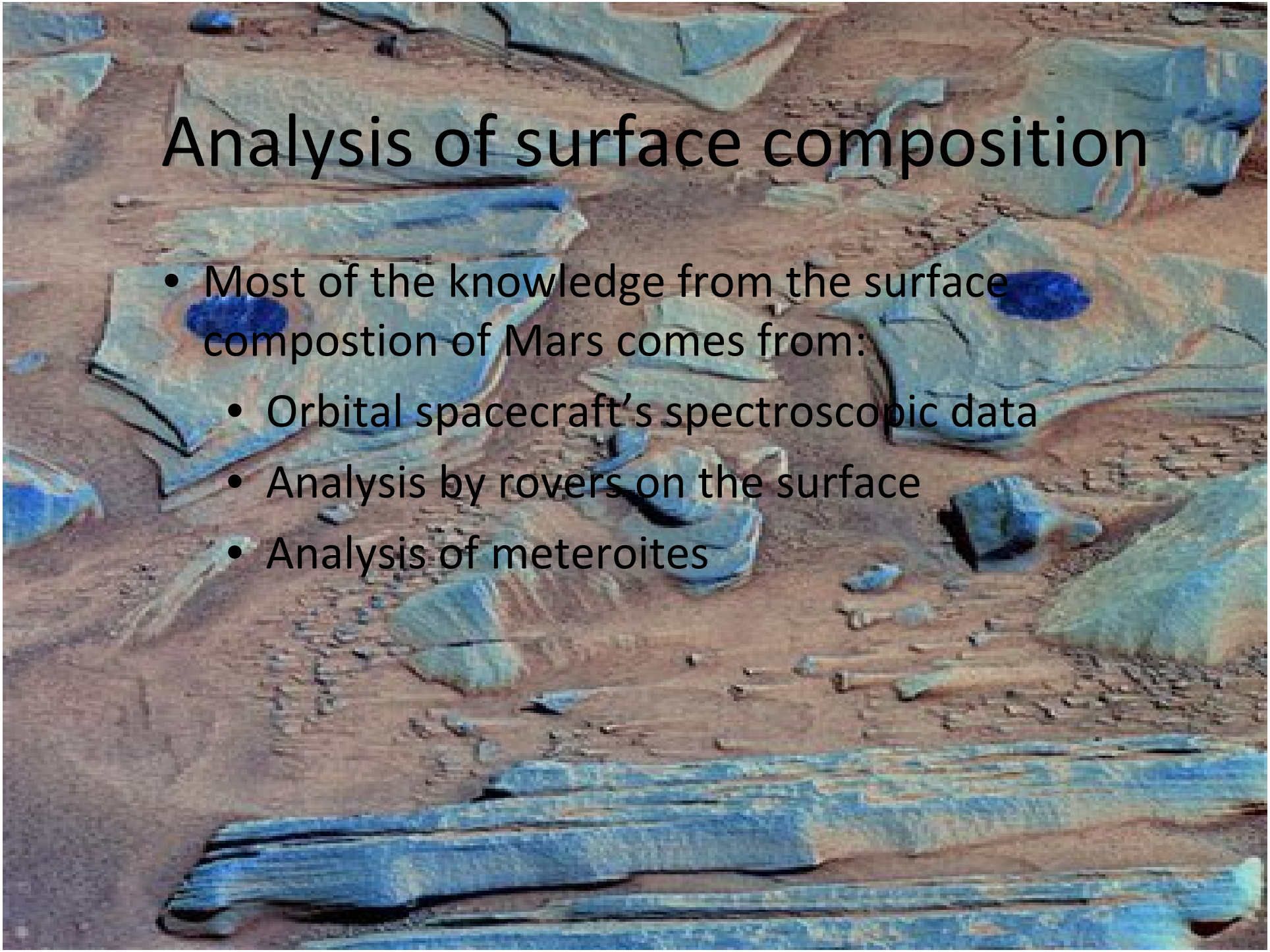

Martian rock types



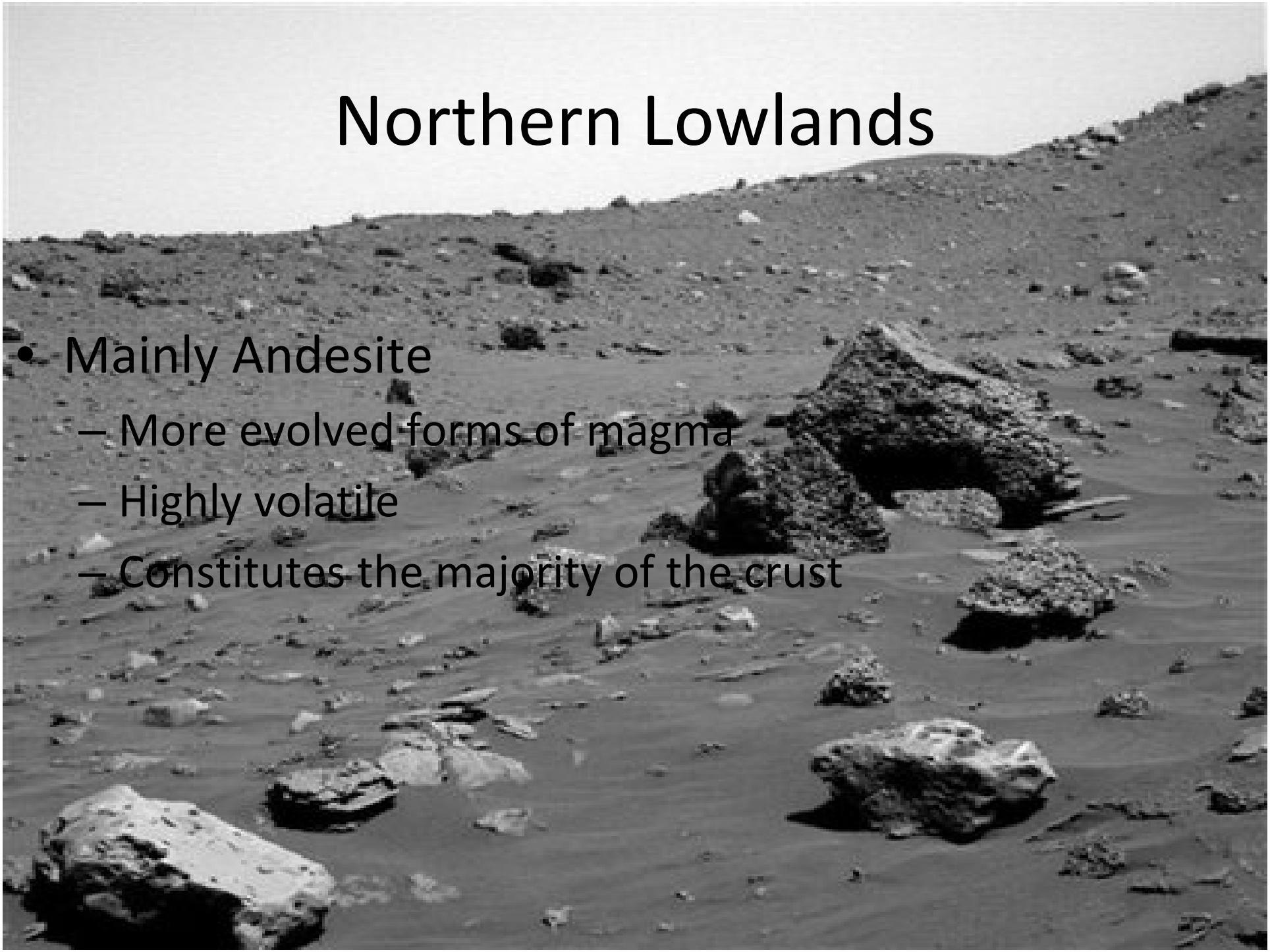
Analysis of surface composition

- Most of the knowledge from the surface compostion of Mars comes from:
  - Orbital spacecraft's spectroscopic data
  - Analysis by rovers on the surface
  - Analysis of meteroites

Southern Highlands

- Mainly Basalts
  - Consists primarily of Olivine, Feldspars and Pyroxenes

Northern Lowlands



- Mainly Andesite
  - More evolved forms of magma
  - Highly volatile
  - Constitutes the majority of the crust

Intermediate Felsic Types

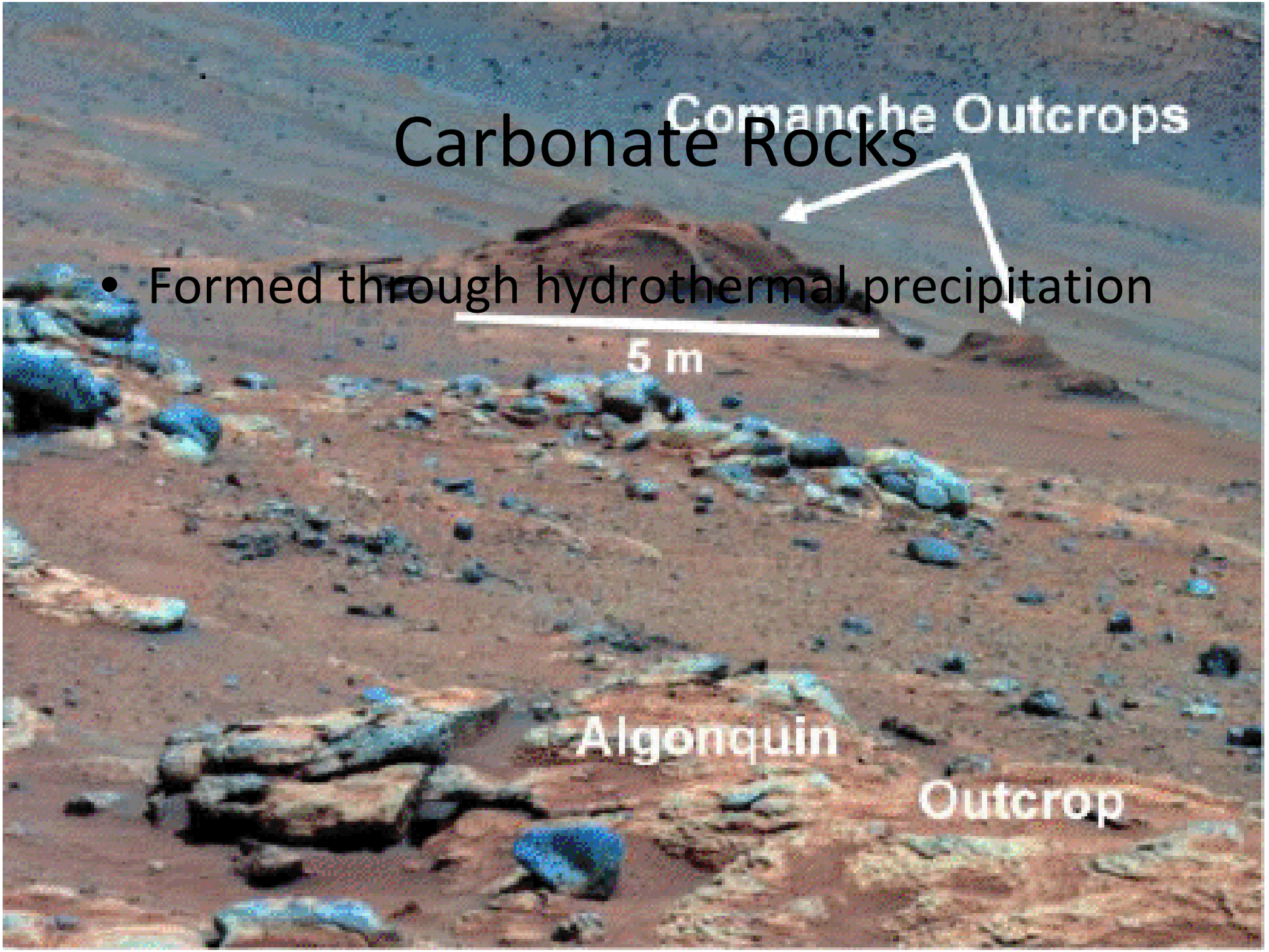
- High Silica Rocks
- Exposed on the surface near Syrtis Major
  - Uncommon but include:
    - Dacites and Granitoids
    - Suggest diverse crustal composition

