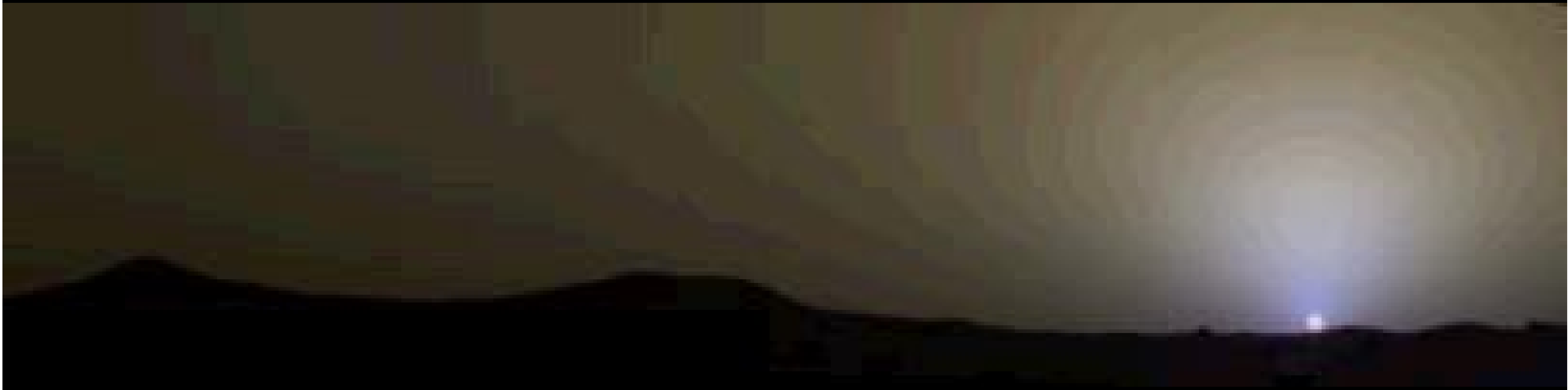
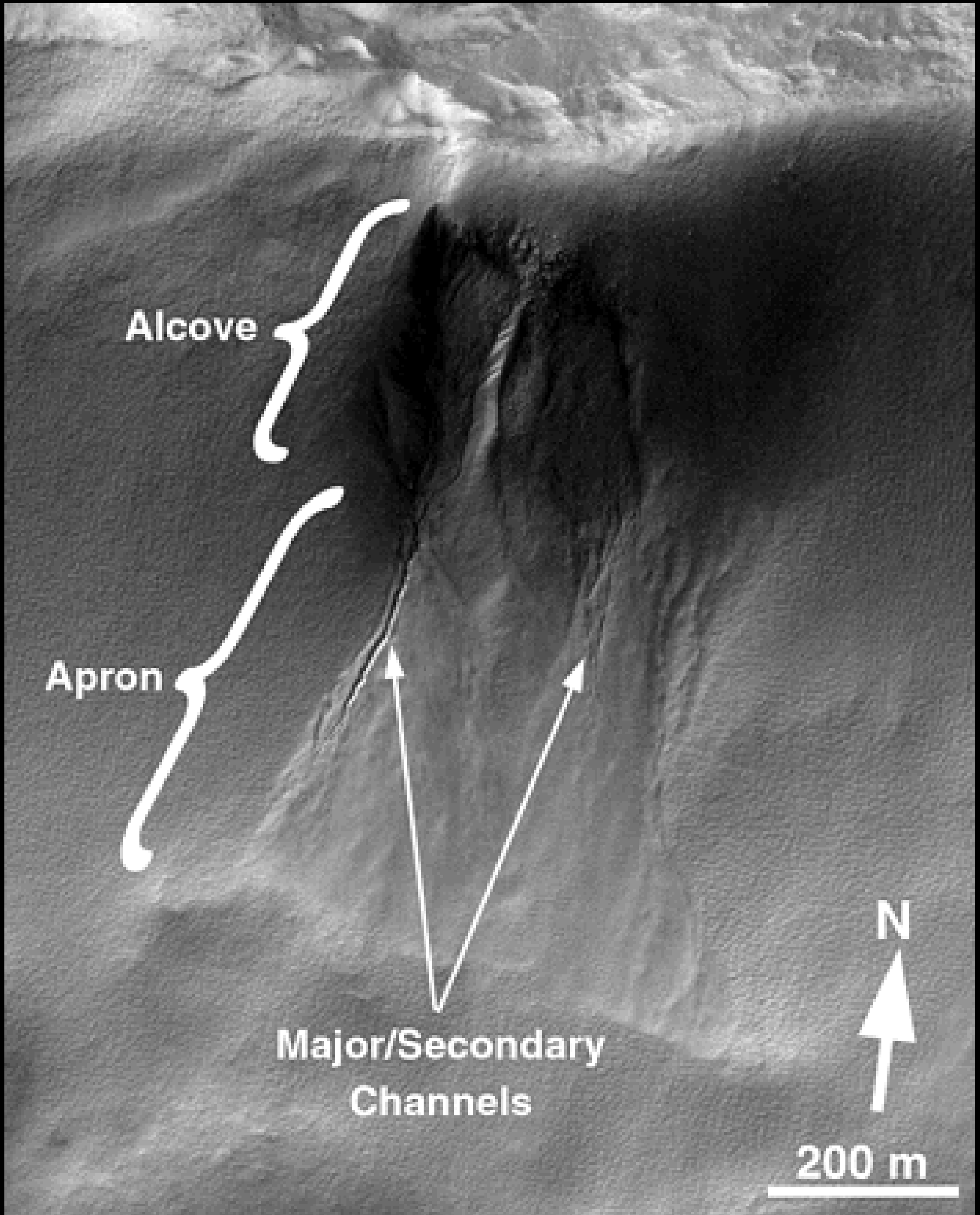
“TRUE COLOR OF MARS”
PATHFINDER LANDER VIEW

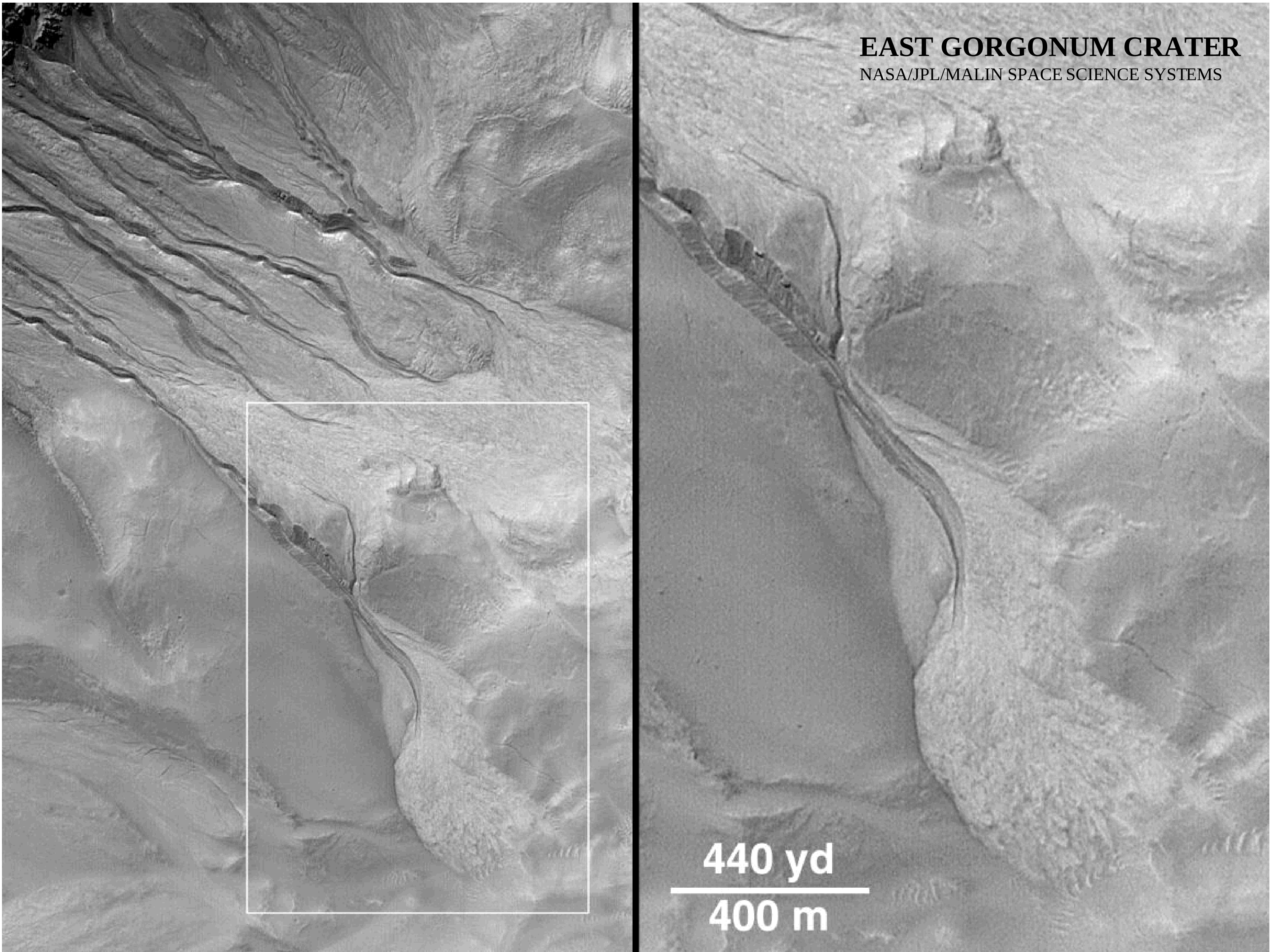
NASA/JPL



EVIDENCE OF RECENT WATER FLOW

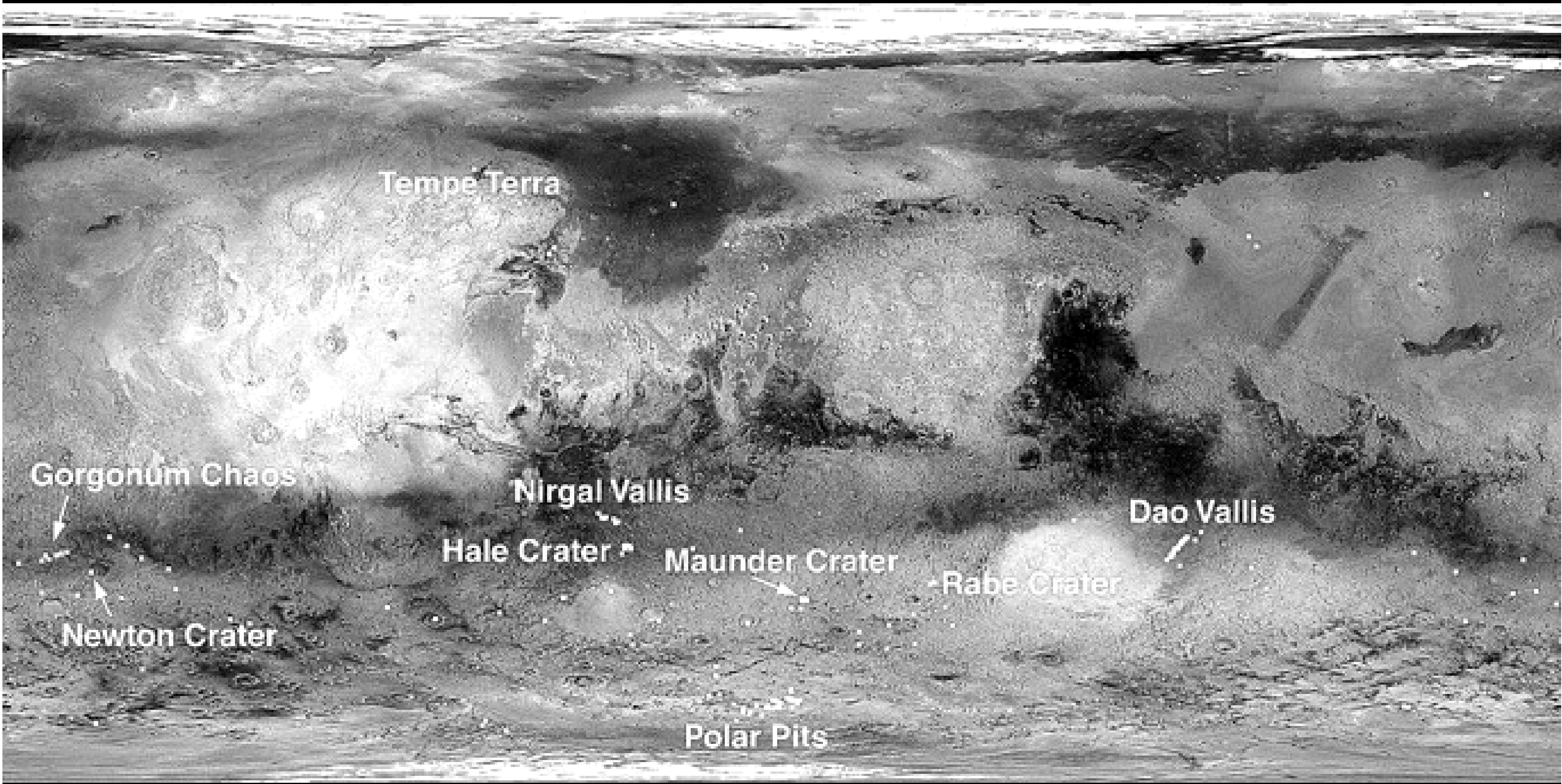
MALIN, M.C., AND K.S. EDGETT, 2000, SCIENCE, 288, 2330-2335




