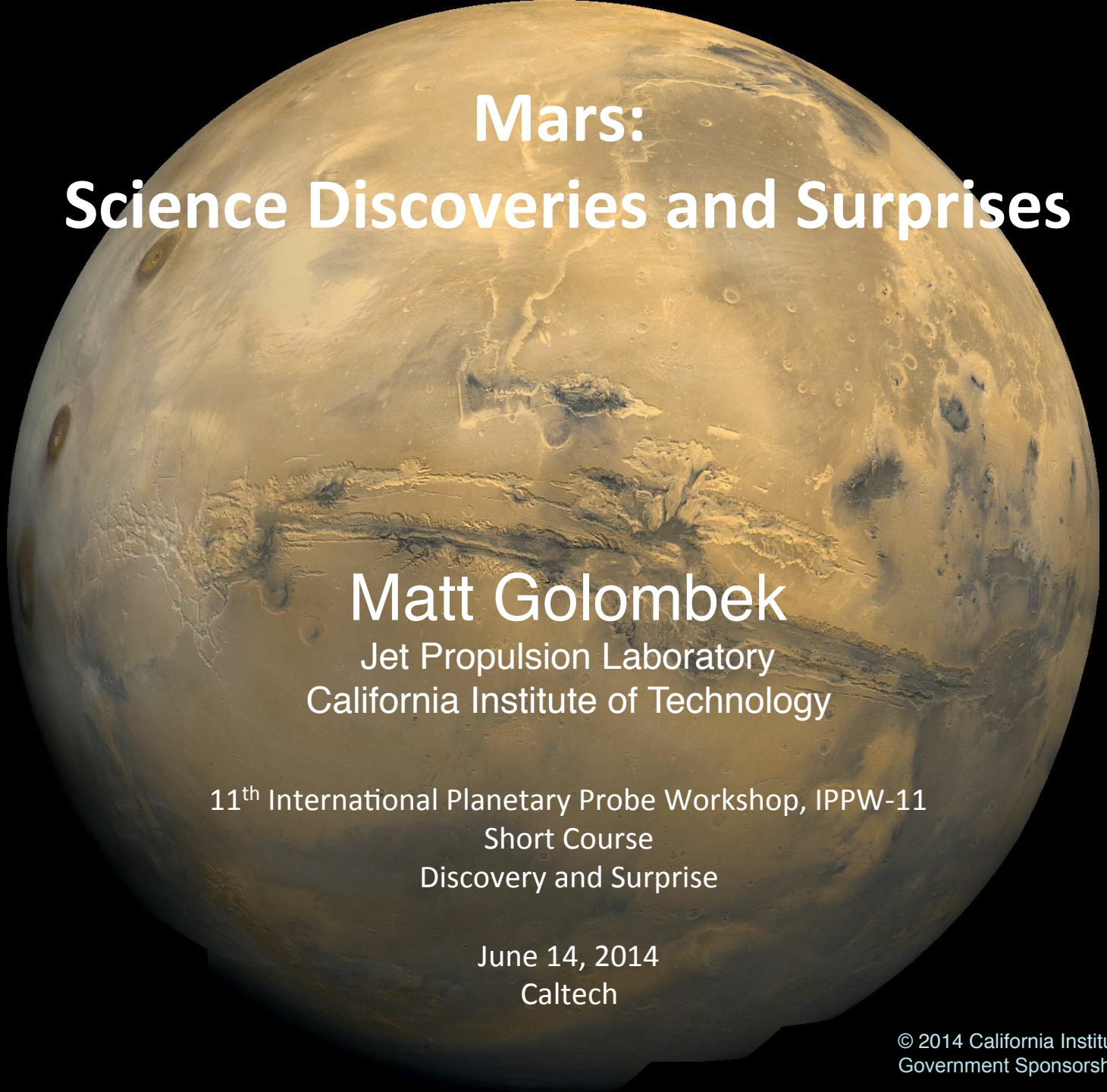


Mars:
Science Discoveries and Surprises

Matt Golombek

Jet Propulsion Laboratory
California Institute of Technology

11th International Planetary Probe Workshop, IPPW-11
Short Course
Discovery and Surprise

June 14, 2014
Caltech

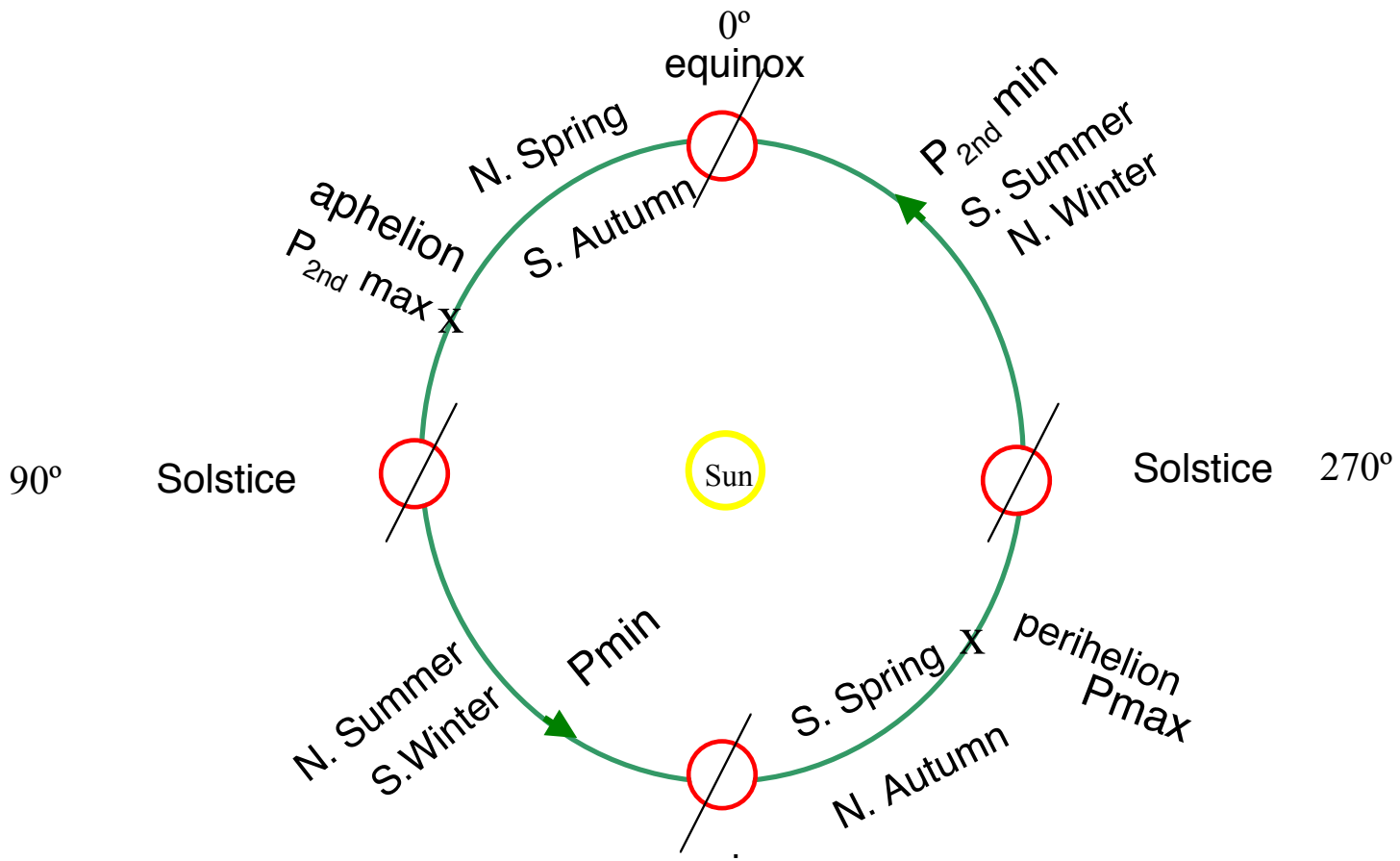
Short Course Themes

- How were the Objectives of the Missions Defined?
  - Generally NASA Appointed Science Definition Team
- Did the Missions Achieve those Objectives as Planned?
  - Generally Yes
- Did the Missions make Discoveries that were not Anticipated?
  - Almost Always

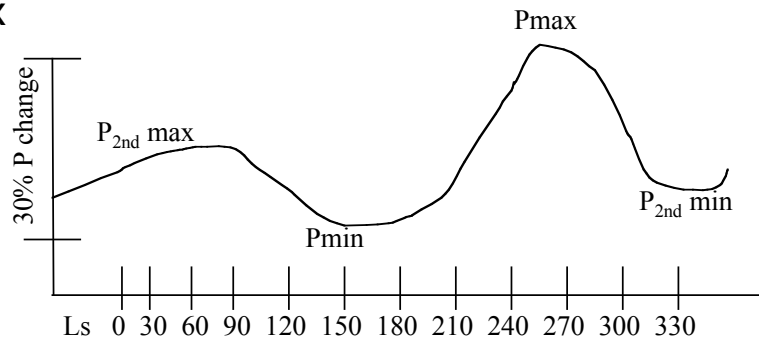
MARS

- 4TH PLANET FROM SUN - LAST TERRESTRIAL PLANET
  - Diameter - 0.53 of Earth; Density - 3.93 g/cm^3 (Earth 5.5 g/cm^3)
  - Less Dense, Gravity - 0.38 Earth (Mass - 0.1Earth)
  - Surface Temperature -225°F to 63°F
  - Satellites - Phobos (28x20 km, 7.5 hr); Deimos (16x10 km, 30.3 hr)
- ORBIT AND ROTATION
  - Elliptical Orbit 1.38-1.67 AU, Mars Year-687 days
  - Rotates - 24 hr 37.5 min (Sol) Axis Inclined 25°
- BIZARRE SEASONS
  - Southern Hemisphere Tilted Toward Sun at Perihelion
  - More Extreme Seasons (North Moderate Seasons)
  - Thin Atmosphere 0.006 Pressure at Surface of Earth
  - 95.3% CO_2, 2.7%N_2, 1.6% Ar, traces of O_2, CO, H_2O
- Polar Caps
  - S Varies in Size More than N, Perm. H_2O, CO_2 20-30% Atm. Cond.
  - Winds - Driven by Seasonal Heating and Cooling of Hemispheres
  - Great Dust Storms - Occur Near Perihelion (S Summer)

Mars Seasons



Atmospheric Pressure Cycle on Mars
Seasonal & Orbital Effects



History of Mars Exploration

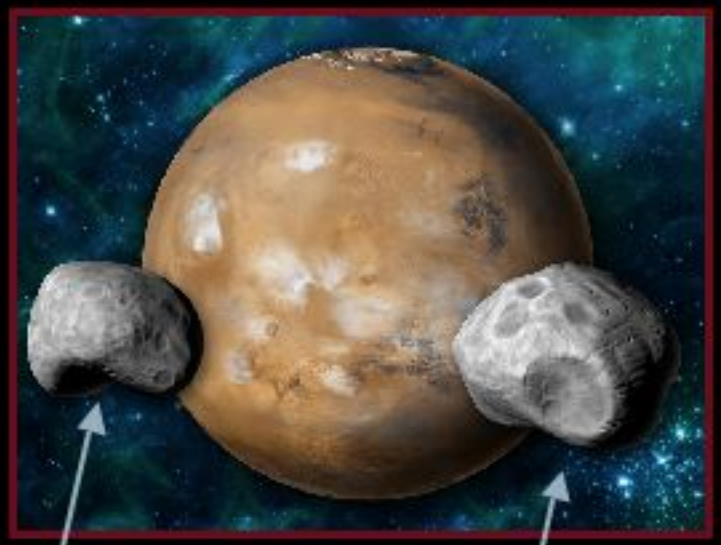
- TELESCOPIC OBSERVATIONS
  - G. Schiaparelli, 1877; Observed Canali-Series Long Straight Dark Markings
  - P. Lowell, 1890-1910, English Translation - Canals
  - Proponent of Intelligent Life on Mars
- MOST KNOWLEDGE FROM SPACECRAFT
  - Mariner 4 Flyby (1965) - 22 Hazy Pictures
  - Mariner 6 & 7 Flyby (1969) - More Pictures
  - Mariner 8 (1971) Launch Failure
  - Mariner 9 Orbiter
    - Into Orbit Nov. 1971, Dust Storm Obscuration Until Jan. 1992
    - 7300 Pictures
  - Mars 1, 2, 3, 4, 5, 6, 7 (Russian) – 1960-70s, Landers - No Data
- Viking 1 and 2 (1976) - *Is There Life on Mars?*
  - Each Had Orbiter and Lander
  - Lander - Imaging, Meteorology, Seismometer, XRF
    - Biology - Labeled & Pyrolitic Release Experiments,
    - Gas Exchange Experiment
  - Orbiter
    - Camera (50,000 Pictures), IRTM, Mawd
- 20 year Hiatus
- Modern Era Mars Exploration - MO, MPF, MGS, Odyssey, MER, MRO …

Early peoples were fearful of Mars given its red color and strange path in the sky.

Early civilizations connected Mars with war and aggression.

Mars:
Roman
God of
War

Ares:
Greek
God of
War



Deimos = "Panic"

Phobos = "Fear"

Moons of Mars

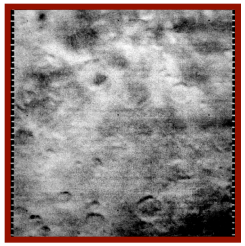

Les canaux de Mars selon G. Schiaparelli

Telescopes brought beliefs of canals and the Martians who could have built them.