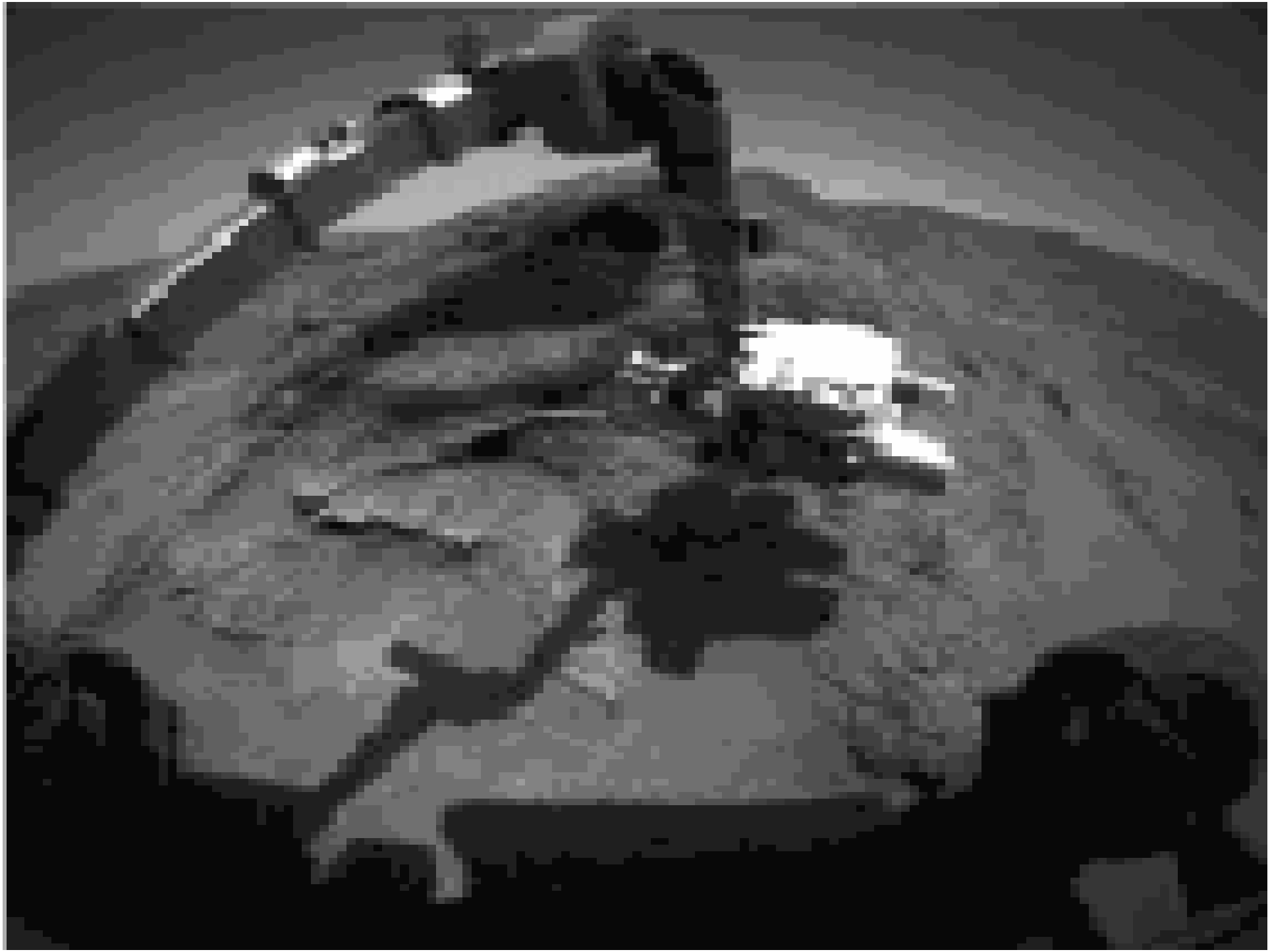
Sedimentary Rocks

- Widespread on the surface
- Makes up the majority of the Northern lowlands deposists
  - May have formed from sea/lake deposits
  - Some show cross-bedding in their layers
  - Hold the best chance to find fossilized life

Carbonate Rocks

- Formed through hydrothermal precipitation





Tracks from rover unveil different soil types

- Most soil consists of finely ground basaltic rock fragments
- Contains iron oxide which gives Mars its red color
- Also contains large amounts of sulfur and chlorine

Tracks from rover unveil different soil types

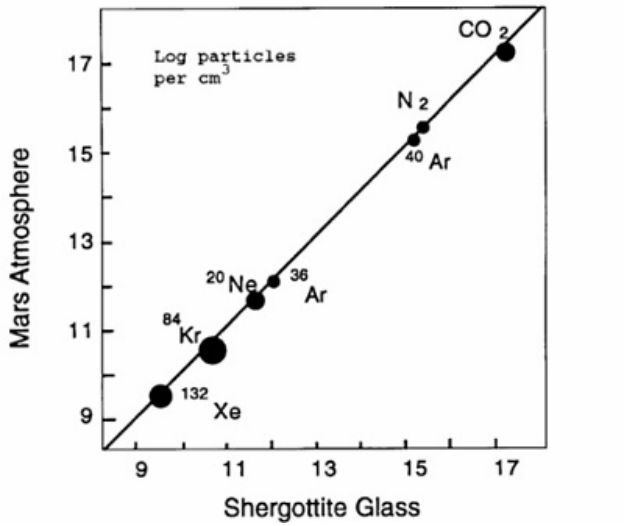
- Light colored soil is silica rich
- High concentrations suggest water must have been involved to help concentrate the silica


Blueberries
• Iron rich spherules

Meteorites on Mars

What is a Martian meteorite?

- Martian meteorites are achondritic meteorites with strong linear correlations of gases in the Martian atmosphere. Therefore, the gas trapped in each meteorite matches those that the Viking Lander found in Mar's atmosphere. The graph below explains this correlation.
- Image: http://www.imca.cc/mars/martian-meteorites.htm



Types of Martian Meteorites

- 34 meteorites have been found that are Martian and they can be separated into 4 major categories with sub-categories. These classifications are based on the meteorites mineral make-up and age.
- The following slides explain the types of meteorites.

- http://curator.jsc.nasa.gov/antmet/marsmets/NakhlitesClinopyroxenites.cfm

Shergottites

- Shergottites got their name because the first Shergottite landed in Shergotty, India. There are 17 members of meteorites discovered belong to this class. They show a young crystallization of 150-200 million years. They also show signs of “shock-metamorphism” which is the effects of shockwave related deformation during heating and impact events. This type of meteorite can be broken down into two subgroups; Basaltic and Lherzotic.
- Image: http://www4.nau.edu/meteorite/Meteorite/Book-GlossaryS.html

NWA 2046 (shergottite)

Basaltic Shergottites

- Basaltic rocks of volcanic origin . Their mineralogy is comprised of mostly pigeonite and augite mostly. The crystallization age of these meteorites is around 200-300 milllion years old. They have fine to course grained textures and several contain evidence of interaction with Martian water, either in the form of hydrated silicates, or in the form of carbonate and sulfate salts They are found in mostly Shergotty, Zagami, Los Angeles, and two of our recent finds from Morocco.
- Image: http://www.meteorites.tv/284-nwa-2975-martian-meteorite.html

Image: http://www.arizonaskiesmeteorites.com/AZ_Skies_Links/Martian/NWA_1950/\

Lherzolitic Sherogottites

Ultramafic rocks of plutonic origin. Crystallization is from residual melts in magma chambers. They share many mineralogical and chemical features shared with the basaltic shergottites. The key difference between Basaltic and Lherzolitic Shergottites is that Basaltics are silicon rich and mafic where Lherzoltic Shergotittes are silicon poor and ultramafic.

Image: http://www.arizonaskiesmeteorites.com/AZ_Skies_Links/Martian/NWA_1950/\

Nakhlites

- The first Nakhlites discovered in El Nakhla, Egypt in 1911. They are easily separated from Shergottites in their mineralogy and composition. The composition of this meteorite is extremely important because they contain carbonate and sulfate salts which suggest that they resided in an environment rich with liquid sea water for some time. They crystallized 1.3 to 1.4 Billion years ago.
- Image: http://www.arizonaskiesmeteorites.com/AZ_Skies_Links/NWA_998_Nakhlite/

Chassignites

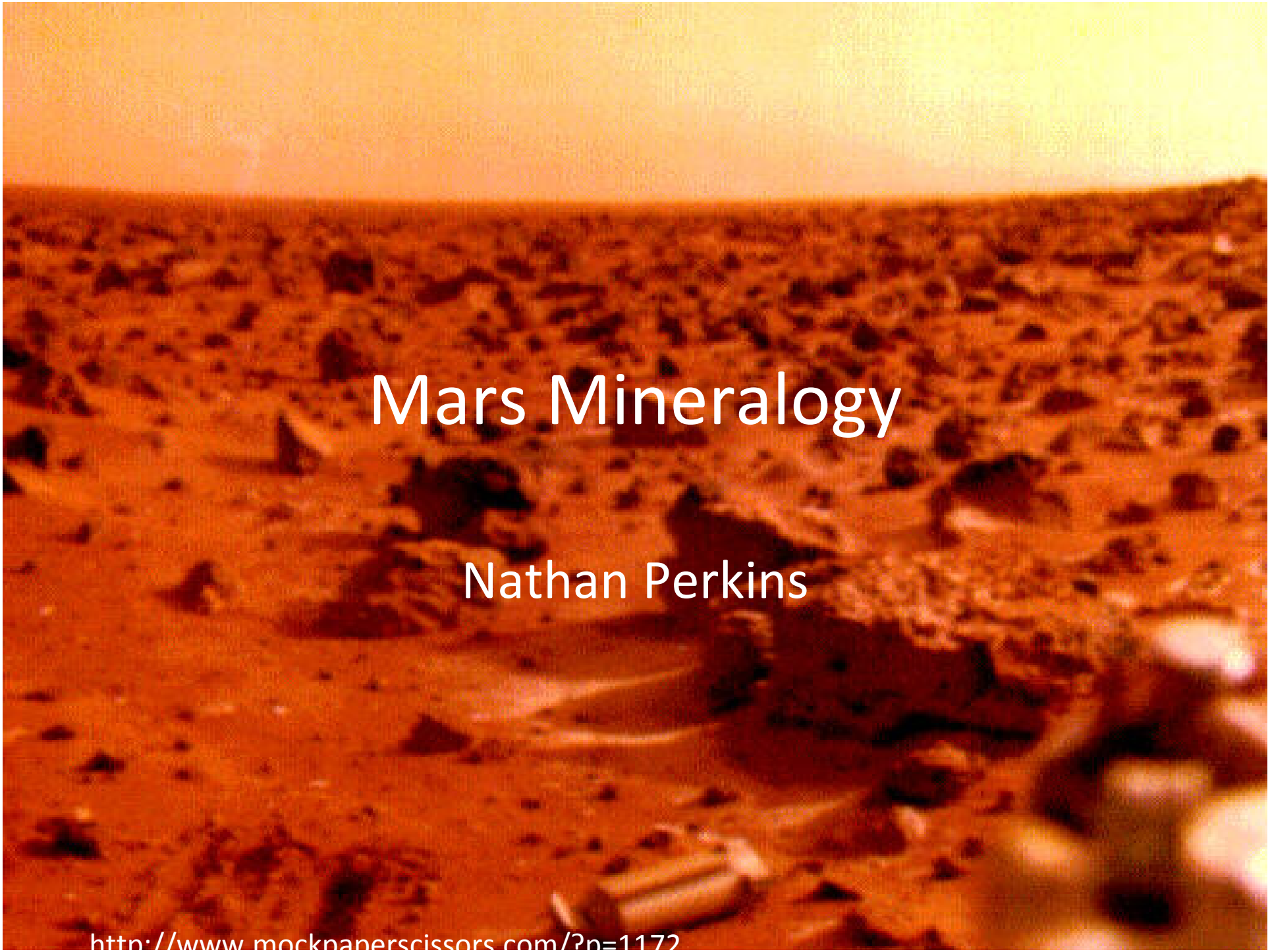
- The first Chassignite was found in Chassigny, France in 1815. One other was discovered in Morocco in August of 2000. They contain Oxygen Isotopes in their mineralogy.
- http://en.wikipedia.org/wiki/Martian_meteorite
- Image: http://www.meteoritestudies.com/protected_NWA2737.HTM

Orthopyroxenites

- There is only one meteorite of this classification and that it ALH84001. This in undoubtedly the most famous of all Martian meteorites. Allen Hills 84001 was discovered in 1984. It is unique because of its mineral composition and age. It contains oxidized iron in its cromate. McKay and coworkers studied ALH84001 and announced the discovery of terrestrial nanobacteria, microfossils and organic molecules which suggest the presence of life. This has been debated ever since. It was thought to have a crystallization age of 4.4-4.5 Billion years. It was also thought to be formed in liquid water. In May of 2010, a new age was proposed at 4.091 Billion years. This new age proved that it was in fact not formed in liquid water.
- Info and image: http://www.psrd.hawaii.edu/May10/YoungerALH84001.html

Bounce Rock

- Info: http://www.jpl.nasa.gov/releases/2004/104.cfm
- Though we have found many meteorites from Mars on Earth. There has only been one discovery of such meteorites on Mars. The only meteorite found to match Martian meteorites on earth is called bounce rock. The composition of Bounce Rock is identical to that of Shergottites found on Earth. It was believed to have been ejected by impact of large of large asteroids of comets. It is composed of mainly the volcanic mineral, pyroxene. It is unlike any rock or volcanic deposit on Mars.