EAST GORGONUM CRATER
NASA/JPL/MALIN SPACE SCIENCE SYSTEMS
440 yd
400 m

GLOBAL DISTRIBUTION OF OBSERVED GULLY LANDFORMS

MALIN, M.C., AND K.S. EDGETT, 2000, SCIENCE, 288, 2330-2335

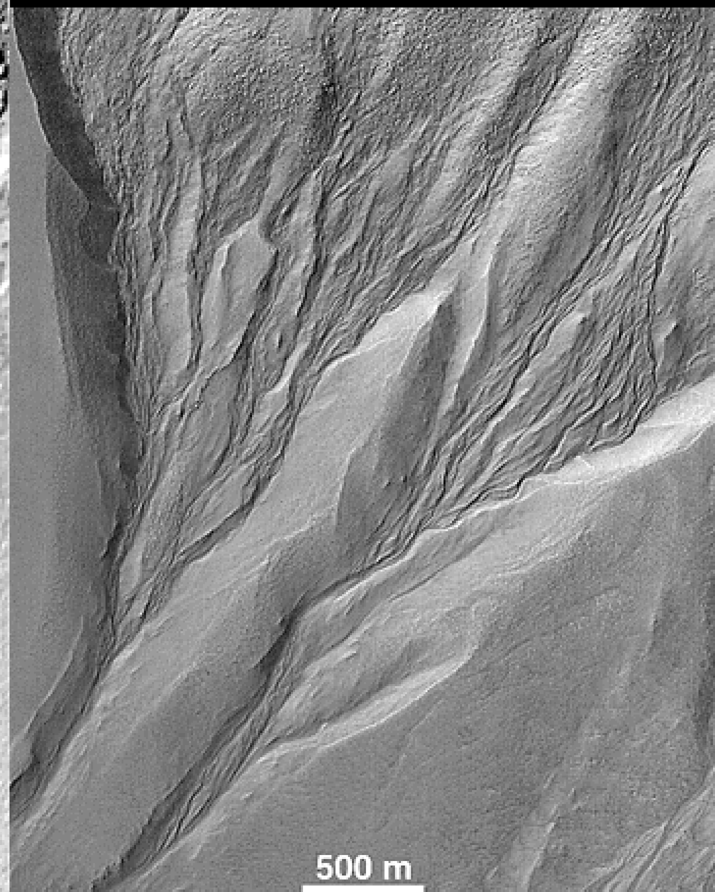


SOUTH POLE

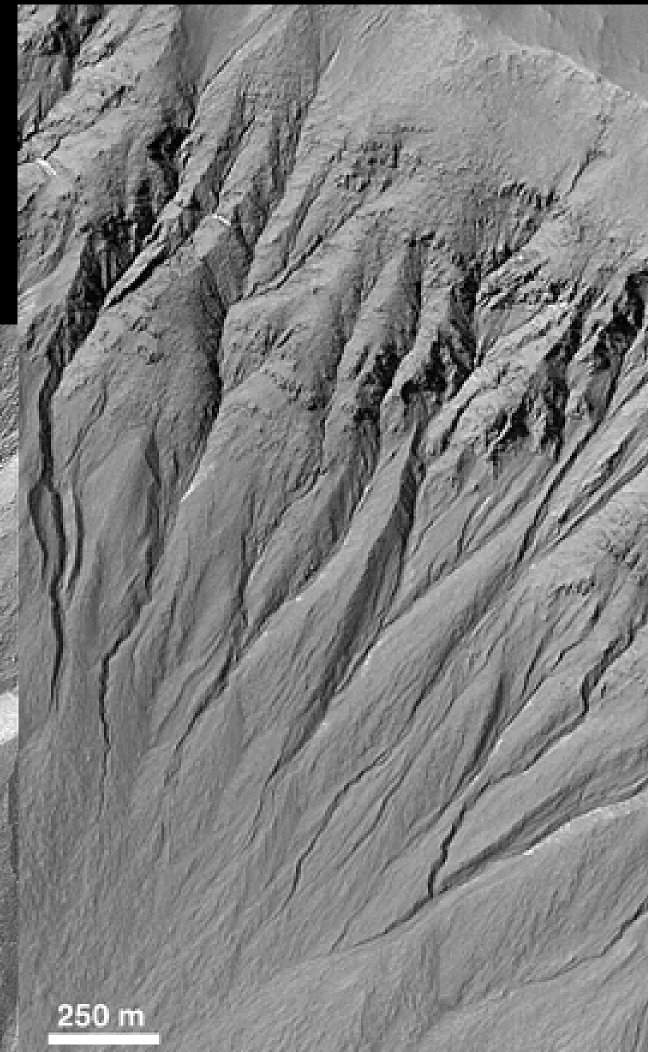
NOTE: SLOPES FACE POLE-WARD 2.5 X MORE OFTEN THAN OTHERWISE

DIGITATE APRON

ANASTOMOSING GULLIES



PRIMARY CHANNELS

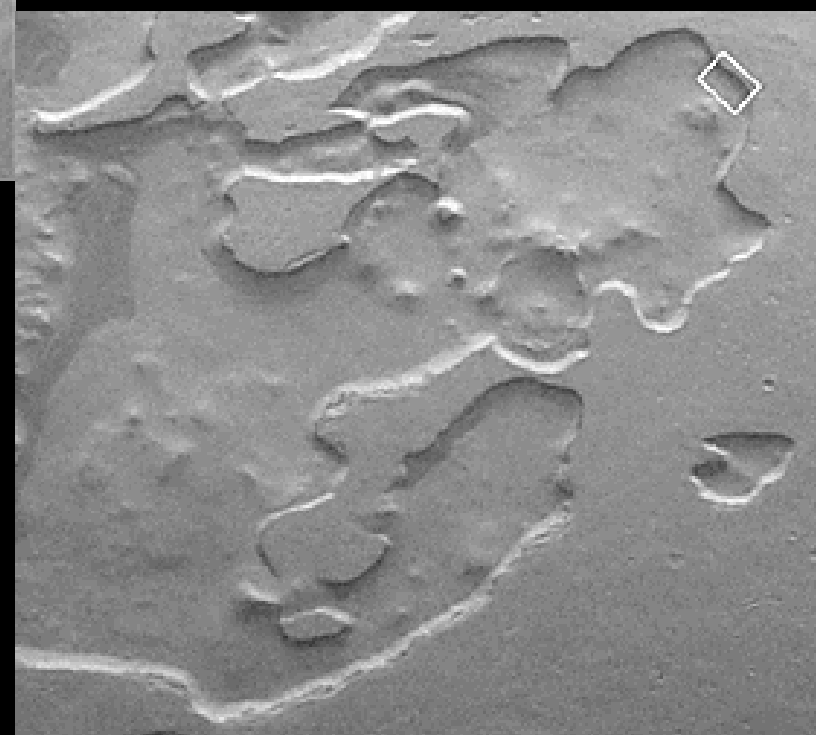


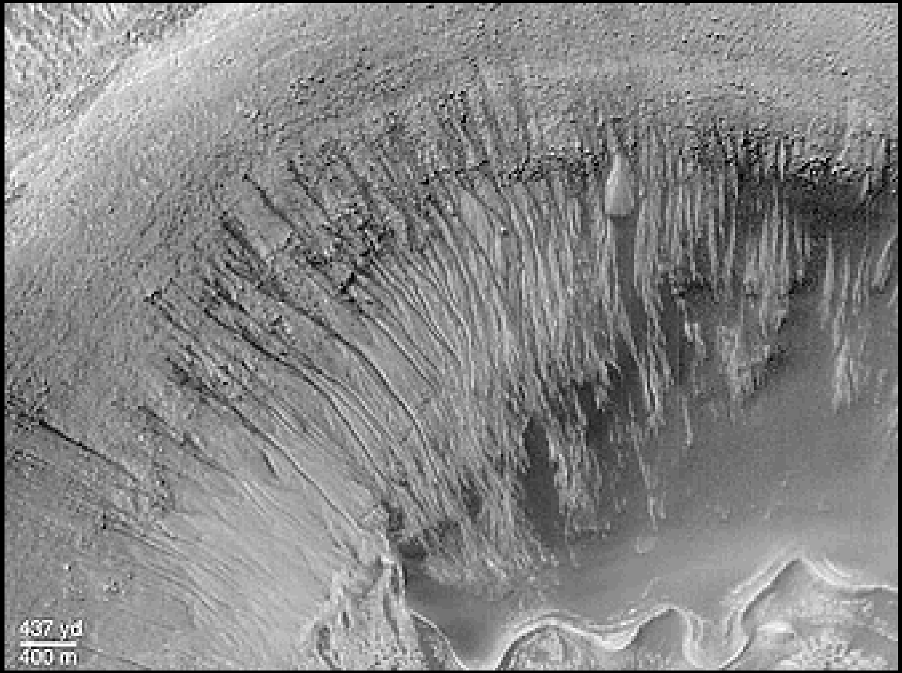
MALIN, M.C., AND K.S. EDGETT, 2000, SCIENCE, 288, 2330-2335