Mars Missions

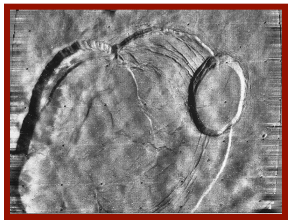
Fuzzy
Telescope View

Mariner 4



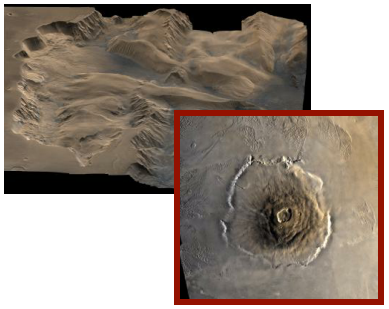
Lunar-like
Surface

Mariner 9



View of
Olympus Mons

Viking



Giant Canyons
& Volcanoes

20 Year Hiatus

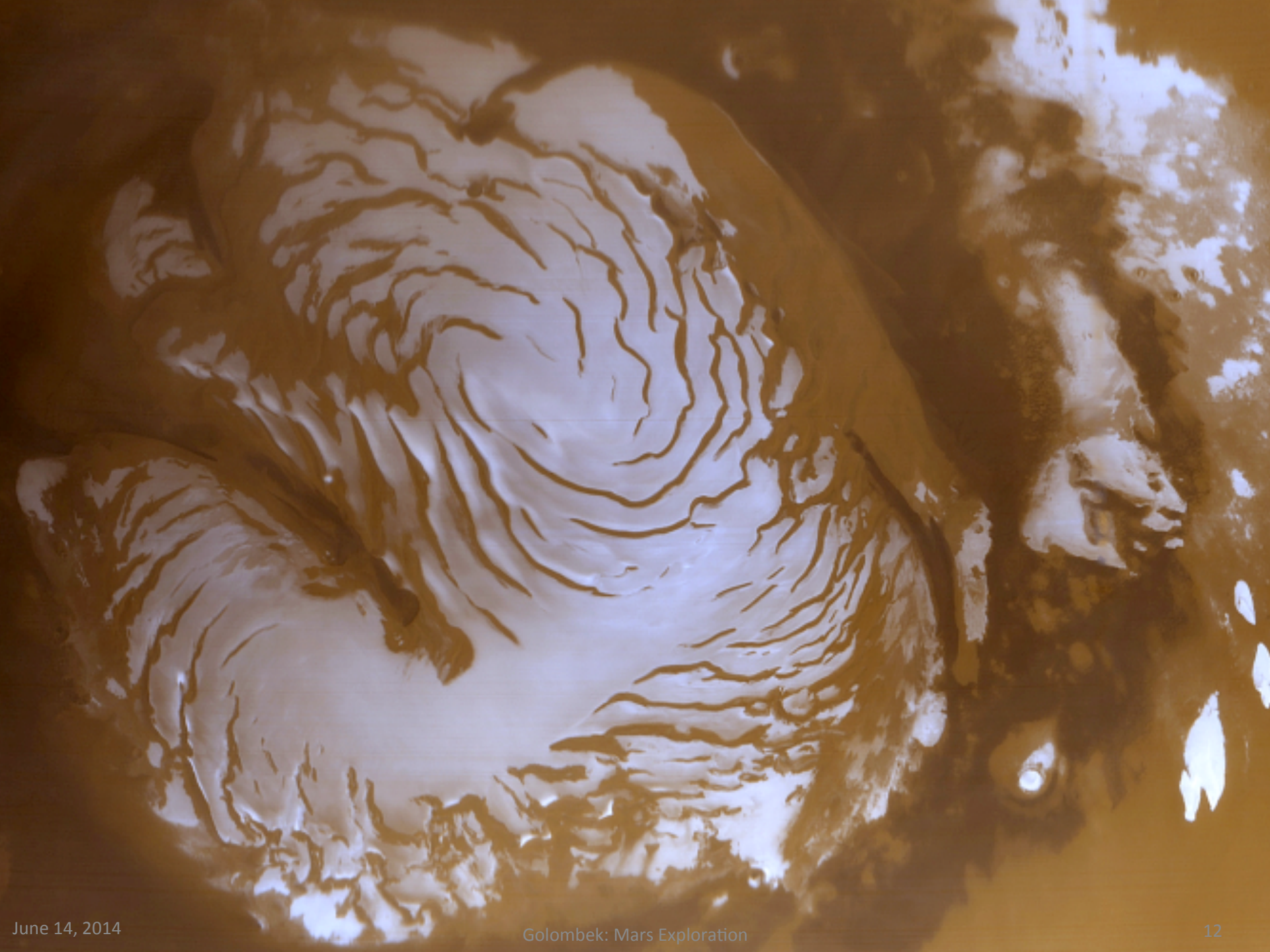
MPF

MGS

…

Modern Era of Mars Exploration

- Modern Era Mars Exploration ~1990s
- Phobos 1 & 2 - 1988 – 1 Failed; 2 Orbital Observations Only
- Mars Observer – 1992 – Failed 1993
- Mars 96 - Failed
- Mars Pathfinder – 1997 Tech Demo – Successful, Airbag Landing, Sojourner rover
- Mars Global Surveyor – 1997 - Recover Part of Science from MO, Operated 7 yr
- Nozomi or Planet B – 1998 - Failed – Ran out of Fuel
- Mars Climate Orbiter 1999 - Burned Up in Atmosphere
- Mars Polar Lander 1999 – Failed during EDL
  - Deep Space 2 Penetrators - Failed
- Mars Odyssey – 2001, Operating
- Mars Express – 2003, Operating
  - Beagle 2 – Failed
- MER Spirit – 2004, Operated for >6 years
- MER Opportunity, 2004, Operating (10+ yr)
- Mars Reconnaissance Orbiter – 2007, Operating
- Phoenix Lander – 2007 – Polar landing, froze in polar night
- Phobos-Grunt – 2011, Failed
- Mars Science Laboratory – Curiosity, 2011, Operating <50% Successful
- MAVEN – 2013 - En Route, Arrives Sept. 2014
- MOM – Mars Orbiter Mission – En Route, Arrives Sept. 2014
- InSight – 2016 – Under Construction
- ExoMars – 2016 EDM & Orbiter, 2018 Rover
- Mars 2020 Rover – Started

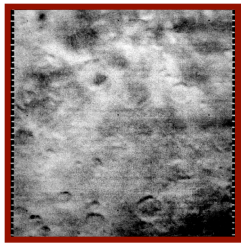


Thin CO_2 Atmosphere

Mars Missions

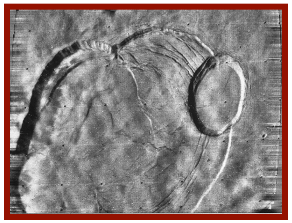
Fuzzy
Telescope View

Mariner 4



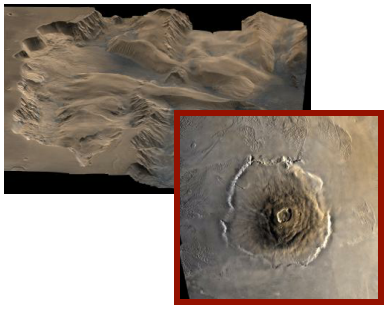
Lunar-like
Surface

Mariner 9



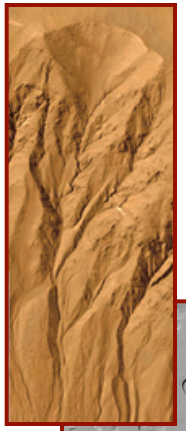
View of
Olympus Mons

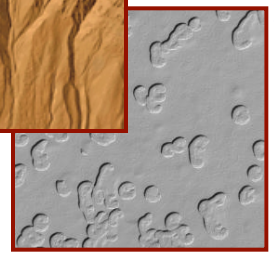
Viking



Giant Canyons
& Volcanoes

MGS





Dynamic Features

Odyssey
& MER

Viking Missions to Mars

- Post Apollo, 1976
  - Apollo Style 3.5B – Major Mobilization
  - RTGs, Landers Heat Sterilized
  - Doubly Redundant Orbiter/Lander Pairs
- Orbiter/Lander
  - Inserted into elliptical orbit
  - Orbiter imaged potential landing sites
    - Missed Landing on July 4
  - Lander released for EDL
- Both Orbiters/Landers Successful
  - Orbiters - Remote Sensing
- Landers Dominated by Life Detection Experiments
  - Is there life on Mars?
    - Partially answering societies fascination
  - Had to Define What Life Is

Viking Biology Experiments

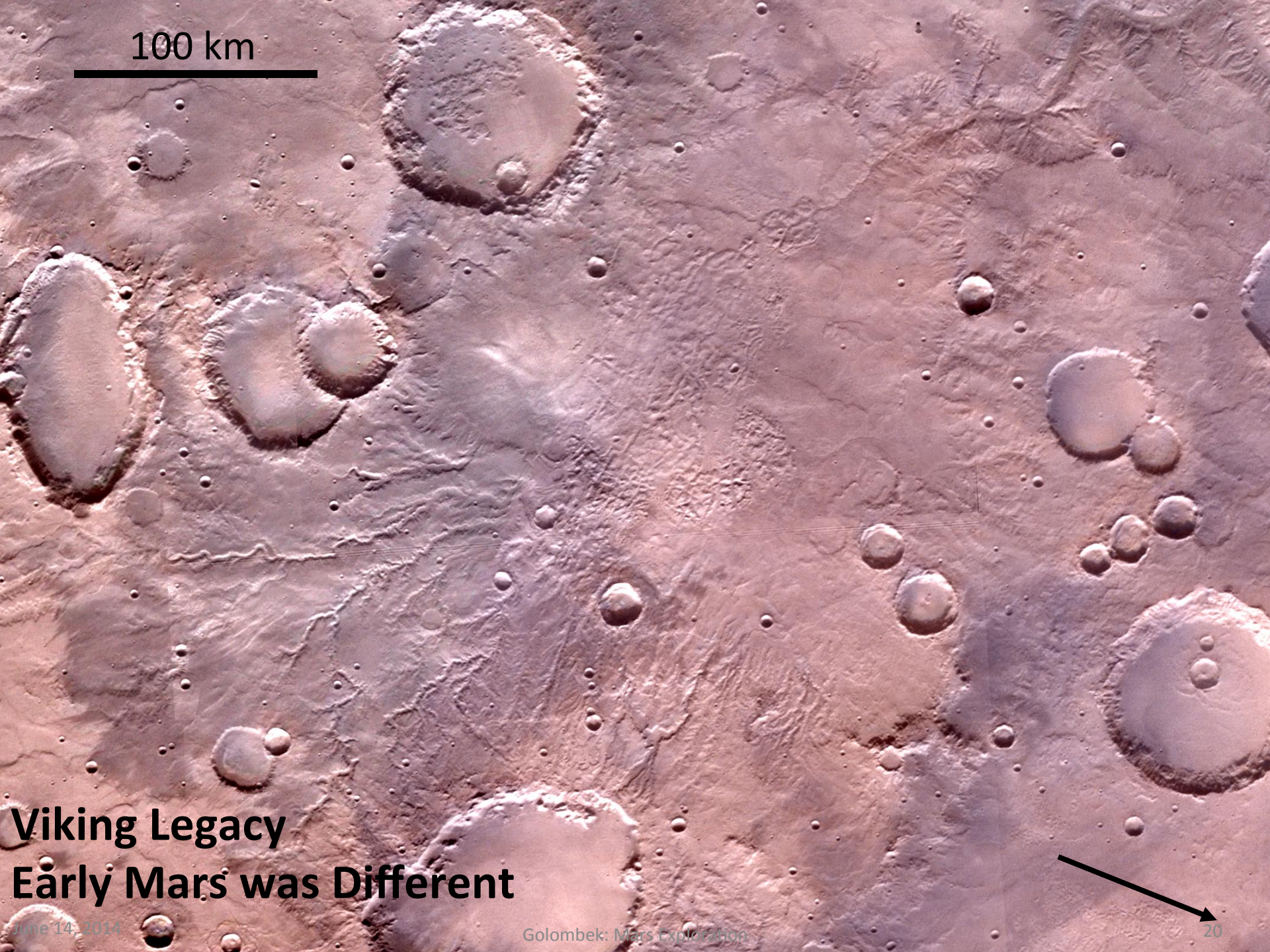
- APPROACH - LOOK FOR SIGNS OF METABOLIC ACTIVITY
  - Changes in Environment
- LABELED RELEASE EXPERIMENT
  - Soil Added to Nutrient Solution (with ^{14}C added)
  - Warmed for Several Days - Measured ^{14}C in Gas
  - If Life Present - Eat Nutrient Produce ^{14}C (Produced by all Life)
  - Did See ^{14}C, but Abruptly Stopped, Not Repeatable on Same Sample
- PYROLITIC RELEASE EXPERIMENT
  - Soil Added to Gas (CO and CO_2 with ^{14}C); Light Source
  - Looking for Photosynthesis
  - Flush Out Gas, Heat Soil Look for ^{14}C
  - Found None (only trace quantities)
- GAS EXCHANGE EXPERIMENT
  - Soil Added to Nutrient and Inert Gas; Look for Respiration
  - Some CO_2, N_2, O_2 - Quantities Expected from Non Organic Reactions
- XRF
  - No Organics; Oxidizing Surface

Viking Lander 1

Viking Lander 2

Twenty Year Hiatus

- Why?
- What happened during that time?
- What brought Mars to the Fore Again?