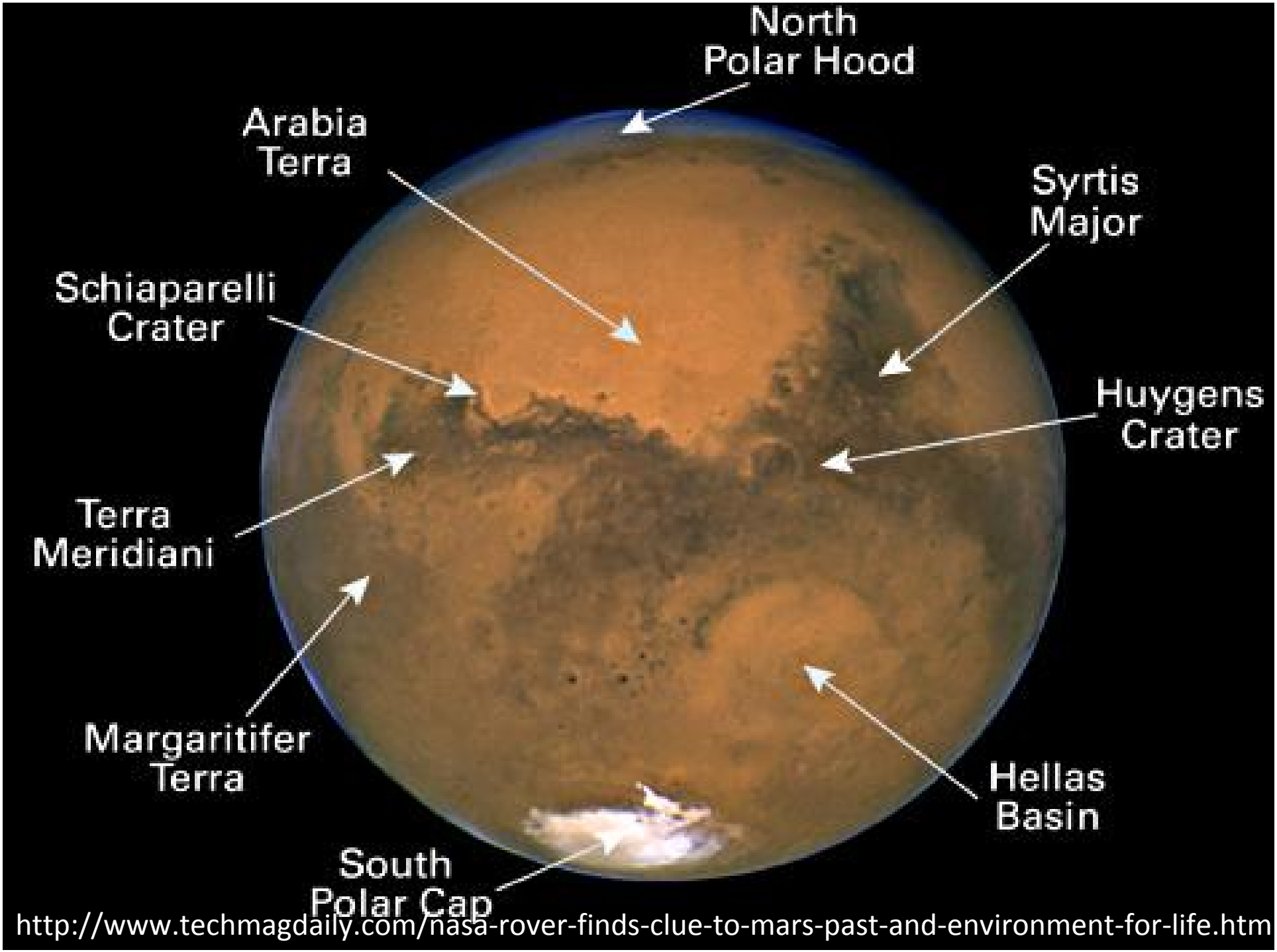

Mars Mineralogy
Nathan Perkins
http://www.mockpaperscissors.com/?p=1172

Why Mineralogy is Important

- The presence of certain minerals will give clues as to the current and past climates
- The depositional and formation processes of certain minerals can create habitable microenvironments

Orbiters

- OMEGA Orbiter – European Space Agency launched in 2003
  - Study subsurface, surface, and atmospheric composition.
- Mars Reconnaissance Orbiter – NASA JPL launched 2005
  - Map surface



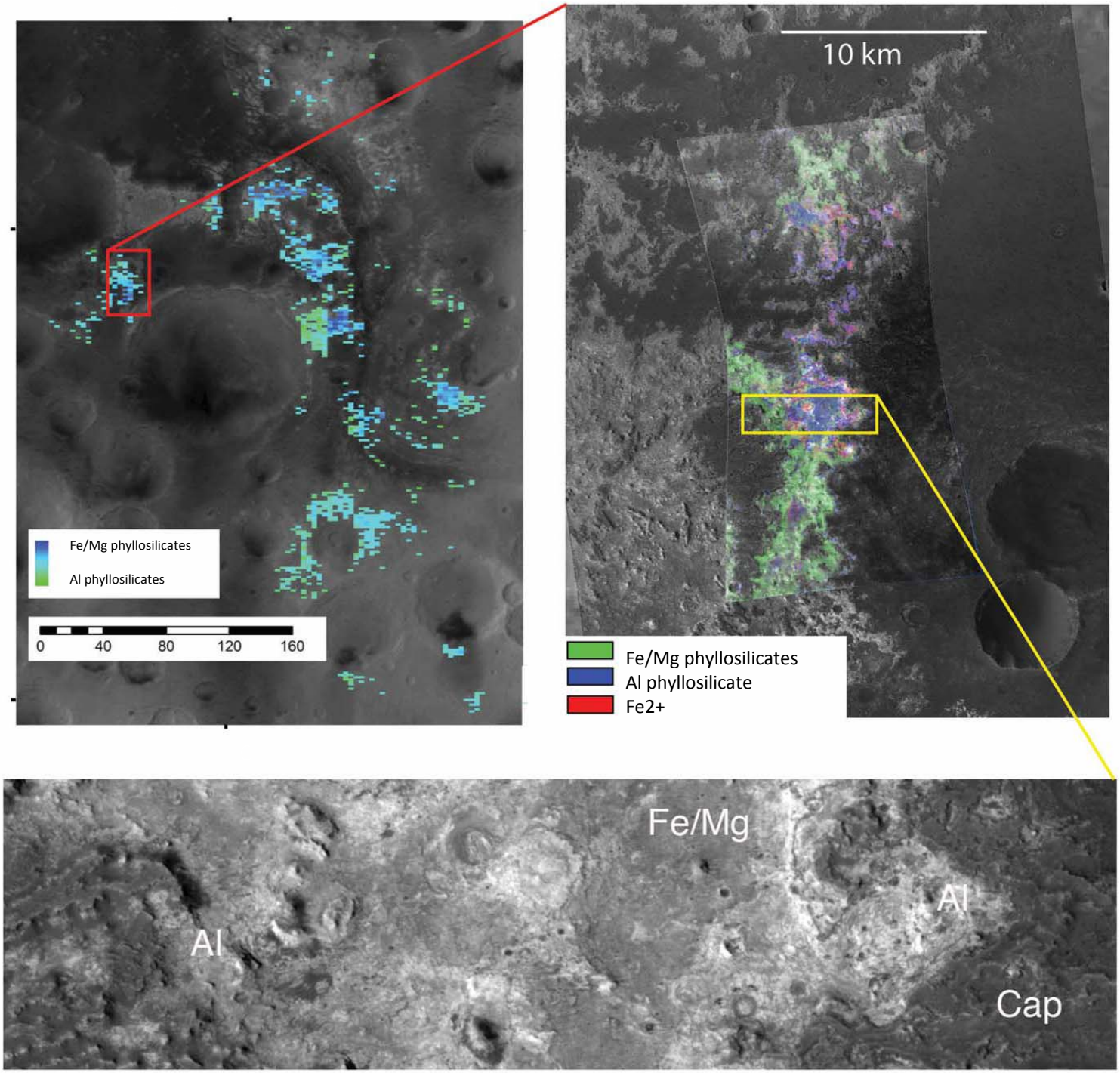
http://www.techmagdaily.com/nasa-rover-finds-clue-to-mars-past-and-environment-for-life.htm

