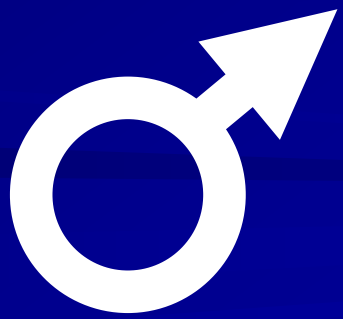
The Planet Mars

Our Current Knowledge
&
Implications for Human Missions and Settlements

Mars as been an object of interest since antiquity

- The first striking feature of Mars is its red color.
- The Romans gave the planet its name after Mars, their god of war, because of the planet's “blood-stained” countenance.
- The red planet, like a drop of blood in the sky, has long stood for gods of war in many ancient cultures.
- The shield and spear of the warrior form the planet's symbol.



Why is Mars Interesting?

- Mars is the only planet whose solid surface can be seen in detail from the Earth.
- Mars has the most Earth-like appearance of any planet in our solar system
  - Regional differences
  - Polar caps
  - Seasonal changes
- Since the late 19th century, Mars has been suggested as a possible abode for life.
- Mars has been identified as a potential goal for human exploration and/or settlement from the earliest human spaceflight concepts.

Why Go to Mars?

- **Biological**
  - Biological systems expand into new environments.
- **Social & Cultural**
  - Societies without external boundaries tend to become more internalized and restrictive.
  - Increase the number of “baskets”.
- **Technical**
  - Attempting the difficult is how progress is made.
- **Scientific**
  - Life on Mars?
  - Comparative planetology

Is Mars Too Hostile for Human Settlement?

> Extreme low temperatures

> No oxygen in atmosphere

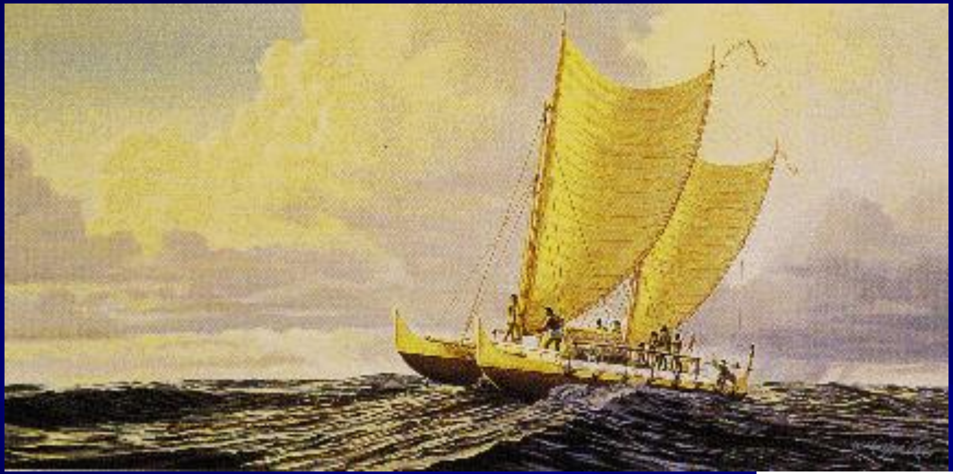
Humans Surviving or Flourishing in Lethal Environments - I

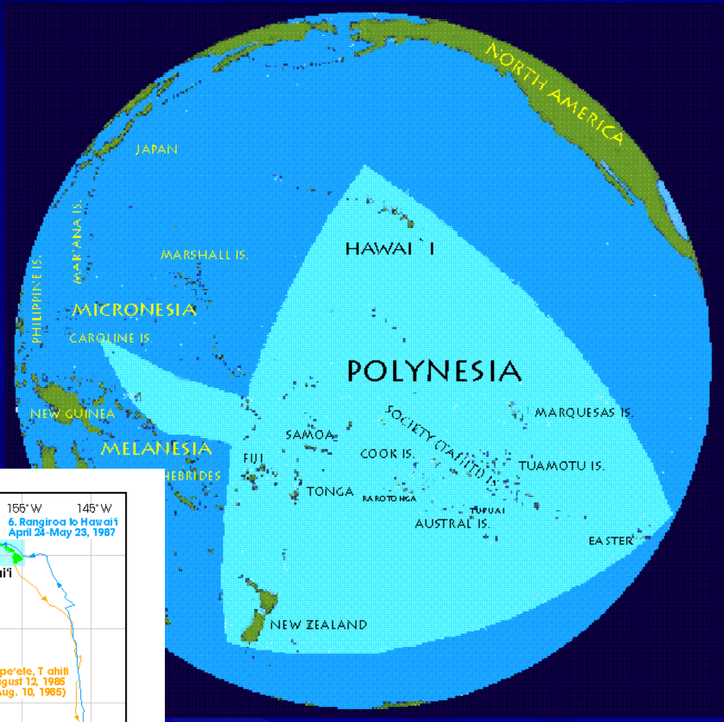
A technology-based approach using local resources

Humans Surviving or Flourishing in Lethal Environments - II


High daytime temperatures
Low nighttime temperatures
Extreme aridity
No significant vegetation

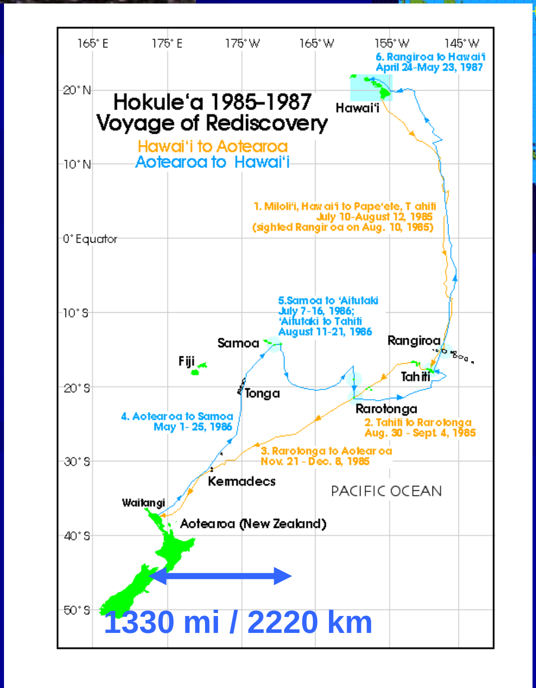
Humans Surviving or Flourishing in Lethal Environments - III



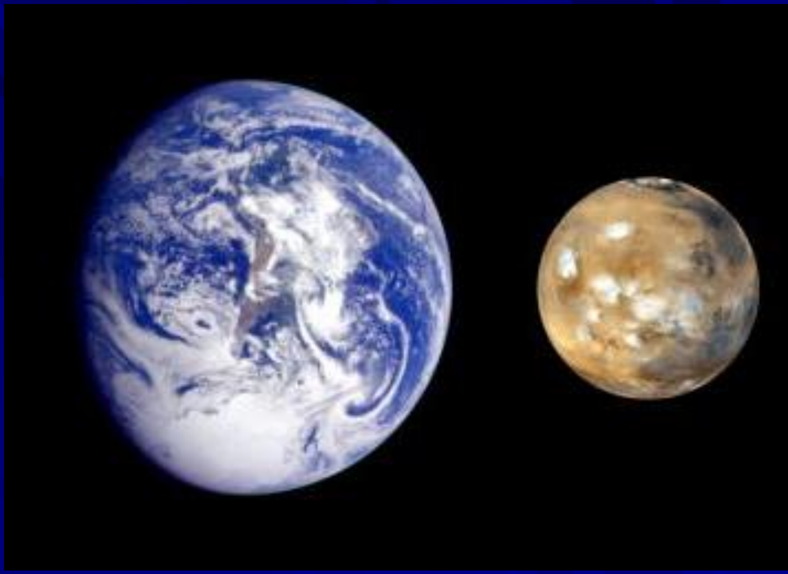


Navigating between tiny islands in a vast and unforgiving ocean.

Virtually no fresh water except what you bring.