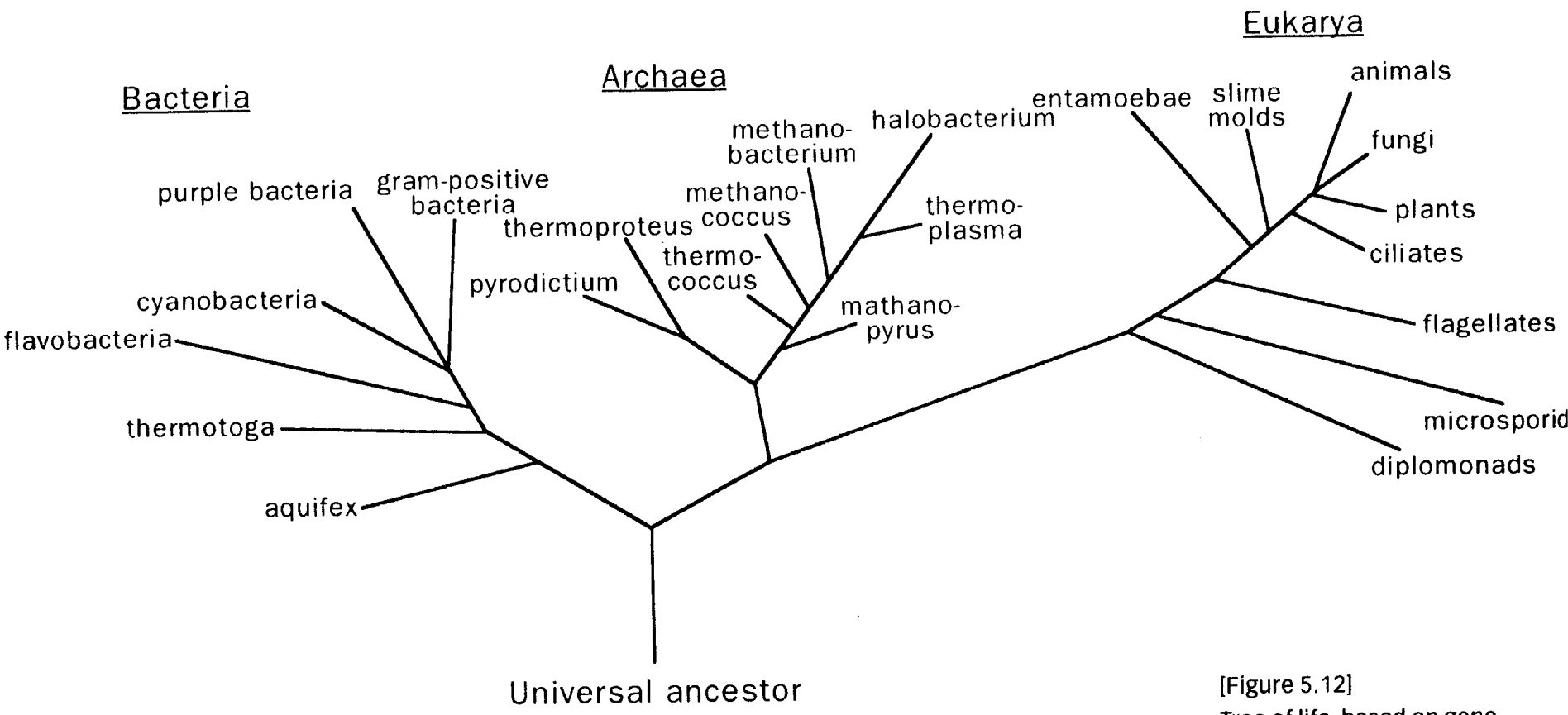


Viking Legacy
Early Mars was Different

Why a Mars Exploration Program? 1990s

- MOST EARTH-LIKE OF TERRESTRIAL PLANETS
  - First Planet Humans will Visit
- BETTER UNDERSTANDING LIFE ON EARTH
  - Water is Required – All Life related
- ONLY PLANET THAT COULD SUPPORT LIFE IN FUTURE [Terraforming]
  - Everything Necessary to Support Life is Present
  - Only Terrestrial Planet (besides Earth) with Abundant Water
- ONLY PLANET WHERE EVIDENCE INDICATES EARLY CONDITIONS WERE CONDUCIVE TO FORMATION OF LIFE
  - Early Mars May Have Been Like Early Earth
    - Warmer, Wetter, Thicker Atmosphere
  - Did Life Develop Early on Mars?; If Not Why Not?
  - If Life Did Develop - What Has Been Its Fate?
    - Gets at Fundamental Question - Are We Alone in the Universe?
- MARS IS UNIQUE TERRESTRIAL PLANET
  - Evidence Indicates It Has Undergone Major Climatic Fluctuations
    - What Triggered These Changes?
    - What do they tell us about Climate Change on Earth?
  - Geologic Activity Produced Rocks of All Ages Present on Surface
    - Record Entire History of Solar System Including Climate Change

Tree of Life



[Figure 5.12]
Tree of life, based on gene sequences in rRNA molecules. The line segments represent the genetic distance that each organism has evolved since splitting off from the rest of

Life Related by RNA -
Length of Line is Genetic Distance
Most Primitive Life - Hydrothermophylic
Most Life Primitive (90% Biomass) - Single Cell Organisms

Shergotty, Nahkla, Chassigny (SNC) Meteorites

Orthopyroxenite-Found Antarctica, 1984

Shergottite
Found Los Angeles county, 1999

Shergottite-Found Los Angeles county, 1999

- They came from Mars!
- Much younger than other meteorites found
- Isotopic analysis matches Mars
- Trapped gases similar to Mars
- They contain small amounts of water

SNC METEORITES 1990s

- 26 EXISTING METEORITES
  - Shergottites, Nakhlites, and Chassigny
  - 4 Observed to Fall - Chassigny, Nakhla (killed dog), Zagami, Shergotty
  - Others Found in Antarctica and Sahara; 1 in Indiana, 1 in Brazil
- SHERGOTTITES
  - Shergotty, Zagami, EETA79001, ALHA77005, LEW88516
  - Mafic Cumulates, Lherzolites; Strongly Shocked
  - 180 Ma Crystallization Age; Cosmic Ray Exposure Age 2.8, 0.5 Ma
    - Terrestrial Exposure 32-200,000 yrs
- NAKHLITES AND CHASSIGNITES
  - Nakhla, Lafayette, Governador Valdares, Chassigny
  - Mafic Cumulates, Dunite; Weakly Shocked
  - 1.3 Ga Crystallization Age; Cosmic Ray Exposure Age 11 Ma
    - Terrestrial Exposure <200 yrs
- ALH84001
  - Orthopyroxenite; Strongly Shocked (1st at 4.0 Ga)
  - 4.5 Ga Crystallization Age; 2nd Shock 16 Ma
- New Ones
  - 132 Mars Meteorites by 2014

Mars Meteorite Gallery

Allan Hills 84001

Allan Hills 77005

Chassigny

EETA 79001

Governador Valadaros

Los Angeles 001

Lafayette

LEW 88516

Nakhla

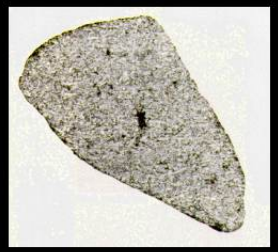
Northwest Africa 480

Northwest Africa 817

QUE 94201

Dar al Gani 476

Shergotty



Zagami

Not Shown:
- Dhofar 019
- Sayh al Uhaymir 005
- Yamato 793605

SNC METEORITES - FROM MARS?

- MINERALOGY AND PETROLOGY
  - Ordinary Mafic Igneous Rocks - Shallow Intrusives & Flows
  - All Oxidizing Conditions; Some Hydrous Conditions (Amphibole)
- CHEMISTRY
  - Overall Similar to Terrestrial Basalts
  - Major Elements - Unusual Fe/(Fe+Mg), Unusual Differentiated Parent
  - Minor Elements - K/La Ratios, Highly Fractionated REE Unique
  - Oxygen Isotopes - Fractionation Line Distinct
- DIRECT EVIDENCE FROM MARS
  - Trapped Gas in Glassy Nodules in ALH77005, EET79001
    - Matches Mars Atmosphere (Measured by Viking)
    - Unique N, Ar, Xe, O Isotopes
  - Chemistry of Shergottites Similar to Martian Soil
- WHERE ELSE?
  - Mars Only Other Choice; Not Earth/Moon; Can't be Venus or Mercury
    - Large Planet with Volcanism Throughout History
    - Oxidizing and Hydrous Environments
- EXCHANGE BETWEEN THE PLANETS - Maybe We All Martians?
  - Earth Sterilizing First 0.6 Ga; Mars Just Right

Evidence for Life on Mars 1996

- WITHIN FRACTURES & PORE SPACE OF ALH84001
  - Carbonate Globules, 1-250 μm; 3.6 Ga
  - Magnetite and Fe-Sulfides, 10-100 nm
  - Polycyclic Aromatic Hydrocarbons (PAHs), Organics
  - Small Elongate Features, 100 nm
- INTERPRETATION
  - Bacteria (microfossils) Produced Carbonate, Magnetite & PAHs
  - *First Scientific Evidence for Life Outside Earth!*
- BUT - No Direct Evidence for Biologic Activity
  - Inorganic Precipitation Possible
  - Minerals Formed Under High or Low Temperature?
  - PAHs Common in Meteorites
  - Elongate Features too Small to fit DNA
- CHANGE IN PERCEPTION OF LIFE ON EARTH
  - Life is Everywhere - Liquid Water, Energy Source
  - Most Primitive Organisms may be Hydrothermal
    - At Mid Ocean Ridges & Buried Beneath Columbia Basalts

Mars Pathfinder

Tech Demo – FBC

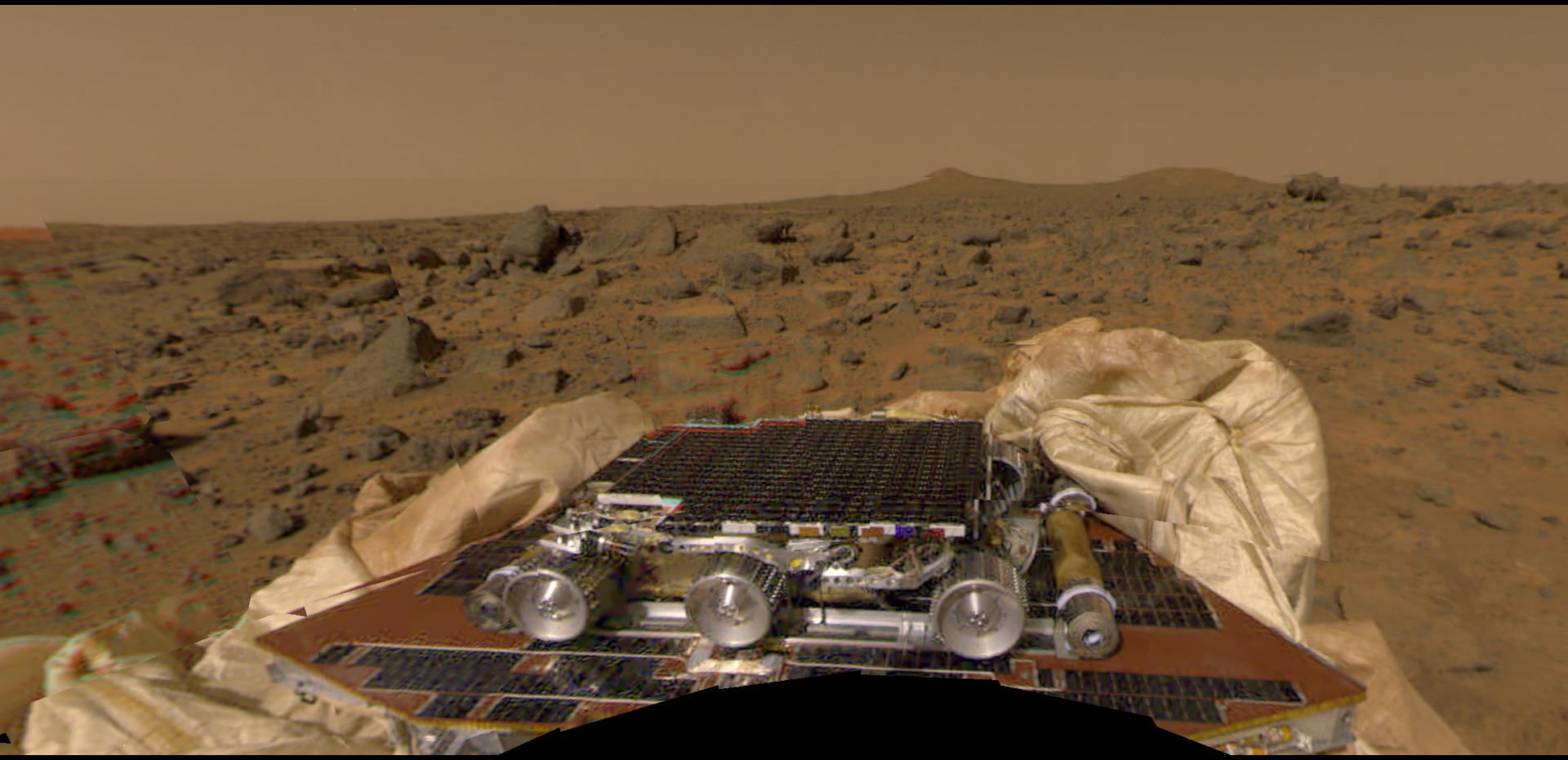
Capability of Rover

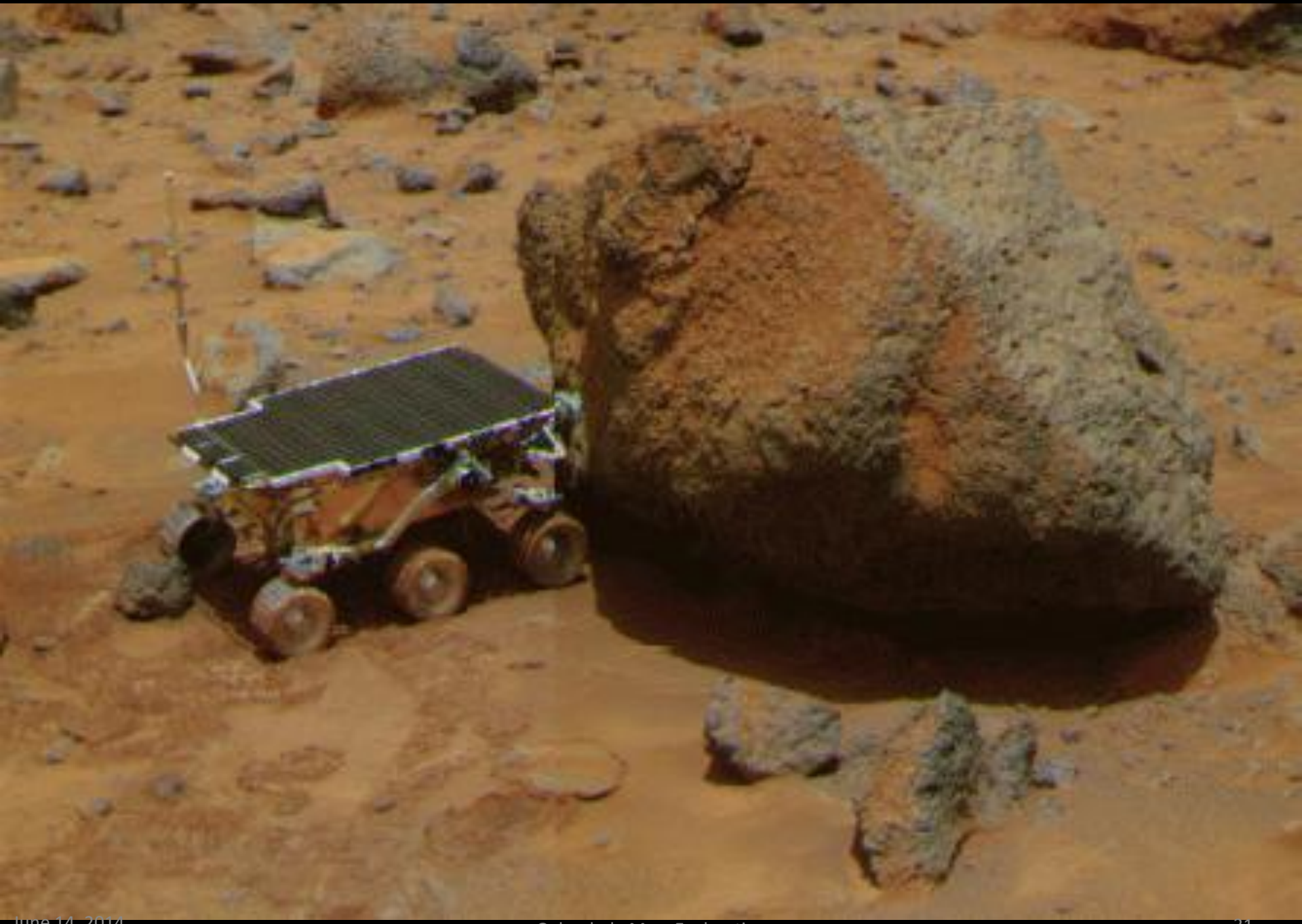
Science - bonus

MARS PATHFINDER

Demonstrated Robust, Inexpensive, Lander - "FCB"