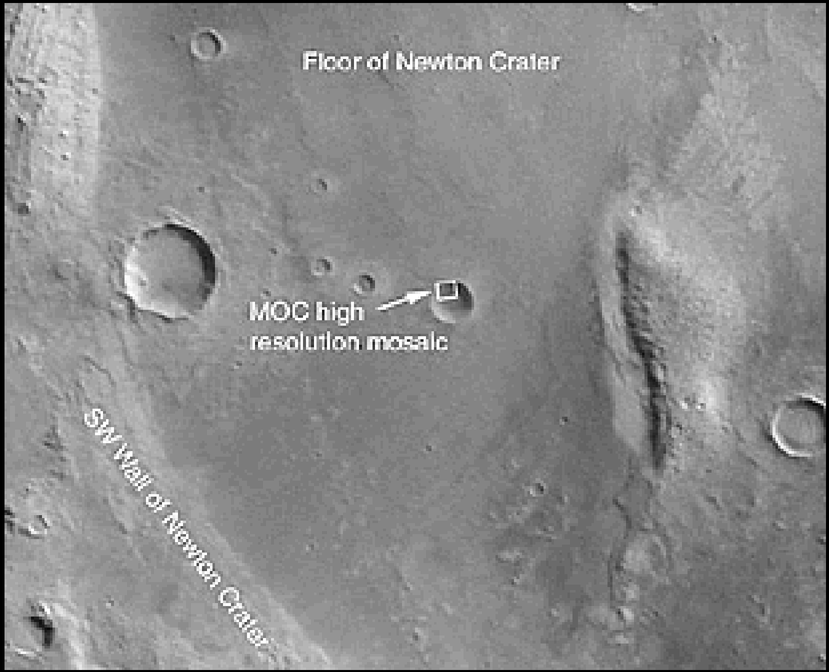
GULLIES AT 70 S. IN POLAR PIT WALL

NASA/JPL/MALIN SPACE SCIENCE SYSTEMS

VIKING CONTEXT







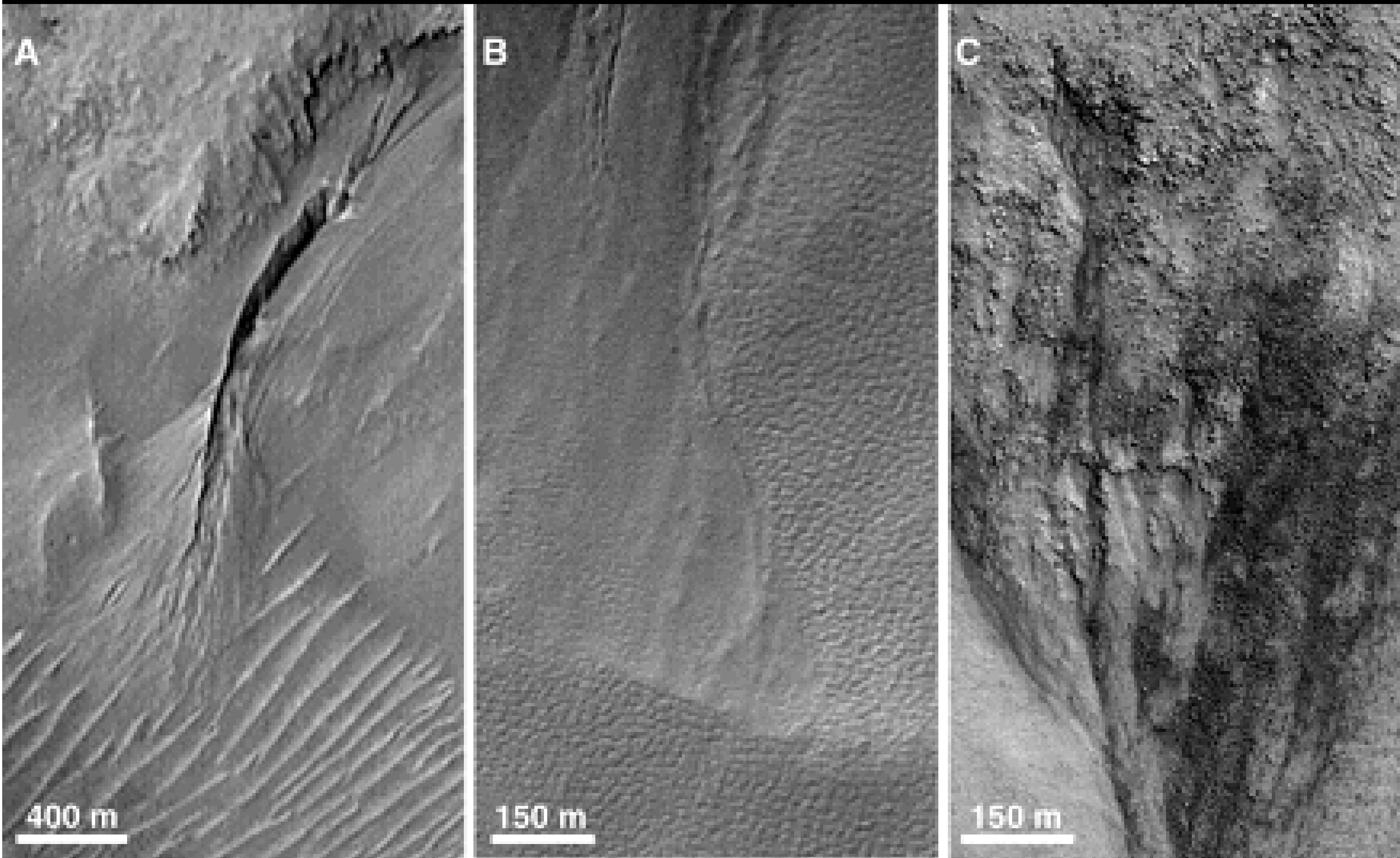
GULLIES IN CRATER IN NEWTON CRATER

NASA/JPL/MALIN SPACE SCIENCE SYSTEMS

YOUNG RELATIVE AGE FOR EROSION

MALIN, M.C., AND K.S. EDGETT, 2000, SCIENCE, 288, 2330-2335

APRON COVERING DUNES | APRON COVERING POLYGONS | FRESH, DUST FREE SURFACES



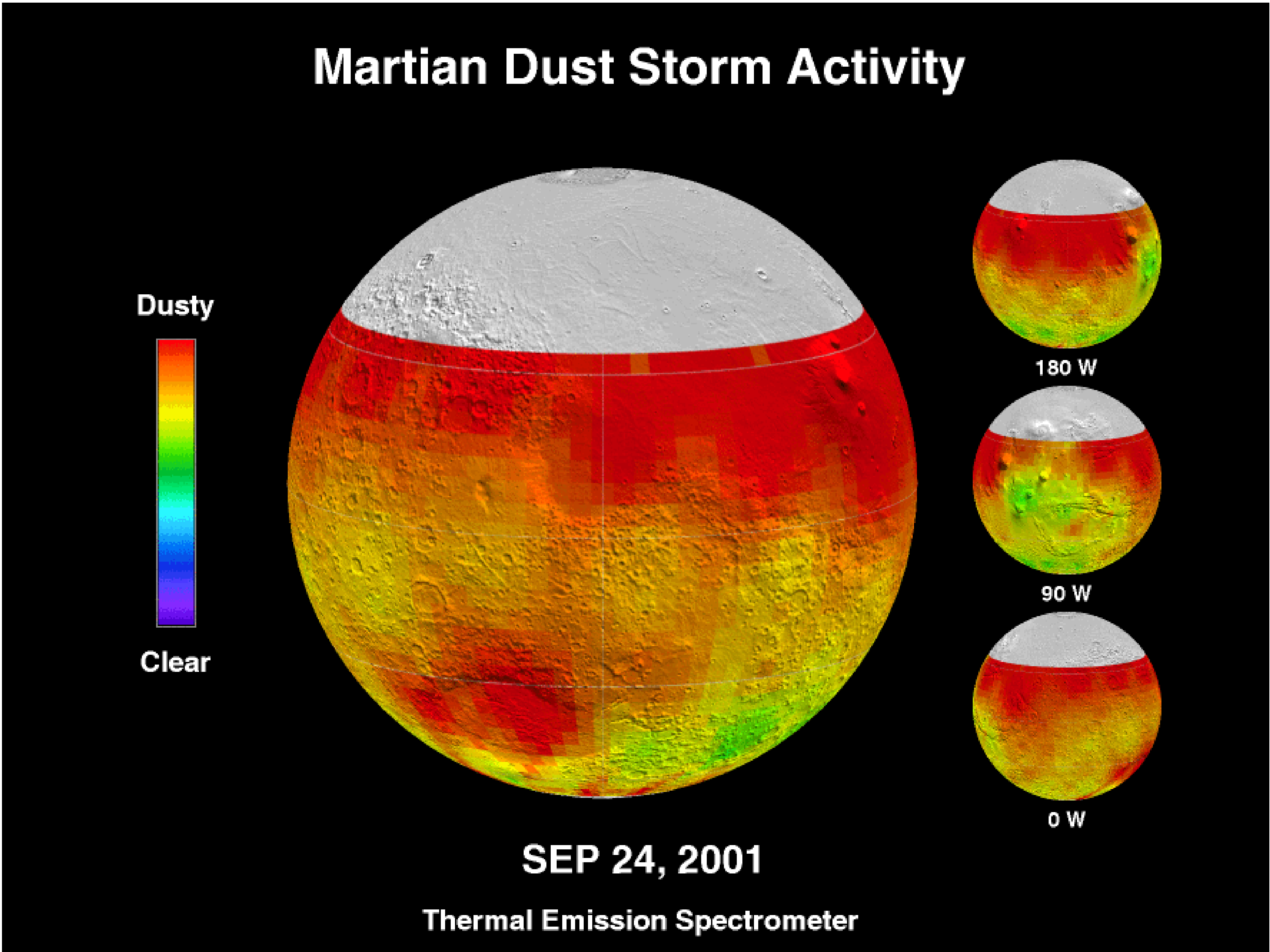
RECENT WATER ACTIVITY

- **ALCOVE / GULLY / FAN FEATURES**
  - **NORTH POLE FACING, HIGH LATITUDE SITES (MOSTLY SOUTH)**
  - **“AQUIFERS” ~150 M BELOW SURFACE ON RELATIVELY YOUNG CLIFFS**
    - **TOO COLD FOR LIQUID WATER TODAY (CARR)**
  - **GEOGICALLY YOUNG, I.E., NO OVERLAPPING FEATURES**
  - **CHANGE IN AXIS INCLINATION IN LAST FEW MILLION YEARS**
    - **45º WOULD GIVE FULL SUN ON THESE SLOPES IN THE SUMMER**
    - **MELTING OF SOUTH POLAR CAP WOULD INCREASE ATMOSPHERIC DENSITY AND GREENHOUSE**

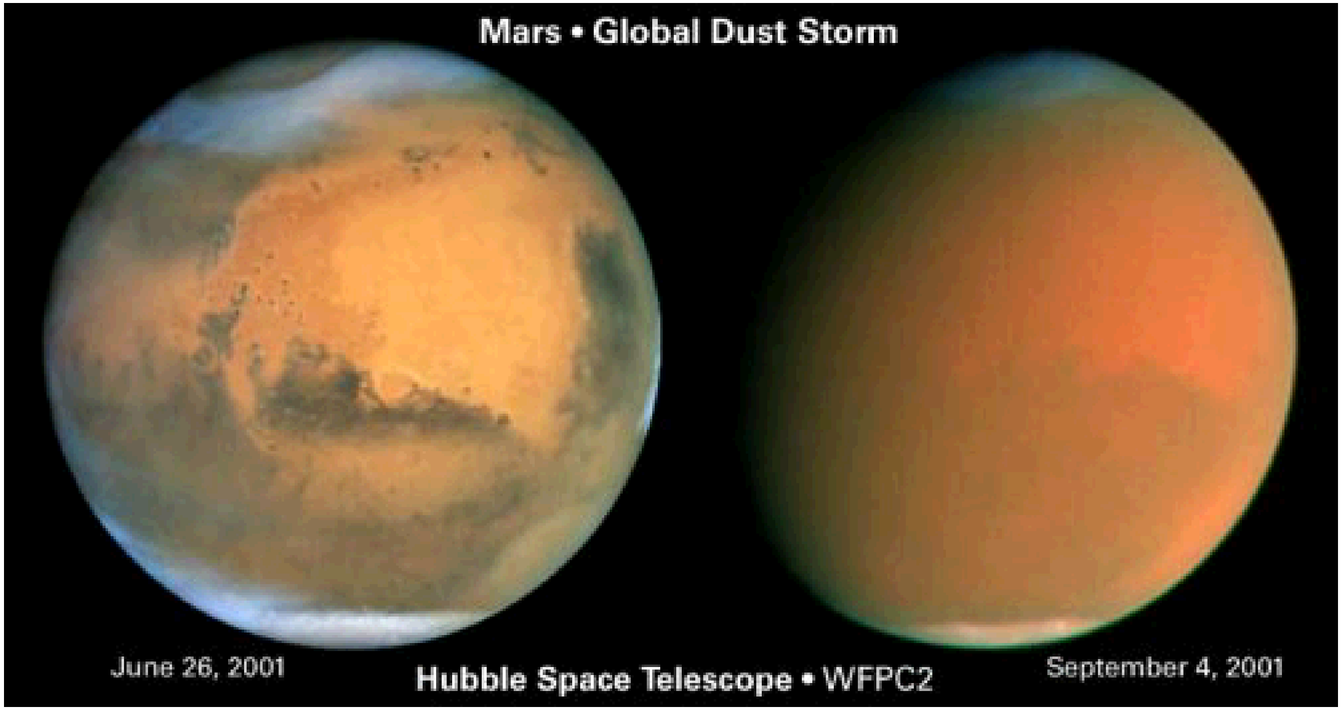
- **ALTERNATIVE FLUIDS**
  - **CO_2-H_20 OR CH_4-H_20 CLATHRATES**
  - **UNKNOWN THERMAL SOURCE IN CRUST**

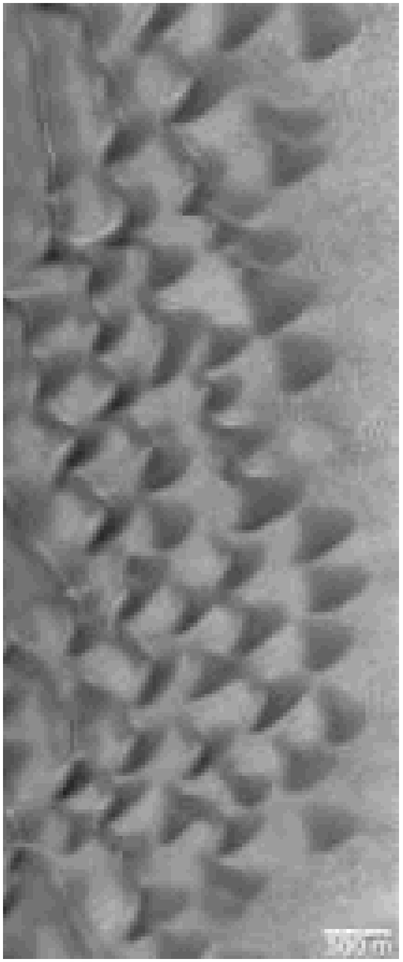
TES INDICATIONS OF CRYSTALLINE HEMATITE IN TERRA MERIDIANI

NASA/ASU/TES

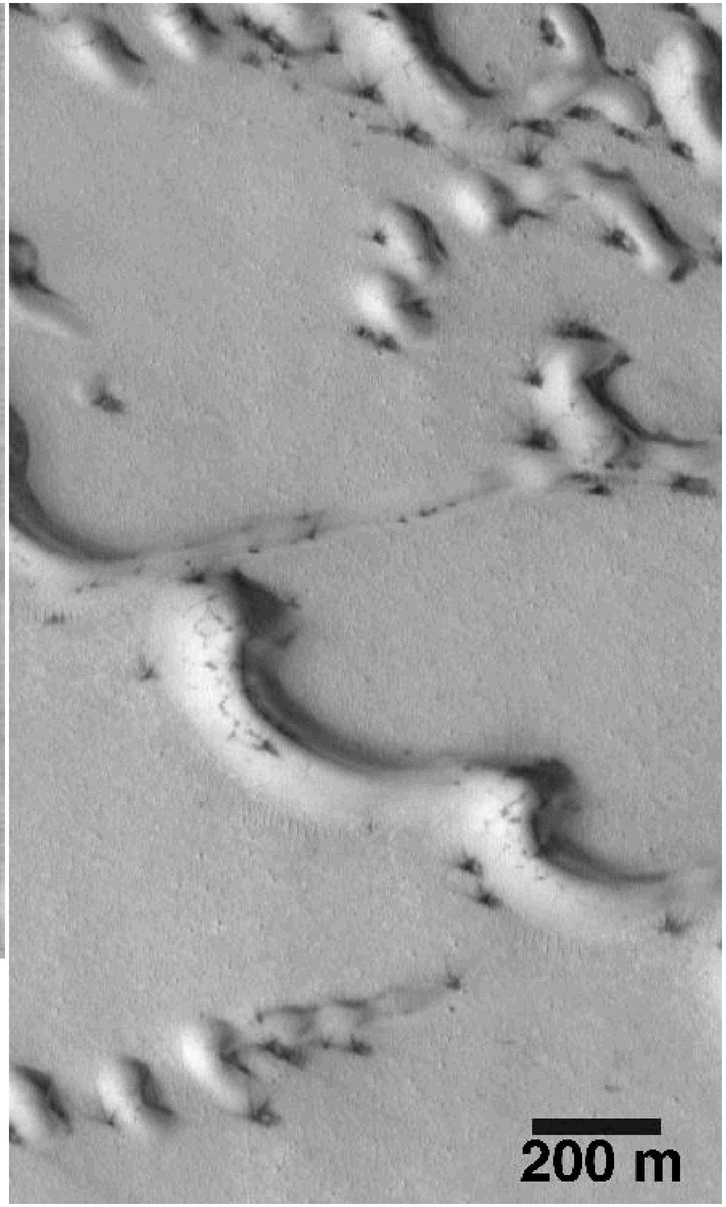


Martian Dust Storm Activity
Dusty
Clear
180 W
90 W
0 W
SEP 24, 2001
Thermal Emission Spectrometer

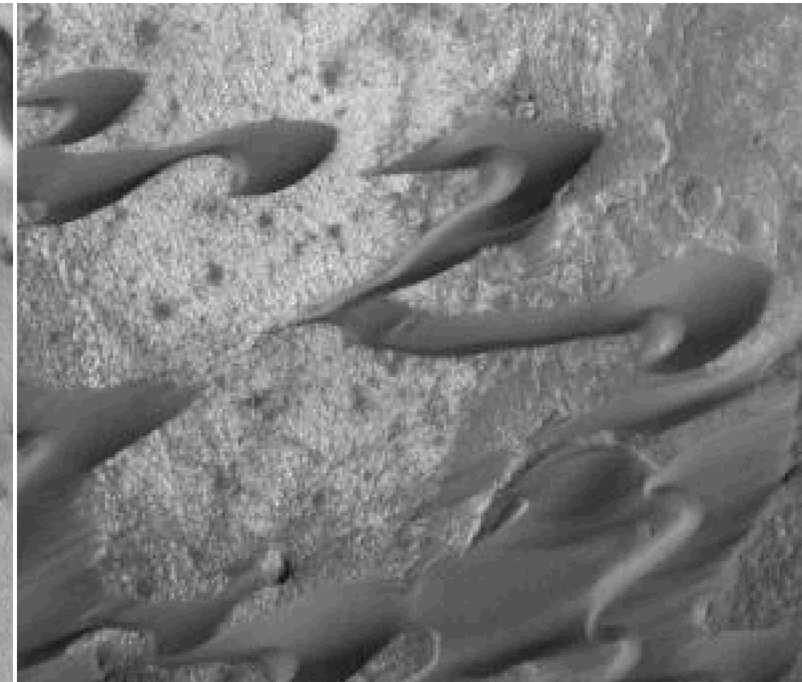

Mars • Global Dust Storm
June 26, 2001
Hubble Space Telescope • WFPC2
September 4, 2001