Comparative Mars



- ~1/2 the diameter of Earth
  - Radius = 3,397 km = 0.532 $R_{\oplus}$
- ~11% the mass of Earth
  - Mass = 6.419 x 10^{23} kg = 0.1074 $M_{\oplus}$
  - Density = 3.91 gm/cm^3 = 0.708 $\rho_{\oplus}$
- ~28% of the surface area of the Earth
  - Approximately equal to the land area on Earth
- Surface Gravity
  - 3.7 m/sec^2 = 38% of Earth gravity
- Escape Velocity
  - 5.02 km/sec = 45% of Earth escape velocity

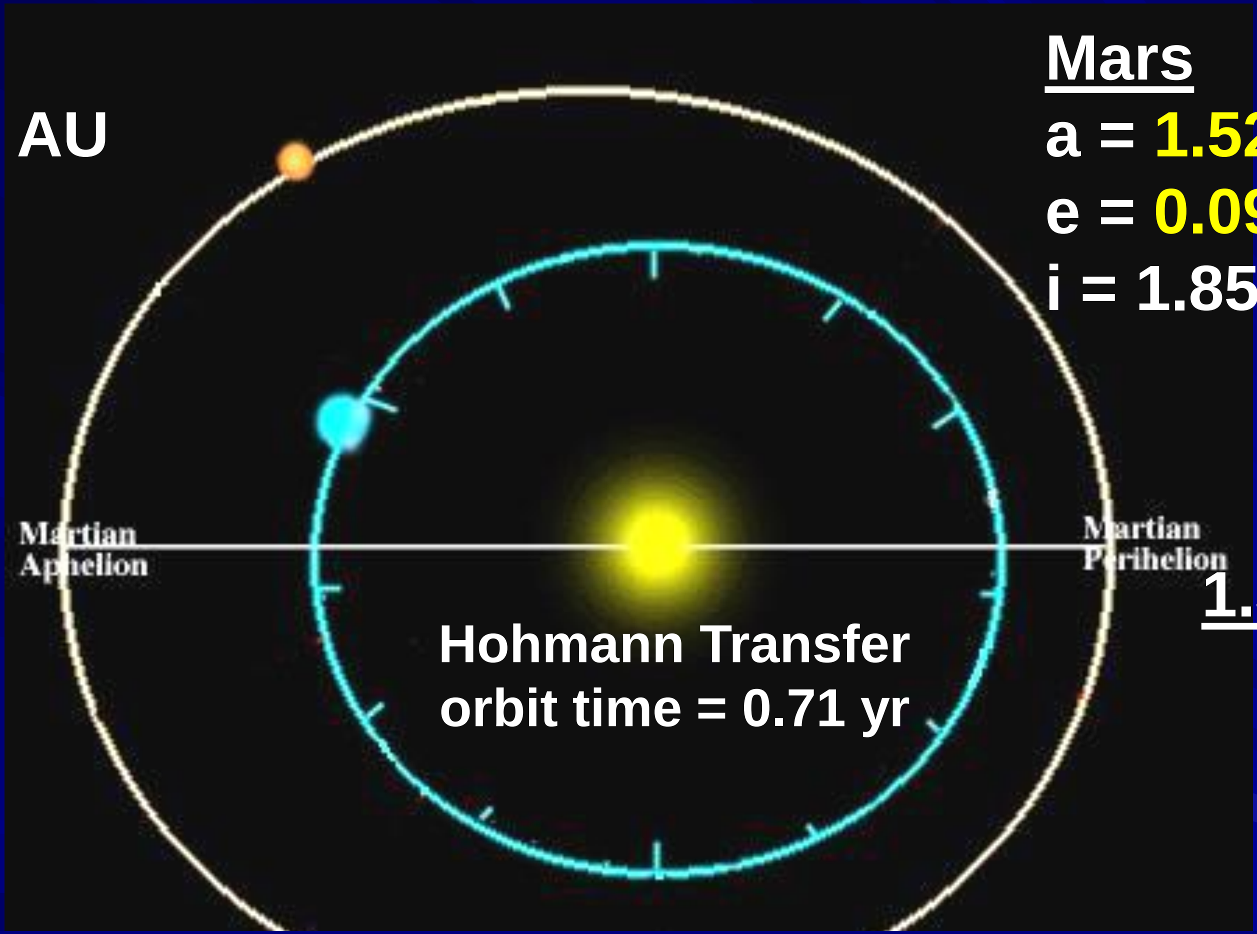
Martian Atmosphere

- CO_2 = 95% [Earth = 0.03%]
- N_2 = 2.7% [Earth = 78%]
- Ar = 1.6% [Earth = 0.9%]
- H_2O = 0.006% [Earth = 0.01%]
- Surface pressure ~ 6 mbar ~0.006 $P_{\oplus}$ ~0.6% $P_{\oplus}$
- Atmospheric pressure varies with seasons.
- Atmospheric pressure varies with elevation.
  - ~11 mbar on floor of Hellas basin
  - ~0.3 mbar at summit of Olympus Mons

Orbits of Earth and Mars

Earth
a = 1.000 AU
e = 0.017
i = 0.0 °

Mars
a = 1.524 AU
e = 0.093
i = 1.85°



1.666 AU

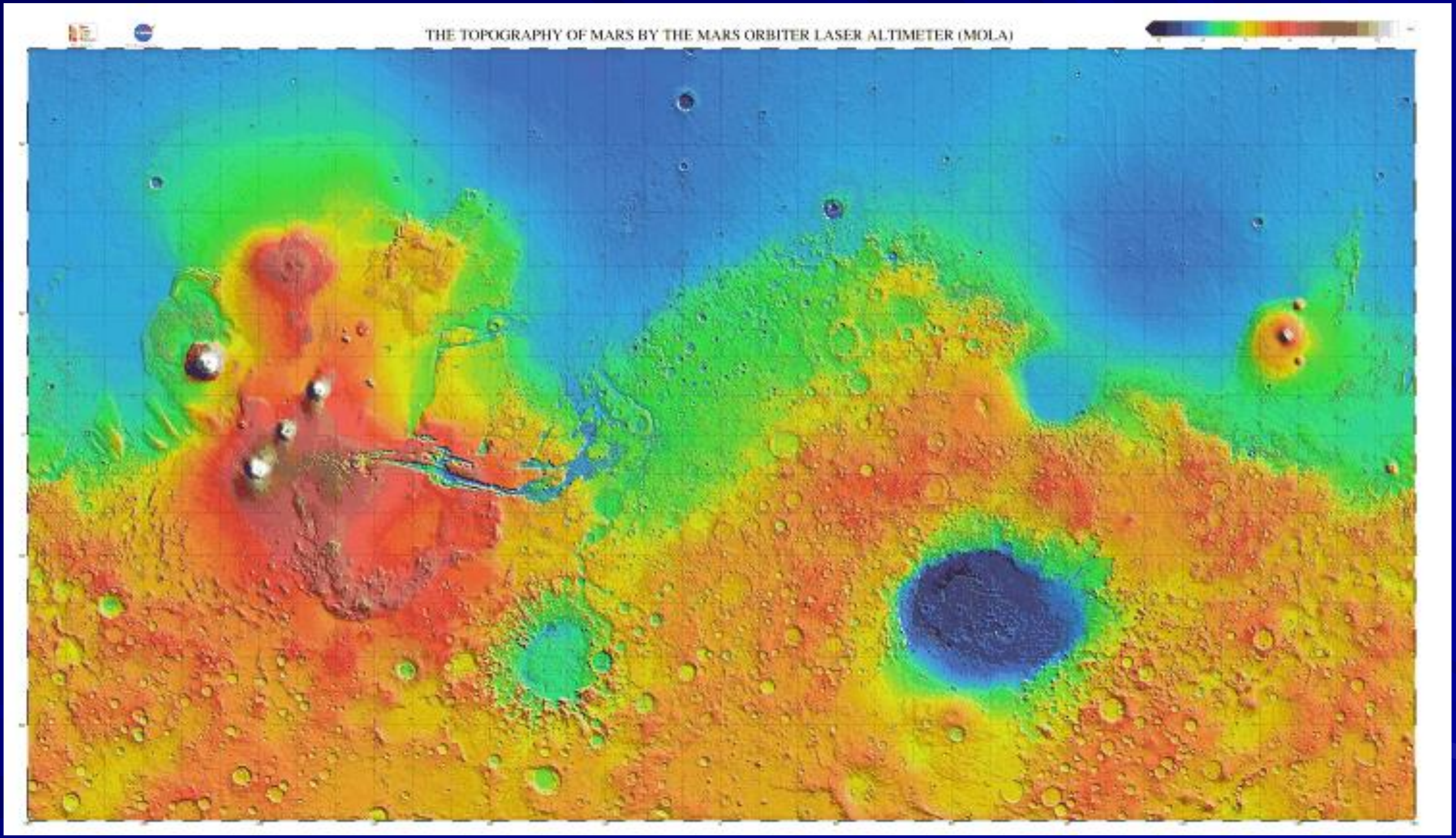
1.382 AU

At aphelion Mars receives only 69% as much energy from the Sun as it does at perihelion.