- SURFACE OPERATIONS ~3 MONTHS
  - 3 Science Instruments - IMP, APXS, ASI/MET
  - Rover - 3 Imagers
    - ~10 Technology Experiments
- RETURNED ~2.3 Gbits DATA
  - >16,500 IMP Images; >550 Rover Images
  - 16 Chemical Analyses Rocks and Soil; 9 Rocks
  - 8.5 Million P, T, Wind Measurement
- ROVER
  - Circumnavigated Lander, Traversed ~100 m
  - Explored ~200 Square Meters of Surface
  - 234 Commanded Movements, 24 Soil Mechanics Experiments
- CAPTURED IMAGINATION OF PUBLIC
  - Front Page Headlines for a Week
  - 566 Mhits First 30 Days; 47 Mhits on July 8th
  - Largest Internet Event in History at the Time





Mars Pathfinder Landing Site

Rocky
Dusty
Depositional Plain from Catastrophic Flood

MPF SCIENCE RESULTS

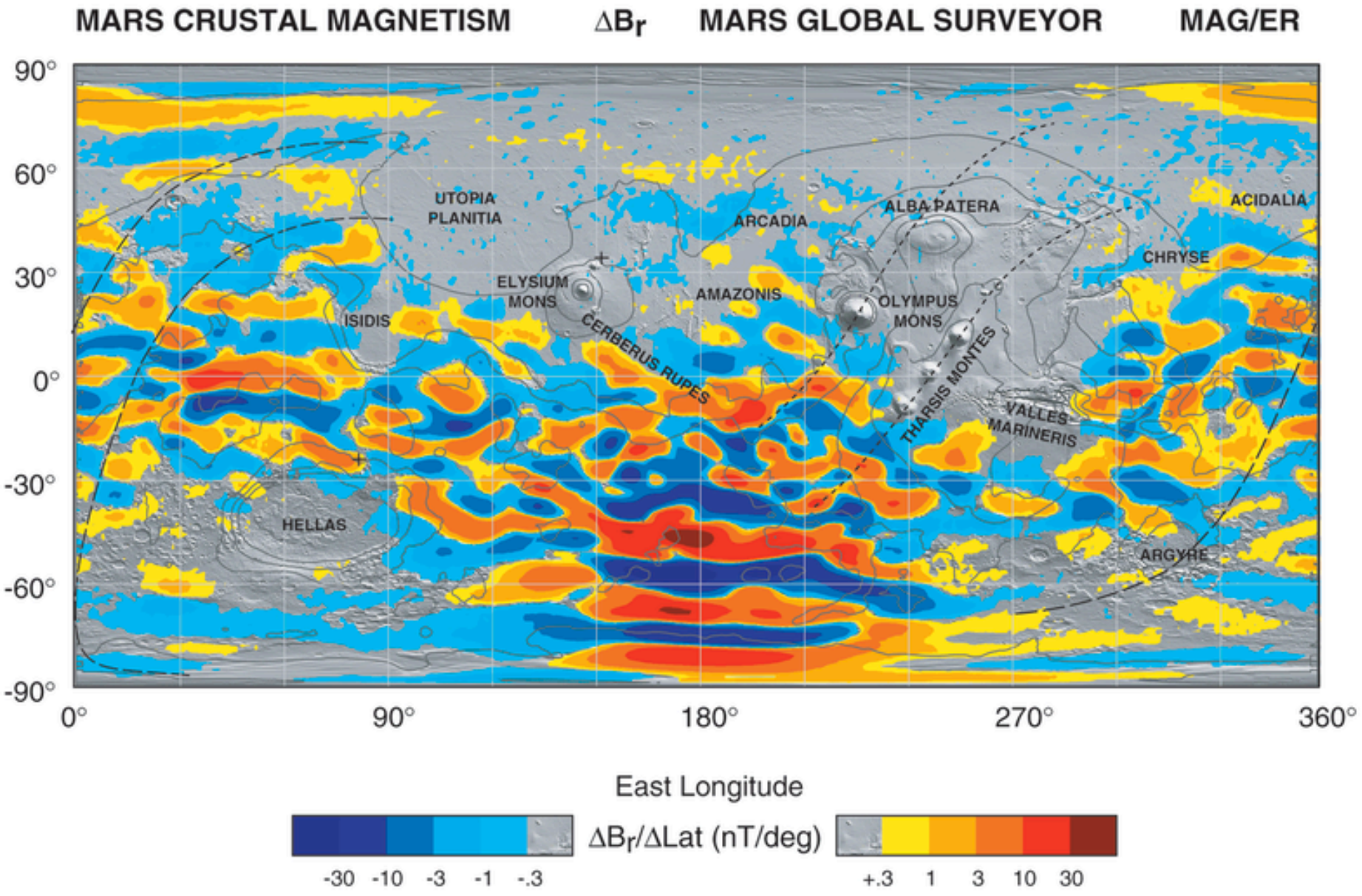
Mars is More Earth Like

- HIGH SILICA ROCKS - Differentiated Parent Materials
- ROUNDED PEBBLES, COBBLES AND POSSIBLE CONGLOMERATE
  - Suggest Fluvial Processes Over Long Time *Sand*
  - Liquid Water in Equilibrium w/Atmosphere Warmer/Wetter Past
- MOMENT OF INERTIA 0.3662±0.0017
  - Metallic Core >1300 km Radius <~2000 km Radius
- AIRBORNE DUST MAGNETIC
  - Composite Particles, 20% Magnetic Mineral, Likely Maghemite
  - Freeze Dried Precipitate (Stain or Cement) of Fe Hydrologic Cycle
- LANDING SITE AS PREDICTED FROM REMOTE SENSING AND ANALOG
  - Rocky Plain Safe for Landing and Roving
  - Variety of Rocks Deposited by Flood, Relatively Dust Free
  - Mars Climate Cold and Dry Since Deposited, Warmer and Wetter Before
- ATMOSPHERE
  - Water Ice Clouds; Dust Devils
  - Abrupt T Fluctuations with Time and Height in Morning

Mars Global Surveyor

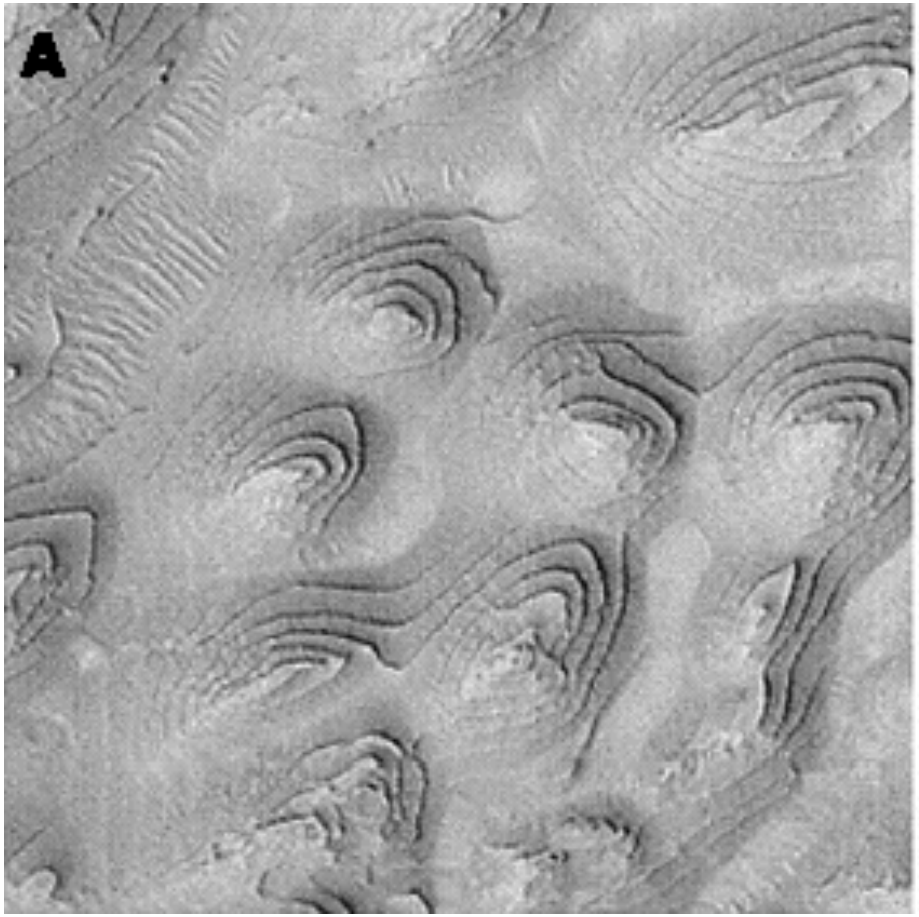
- Reflight of Much of Mars Observer
- Global Survey of Mars
  - Surface Materials, Surface Features
  - Topography, Gravity
  - Weather
- MOC – Mars Orbiter Camera
- TES – Thermal Emission Spectrometer
- MOLA – Mars Orbiter Laser Altimeter
- MAG/ER – Magnetometer, Electron Reflectometer
- First Systematic Study of Planet
  - Circular Polar Orbit – Fixed Time of Day
  - Redefined Global Mars
- Aerobrake Using Atmosphere
  - Damaged Solar Panel
  - Lower periapsis yielded surprising discovery

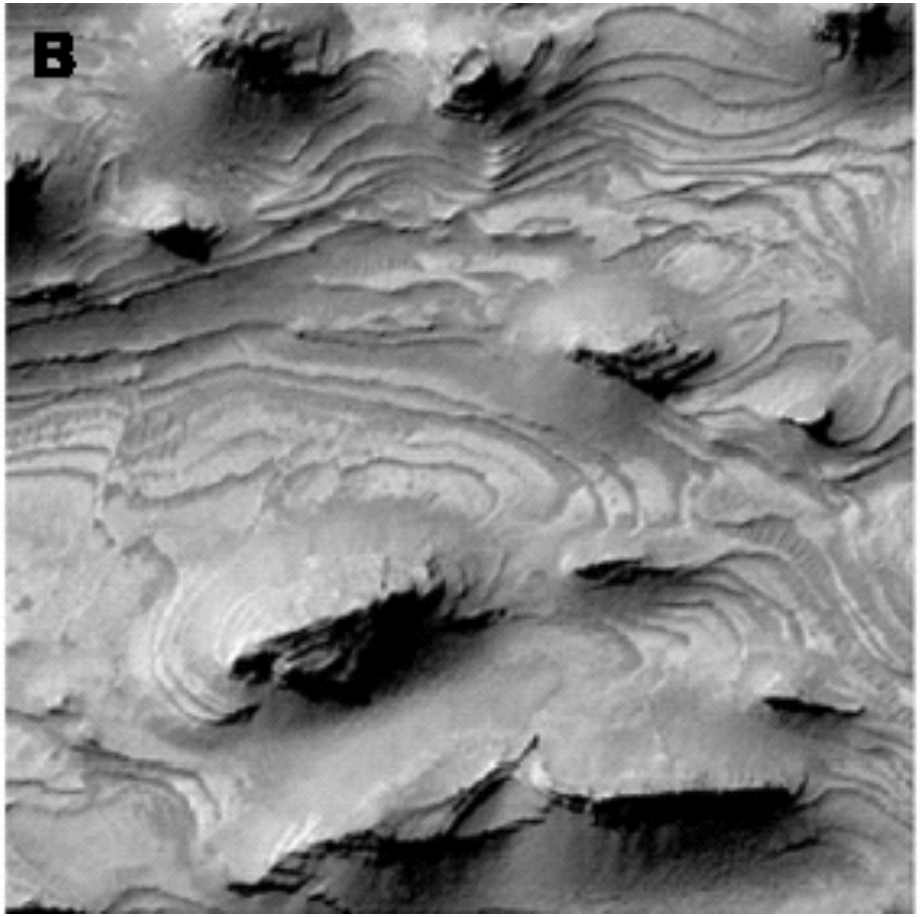
Magnetism



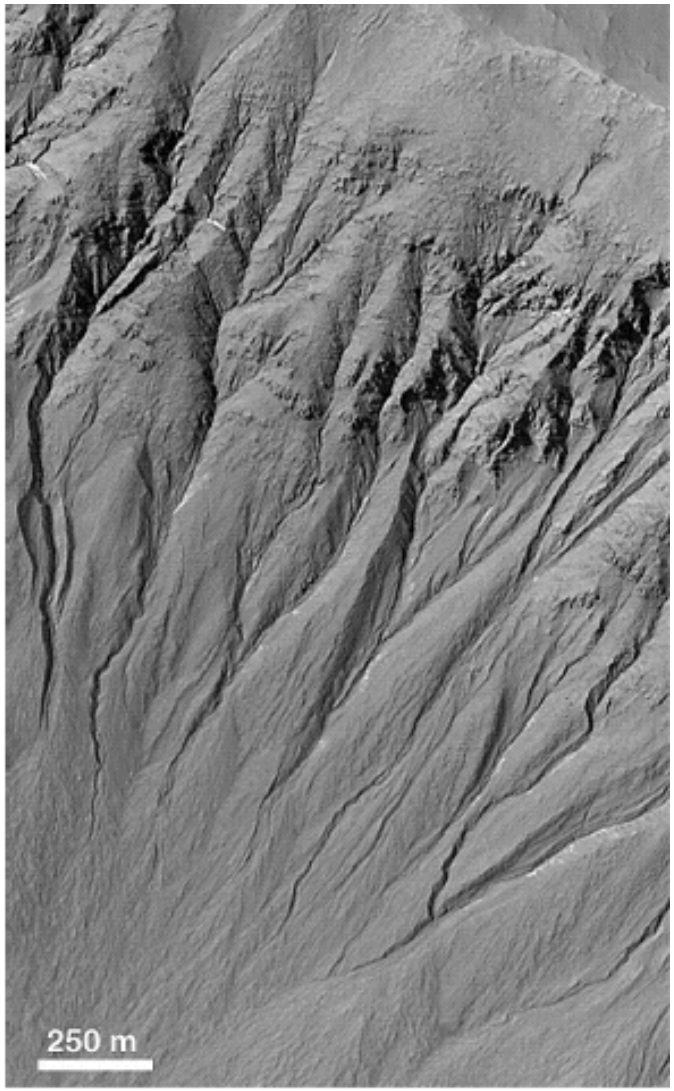
Connerney, J. E. P. et al., (2005) Proc. Natl. Acad. Sci. USA, 102, No. 42, 14970-14975