PROTOR CRATER DUNES

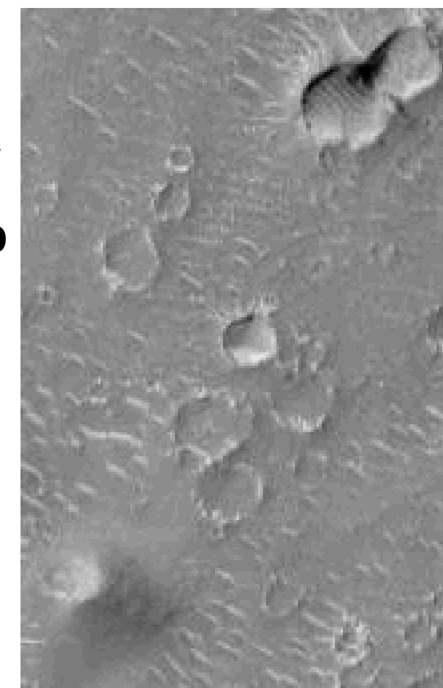


FROST ON NORTH POLAR DUNES

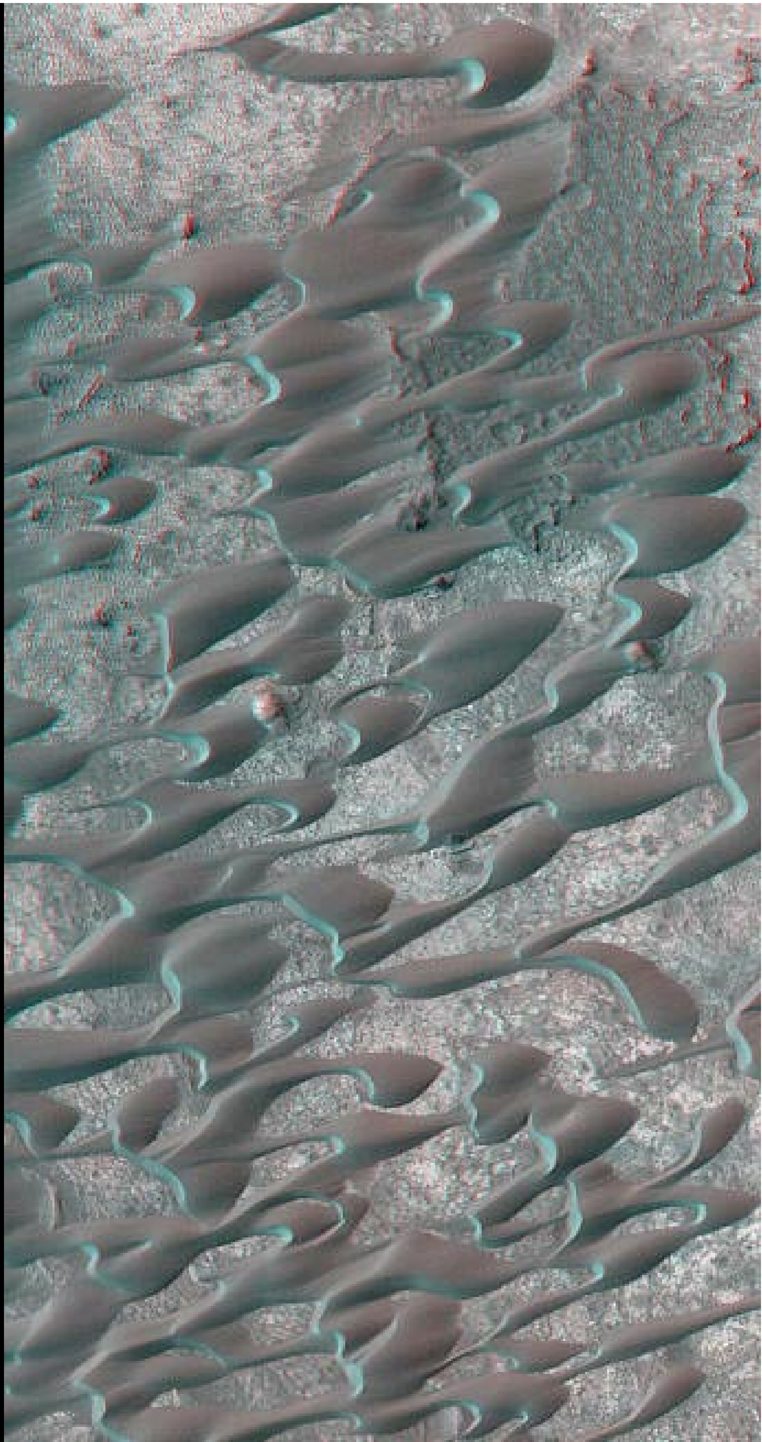


NILI PATERA, SYRTIS MAJOR DUNES

ISIDIS PLANITIA LIGHT COLORED DUNES

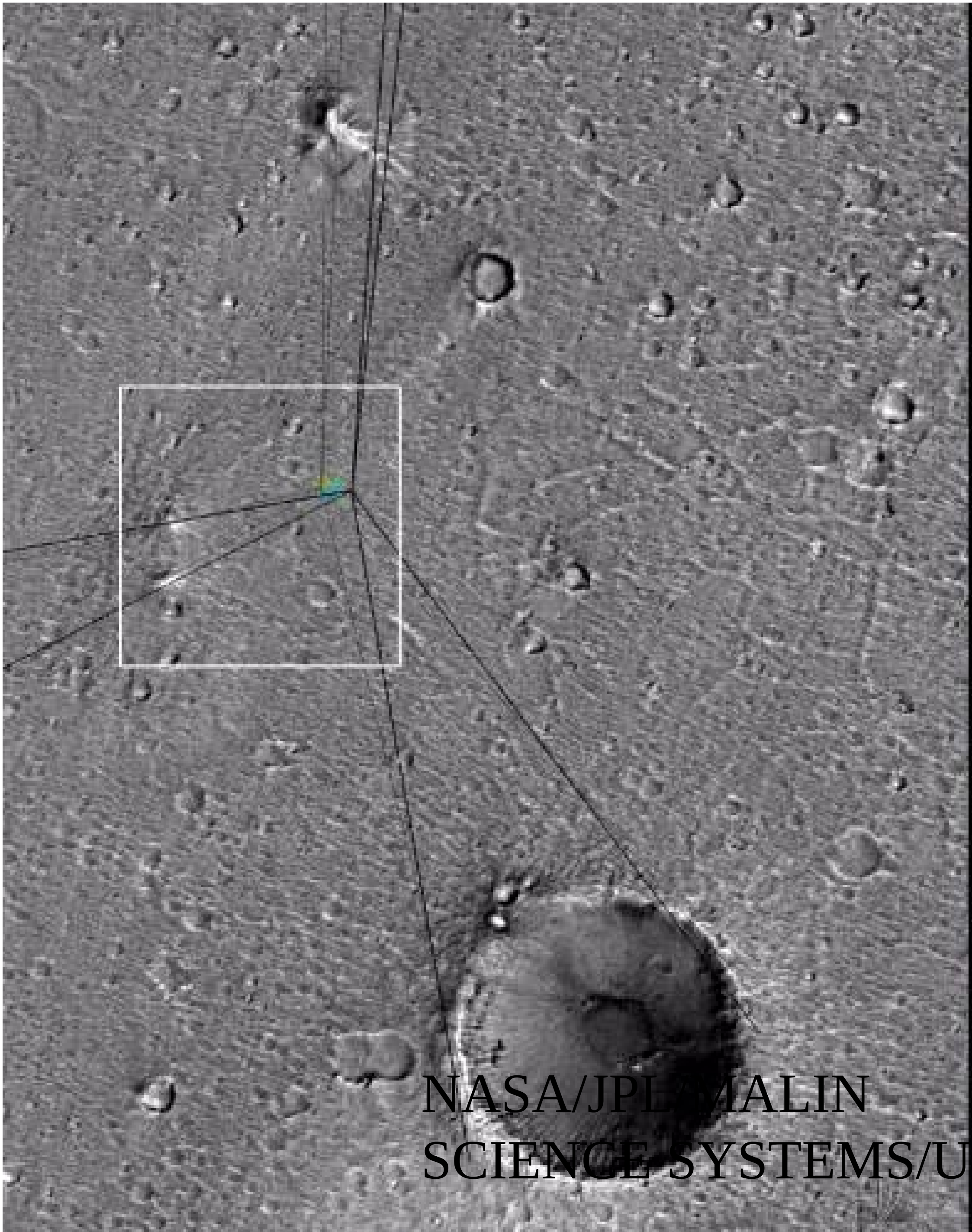


NILI PATERA DUNES IN 3D

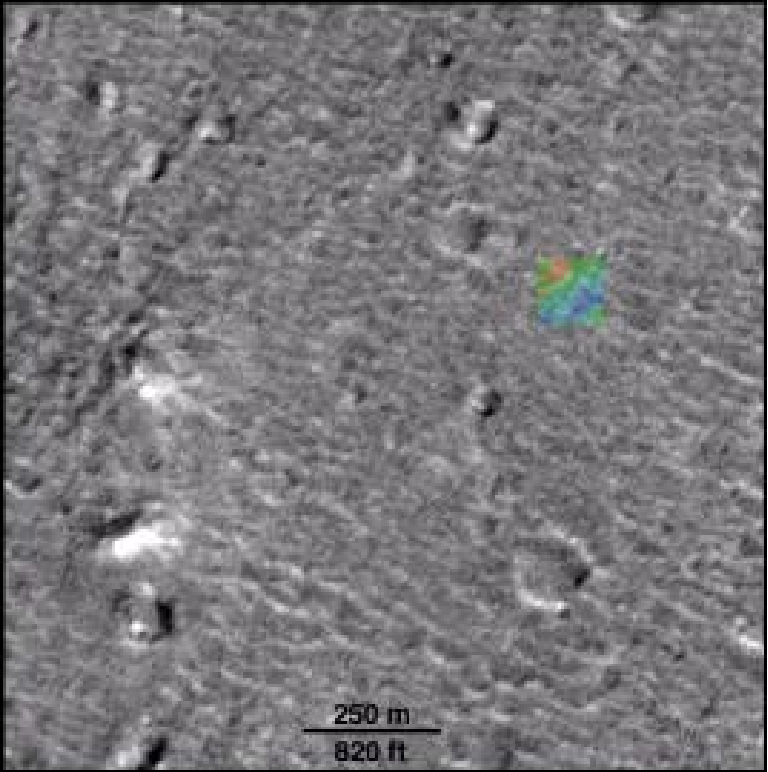


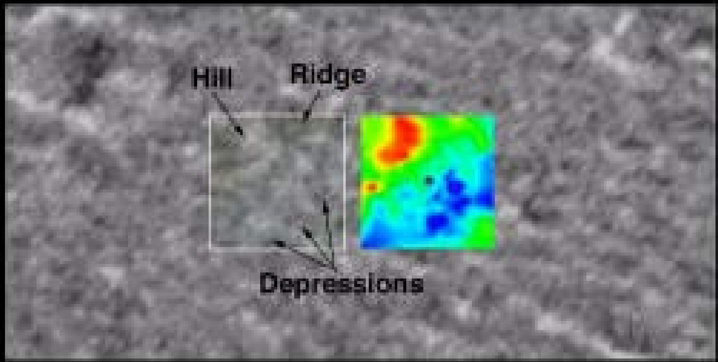
NASA/JPL MALIN SCIECE SYSTEMS

PATHFINDER LOCATION