Major Martian Terrain Types

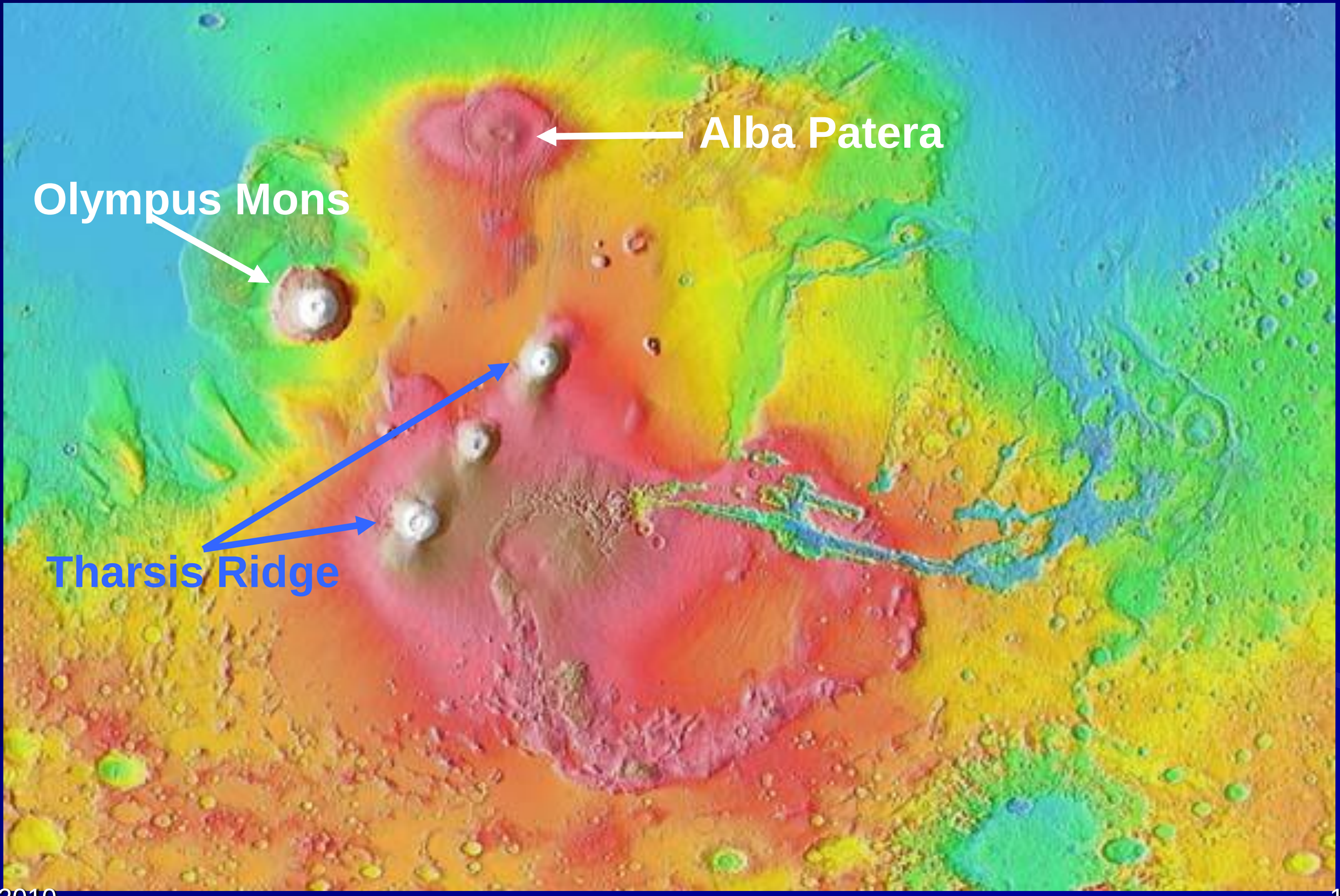
- Cratered highland terrains
  - Southern hemisphere (Older)
- Volcanic terrains
  - Tharsis and Elysium regions
- Lowland plains
  - Northern hemisphere (Younger)
- Polar caps and layered terrains
- Canyons and channels