Layered Sedimentary Rocks

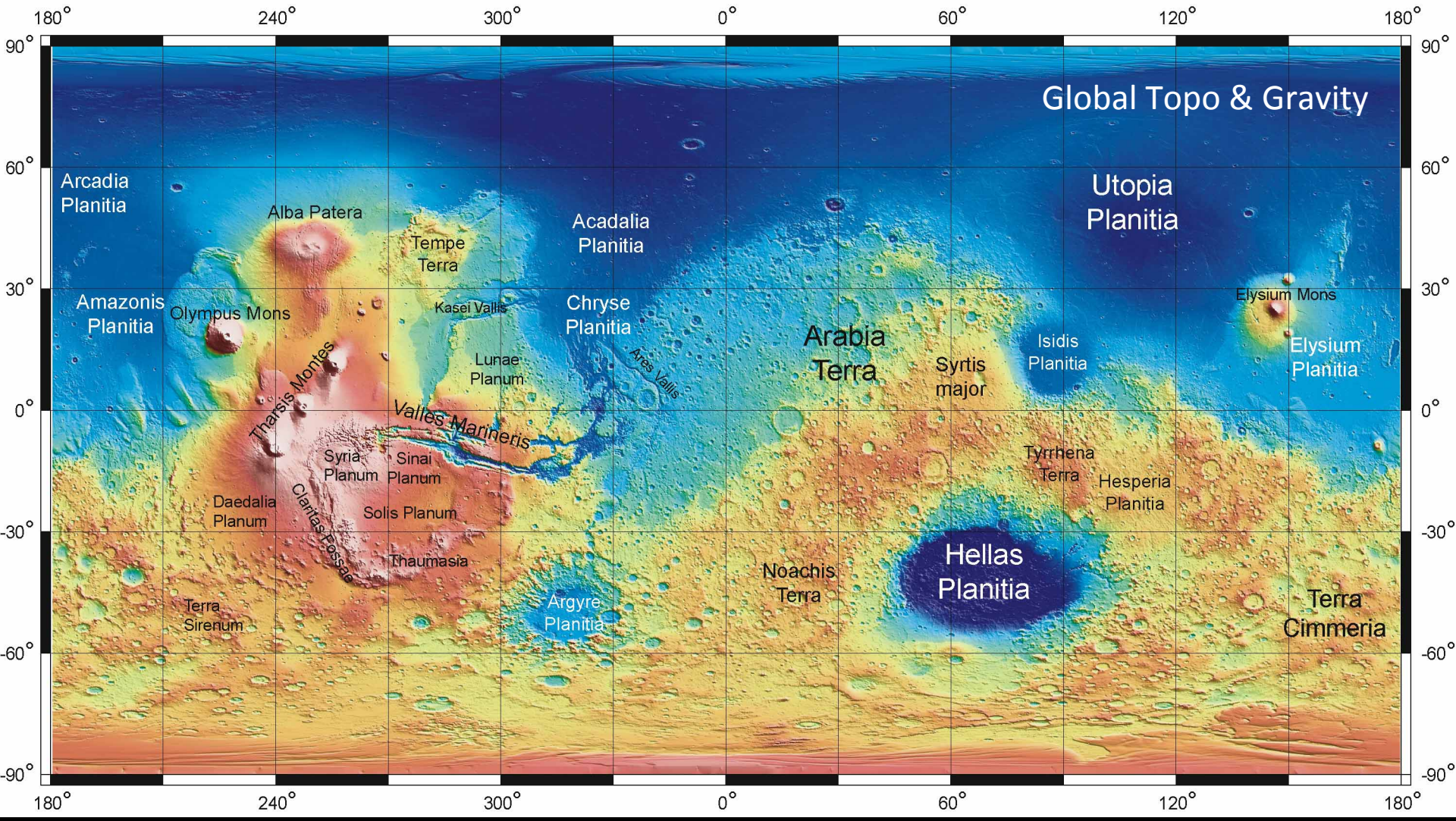




GULLIES




MOC - Mars Orbital Camera



Highland/Lowlands – Bimodal Hypsometry
Tharsis - The Largest Tectonic Entity in Solar System
Bulge 1/4 Planet, Structures 1/2 Planet
Outflow Channels Around Tharsis Flow into N Plains
Geologists Wrested Control of Inner Solar System from Astronomers

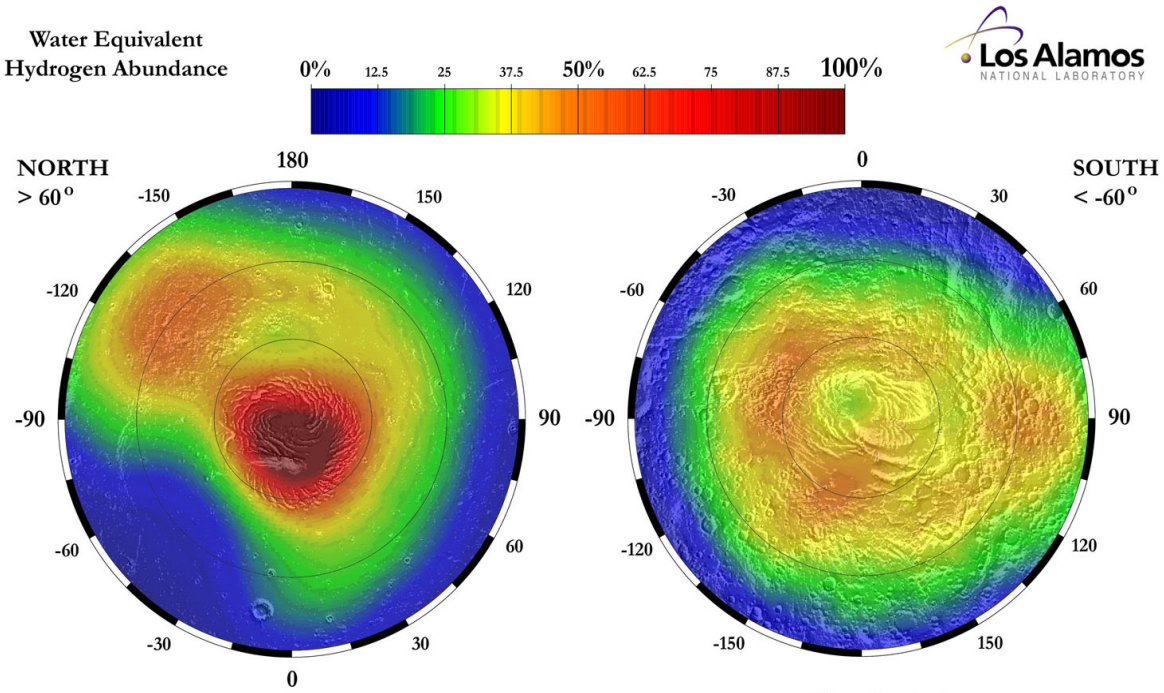
MGS SCIENCE RESULTS

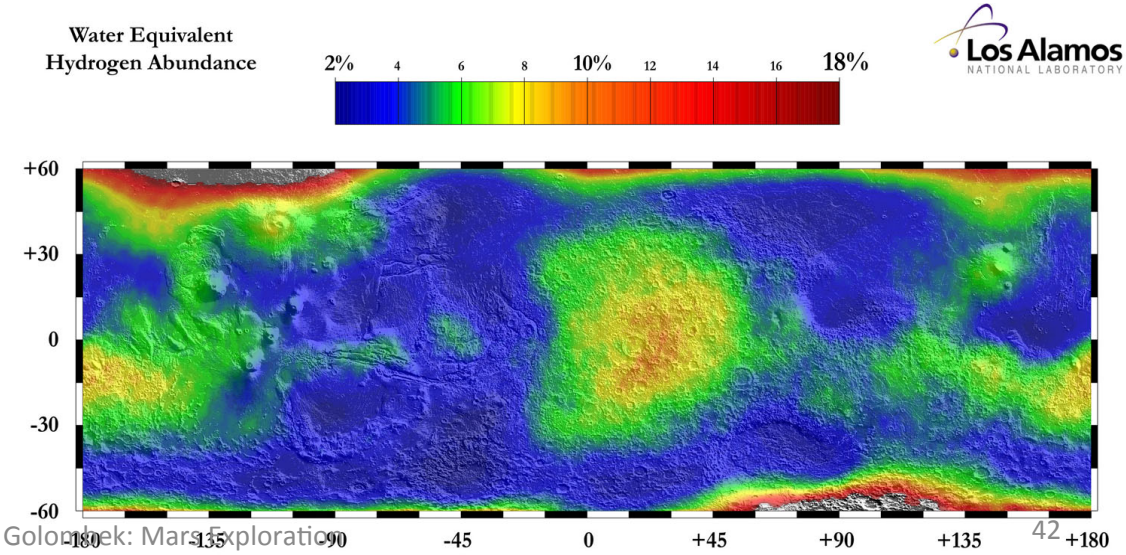
- STRONG REMANENT MAGNETIC ANOMOLIES
  - Early Magnetic Field; Convecting Core - Dynamo
  - Serendipitous Discovery
- GLOBAL TOPOGRAPHIC & GRAVITY FIELDS
  - Defined Geoid, Atmospheric Pressure & Seasons
  - Northern Plains Consistent with Ocean
- Defined Tharsis – Tectonics of Mars
  - Massive Load on Lithosphere – Membrane Stresses Dominate
- GULLIES
  - Recent Liquid Water Outbursts
- LAYERED SEDIMENTARY ROCKS
  - Interpreted as Deposited by Water into Water
  - Early Warmer, Wetter Environment
- MINERALOGY
  - Basalt, Andesite & Dust; Some Hematite
- Early Mars Warmer & Wetter
  - Early High Erosion Rates, Formation of Tharsis Trigger W & W

MARS ODYSSEY - 2001

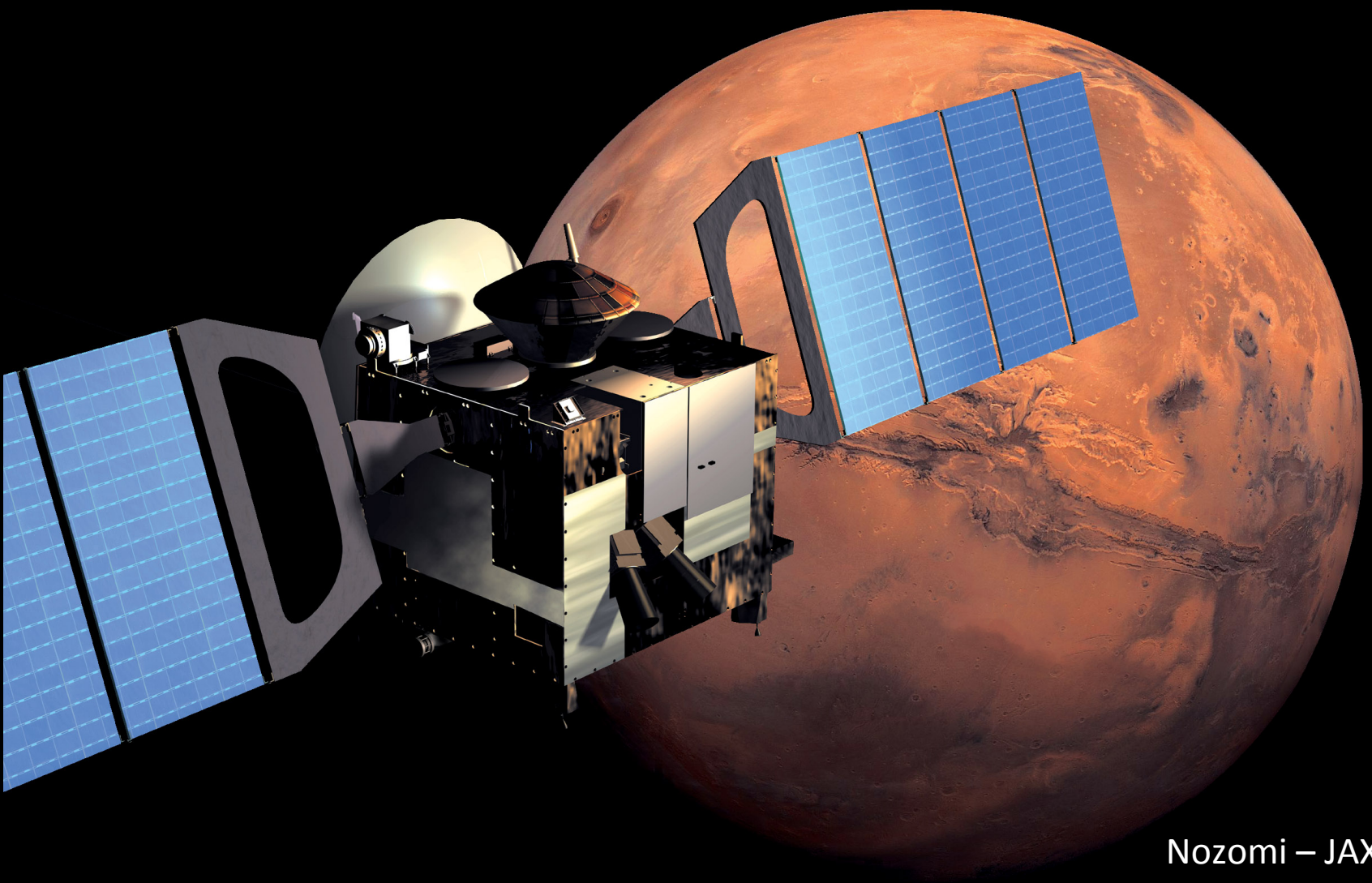
- THEMIS
- Gamma Ray Spectrometer/HEND
- MARIE
- Comm Link
- Water on Mars
- Ground Ice Poleward of 60°
  - High Concentrations of Frozen Water
  - Could Extend to Significant Depths
- THEMIS IMAGES
  - Global Thermal Imaging 100 m/pixel
  - Global Visible Imaging 18 m/pixel
  - Show Thermophysical Properties
  - Visible Images Show Synoptic View
  - Global Mineralogy of Surface from Thermal Spectroscopy
    - Basaltic Surface – Andesitic Lowlands