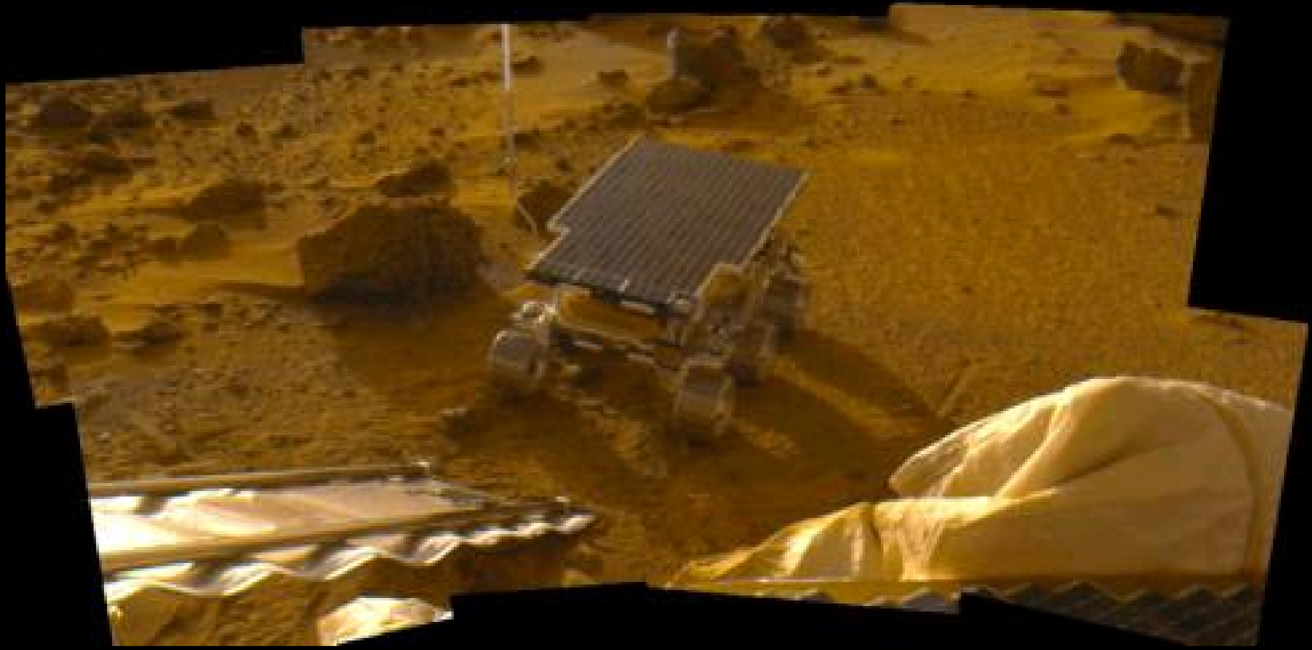
NASA/JPL/MALIN
SCIENCE SYSTEMS/U



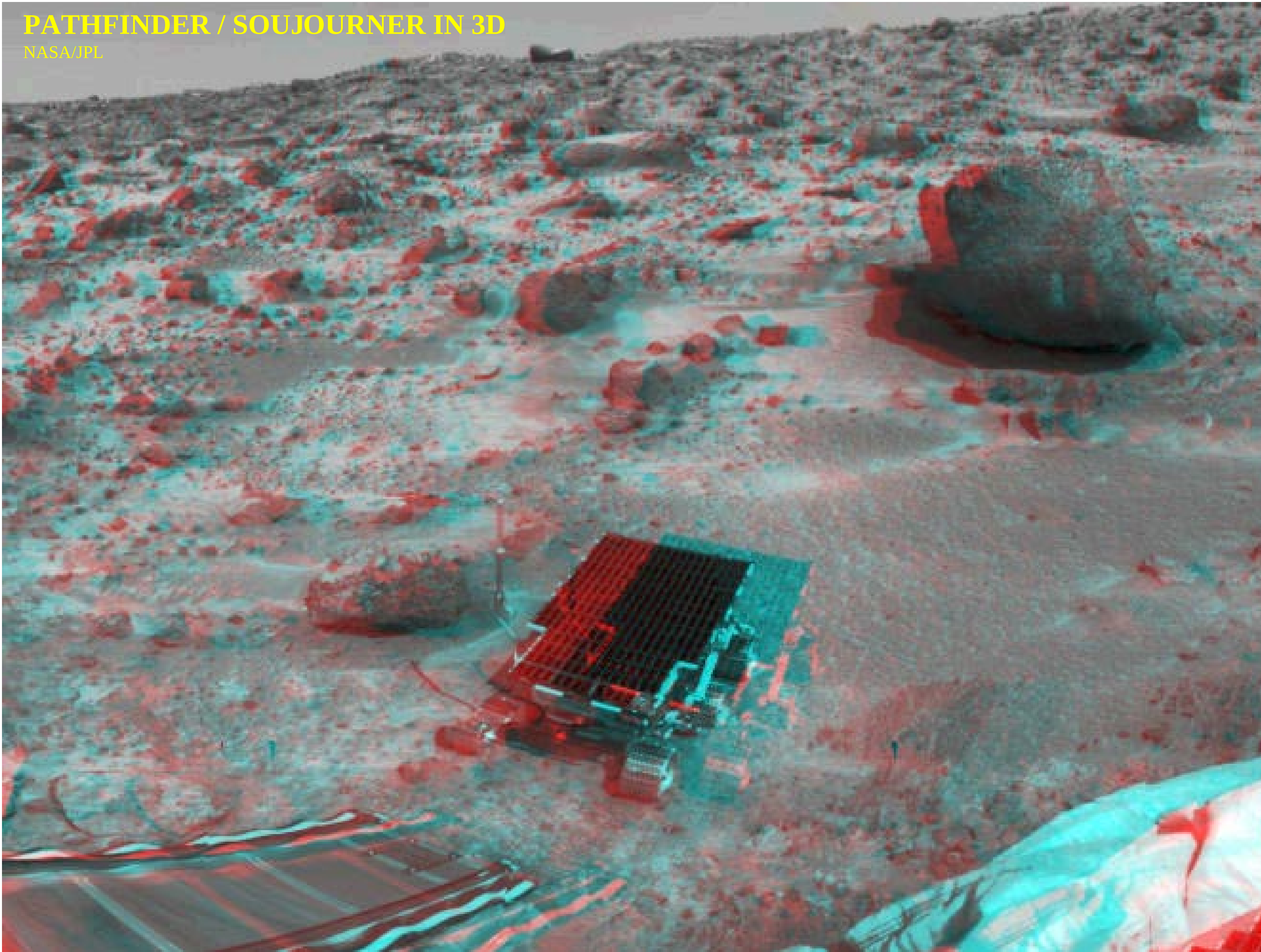


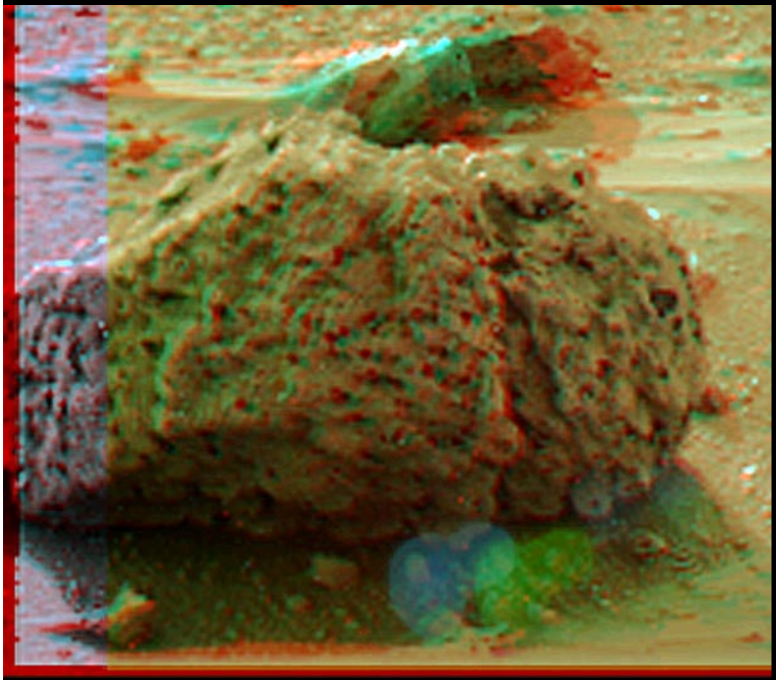
NASA/JPL/MALIN SCIENCE SYSTEMS/USGS

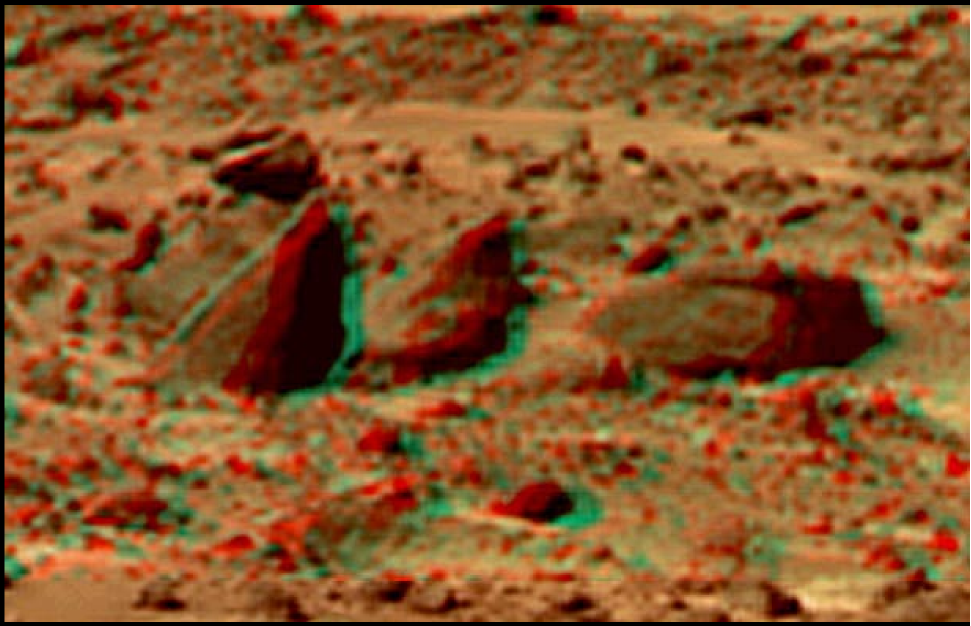
PATHFINDER/SOUJOURNER

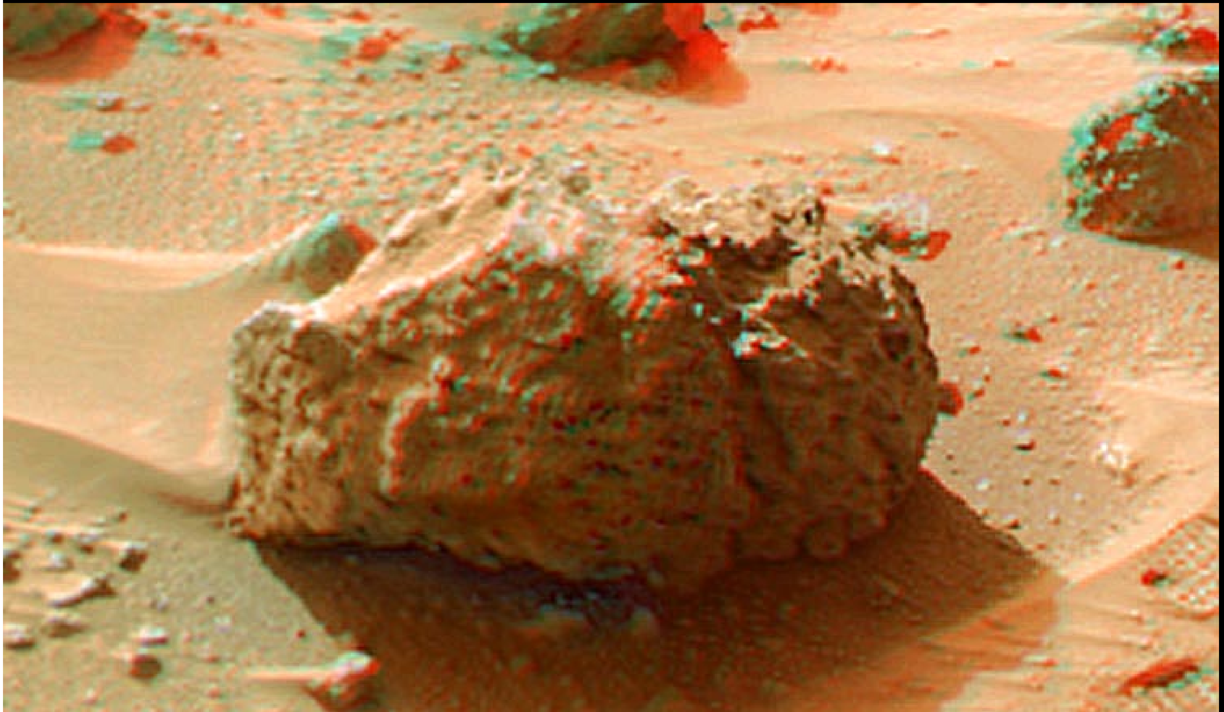


NASA/JPL


PATHFINDER / SOUJOURNER IN 3D
NASA/JPL

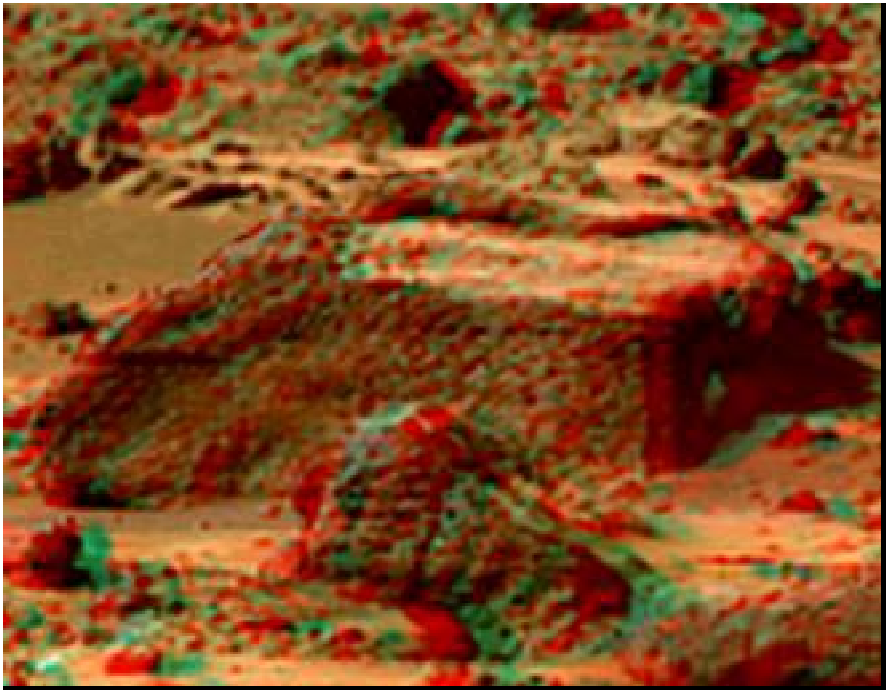


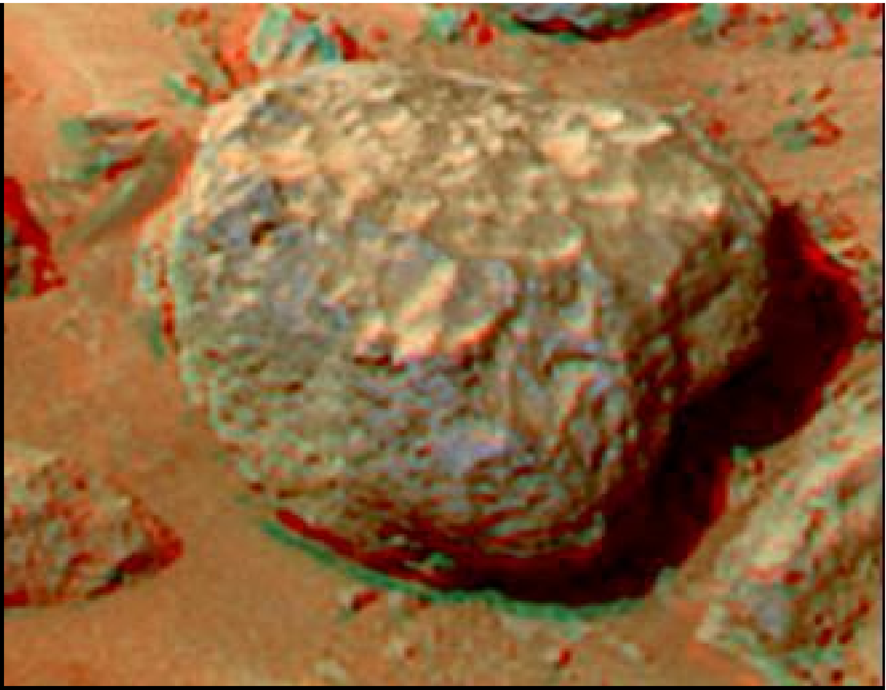