Mars Topography



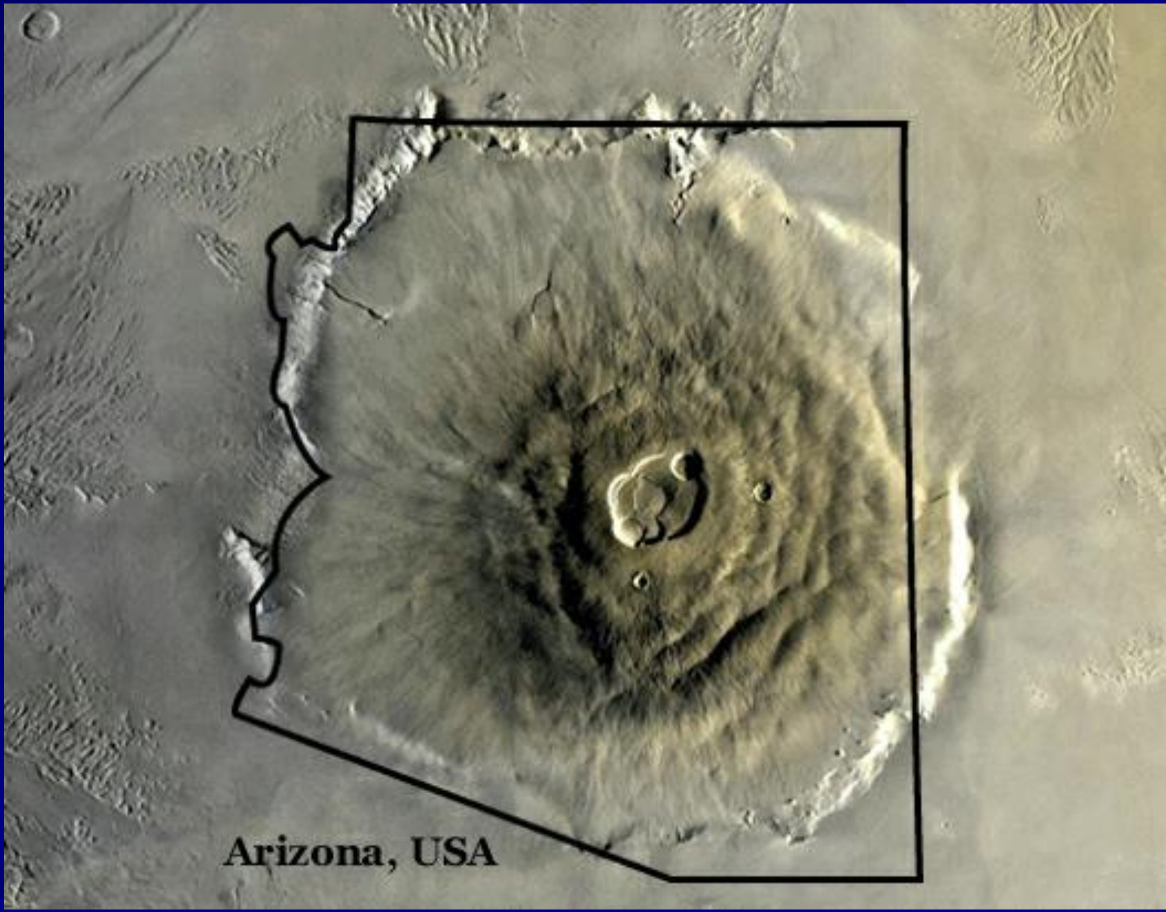
MOLA Science Team
Mars Global Surveyor

Large Volcanic Features

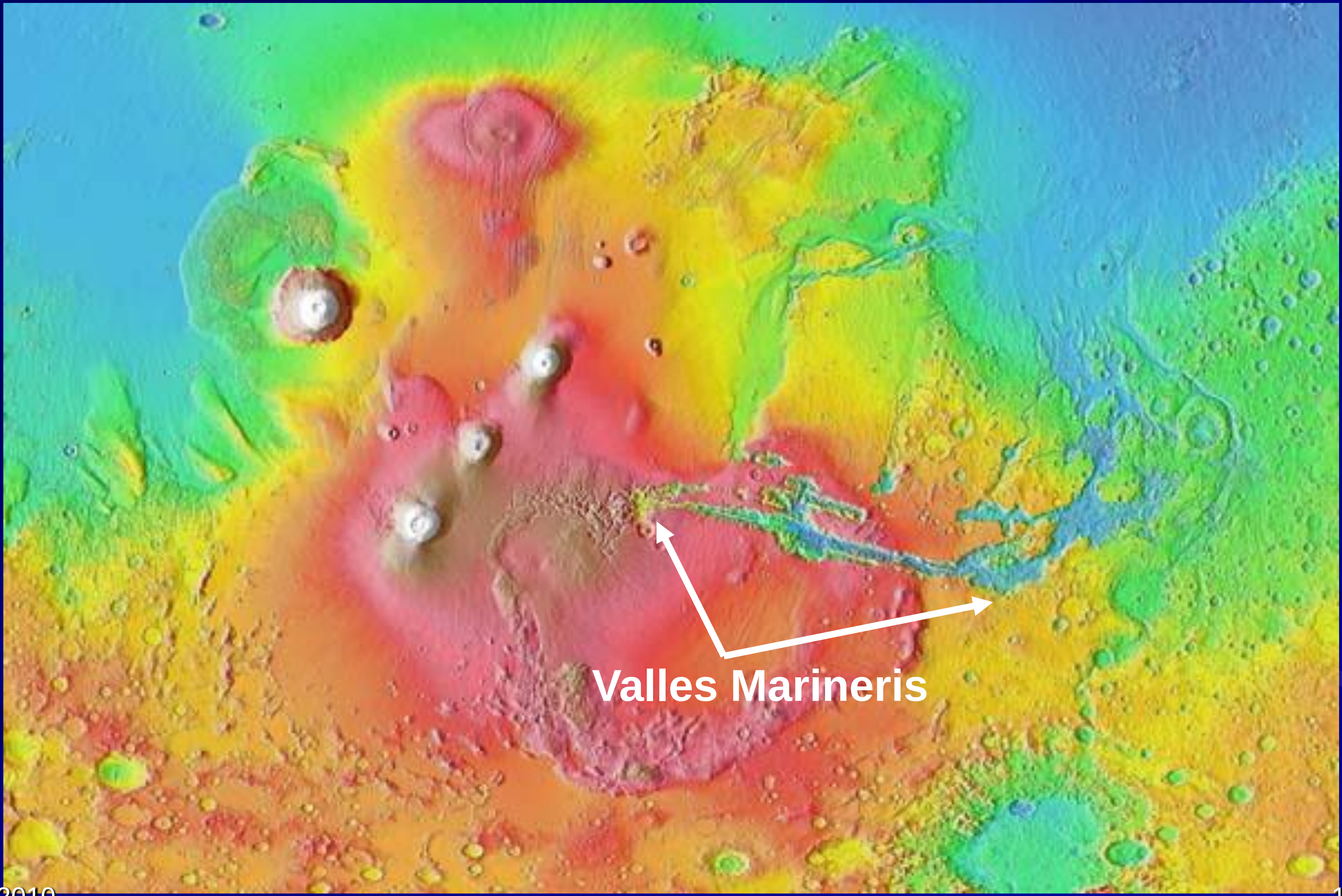


Olympus Mons

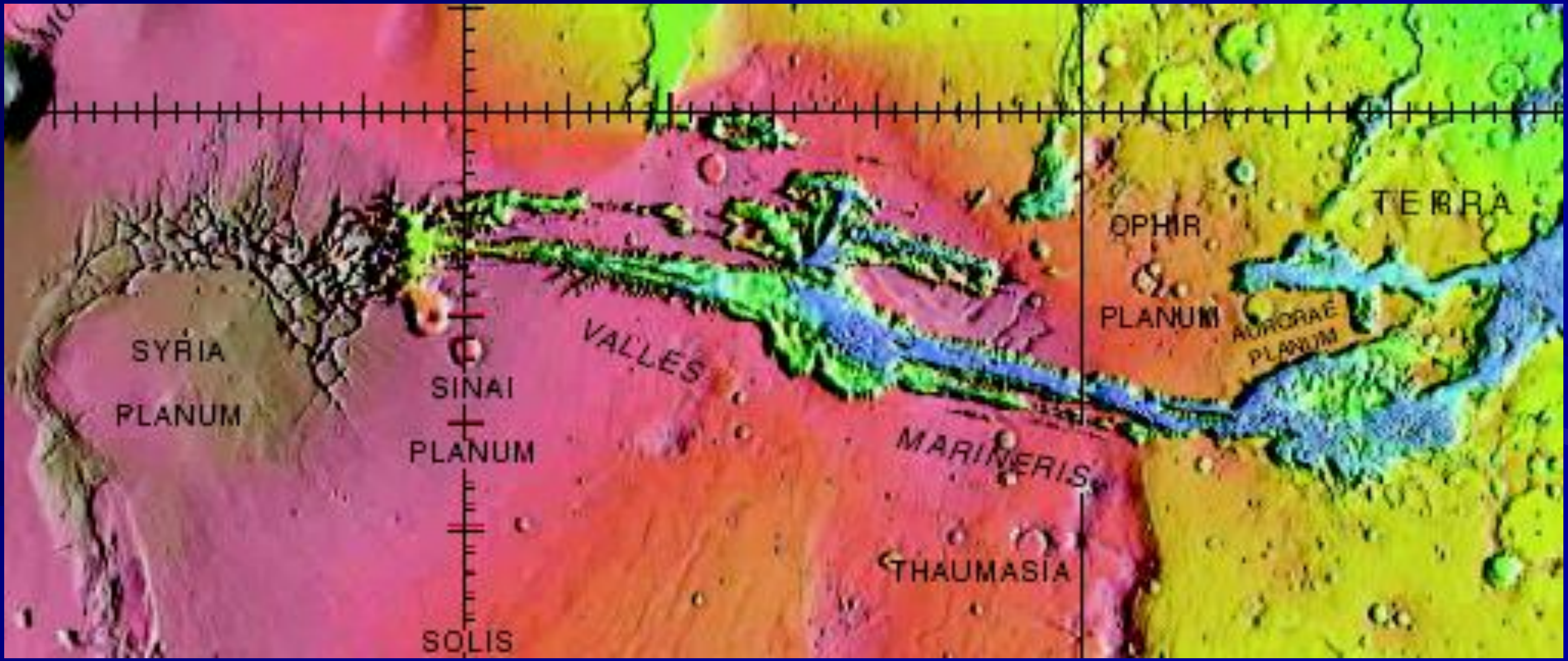
- Shield volcano.
- Tallest mountain in the solar system.
- Summit ~24 km above base level
- Very broad