Neutron Spectrometer
Calibrated Hydrogen Abundance





ESA Mars Express and Beagle 2 - 2013

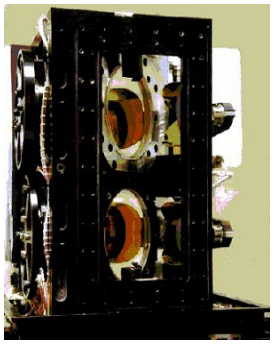


Nozomi – JAXA
2013 Invasion

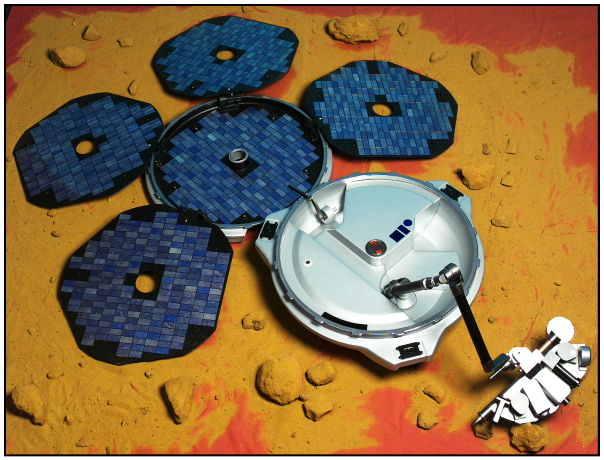
Science Payload

MARS EXPRESS INSTRUMENTS

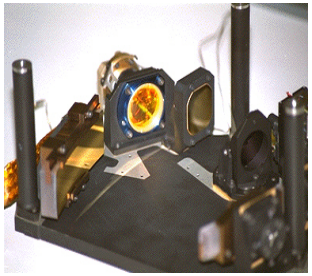
HRSC – High resolution stereo colour imager
G. Neukum, FUB/DLR Berlin (DE)



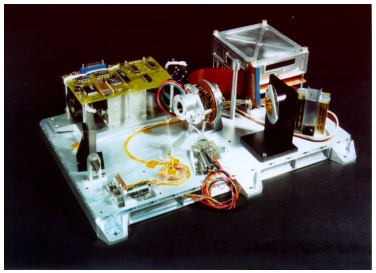
PFS – Planetary Fourier spectrometer
V. Formisano, CNR Rome (IT)



BEAGLE-2 Lander
C. Pillinger, Open Univ. (UK)

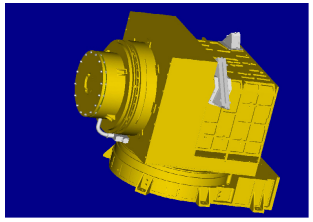


OMEGA – IR mineralogical mapping spectrometer
J-P. Bibring, IAS Orsay (FR)

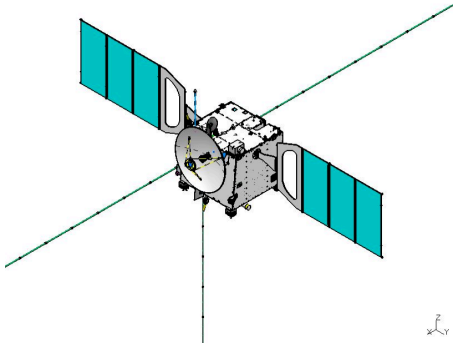


SPICAM – UV and IR atmospheric spectrometer
J-L.Bertaux, CNRS Verrières (FR)

MARSIS – Subsurface sounding radar
G. Picardi, Univ. Rome (IT)



ASPERA – Energetic neutral atoms analyser
R. Lundin, IRF Kiruna (SE)



MaRS – Radio Science
M. Pätzold, Univ. Köln (DE)

Early Aqueous Conditions

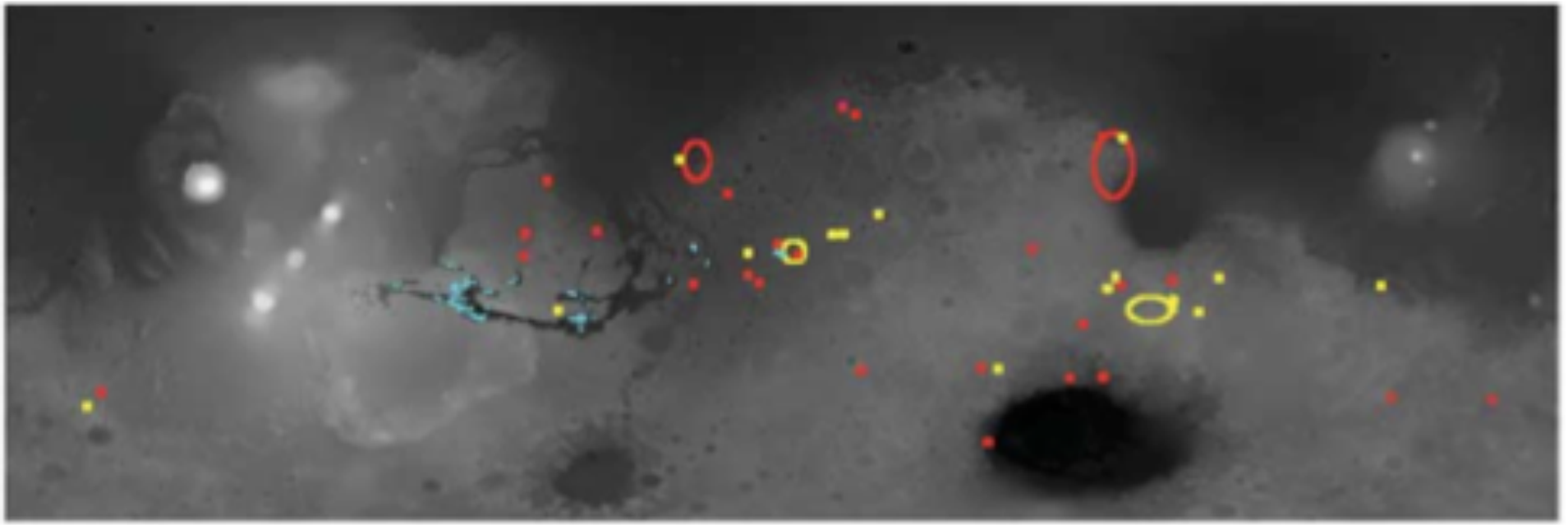


Fig. 3. Global map of hydrated minerals (**top**) plotted over a MGS Mars Orbiter Laser Altimeter (MOLA) altitude reference map (**bottom**). Red, phyllosilicates; blue, sulfates; yellow, other hydrated minerals, with no marked feature (such as being driven by metal-OH vibration) enabling the

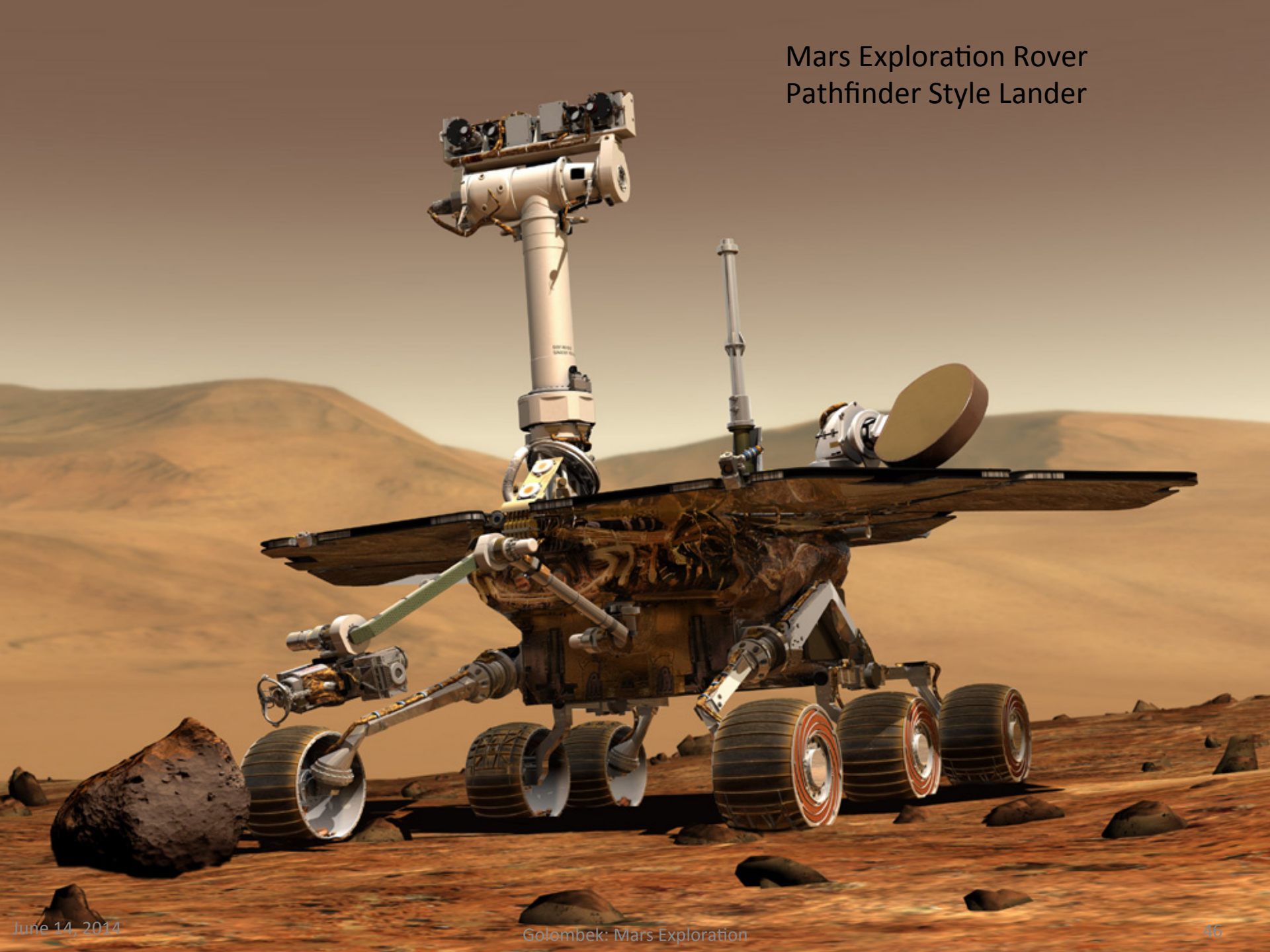
Prior to Acidic Conditions - Sulfates

Neutral Aqueous Conditions to Form Clays

Maybe More Conducive to Formation of Life

Methane

Mars Express,


Mars Exploration Rover
Pathfinder Style Lander

MER Science Goal and Objectives

Science Goal:

- Determine the aqueous, climatic, and geologic history of two sites on Mars where conditions may have been favorable to the preservation of evidence of pre-biotic or biotic processes.

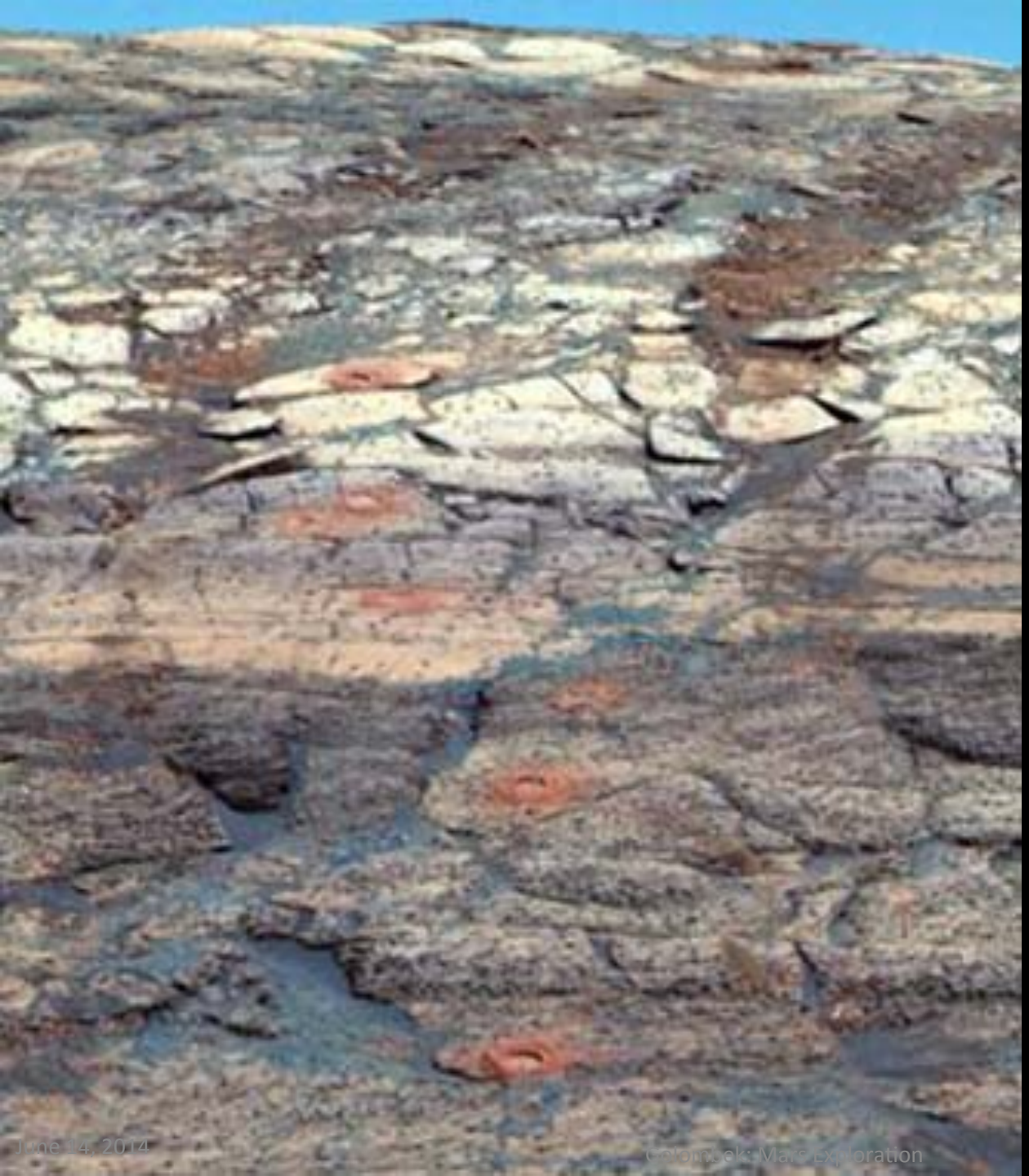
Objectives:

- Identify hydrologic, hydrothermal, and other processes that have operated at the sites.
- Identify and investigate martian rocks and soils that have the highest possible chance of preserving evidence of ancient environmental conditions and possible pre-biotic or biotic activity.
- Respond to other discoveries associated with rover-based exploration.