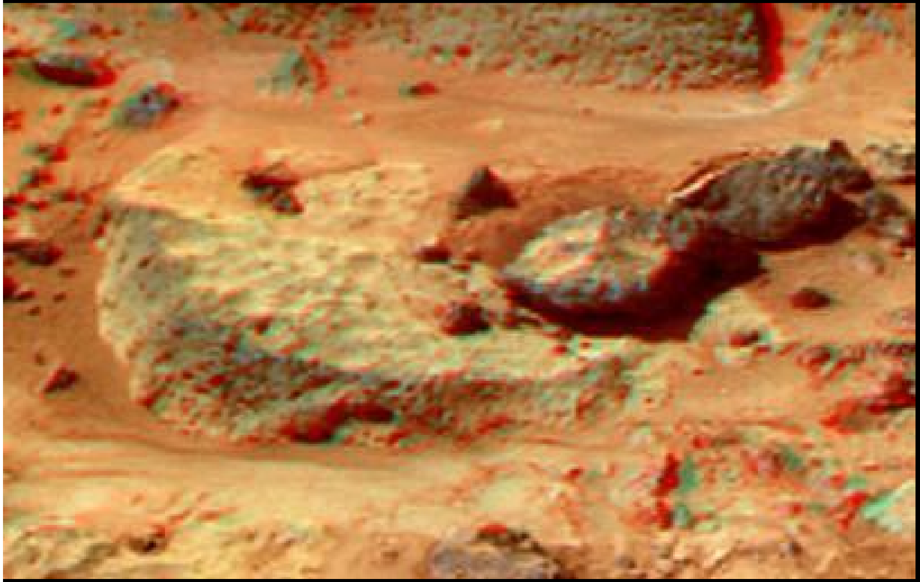
PATHFINDER ROCKS
AND SURROUNDINGS
IN 3D

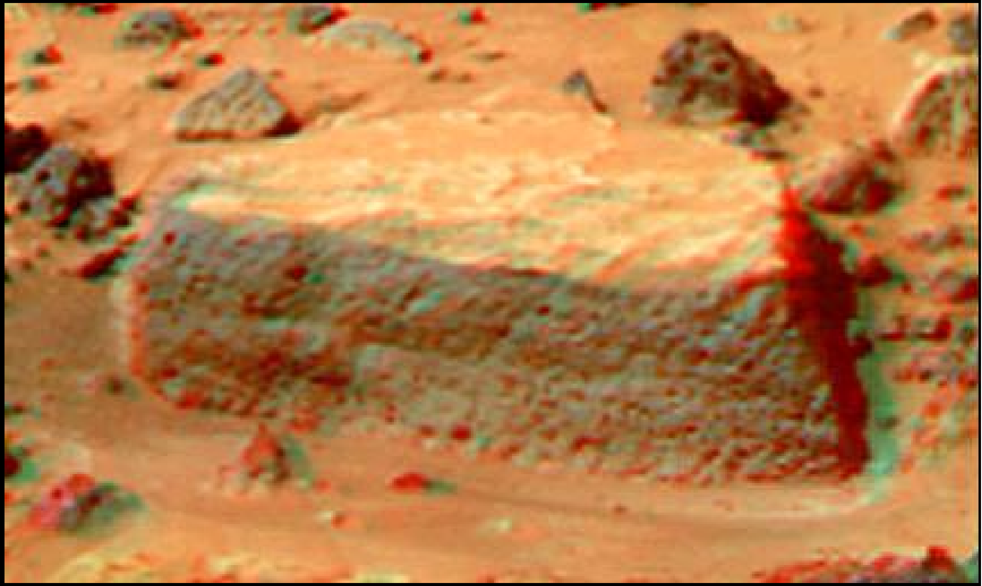
NASA/JPL





MORE PATHFINDER ROCKS IN 3D

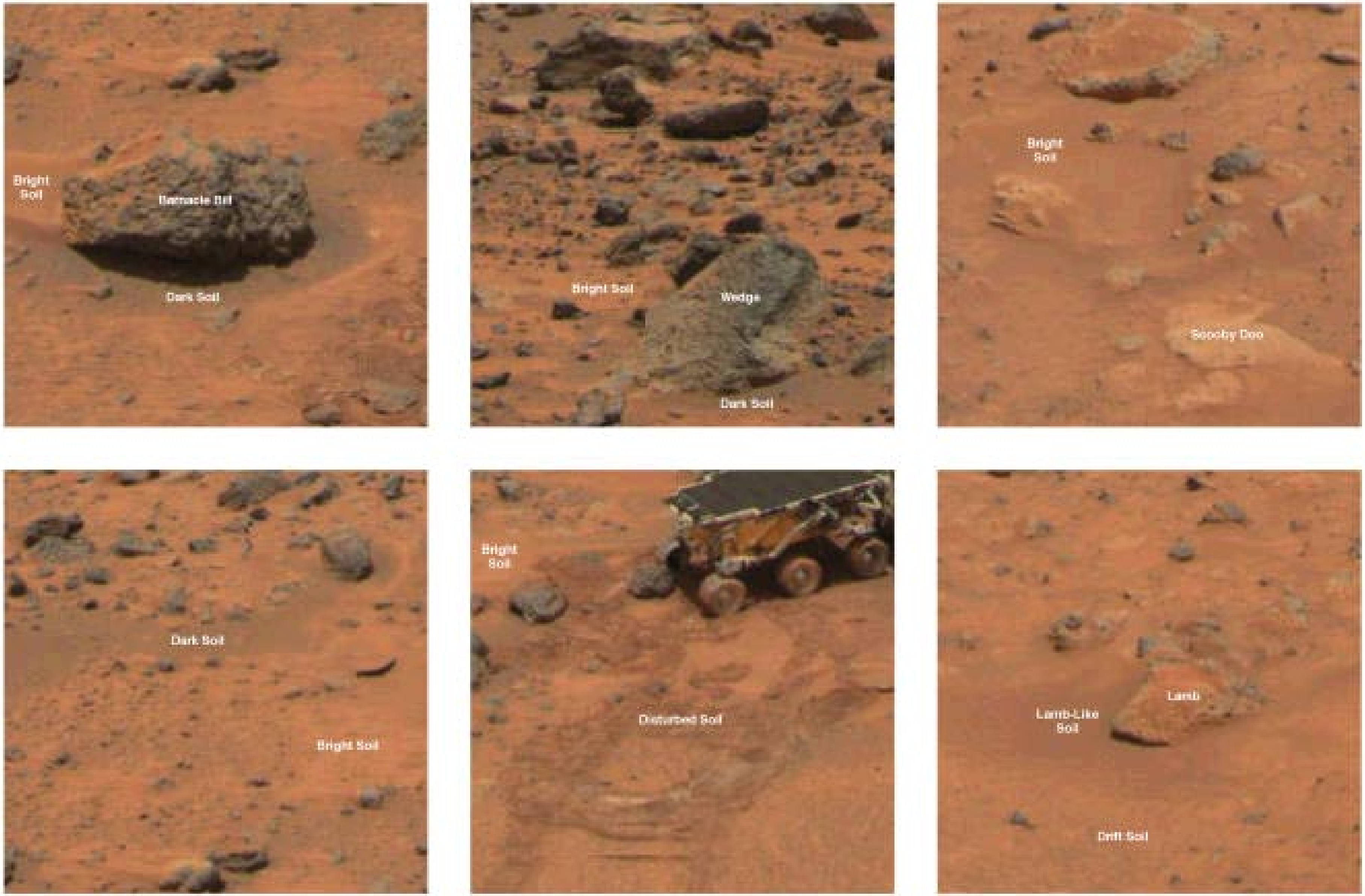




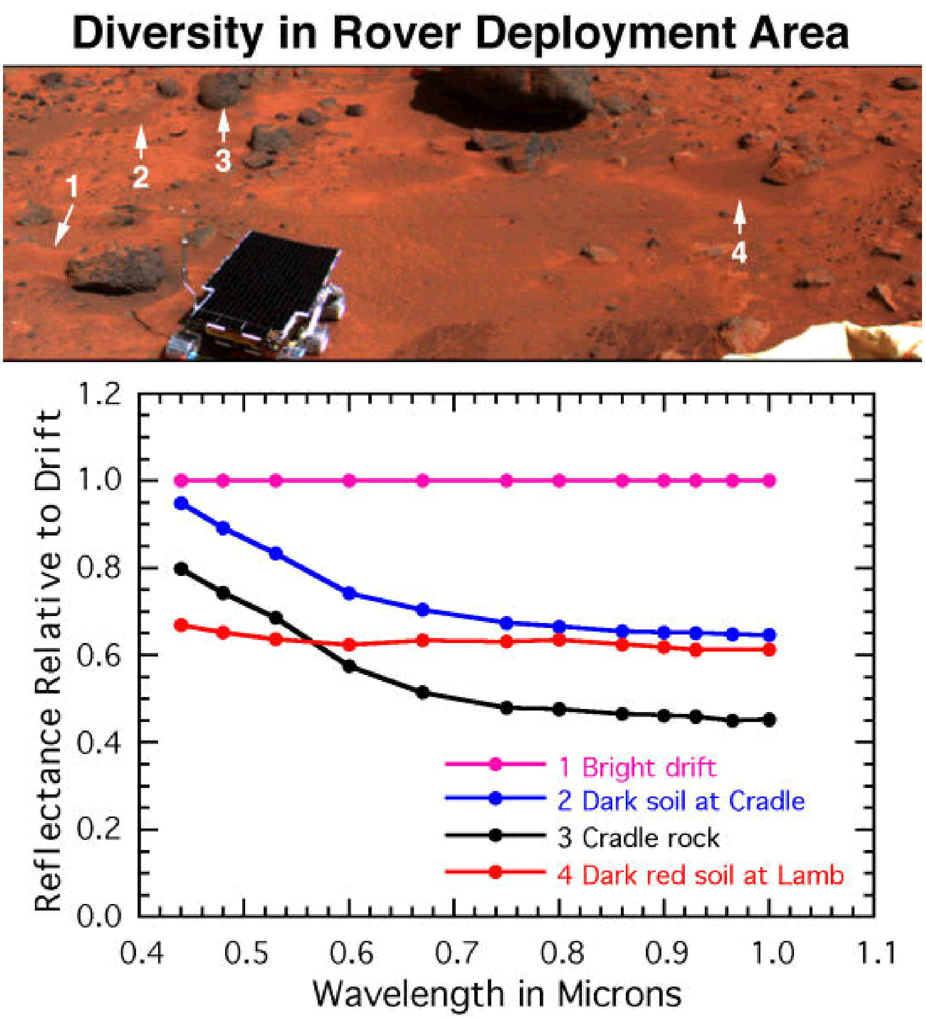
NASA/JPL

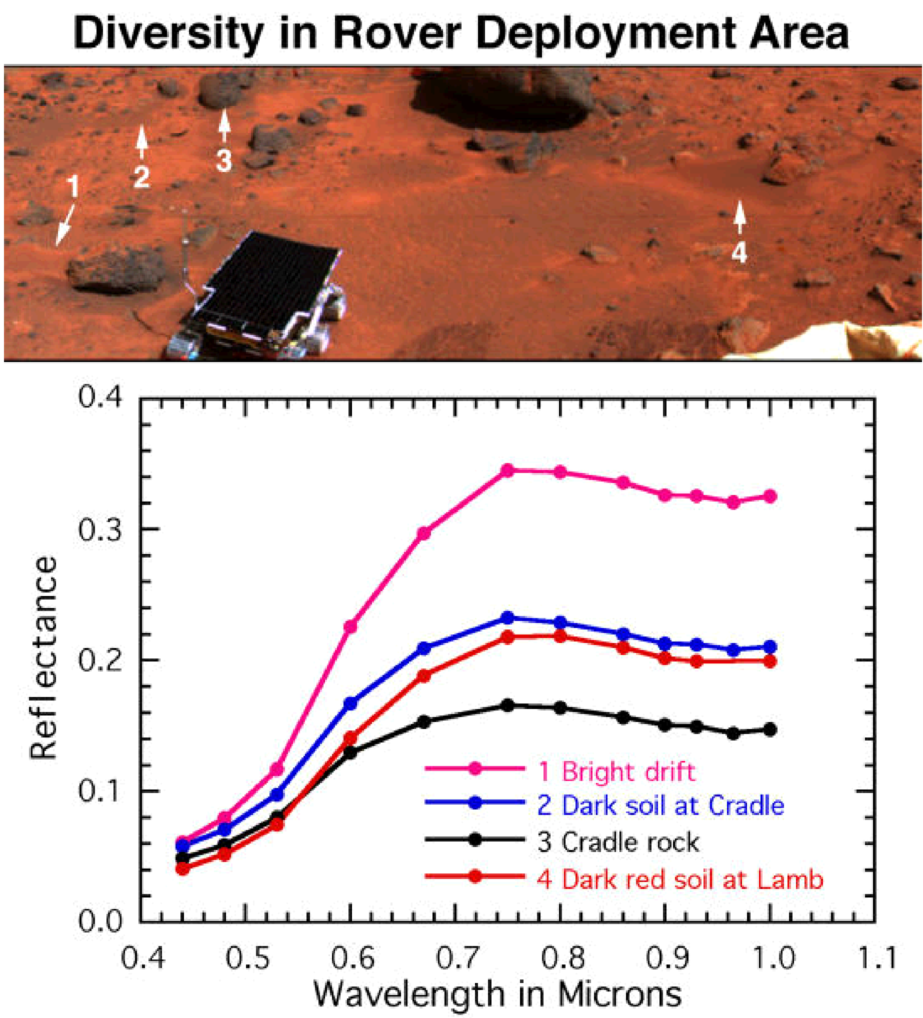
SOIL TYPES AT PATHFINDER SITE

NASA/JPL

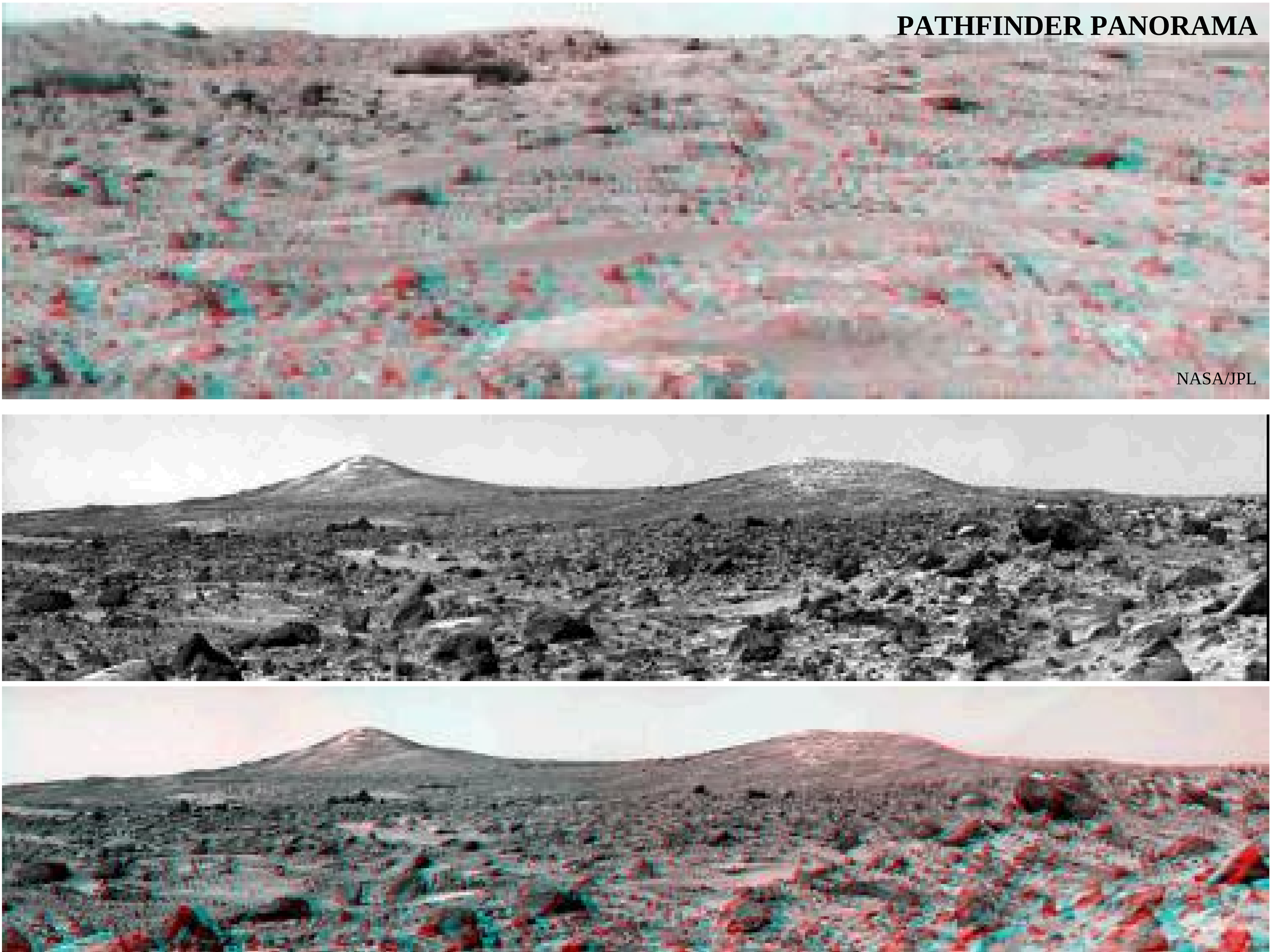


PATHFINDER SOIL





NASA/JPL/JOHNS HOPKINS UNIV.