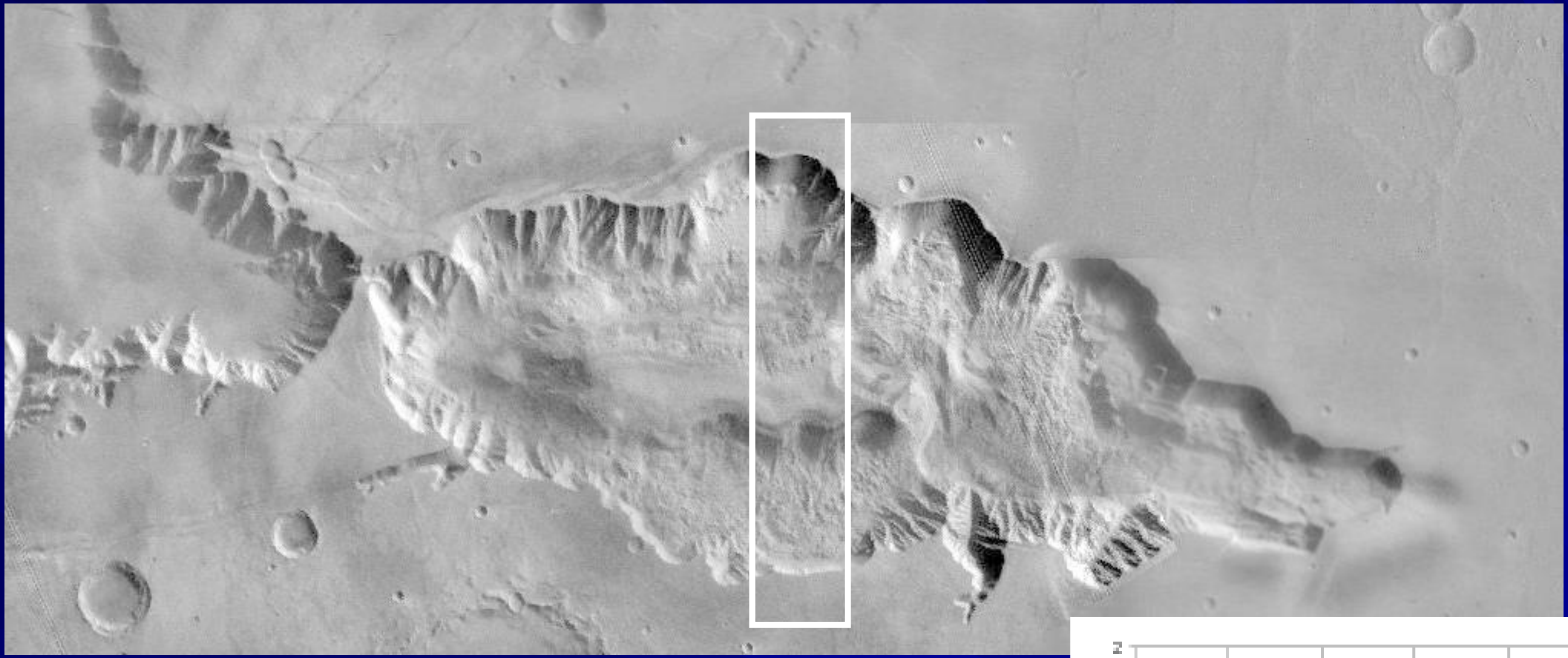
Canyons



- The canyons of the Valles Marineris form a long series of parallel troughs up to 11 kilometers deep.
- The canyons formed within the volcanic plains of the Tharsis Montes plateau.



Hebes Chasma



Hebes has a central mesa.

Depth north of the mesa ~7 km.

Depth south of the mesa ~5 km.

Hebes is a closed basin!

Jernsletten (2002)

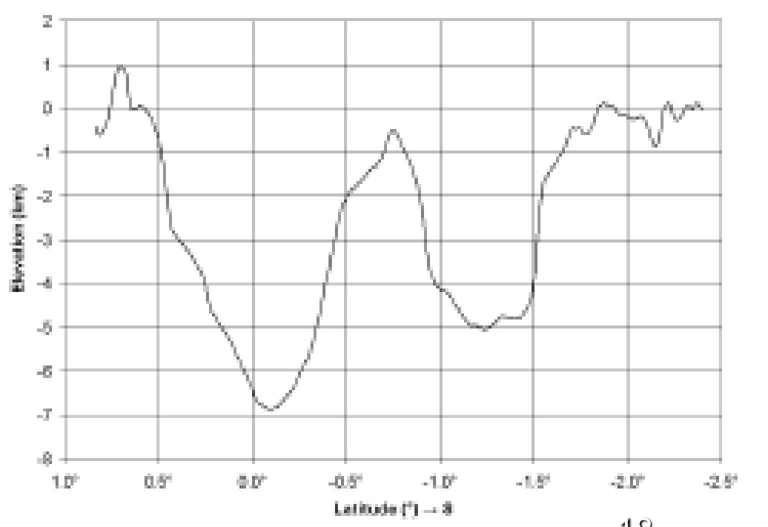
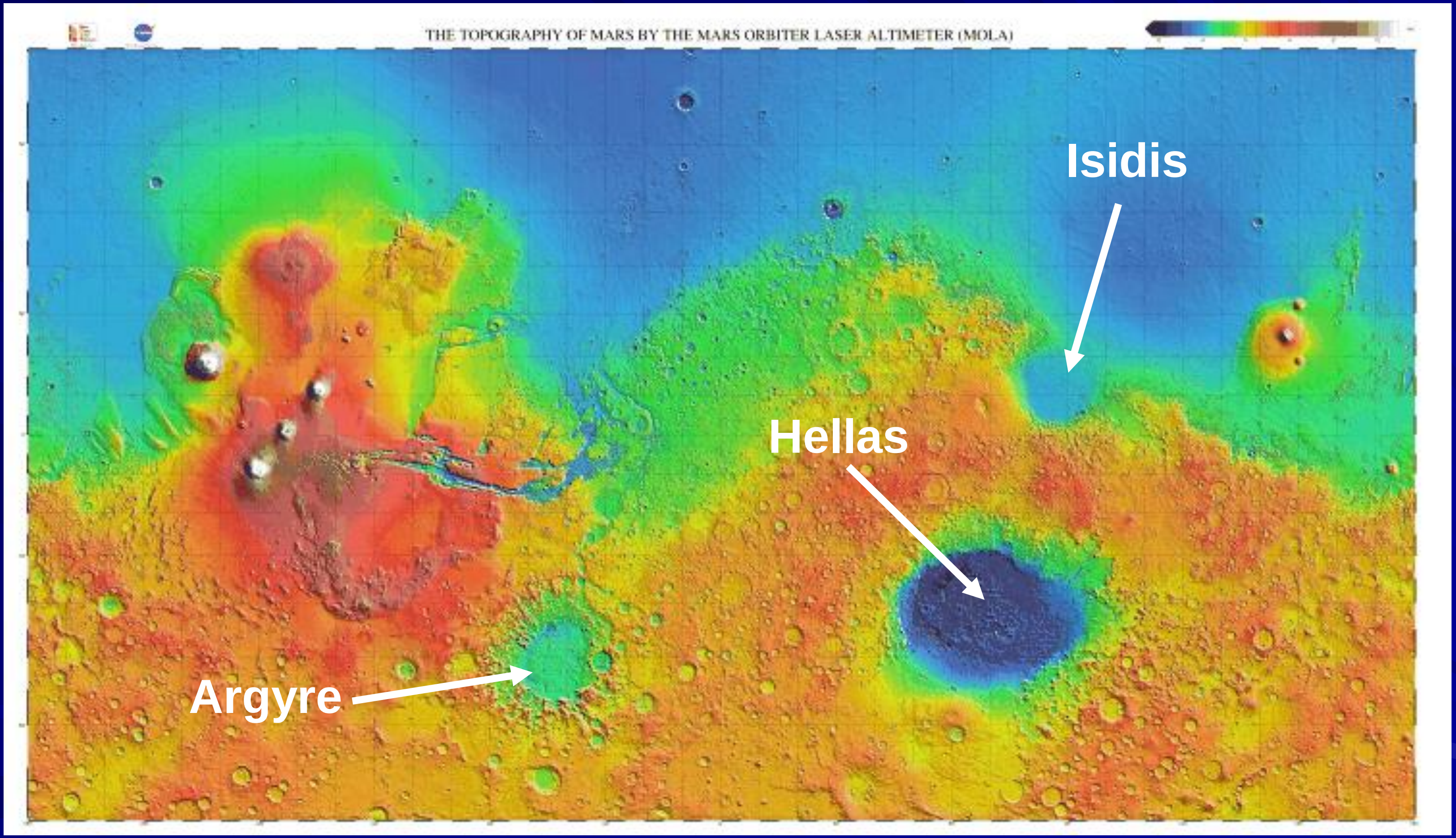


Figure 4. Profile of Hebes Chasma.