MER-A, June 10, 2003

MER-B, July 7, 2003


Spirit
Si Deposits
Uncovered Dragging Right Front Wheel



RAT Hole Track

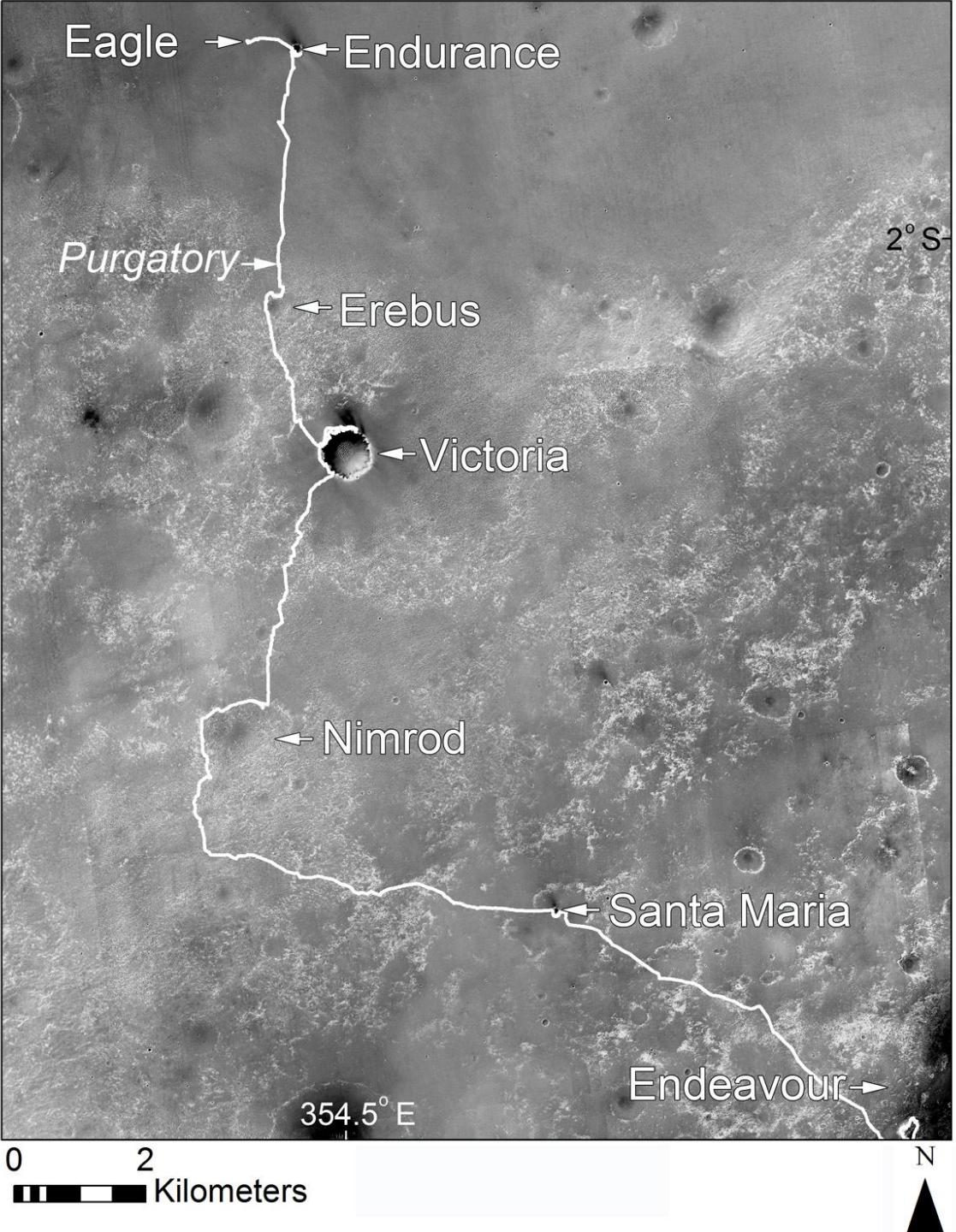
Opportunity

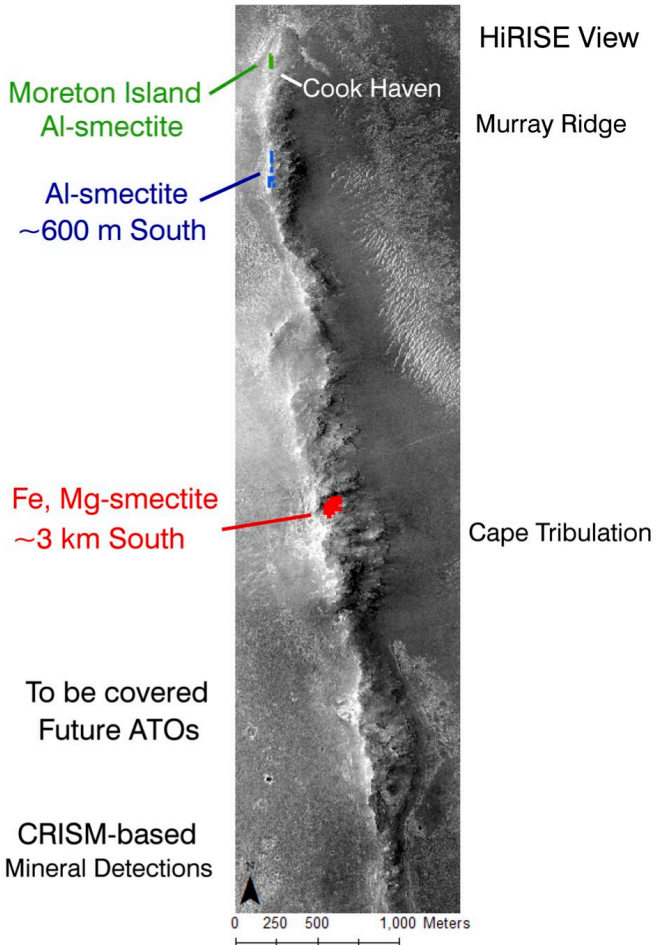
Sulfate Sandstones

Dirty Evaporites

Opportunity's Traverse >38 km

Rim of Noachian Endeavour Crater





2005 Mars Reconnaissance Orbiter

- High resolution imaging and mineralogic characterization of the surface
- Recovers the Mars Climate Orbiter climatology investigations for atmospheric sounding and context imaging
- Searches for mineralogic and morphologic evidence of water-related processes on a targeted, global basis

Hyperspectral Imaging
(Visible/Near Infrared)

Mauna Kea summit, Hawaii

MGS Resolution (approx. 3 m / pixel)

Surtsey Island, Iceland

MRO Resolution (approx. 25 cm / pixel)

MRO Results

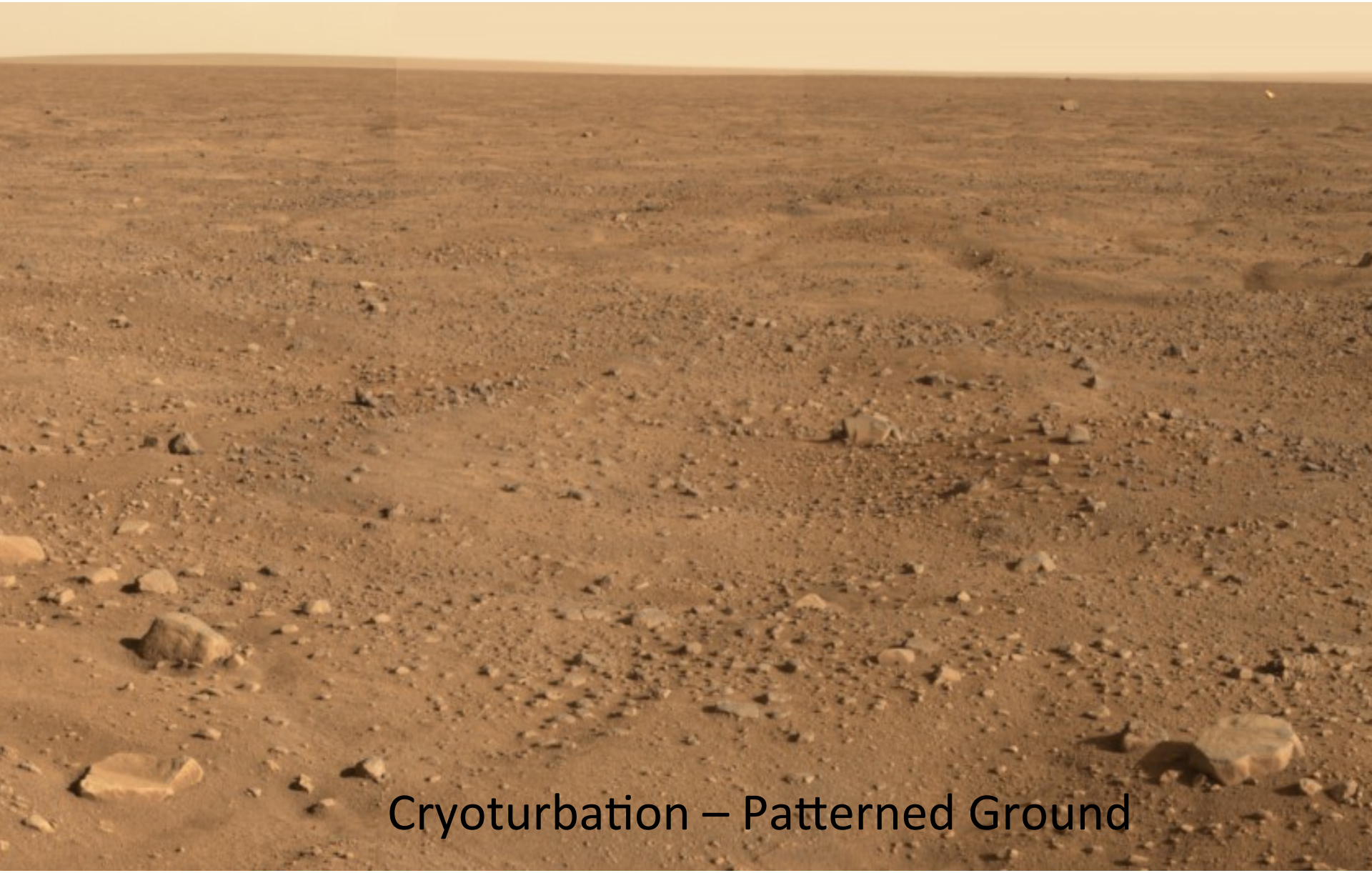
- Aqueous Mineralogy
  - Sulfates
  - Phyllosilicates
  - Carbonates
  - Chloride Salts
- Fine Scale Surface Structure
- Remote Sensing to Select MSL & Future Landing Sites
- Recurring Slope Linea
  - Thin Films of Water
  - Ground Ice at High Latitude
  - Current Cratering Rate
- Subsurface Structure of Polar Caps
  - Subsurface CO_2 Ice