Important Minerals to look for

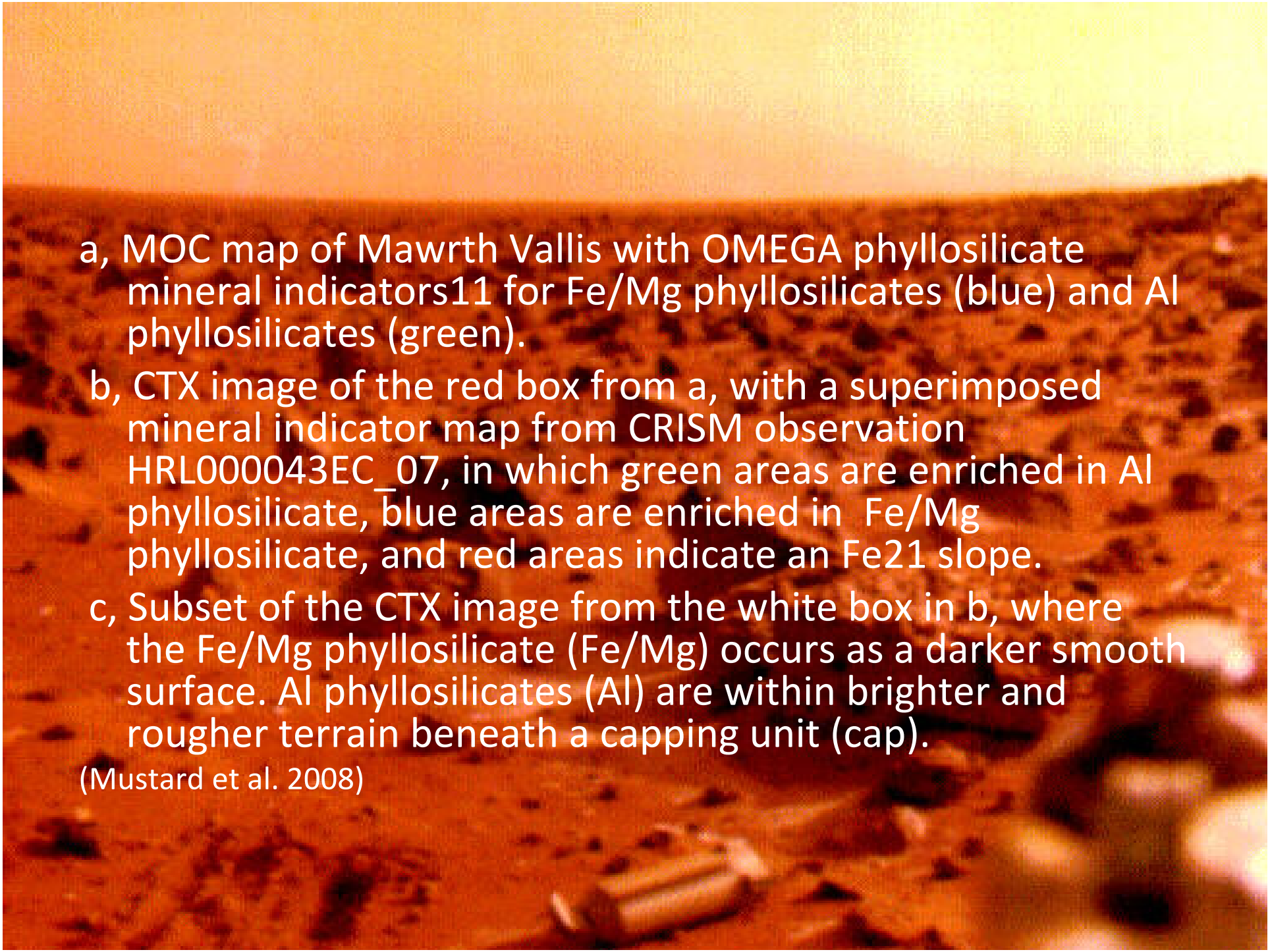
- Phyllosilicates – Hydrated silicate minerals (clays)
- Carbonates – minerals that precipitate from water
- Hematite – Iron oxide mineral formed by precipitation from water
- Olivine – mafic mineral susceptible to weathering in the presence of water
- Pyroxcene - mafic mineral mineral susceptible to weathering in the presence of water

Phyllosilicates

- Phyllosilicates are hydrated silicate minerals
- These minerals are evidence of aqueous alteration processes (Poulet et al. 2005)
- Phyllosilicates are found over a wide range on the surface (Banfield 2002)
- Presence of Phyllosilicates indicate a wet environment but nothing of the acidity



(Mustard et al. 2008)



a, MOC map of Mawrth Vallis with OMEGA phyllosilicate mineral indicators11 for Fe/Mg phyllosilicates (blue) and Al phyllosilicates (green).

b, CTX image of the red box from a, with a superimposed mineral indicator map from CRISM observation HRL000043EC_07, in which green areas are enriched in Al phyllosilicate, blue areas are enriched in Fe/Mg phyllosilicate, and red areas indicate an Fe21 slope.

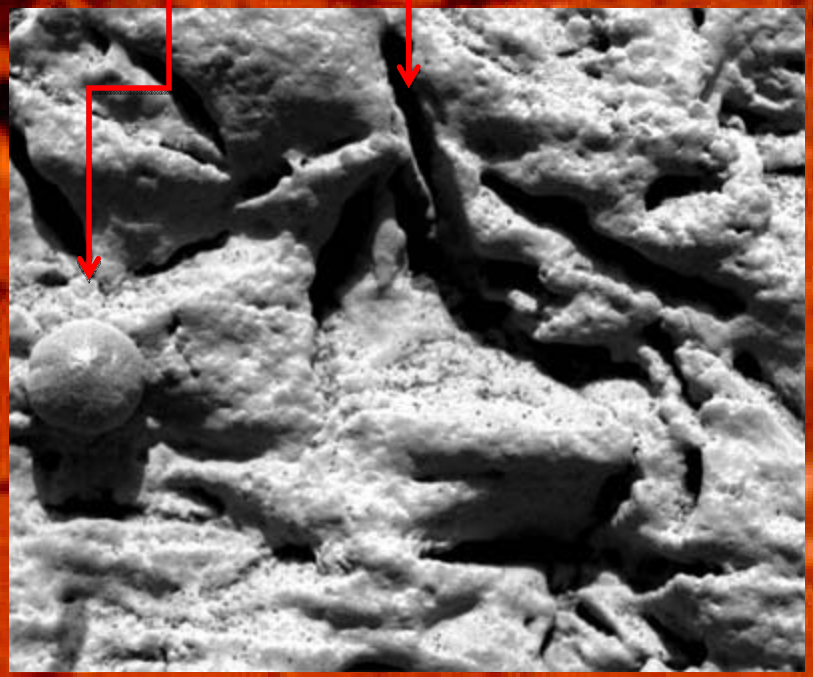
c, Subset of the CTX image from the white box in b, where the Fe/Mg phyllosilicate (Fe/Mg) occurs as a darker smooth surface. Al phyllosilicates (Al) are within brighter and rougher terrain beneath a capping unit (cap).

(Mustard et al. 2008)

Carbonates

- Presence of Carbonates indicate a wet non-acidic environment
- Gives evidence of possible hydrothermal activity
- There is debate as to whether the Carbonates on Mars are due to hot or cold water
  - Hot water would be more likely to create a habitable microenvironment
- This type of environment would be the most likely to support life

Hematite

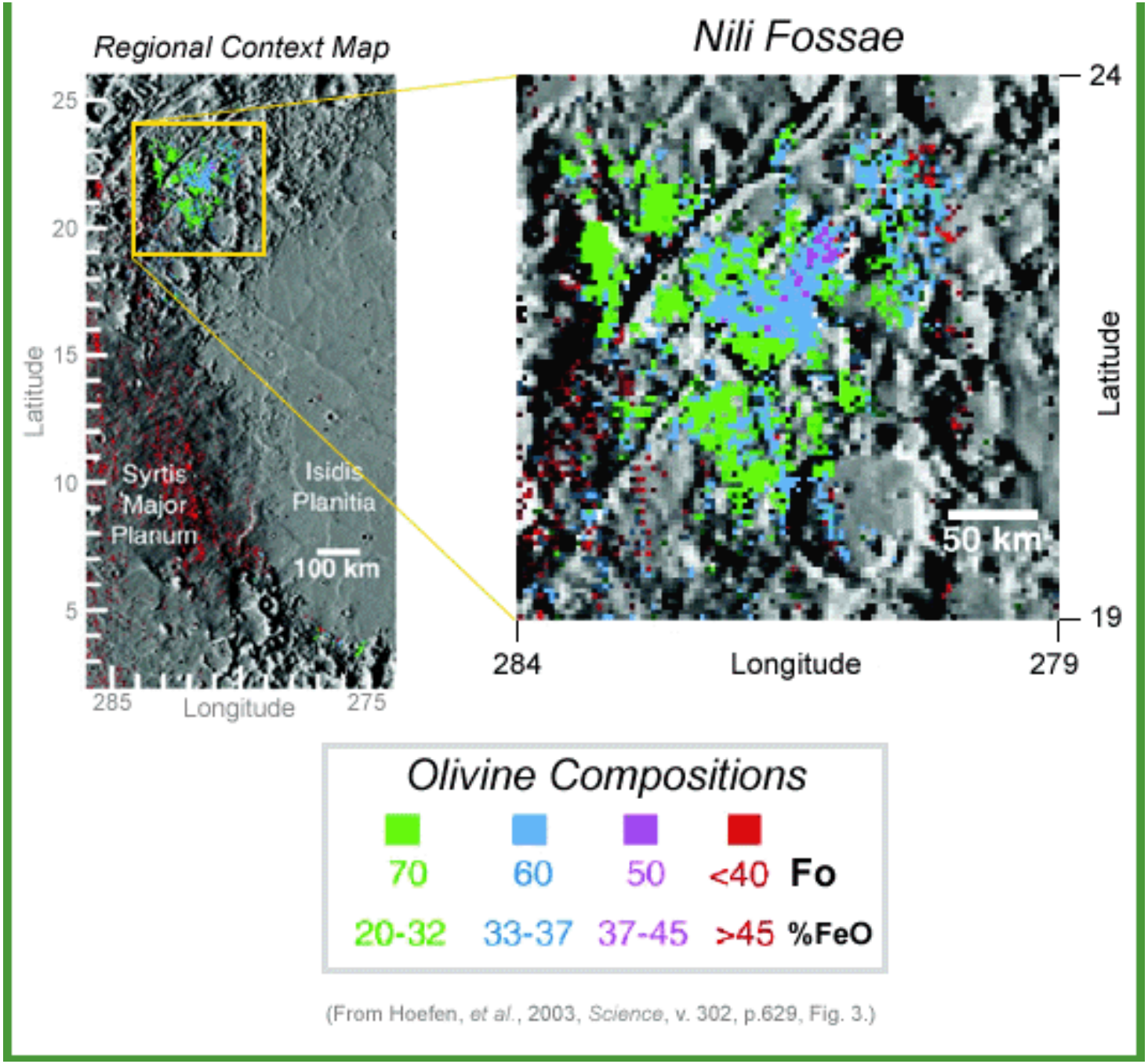


- Precipitates out of water
- Presence of hematite gives evidence of a wet environment
- Presence of coarse crystalline Hematite in the Sinus Meridiani regions gives evidence for near-surface water
(Christensen etal. 2000)

http://spaceflightnow.com/mars/mera/040318blueberries.html

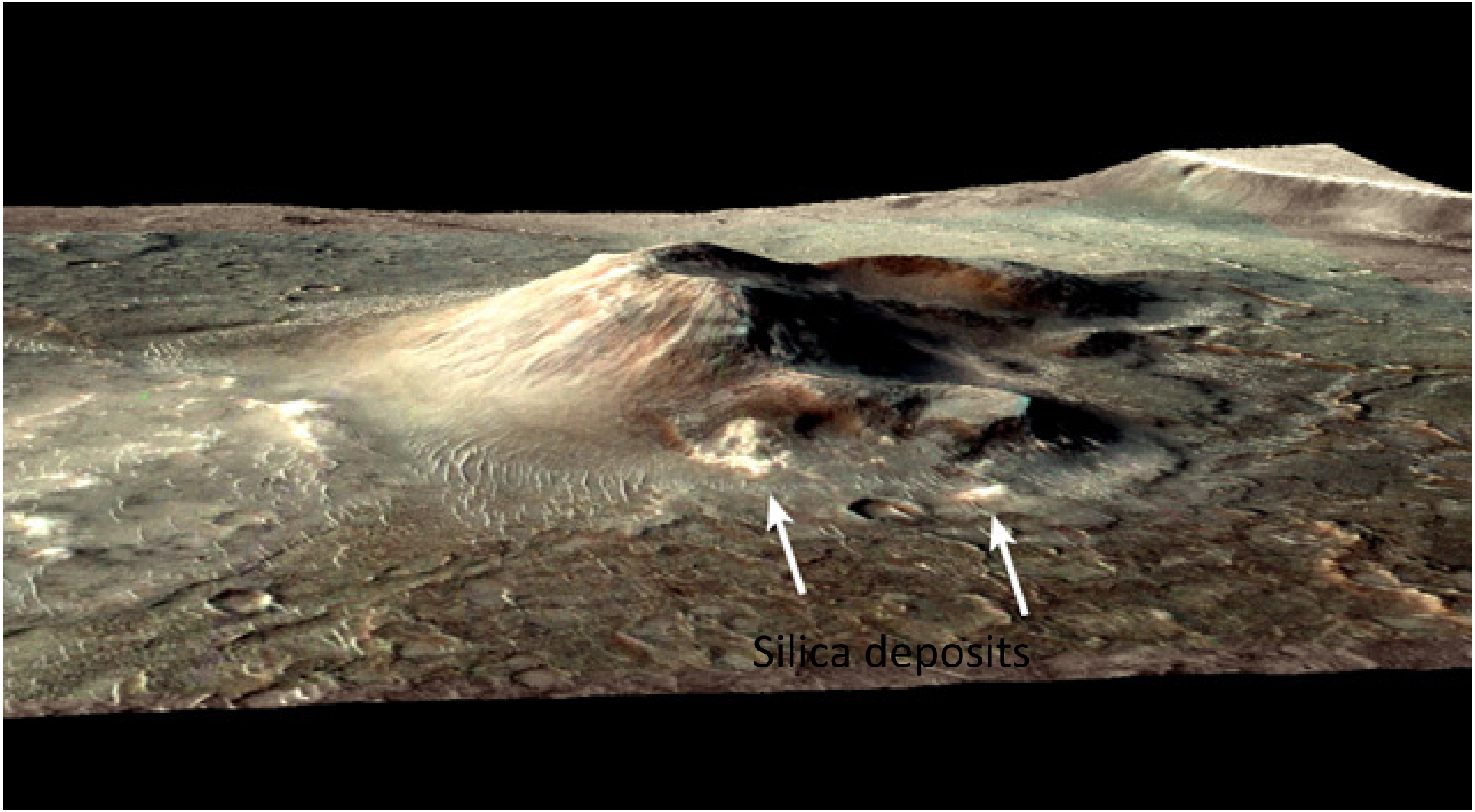
Olivine & Pyroxcene

- Mafic minerals formed during the crystallization of lava/magma
- Extremely susceptible to chemical weathering
- Presence of these minerals in strata indicate a dry environment
- Wide spread on the surface and present in dust clouds (Bibring etal. 2006)
  - This indicates a long dry period