Impact Basins



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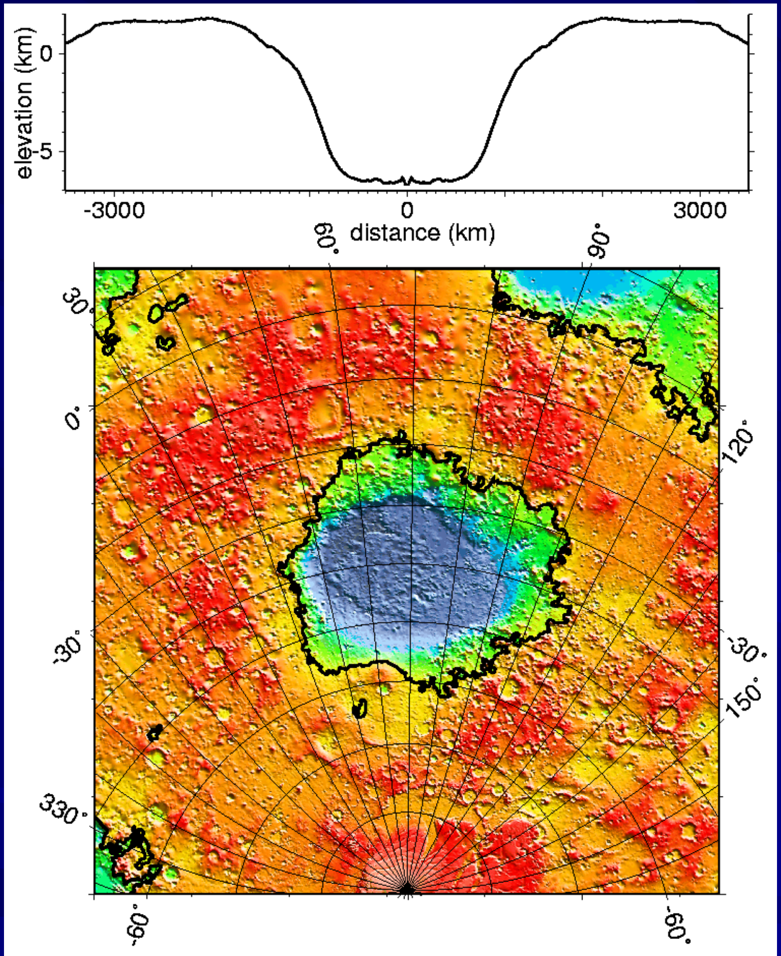
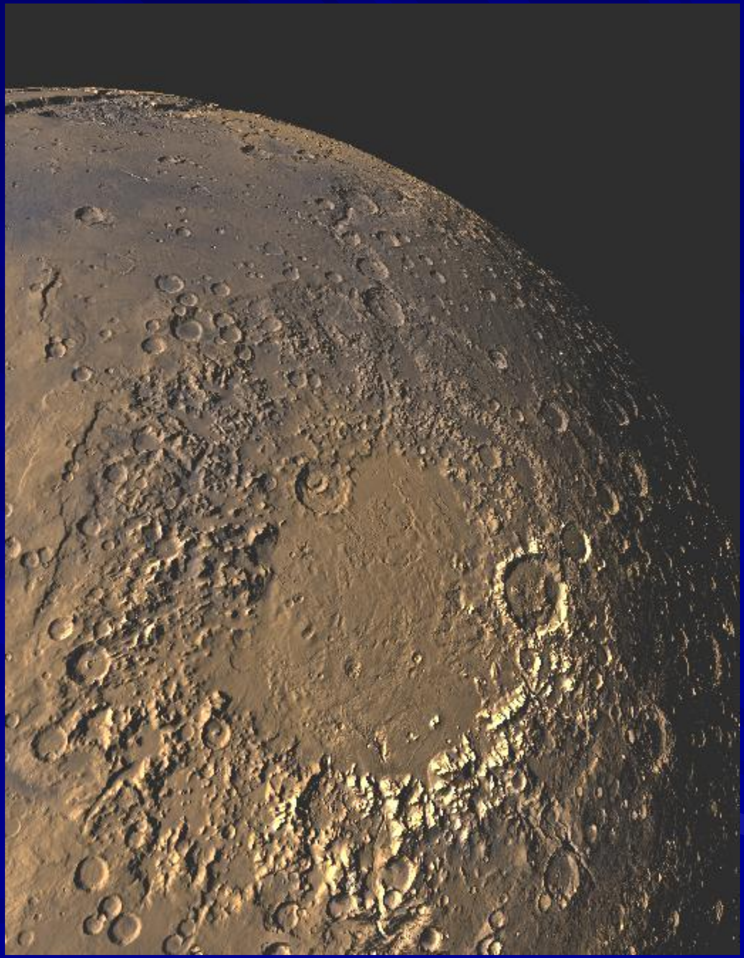
Mars Global Surveyor