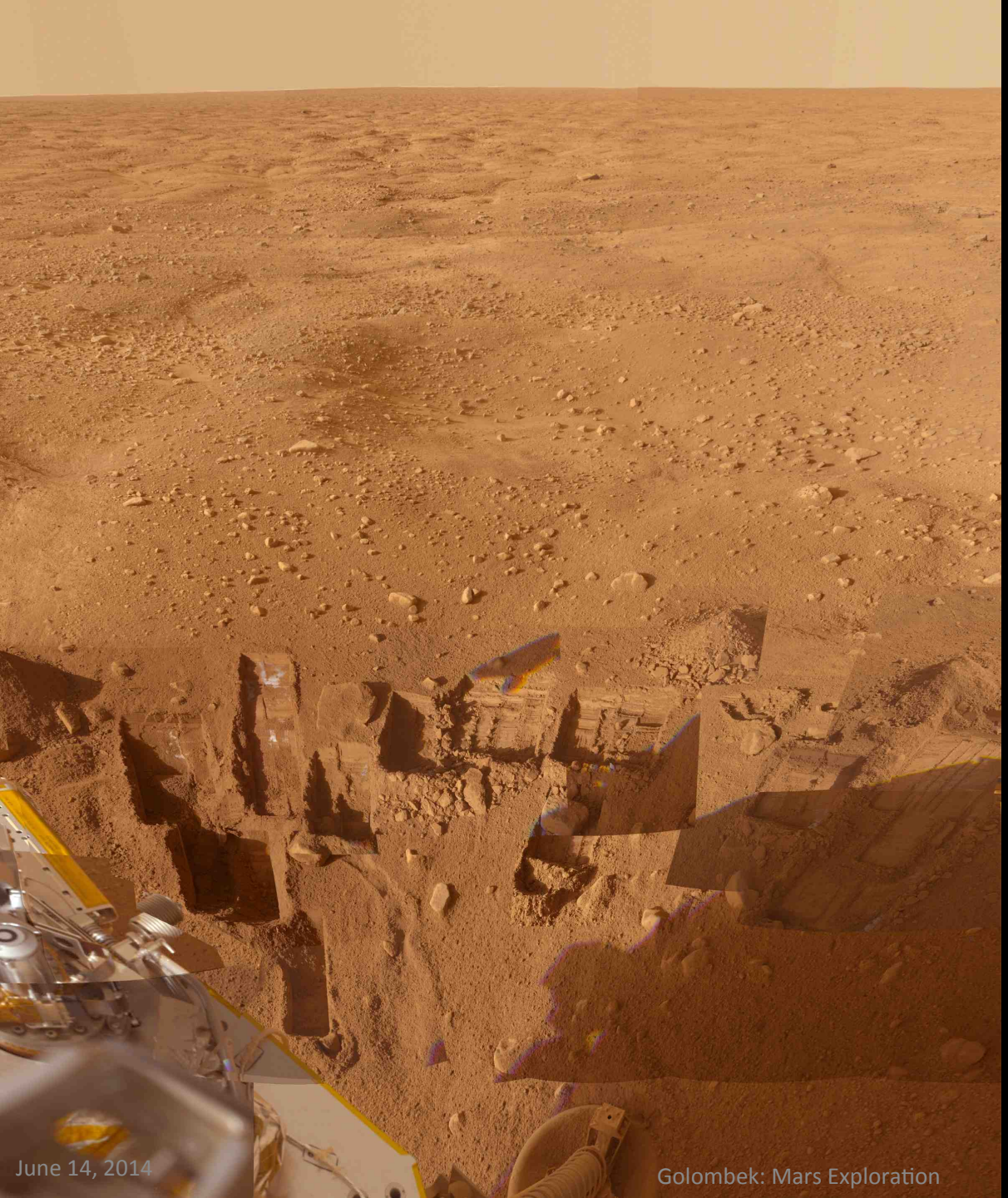
Phoenix Scout

Imager
Robotic Arm
TEGA
MECA
MET Station

2007

Phoenix –Northern Plains

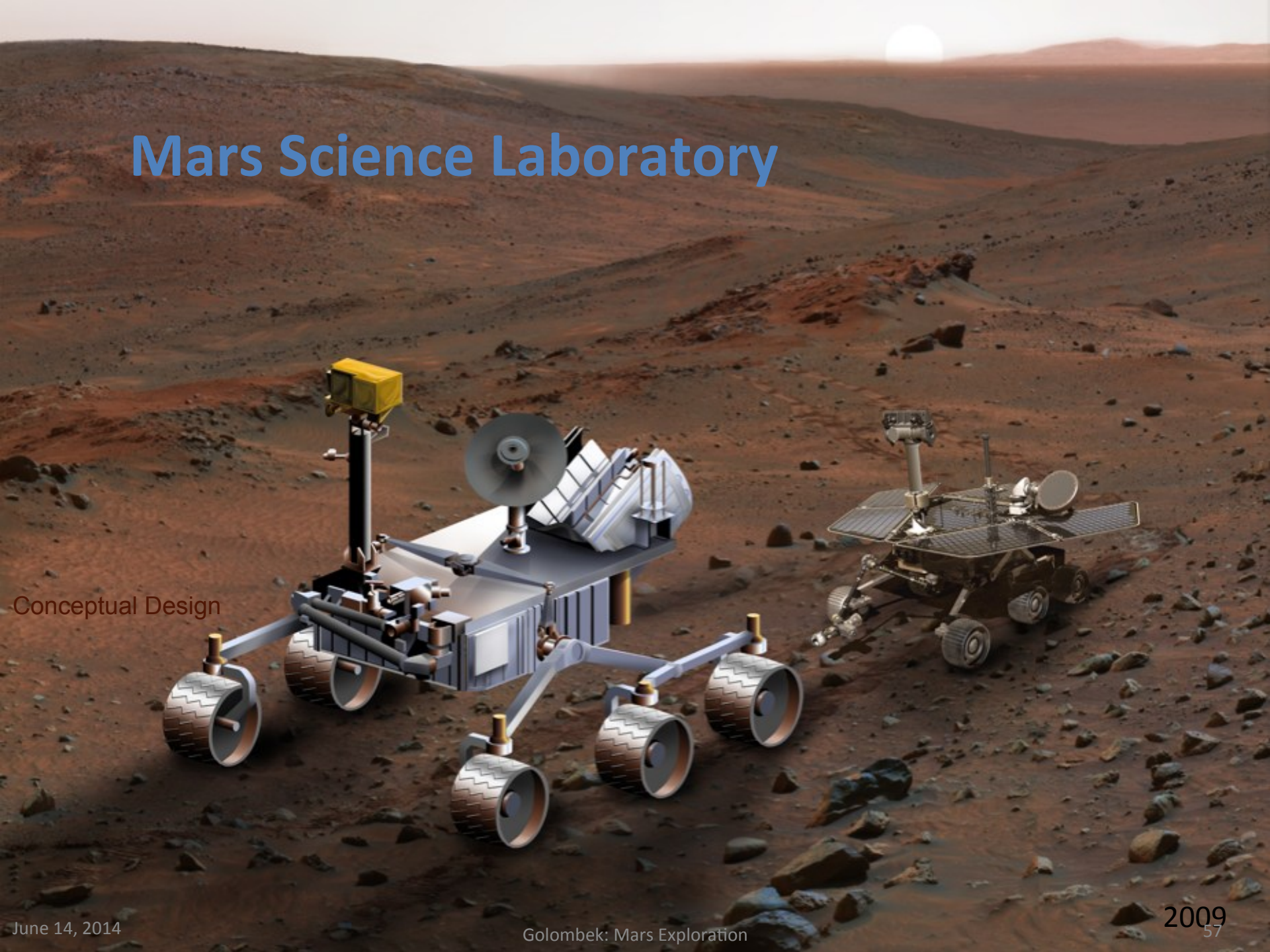




Phoenix Lander
Northern Plains

Ice beneath few cm where expected
Cryoturbation
Perchlorate
TEGA – doors failed

Mars Science Laboratory

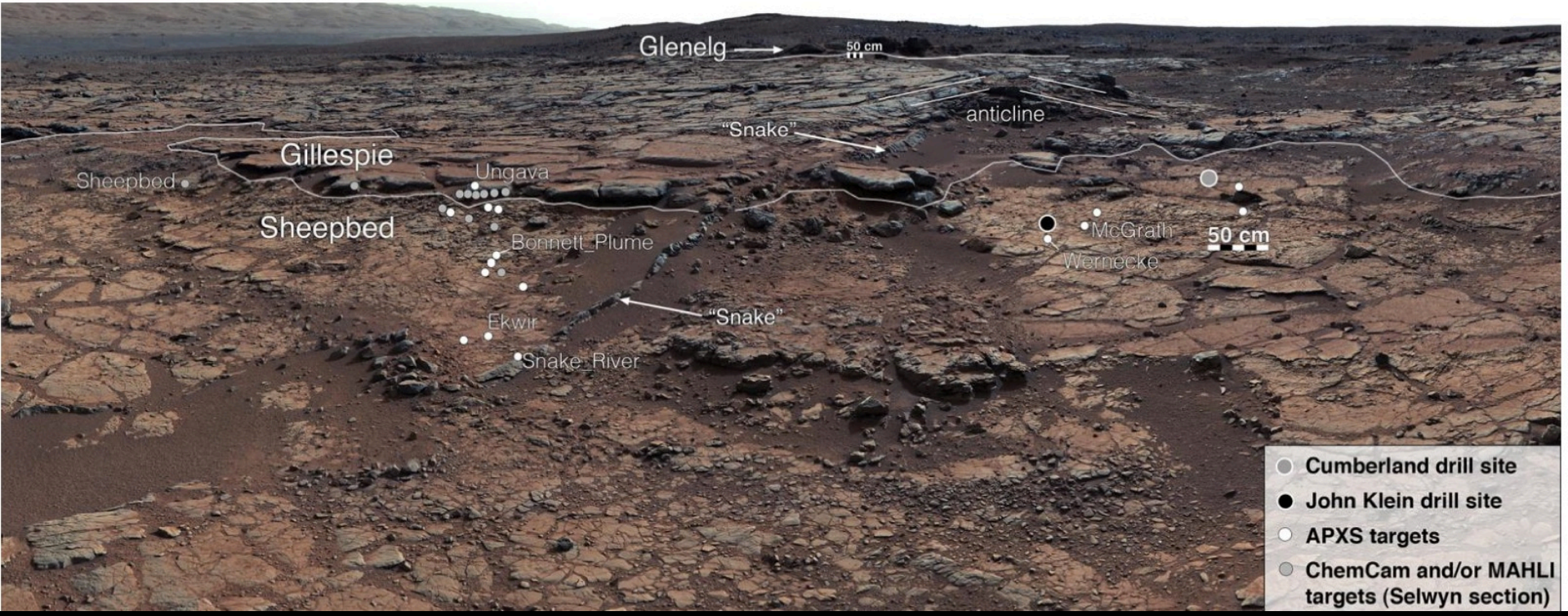


Conceptual Design

2009

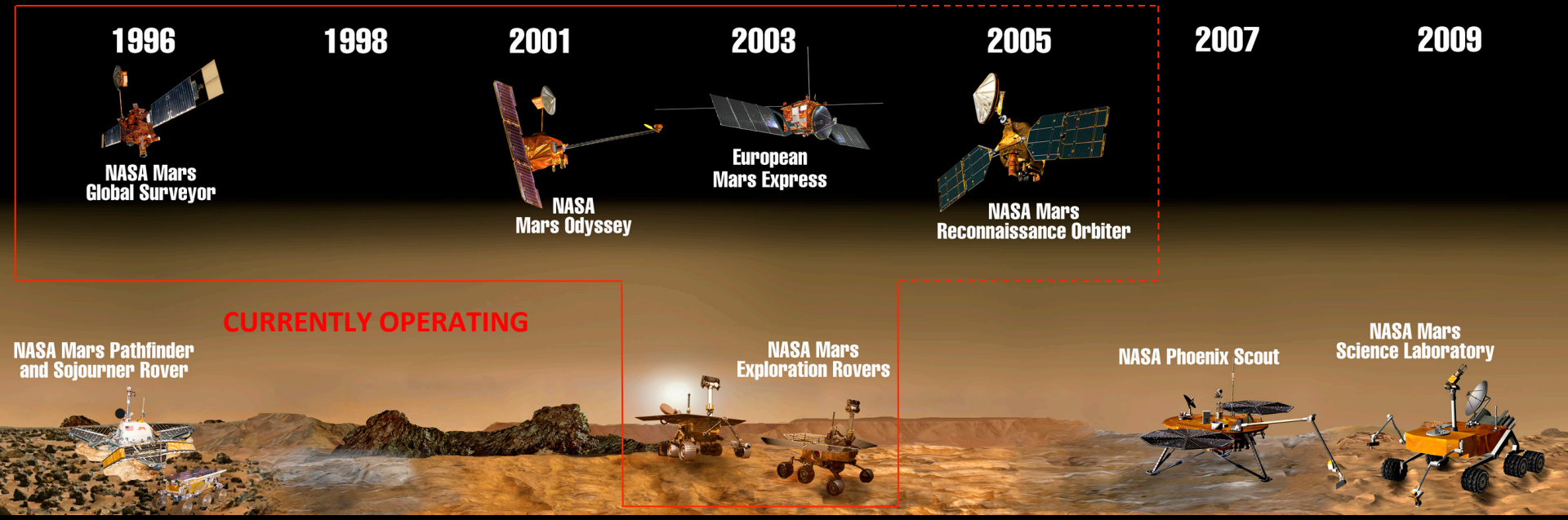

Mars Science Laboratory
Major Mission ~2.5B
Lab Instruments CheMin, SAM
Imaging, ChemCam, Sampling
Ancient Habitable Environments

Yellowknife Bay



Fine-grained Sedimentary Rocks – Fluvial-Lacustrine Setting
Neutral pH, biogenic elements, habitable

Mars Exploration Program



Pathfinder - Hints of a More Earth Like Mars
MGS & Odyssey - Evidence Wetter Past, Ice Rich Present, Gulleys
MER - Definitive Evidence for a Wet and Likely Warm Early Mars
Mars Express - Spectral Evidence Early Clays and Later Sulfates
MRO - TBD; Improved High Resolution and Spectral Images,
Select Landing Sites for MSL
PHX – Polar Ground Ice, Perchlorate
MSL – Habitable Environment

Future Mars Exploration

- MAVEN – 2013 - En Route, Arrives Sept. 2014
  - Mars Scout Mission
  - Aeronomy, Atmospheric Escape, Evolution of Atmosphere
- MOM – Mars Orbiter Mission – En Route, Arrives Sept. 2014
  - Indian Space Agency, Tech Demo,
  - Remote Sensing – Methane, Deuterium, Atmosphere Particle Composition
  - Thermal & Color Imaging
- InSight – 2016 – Under Construction
  - Discovery Program Mission
  - Internal Structure Mars – Seismometer, Heat Flow Probe, Precision Tracking
- ExoMars – ESA, Roscosmos – Under Development
  - 2016 EDM Tech Demo Lander & Orbiter – Trace Gas Orbiter
  - 2018 Rover - Biosignatures
- Mars 2020 Rover – Started
  - Rebuild of MSL Rover, Sample Collection Instead of Laboratory Instruments
  - Collect Sample Cache for Eventual Return to Earth
  - Subsequent Fetch Rover and Mars Ascent Vehicle
  - Subsequent Earth Return Vehicle & Capsule
- Science Goal of Program
  - Was Mars Habitable? Did Life Form on Mars? Was there a Second Genesis?
  - Will Life Form Anywhere that Liquid Water is Stable or are We a Chance Occurrence?
  - Are we alone in the Universe?
- NASA Goal
  - Humans to Mars in 2030s