PATHFINDER PANORAMA
NASA/JPL

VIKING 1 LANDER VIEWS, CHRYSE, 7500 KM SW OF VIKING 2 SITE NASA/JPL
(IN OUTFLOW REGION, ~1200 KM FROM PATHFINDER SITE)

VIKING 2 LANDER VIEWS UTOPIA, NORTHERN LOWLANDS 7500 KM NE OF VIKING 1 SITE

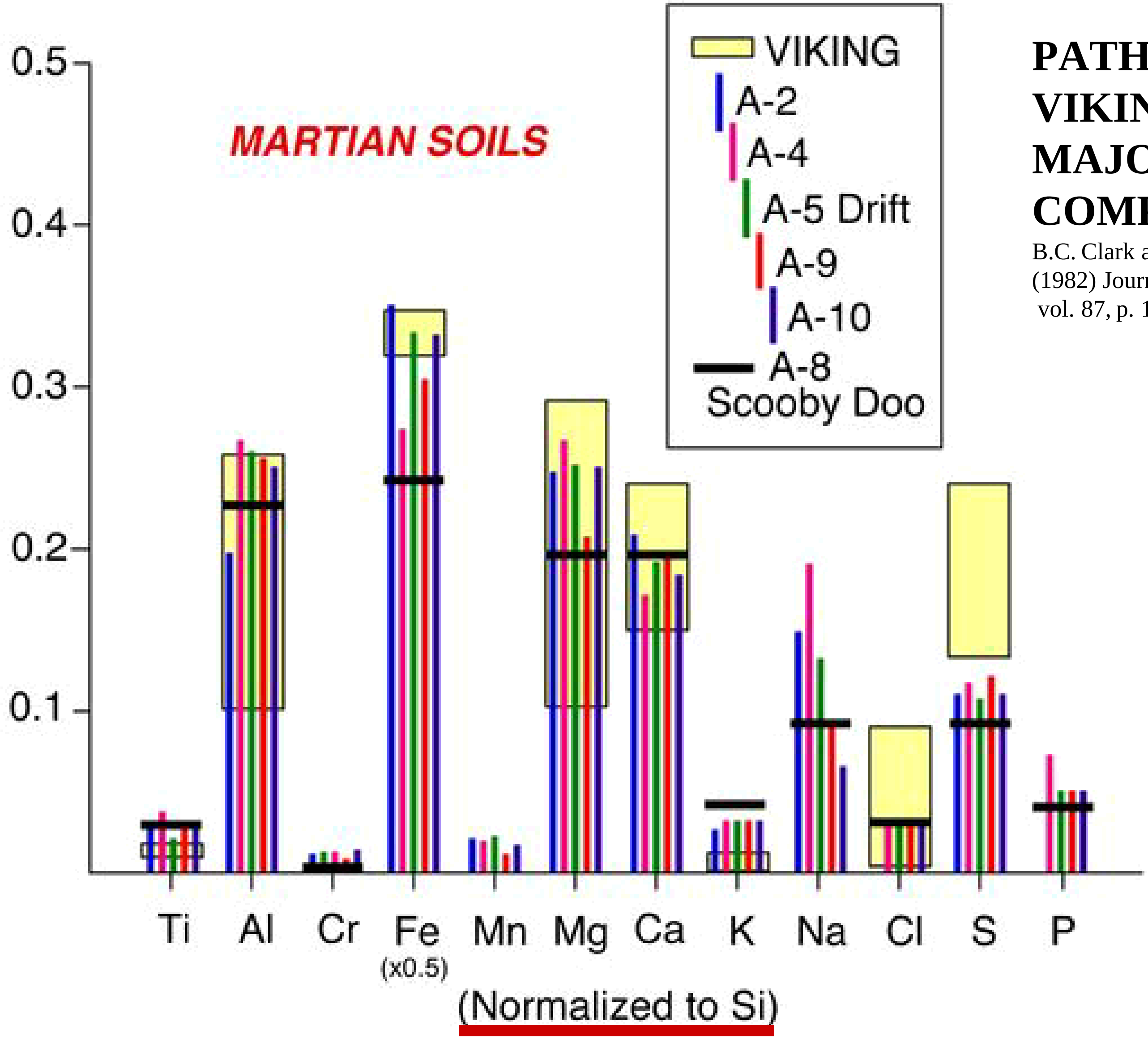
NASA/JPL

X-Ray Fluorescence Analyses of Different Samples at the Two Viking Landing Sites (Carr et al., 1984)

	Chryse Fines	Chryse Duricrust (1)	Chryse Duricrust (2)	Utopia Fines	Estimated Absolute Error	Pathfinder
SiO_2, wt %	44.7	44.5	43.9	42.8	5.3	~50
Al_2O_3, wt %	5.7	N/A	5.5	N/A	1.7	~8
Fe_2O_3, wt %	18.2	18.0	18.7	20.3	2.9	~16
MgO, wt %	8.3	N/A	8.6	N/A	4.1	~8
CaO, wt %	5.6	5.3	5.6	5.0	1.1	~6
K_2O, wt %	<0.3	<0.3	<0.3	<0.3	---	~0.3
TiO_2, wt %	0.9	0.9	0.9	1.0	0.3	~1.1
SO_3, wt %	7.7	9.5	9.5	6.5	1.2	~5.5
Cl, wt %	0.7	0.8	0.9	0.6	0.3	~0.6
Sum	91.8	N/A	93.6	N/A	---	
Rb, ppm	<30			<30		
Sr, ppm	60 ± 30			100 ± 40		
Y, ppm	70 ± 30			50 ± 30		
Zr, ppm	<30			30 ± 20		

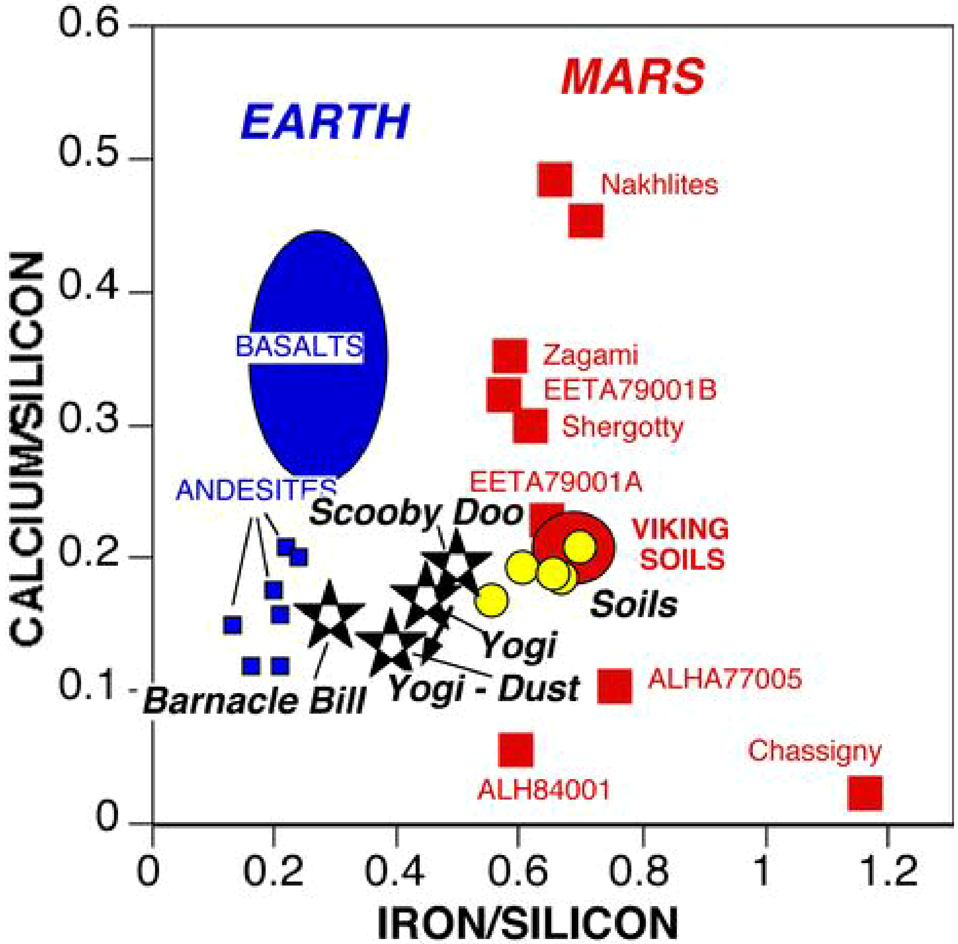
PATHFINDER / VIKING MAJOR ELEMENT COMPARISON

B.C. Clark and others (1982) Journal of Geophysical Research, vol. 87, p. 10,064



Soils at the Pathfinder site generally have higher aluminum and magnesium, and lower iron, chlorine, and sulfur relative silicon. Scooby Doo, which appears to be a sedimentary rock composed primarily of compacted soil, also exhibits a few Chemical differences form the surrounding soils. Analysis A-5 represents a deposit of windblown dust (called drift), whereas the other soil analyses may be cemented materials.

PATHFINDER AND VIKING ANALYSES RELATIVE TO SNC METEORITES, ETC.



NOTE DIFFERENCES BETWEEN EARTH BASALTS AND ANDESITES RE. THE GLOBAL SURVEYOR TES ANALYSES

The analysis of Yogi appears to be contaminated by dust adhering to the rock's surface. The rock composition can be estimated by subtracting a portion of dust; the resulting Yogi composition is very similar to that of Barnacle Bill (we assumed 50% dust having the composition of drift analysis A-5 and used a linear mixing model to subtract the dust which is only strictly valid if the dust, where present, is thicker than the APXS penetration depth). Barnacle Bill is also contaminated by dust, but to a lesser extent. Much of the finer dust is slightly magnetic with two mineralogical alternatives proposed (Hviid, et al., 1997): (1) Clay phase + Maghemite (gamma-Fe2O3) which may imply previous leaching of Fe2+ by liquid water and (2) titanomagnetite or titanohaghemite in palagonite from direct weathering of glassy basalt.

SOILS CHEMISTRY

- **ARGUMENTS AND EVIDENCE FOR CLAY MINERALS AT THE SURFACE**
  - **The chemistry of the soils analyzed by Viking and Pathfinder suggests that the soil has been produced by palogonitic weathering of iron rich silicate and include poorly crystalline, Fe+-rich gels, containing nanophase ferric oxide (Stoker, et al., 1993, Rieder, et al, 1997).**
  - **Actual clay minerals, such as iron rich montmorillonites, could be up to 15% and not be detected by present spectral techniques.**
  - **Spectral studies also indicate some water bound in mineral crystal structures.**
  - **Weathering near freezing 10^5 slower than on Earth Burns and Fisher, 1993) but may have been much more rapid during cyclic wet periods.**
  - **Soils also include minor sulfates, carbonates and oxides (Stoker, et al., 1993).**
- **EVIDENCE OF SURFACE CRUSTS ("DURICRUST") DUE TO CHEMICAL PRECIPITATION**
  - **possibly Mg,Na sulfates, Ca, Mg, Fe carbonates, and Na chlorides salts (Stoker, et al., 1993)**
  - **modeling of spectral data indicates that atmospheric dust may include 0-3% carbonate and 10-15% sulfate-bearing compounds.**
  - **crustal carbonates are indicated by some of the Martian meteorites**
- **VIKING SOILS APPEAR TO BE OXIDIZING (1-10 PPB OF REACTING OXIDANTS) RATHER THAN REDUCING (NASA, 1988)**

SOIL MINERALS - 1

VIKING AND PATHFINDER ANALYSES

- **SUGGEST WEATHERED BASALT**
  - **MINOR SULFATES, CARBONATES, AND OXIDES**
- **EARTH-BASED SPECTRA INDICATE WATER IS BOUND IN MINERALS**
  - **CLAY, E.G. FE-RICH MONTMORILLONITES, COULD BE UPTO 15%**
- **SPECTRA ALSO INDICATE DUST MAY INCLUDE 10-15% SULFATES BUT <3% CARBONATE**
- **PATHFINDER MAGNETS AND MGS TES DATA SHOW MUCH IRON IS OXIDIZED (FE_2O_3)**
- **SURFACE CRUST "(DURICRUST" OR MARTIAN “CALICHE”)**
  - **MG AND NA SULFATES (?)**
  - **CA, MG, AND FE CARBONATES SUBSURFACE**
    - **CARBONATES APPARENTLY DECOMPOSED BY UV RADIATION**
  - **FE CARBONATE (SIDERITE) IN MARTIAN METEORITES**
  - **CHLORIDE SALTS**
- **SOILS APPEAR TO BE OXIDIZING (1-10 PPB OF REACTING OXIDANTS)**