(From Hoefen, *et al.*, 2003, *Science*, v. 302, p.629, Fig. 3.)

http://www.psrd.hawaii.edu/Nov03/olivine.html



http://www.jpl.nasa.gov/news/news.cfm?release=2010-361

Mars Exploration Rovers

http://emm-media.blogspot.com/2009/12/planet-51.html

Launch History

- Dec. 4, 1996 *Sojourner (Carl Sagan Memorial Station-Pathfinder)*
- June 10, 2003 *Spirit*
- July 7, 2003 *Opportunity*

Sojouner

- 1st successful mission of rover landing
- Mission to analyze atmosphere, climate, geology and the composition of rocks and soil on Mars
- Barnacle Bill
- Yogi
- Scooby Doo

http://beyondapollo.blogspot.com/2010/10/microtech-mars-sample-return-1991.html

Mars Exploration Rover Mission (MER)

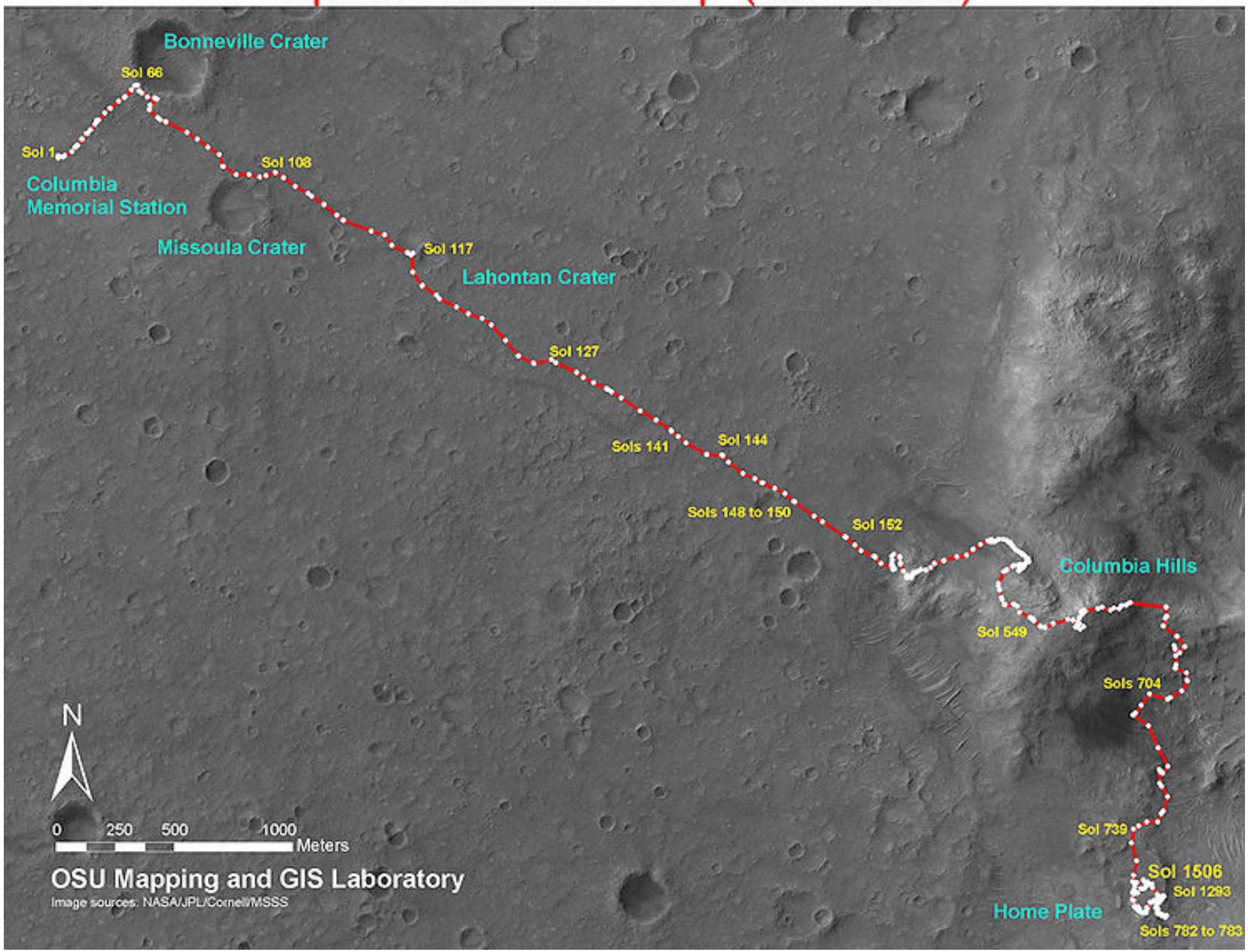
- MER-A *Spirit*
- MER-B *Opportunity*
- Mission Objective: Rock and soil samples indicative of presence of water on Mars, opposite sides of planet
- Pricetag for the mission = $820B (for intended 90 Sol mission)

Spirit

- Landed Jan. 4, 2004
- Adirondack (RAT)
- Humphrey
- Bonneville Crater
- Paso Robles
- Dust Devil phenomena
- Husband Hill Summit
- Home Plate - Sol 744
- Spirit now quiet

http://www.amusingplanet.com/2010/02/in-memory-of-spirit-mars-rover.html

Spirit Traverse Map (Sol 1506)

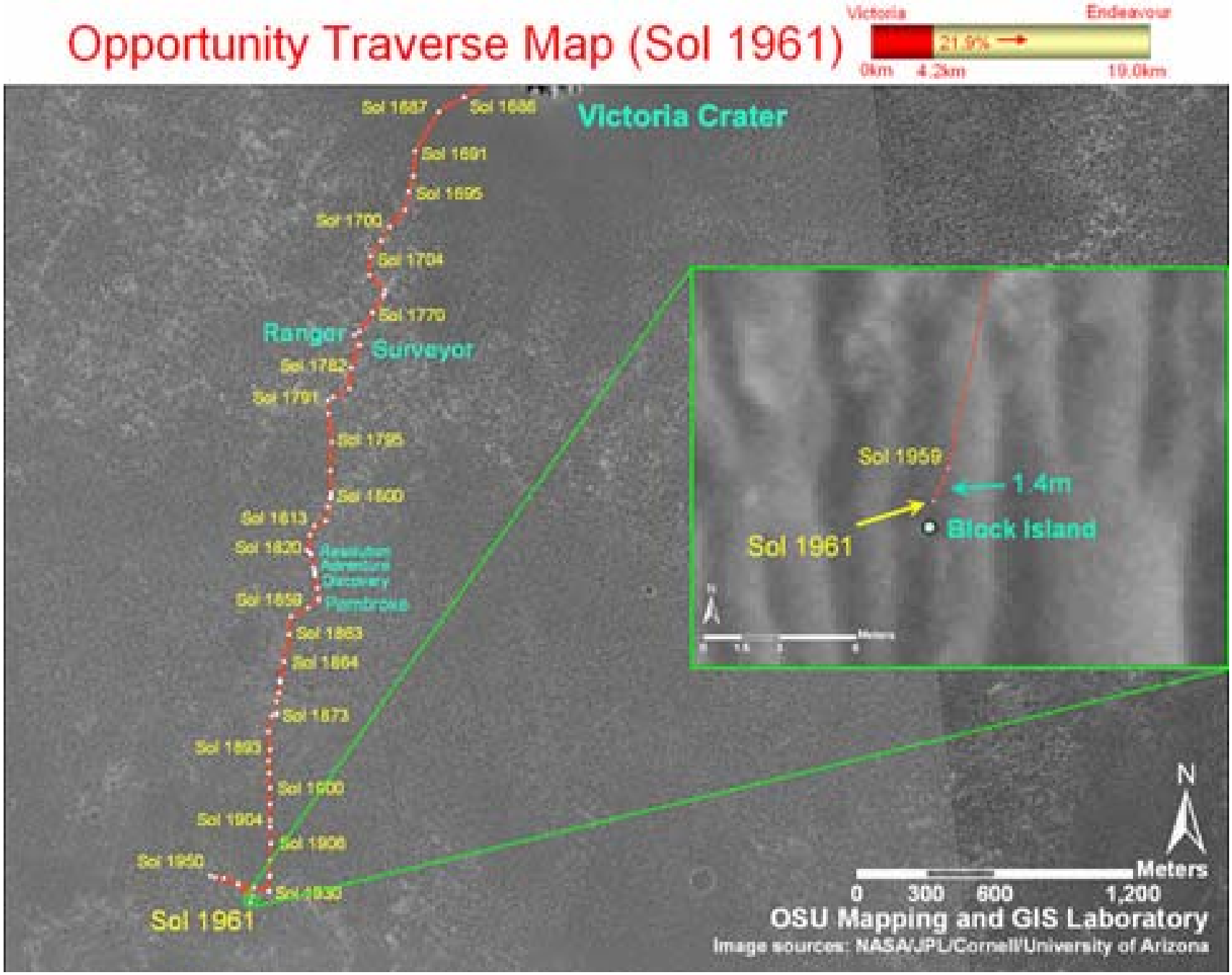


http://rst.gsfc.nasa.gov/Sect19/Sect19_13a.html

Opportunity

- Landed Jan. 25, 2004 *Eagle Crater*
- Longest Mars surface mission to date
- *El Capitan*
- Heat Shield Rock
- Victoria Crater
- Endeavor Crater
- Sep. 8, 2010 halfway point of 19 km distance