Impact Basins



Hellas



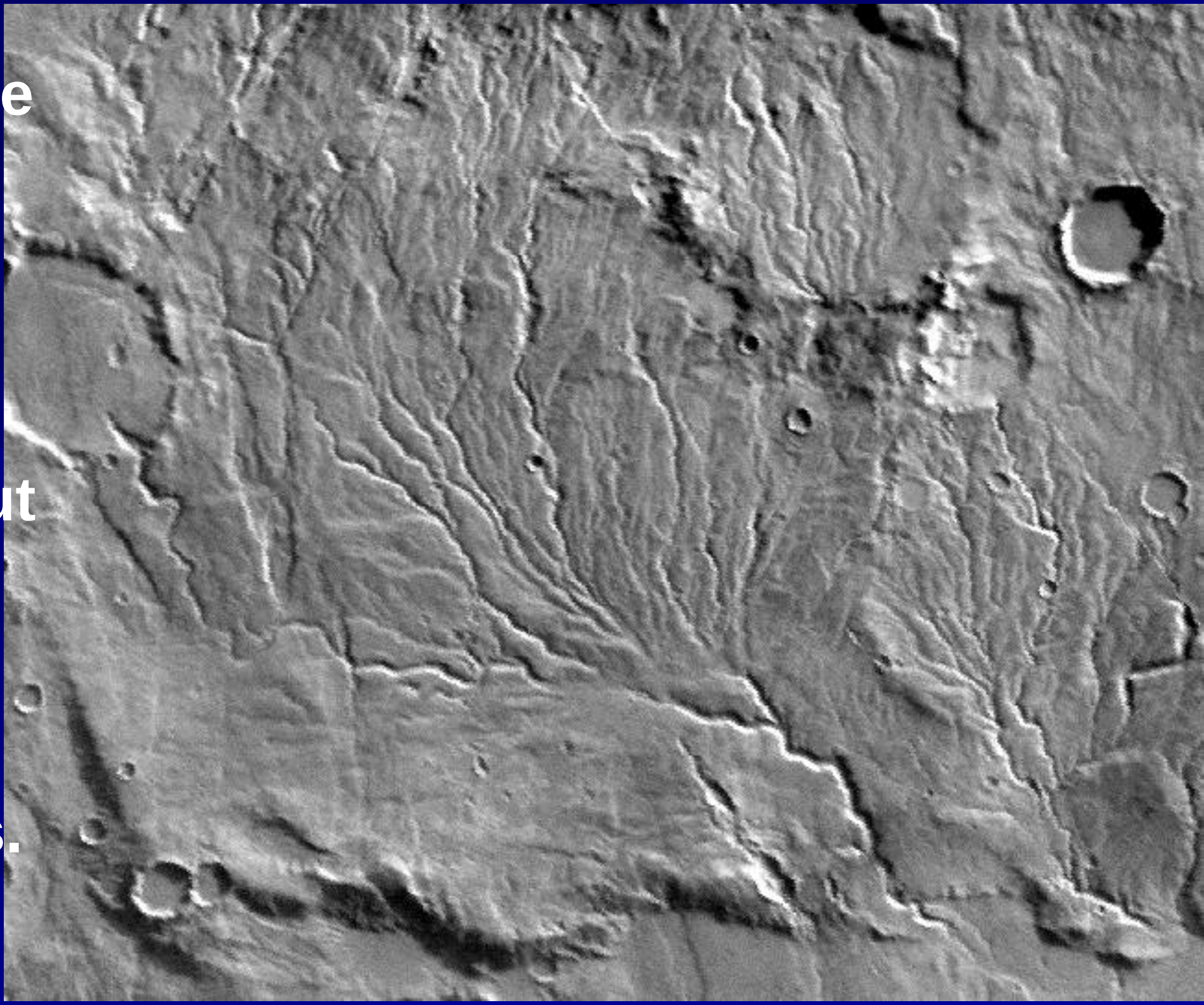
Argyre

Channels

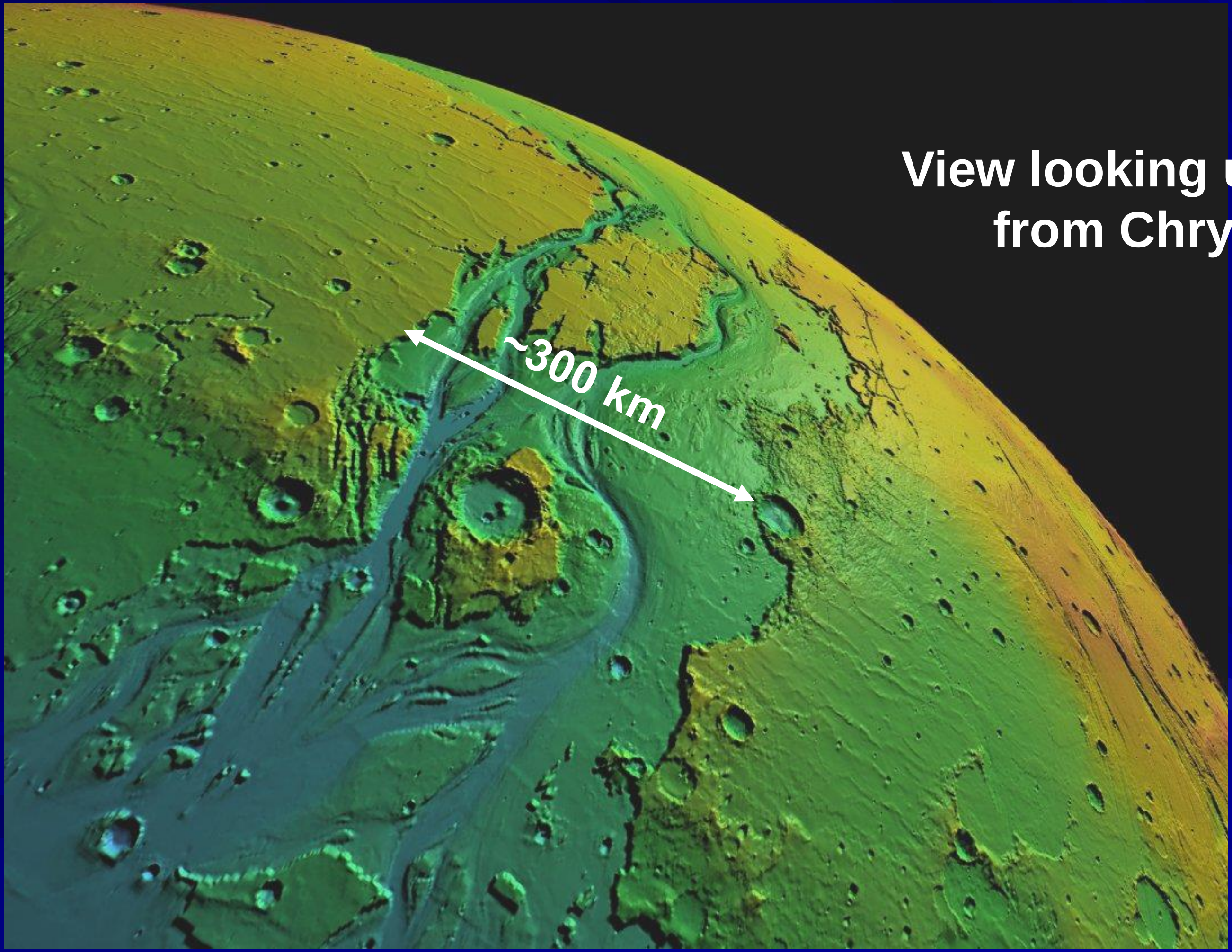
- **Runoff channels (dendritic)**
  - River-like patterns / valley networks in southern highlands
  - Indicate precipitation or snowmelt running across surface
  - Implies a much thicker atmosphere and warmer climate early in Martian history
- **Outflow channels**
  - Equatorial regions
  - Formed by massive floods triggered by the sudden release of underground water or melted ice
  - Chryse outflow: implies enough water to cover Mars to depth of 50 m!

Dendritic Drainage Patterns
Valley Networks

- Resembles drainage systems on Earth (channels merge together to form larger channels).
- Area shown is about 200 km across.
- Located in older regions of the southern highlands.