SOIL MINERALS - 2

VIKING AND PATHFINDER ANALYSES

- **MODEL MARTIAN "SOIL" COMPOSITION (VIKING) [STOKER, ET AL, 1984]**
  - **SILICATE MINERALS** **84-79%**
  - **MAGNETIC MINERALS** **3%**
  - **SULFATE SALTS** **12%**
  - **CHLORIDE SALTS** **1%**
  - **CARBONATES** **0%**
  - **NITRATES** **0-1%**
  - **WATER (MAY BE MUCH HIGHER)** **>1%**

- **SOIL COMPOSITION FROM PATHFINDER**
  - **HIGHER SIO_2 AT PATHFINDER THAN FOR VIKING SITES**
    - **GREATER WEATHERING OR WATER SORTING (?)**

MARTIAN ATMOSPHERE
VIKING DATA

NAS9-17779 - Phase III
Final Report

Average Composition of the Martian Atmosphere (Carr et al., 1984)

Gas	Mole fraction
Carbon dioxide (CO_2)	95.32%
Nitrogen (N_2)	2.7%
Argon (Ar)	1.6%
Oxygen (O_2)	0.13%
Carbon Monoxide (CO)	0.07%
Water vapor (H_2O)	0.03%
Neon (Ne)	2.5 ppm
Krypton (Kr)	0.3 ppm
Xenon (Xe)	0.08 ppm
Ozone (O_3)	0.03 ppm

Isotope Ratios

Ratio	Earth	Mars
$^{12}C/^{13}C$	89	90
$^{16}O/^{18}O$	499	500
$^{14}N/^{15}N$	277	165
$^{40}Ar/^{36}Ar$	292	3000
$^{129}Xe/^{132}Xe$	0.97	2.5

VOLATILE RESOURCES -1 ATMOSPHERE

- **CARBON DIOXIDE**
  - **CH_4 DERIVED FROM THE ATMOSPHERE COULD BE PARTICULARLY IMPORTANT AS A PROPULSION FUEL SOURCE EVEN ON EARLY EXPLORATION MISSIONS (ZUBRIN AND BAKER, 1991).**
    - **METHANE PRODUCED BY THE WELL-KNOWN INDUSTRIAL REACTION:**
      - **$CO_2+4H_2 = CH_4+2H_2O$**
      - **EXOTHERMIC AND SPONTANEOUS WITH A NICKEL CATALYST WITH 99% FIRST PASS CONVERSION**
    - **OXYGEN CAN BE PRODUCED, AND SOME HYDROGEN RECOVERED AND RECYCLED, BY ELECTROLYSIS OF H_2O**
      - **HYDROGEN MAY INITIALLY COME FROM LUNAR OR TERRESTRIAL SOURCES**

- **NITROGEN (3%)**
- **WATER (VERY MINOR)**

VOLATILE RESOURCES -2
NEAR SURFACE

- **CHLORINE AND FLUORINE FROM PYROCLASTICS AND VOLCANIC HOT SPRING DEPOSITS**
  - **COPPER, ZINC, LEAD, PRECIOUS METALS, ETC.**

- **SULFUR FROM FES (TROILITE) IN BASALTIC REGOLITH AND FROM VOLCANIC FUMEROLE DEPOSITS**

- **UNKNOWN VOLATILES AND OTHER ELEMENTS FROM SOIL CRUSTS**

- **HYDROCARBON COMPOUNDS DEPENDING ON THE EXISTENCE AND EXTENT OF EARLY LIFE AND / OR PRESENT LIFE FORMS**
  - **DARK FLOWS DOWN SLOPES OBSERVED BY MGS AND THOUGHT TO BE LANDSIDES**
  - **EVIDENCE FOR LIFE FORMS AT THE VIKING LANDER SITES "NOT" PRESENT (HOROWITZ, 1988)**
    - **LOW CONCENTRATIONS OF LICHEN-LIKE FORMS ARE A POSSIBILITY (LEVIN AND STRAAT, 1988)**
  - **DEBATE OVER RELIC LIFE FORMS IN SNC METEORITE ALH84001**

EXISTING LIFE ON MARS?
WHAT IS THE LOGIC PATH?

MARS LOGIC

EVIDENCE OF BODIES OF WATER PAST AND PRESENT

PROBABLE, EARTH-LIKE “EXTREME” ENVIRONMENTS

- **HOT SPRINGS**
- **BURIED HYDROSPHERE**
- **POLAR AND GROUND ICE**
- **“WET” ROCKS AT DEPTH**
- **HYDROTHERMAL VENTS IN LAKES/OCEAN (PAST)**

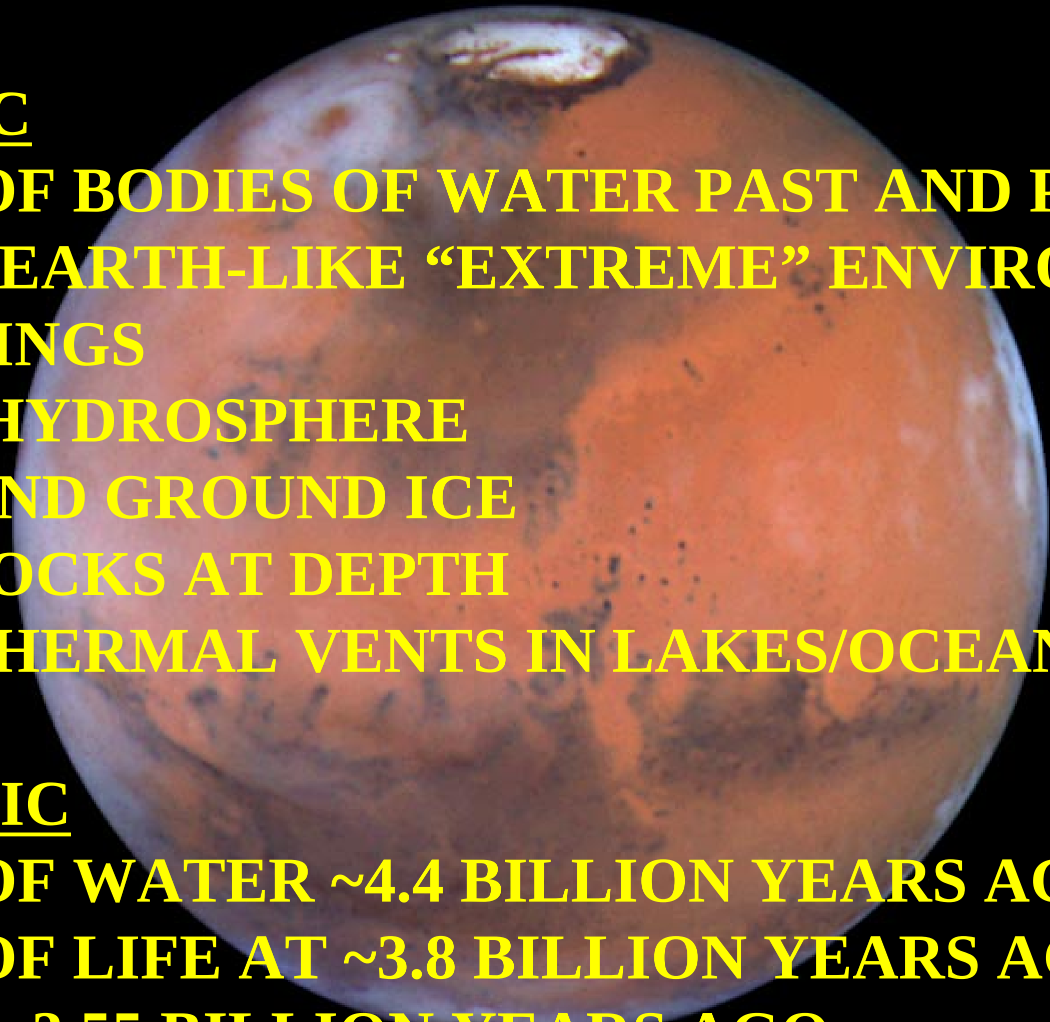
EARTH LOGIC

EVIDENCE OF WATER ~4.4 BILLION YEARS AGO

EVIDENCE OF LIFE AT ~3.8 BILLION YEARS AGO

FOSSILS AT ~3.55 BILLION YEARS AGO

“SIMPLE” LIFE FORMS IN EXTREME ENVIRONMENTS



NASA HST IMAGE

RESOURCES RESULTING FROM PRESENCE OF WATER

- **DENSITY CONTRASTS**
  - SORTING OF HEAVY AND LIGHT MINERALS FROM SAND AND GRAVEL BY WATER
  - SORTING OF CLAYS AND SILICA FROM SAND BY WIND
  - SORTING OF CLAYS FROM SAND BY SETTLING RATES IN LAKES (LAYERED SEDIMENTS)

- **CHEMICAL PRECIPITATION IN WATER**
  - CHEMICAL EVAPORITE PRECIPITATES OF CARBONATE, IRON OXIDES, AND VARIOUS SALTS (SODIUM, POTASSIUM, ETC.) IN LAKES
  - METAL SULFIDE PRECIPITATES IN LAKE BEDS
  - "BLACK SMOKER" SULFIDE DEPOSITS IN LAKE BEDS

- **PRODUCTS OF WEATHERING**
  - BAUXITE (ALUMINUM), IRON OXIDES, COBALT, NICKEL

- **HYDROTHERMAL PRECIPITATION**
  - VEINS OF METALS, SULFIDES, CARBONATES, ETC. NEAR VOLCANOS
    - LEAD, ZINC, COPPER, GOLD, SILVER, ETC.
  - VEINS AND DISSEMINATED METAL DEPOSITS IN THE UPLANDS CRUST

METALLIC RESOURCES (NEAR SURFACE)

- METALLIC MATERIALS REQUIRED FOR MARTIAN MANUFACTURING AND OPERATIONS
  - SILICON FROM SORTED SEDIMENT OR DUNES
  - TITANIUM FROM ILMENITE IN SORTED SEDIMENTS OR DUNES
    - OXYGEN AND IRON CAN BE BY-PRODUCTS
  - ALUMINUM
    - PLAGIOCLASE (CAAL2SI2O8)
    - SCAPOLITE ($NA_4AL_3SI_9O_2$ [4CL]-$CA_4AL_6SI_6O_2$ [4(CO3,SO4)]
    - CLAY MINERALS
  - CHROMIUM
    - CHROME-SPINEL (CR_2O_3 FROM $(FE,MG)(CR,AL,TI)_2O_4$ IN BASALT)
  - MANGANESE, IRON, ALUMINUM, COBALT, NICKEL
    - OXIDES AND CLAYS IN WEATHERING OR SHALLOW HYDROTHERMAL DEPOSITS
  - MAGNESIUM
    - MGO FROM $(MG,FE)_2SIO_4$ (OLIVINE) IN BASALT AND MG-CARBONATE
  - IRON AND NICKEL FROM METEORITE DEBRIS IN REGOLITH
    - NICKEL AND COBALT
    - PLATINUM GROUP, AND OTHER SIDEROPHILE ELEMENTS, E.G., AU

RESOURCES RESULTING FROM FRACTIONAL CRYSTALLIZATION

- LAYERED EXTRUSIVES AND INTRUSIVES
  - TITANIUM (ILMENITE)
  - CHROMIUM (CHROMITE)
  - IRON AND SULFUR (TROILITE)
  - NICKEL, IRON, AND COPPER (SULFIDES)
  - PLATINUM GROUP METALS

- PEGMATITES (LATE STAGE SILICA- AND WATER-RICH FLUIDS)
  - LITHIUM
  - URANIUM
  - BORON
  - OTHER “INCOMPATIBLE” ELEMENTS

- MARTIAN “KREEP” IF CONCENTRATED
  - PHOSPOROUS, POTASSIUM, RARE EARTH ELEMENTS

NON-METALLIC RESOURCES

- **DUNE MATERIAL FOR INSULATION AND ZENITH RADIATION PROTECTION**
- **ROAD AGGREGATE FROM NATURALLY SORTED MATERIALS**
- **SINTERED DUNE MATRIAL FOR CONSTRUCTION MATERIALS**
- **SILICA SAND FOR SOLAR CELL MATERIAL**
- **CLAY MINERALS FOR CERAMICS**
- **PLANT GROWTH MEDIUM (PROBABLY CONSISTENT PLANET-WIDE AND MAY REQUIRE SPECIAL TREATMENT)**

MARS DIFFERENCES
(RELATIVE TO THE MOON)

- ATMOSPHERE
- GROUND ICE
- POLAR ICE (MAY BE SOME ON MOON)
- WATER AND WIND SORTED MATERIALS

- FINELY PULVERIZED REGOLITH ABSENT
  - ATMOSPHERE PROTECTS (NOTE VIKING LANDERS AND PATHFINDER BOULDER FIELDS)
    - CURRENTLY CRATERS <~30 M NOT FORMED
    - SOLAR WIND (EXCEPT AROUND ZENITH)
  - MARTIAN "REGOLITH"
    - COARSE ROCK DEBRIS MIXED WITH EXTREMELY FINE WIND-BLOWN DUST
    - NO MICROMETEOR “TAMPING” LOCAL WATER-BOURNE MATERIALS
    - GENERALLY LESS DENSE
      - DUNES HAVE VERY LOW BEARING STRENGTH
    - GENERALLY MORE PORUS
      - ~60% VS. ~25%

MARS RESOURCES: CONCLUSIONS

- SELF-SUFFICENCY IS ASSURED FOR FUTURE SETTLERS
  - SOME EXPORTS TO DEEP SPACE USERS ARE LIKELY, I.E., LAUNCHES FROM MARS,
    - BUT NO KNOWN RESOURCES, STANDING ALONE, JUSTIFY EXPORT TO EARTH
      - AT A NET PROFIT (MARS ROCK MARKET LIMITED)
  - SOME CASH-FLOW COULD BE REALIZED FROM
    - BY-PRODUCTS OF OTHER NECESSARY ACTIVITES
- REMEMBER, HOWEVER,
  - THE STATEMENT IN RED, ABOVE, WAS SAID ABOUT THE MOON UNTIL 1985
    - BEFORE IMPORTANCE OF ^{3}HE WAS IDENTIFIED AT WISCONSIN

ENJOY THE VIEW WHEN YOU GET THERE!!!!!

"TRUE COLOR OF MARS"
PATHFINDER LANDER VIEW
NASA/JPL