http://www.gi.alaska.edu/planetary/www/Galleries.html



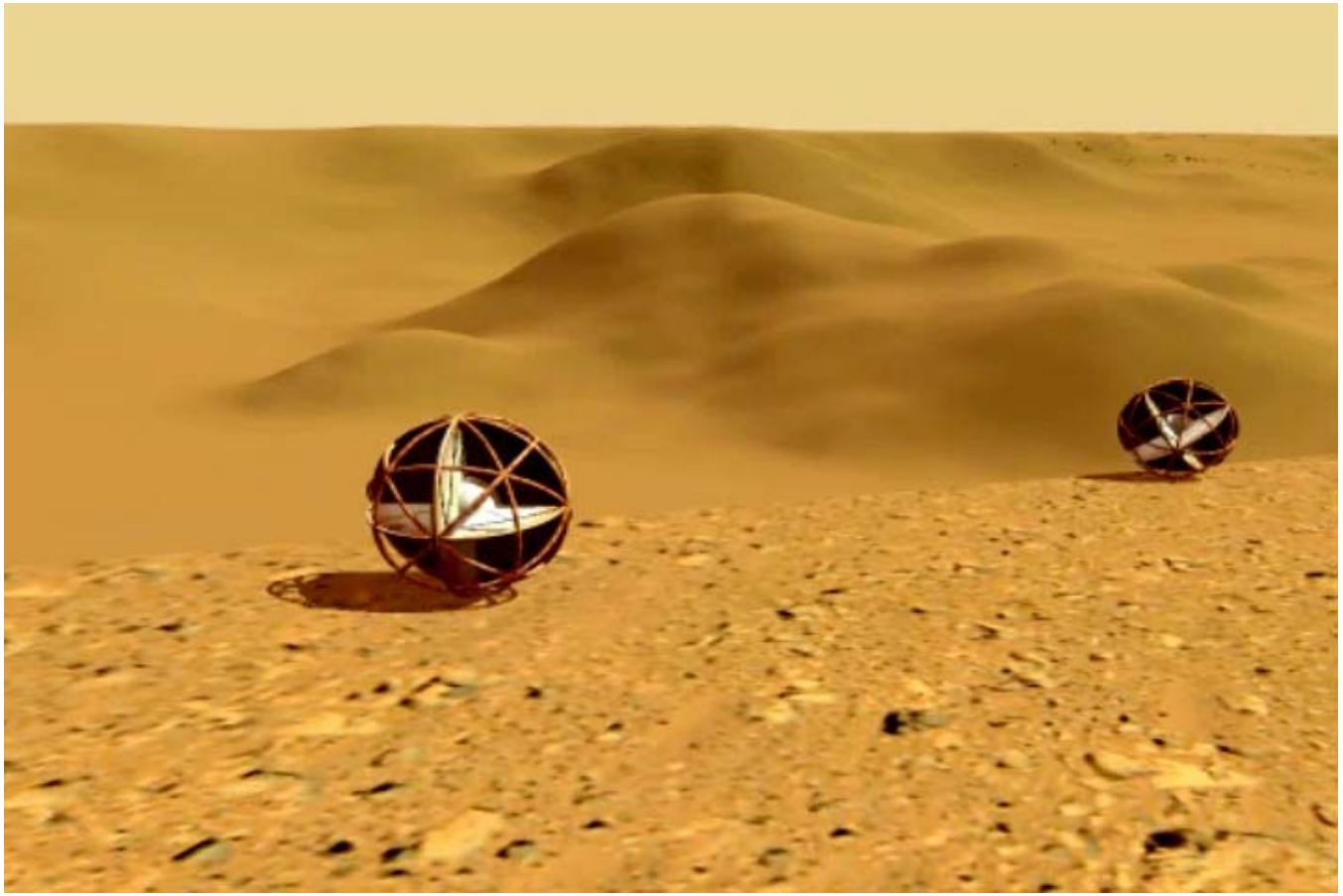
http://blogs.nationalgeographic.com/blogs/news/breakingorbit/2009/08/tracking-a-mars-rover.html

Curiosity

- “Mini Cooper” sized
- New landing system
- 10 science instruments including laser to vaporize rock
- Updates from previous rovers
- Nuclear battery

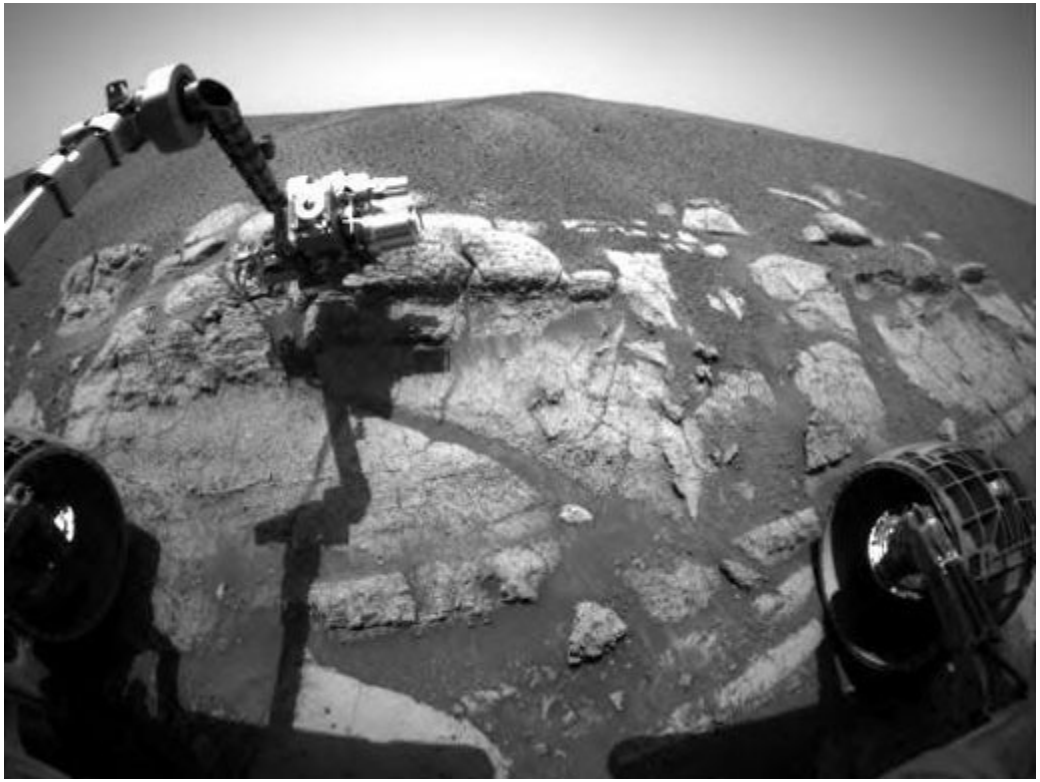
New Rover Proposals

- Biggest problem is mobility in past rovers
- Proposal of “Tumbleweed” Rover



http://news.discovery.com/space/could-the-tumbleweed-rover-dominate-mars.html

Evidence for water by chemical weathering of rocks

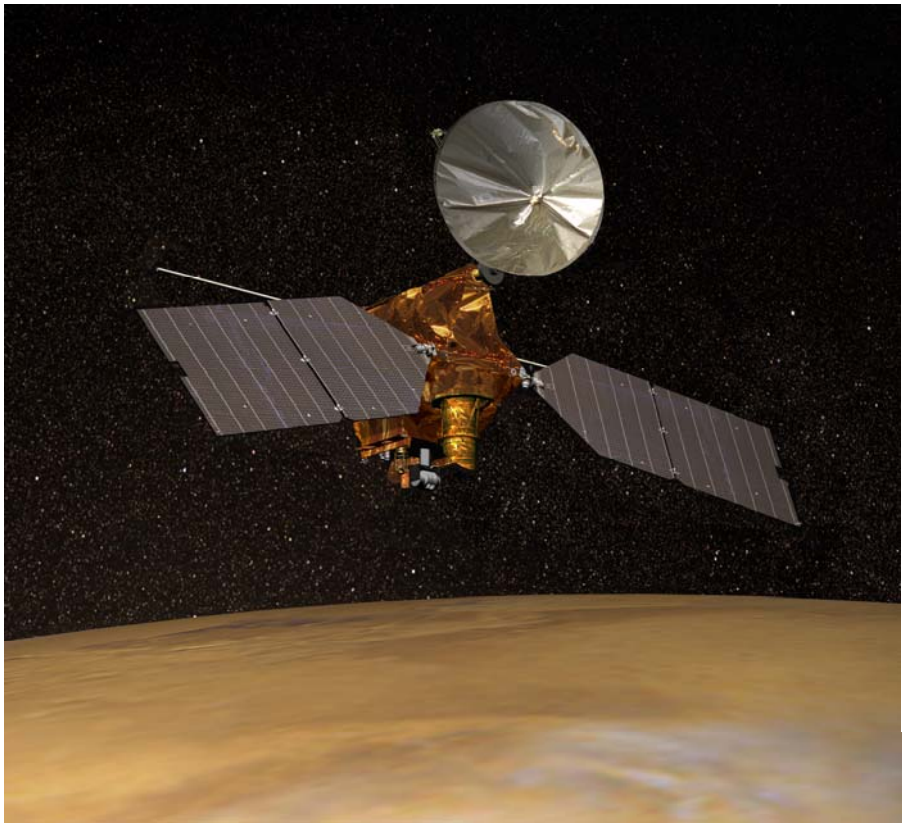


http://www.nasa.gov/mission_pages/mars/images/mer-image_feature_134.html

- Evidence for rocks on mars from physical and chemical characteristics
- Spectromoters tell us chemical composition
- Rover images show us physical characteristics

Methods

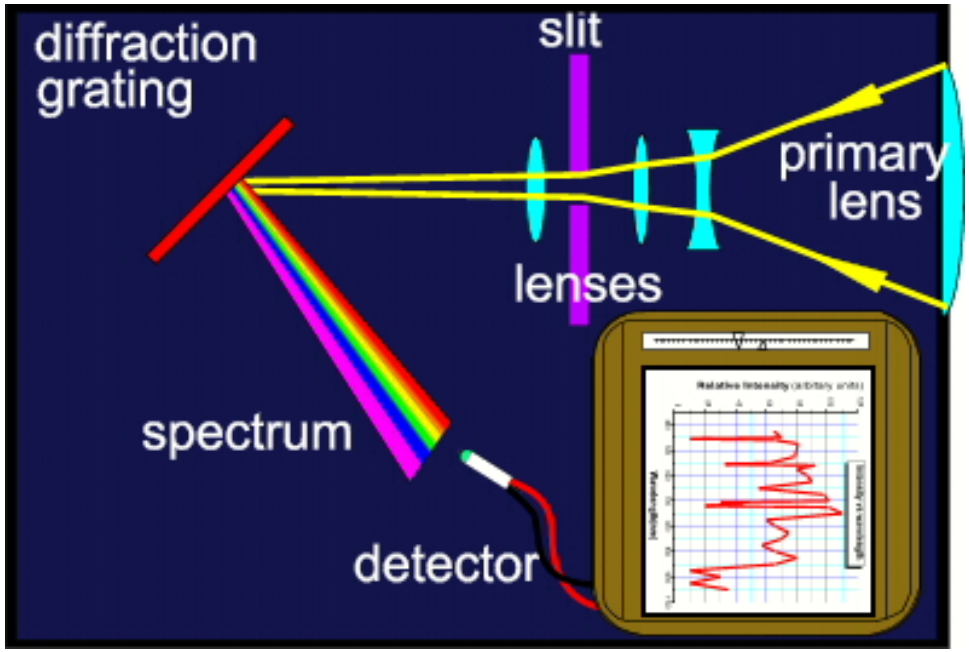
- Mars Reconnaissance Orbiter (MRO)
- Rovers: Opportunity & Spirit



http://solarsystem.jpl.nasa.gov/multimedia/gallery/MRO.jpg

http://www.nasa.gov/audience/foreducators/k-4/features/F_Making_Tracks_on_Mars.html

Both methods use a Spectromoter

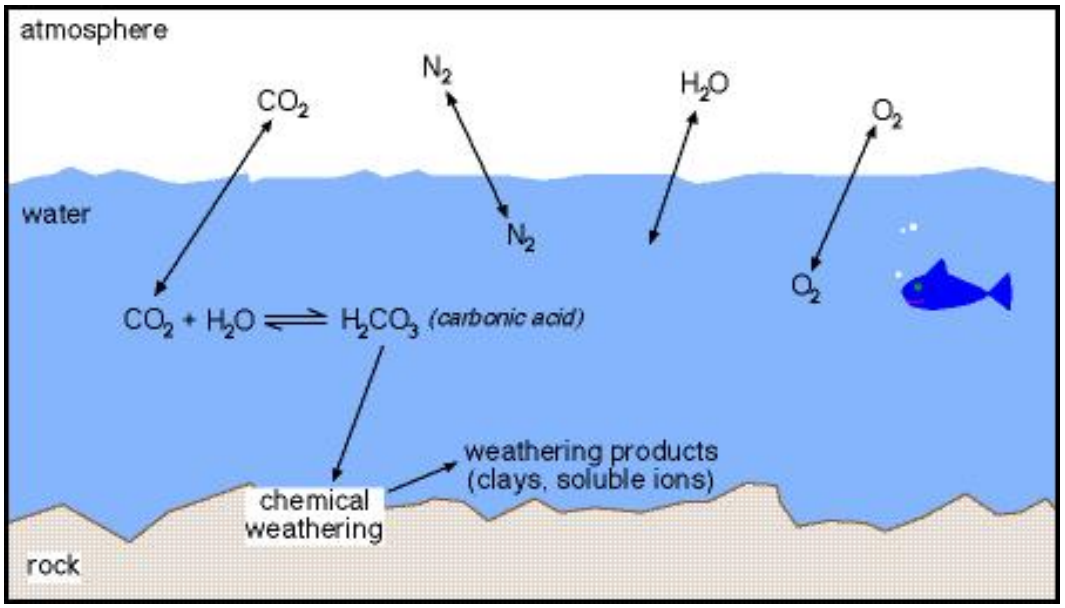


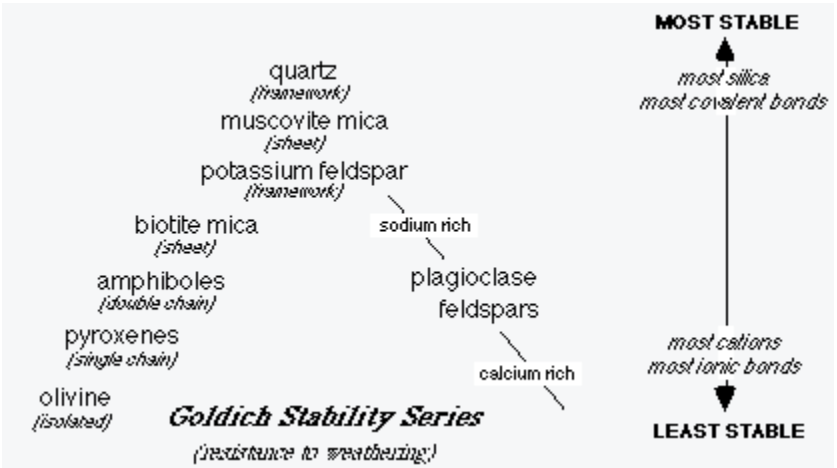
http://www.asc-csa.gc.ca/eng/educators/resources/scisat/grade9-maestro.asp

- Measures intensity of light vs. wavelength.
- Uses absorbance spectrum to determine composition
- Recall that each type of molecule absorbs wavelengths of light in a specific pattern.

http://ozone.gi.alaska.edu/dobson.htm

Basics of chemical weathering

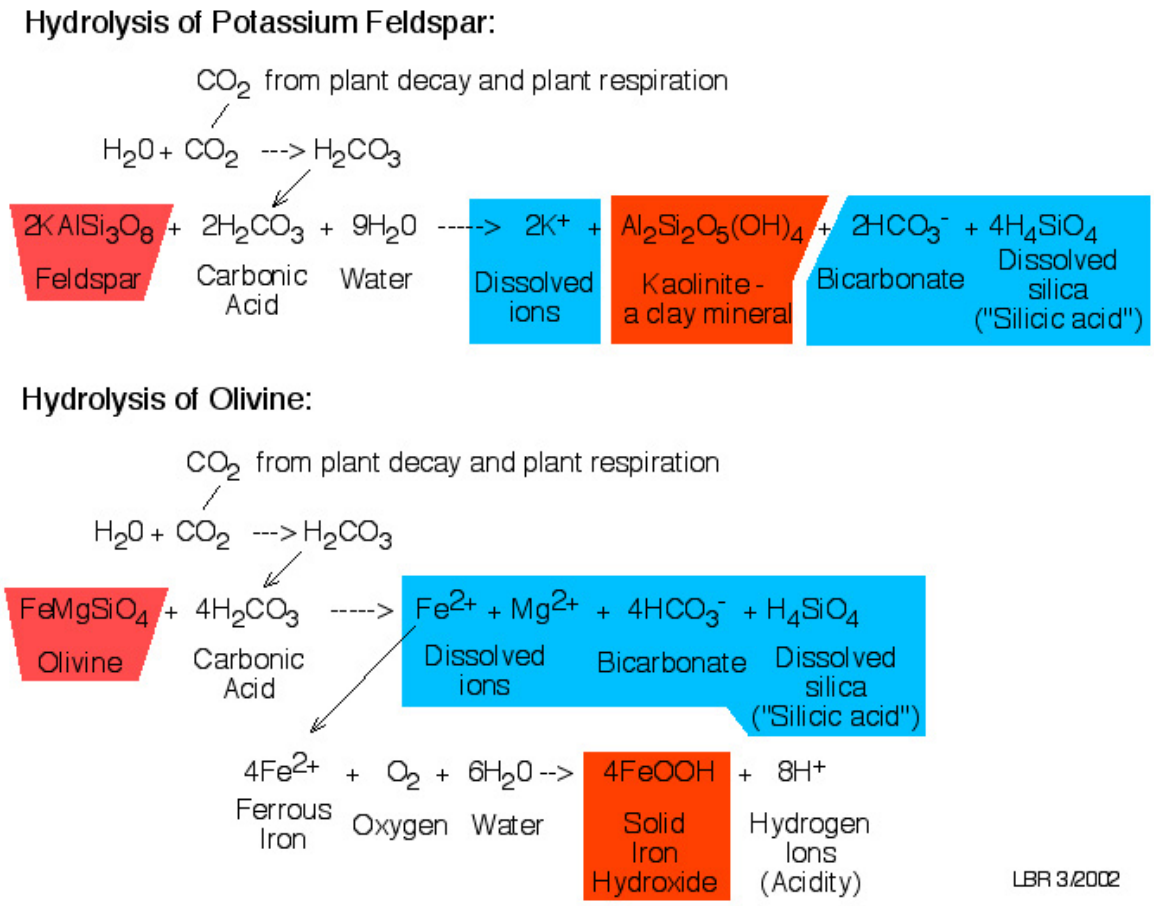




- Hydrolysis: minerals react with H20 and are altered
- Dissolution in water (may later become evaporates)
- Some minerals resistant/not resistant to hydrolysis

http://myweb.cwpost.liu.edu/vdivener/notes/weathering.htm

Basics of chemical weathering



http://www.gly.uga.edu/railsback/1121WeatheringChemHydrol.jpeg

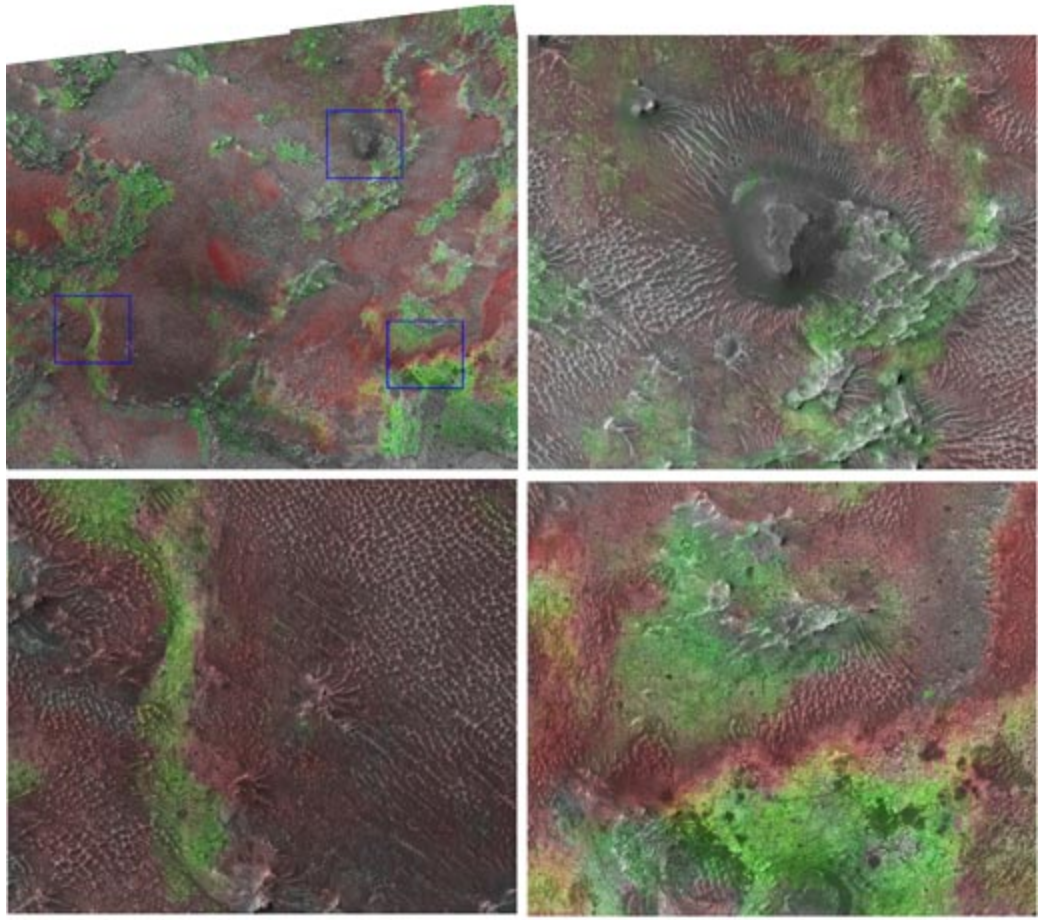
Nili Fossae

Image By MRO

Red areas are olivine rich

Green areas are clay rich

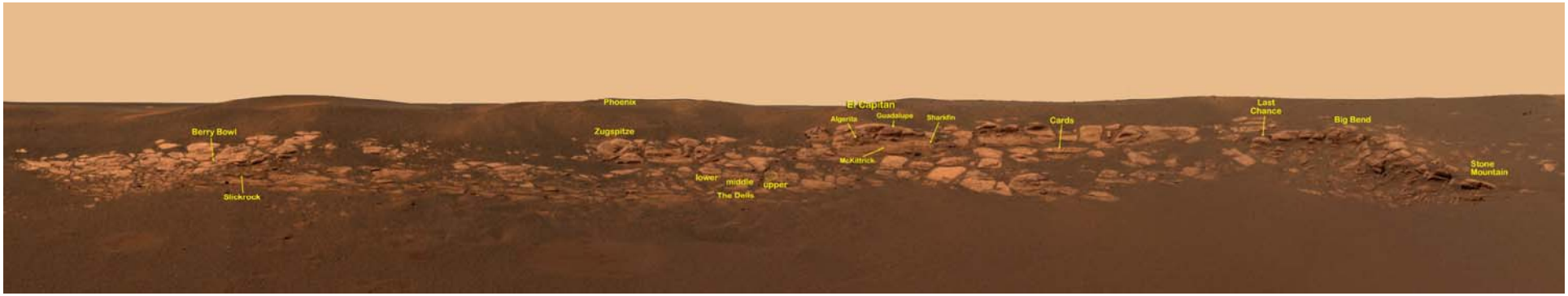
Clay-rich areas are older and olivine-rich areas on top, later eroded



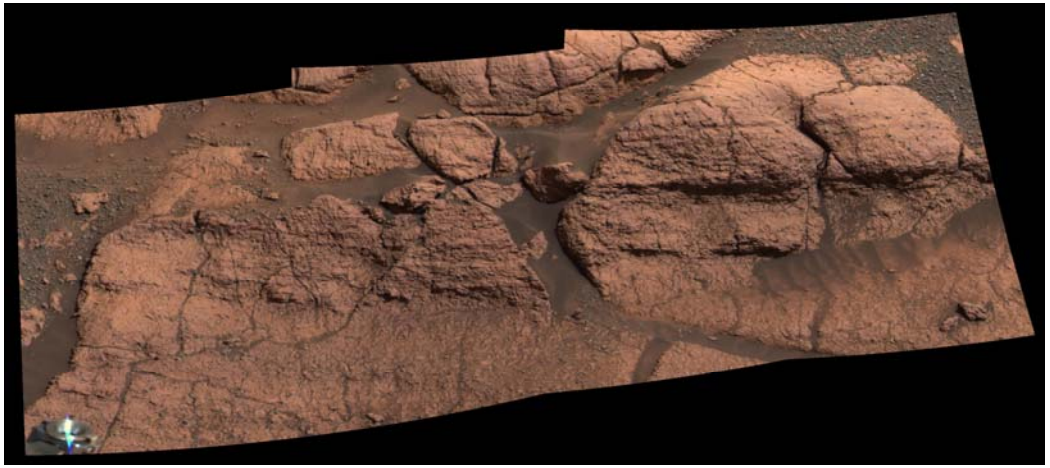
http://www.nasa.gov/mission_pages/MRO/multimedia/pia09093-a.html

Meridani Planum

http://marsrover.nasa.gov/newsroom/pressreleases/20040323a.html



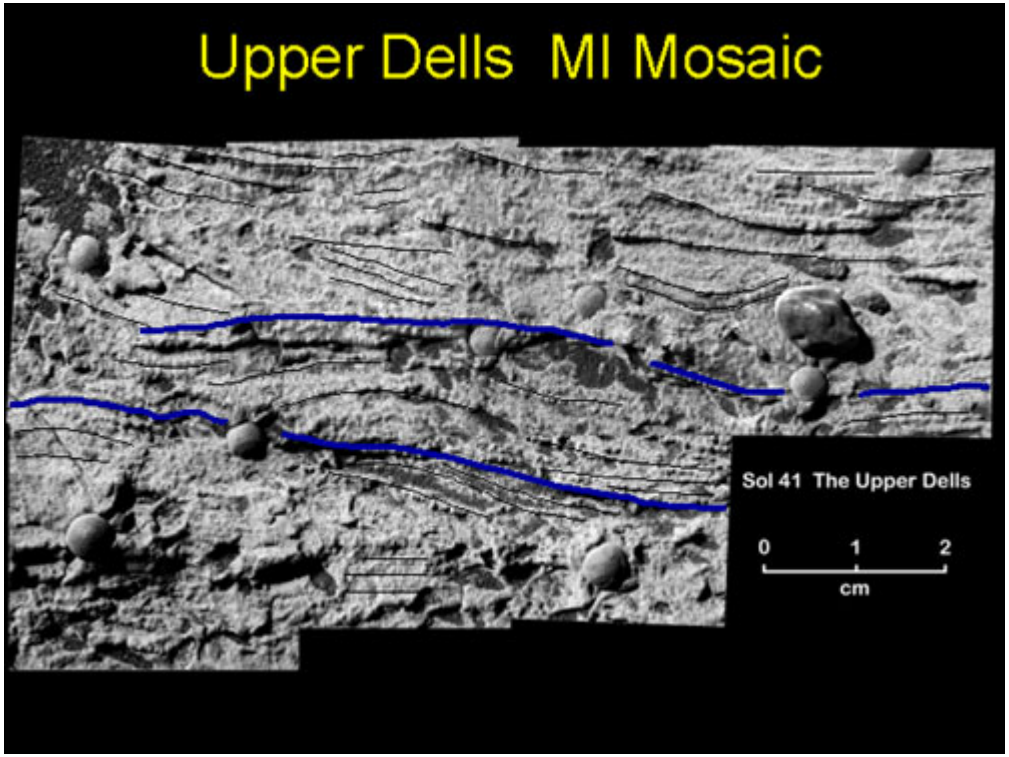
- Rover Opportunity studied rocks in Meridani planum and found evidence of the presence of water.
- Rocks sat at the bottom of a playa or at the shoreline of a salty sea
- Upper Dells, El Capitan, Last Chance, and other locations in outcrop

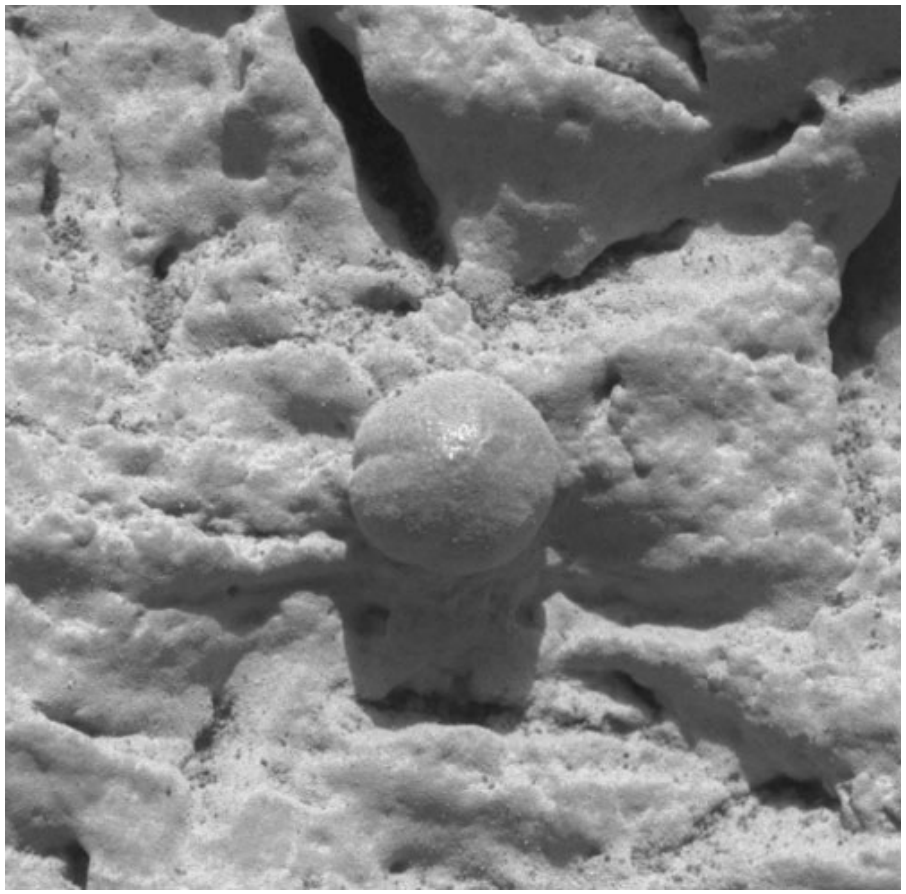


http://nssdc.gsfc.nasa.gov/planetary/image/merb_pan_elcapitan.jpg

Meridani Planum: Chemical

- Sulfates
- Chlorine and Bromine
- Jarosite
- Spherules the size of BB's

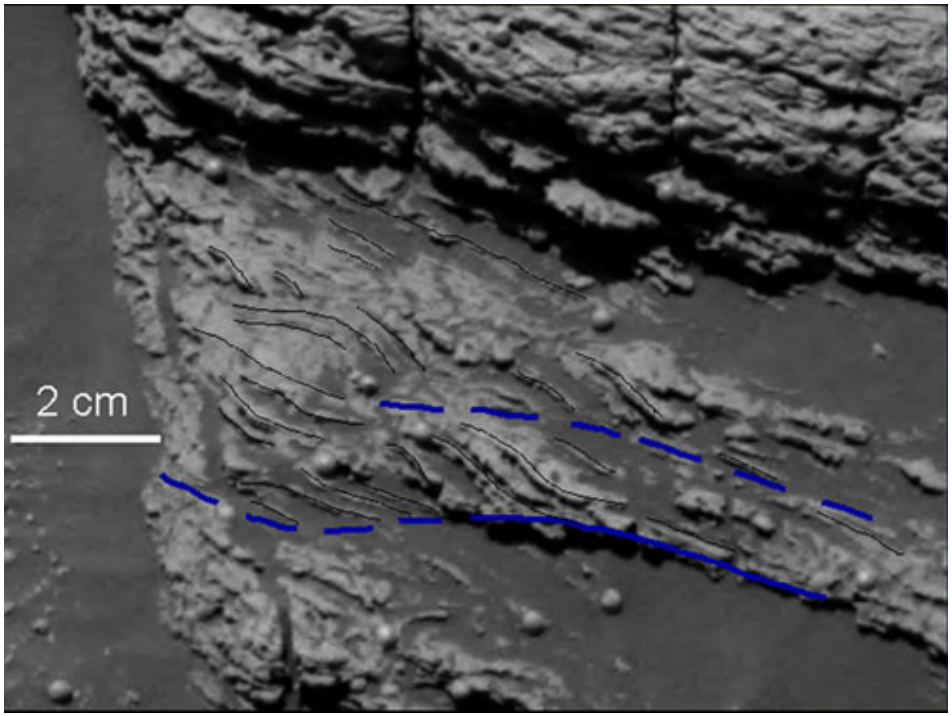


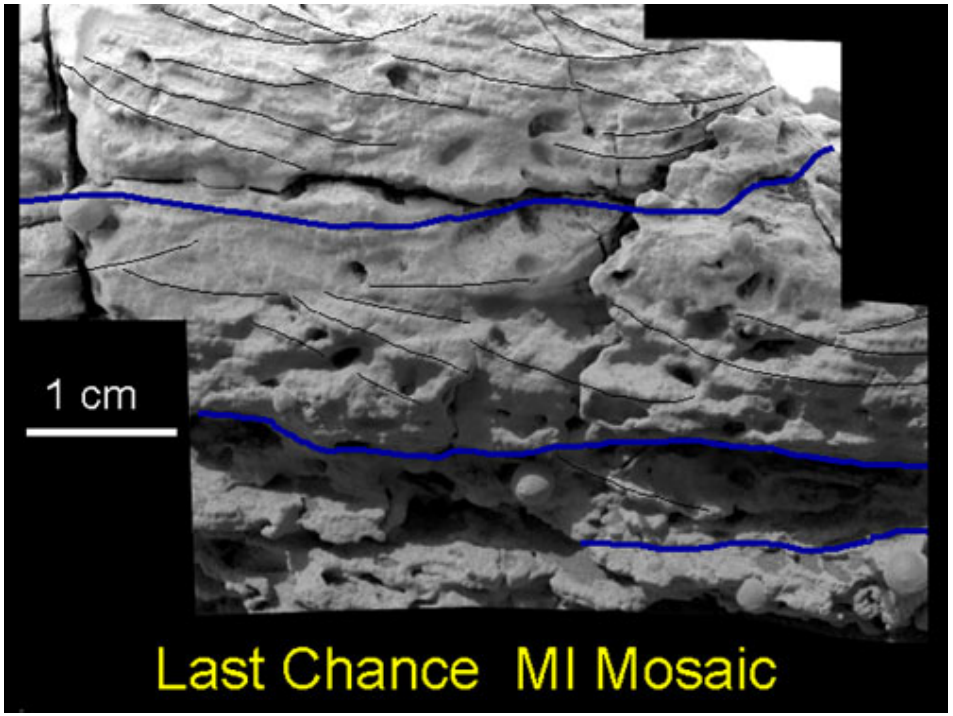


http://marsrovers.jpl.nasa.gov/gallery/press/opportunity/20040323a.html http://science.nasa.gov/science-news/science-at-nasa/2004/02mar_meridianiwater/

Meridani Planum: Physical

- Ripple patterns from water (not wind)
- Cross-bedding
- Stripes on the spherules
- Small spherical holes or “vugs”





http://marsrovers.jpl.nasa.gov/gallery/press/opportunity/20040323a.html http://science.nasa.gov/science-news/science-at-nasa/2004/02mar_meridianiwater/

Humphrey

- Rock found in the Gusev Crater.
- Bright material in cracks and crevices in the rock that look like crystallized minerals.

http://marsrover.nasa.gov/newsroom/pressreleases/20040305a.html

Columbia Hills

- The rover Spirit found:
- Carbonates
- More sulfate salts than found anywhere else so far on Mars.
- Geothite
- Hematite
- Surface water or groundwater

http://marsrover.nasa

Resources

- NASA.gov
- Discoverynews.com
- Space.com
- http://shoreline.eng.ohio-state.edu/dkc/JGR_Spirit.pdf
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- Wyatt, Michael, et. al. 2004. Global Geologic Context for rock types and surface alteration on Mars. *Geology.* 32. 645-648.
- Haskin, Larry, et. al. 2005. Water alteration of rocks and soils on Mars at the Spirit Rover site in the Gusev crater. *Nature.* 436. 66-69.

Resources

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