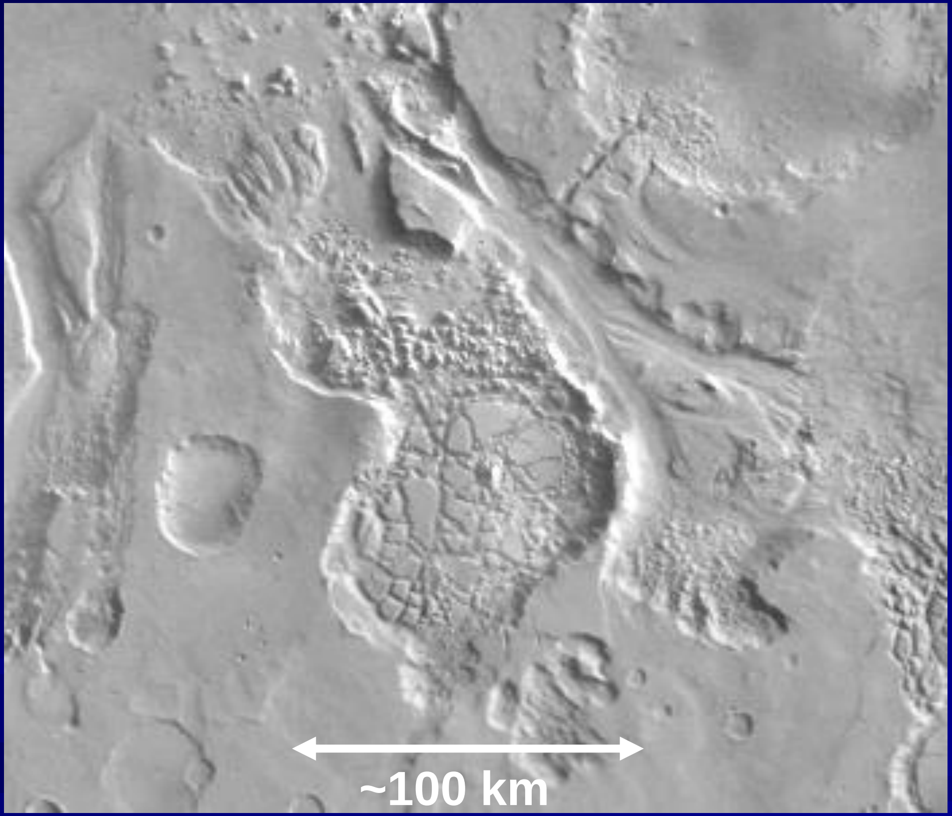


MOLA Perspective of a Large Outflow Channel



View looking up Kasei Vallis from Chryse Planitia

Water Sources for Outflow Channels

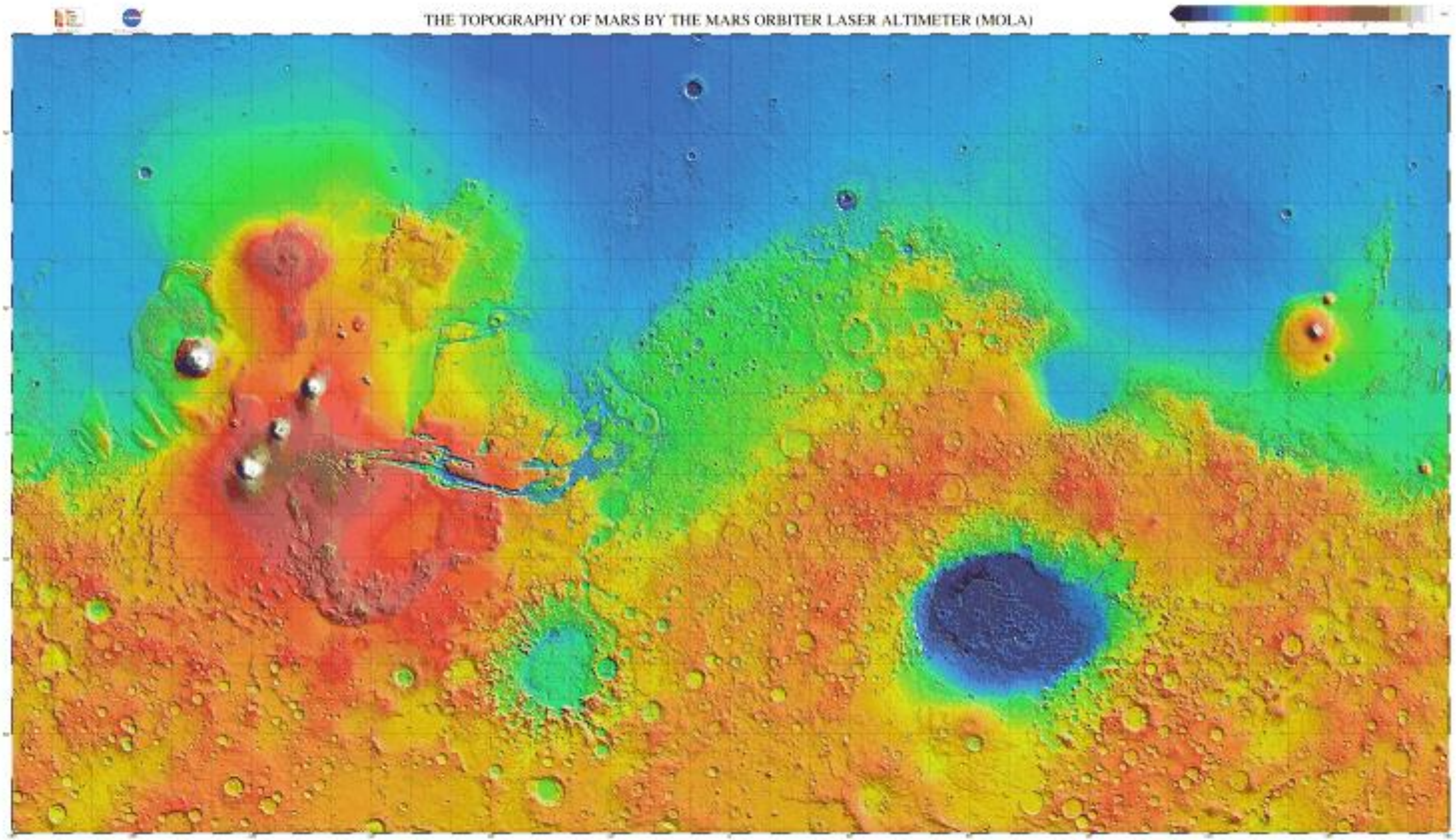


- The chaotic terrain of the Hydaspis Chaos which was the water source source for an outflow channel .
- The chaotic terrain is produced by surface collapse after melting of the subsurface ice and escape of the liquid water.
  - Thermokarst

Crater with Fluidized Ejecta

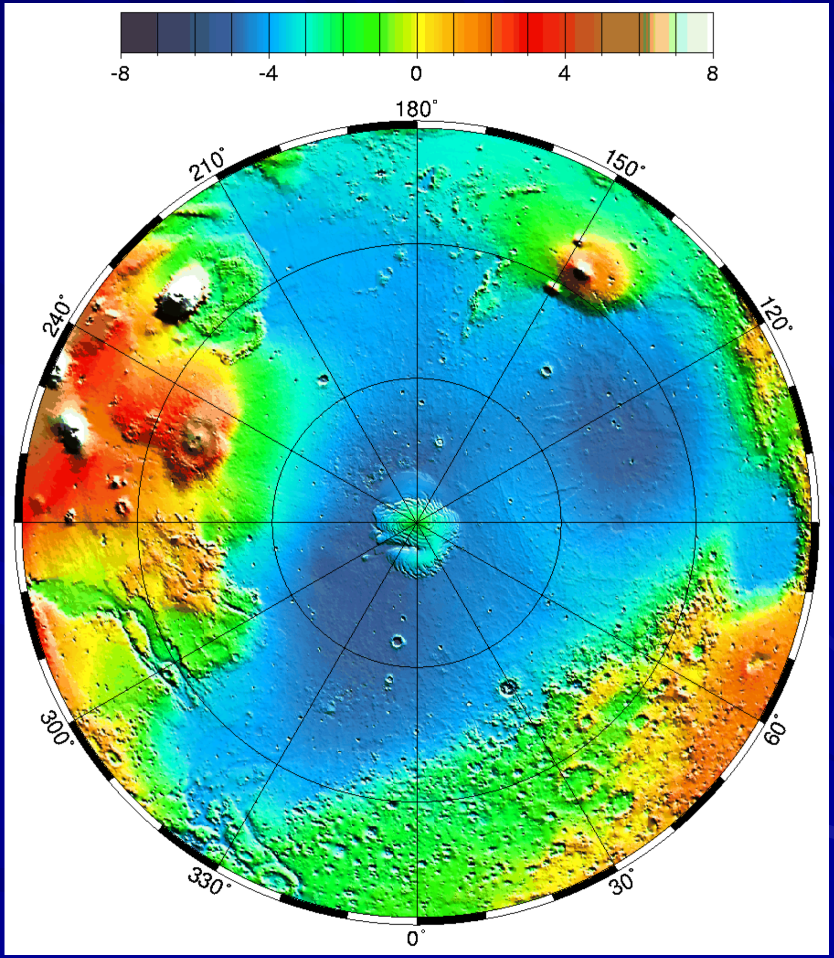
- Overlapping lobes formed by gas-borne flow of ejecta.
- Impacting object vaporized ice (permafrost) present in the subsurface.
- Crater is 18 km in diameter.

Northern Plains



Northern Plains

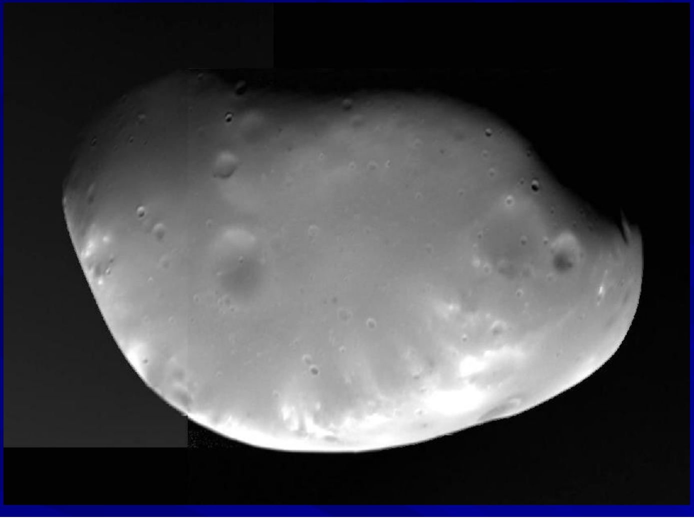
- Topographic lowlands
- Very flat
- Low crater densities
- Deposits of sediments
  - – Wind-borne dust?
  - – Water-borne sediments from outflow channels?
  - – Volcanic ash?
  - – Sea floor deposits?



Crater being exhumed by erosion of plains deposits

- Indicates that kilometers of deposits were laid down in the Northern lowlands.
- Indicates that some regions of the northern lowlands are undergoing erosion in the present epoch.
- Erosion must be primarily by wind.

The Martian Moons: Phobos & Deimos



Phobos

- 28 x 23 x 20 km
- Orbital Radius = 9,380 km
  - Inside synchronous orbit @ 20,400 km
- Orbital Period = $7^{hr}\ 39^{min}$

Deimos

- 16 x 12 x 10 km
- Orbital radius = 23,460 km
  - Outside synchronous orbit
- Orbital period = $30^{hr}\ 18^{min}$

“Hurtling Moons of Barsoom”

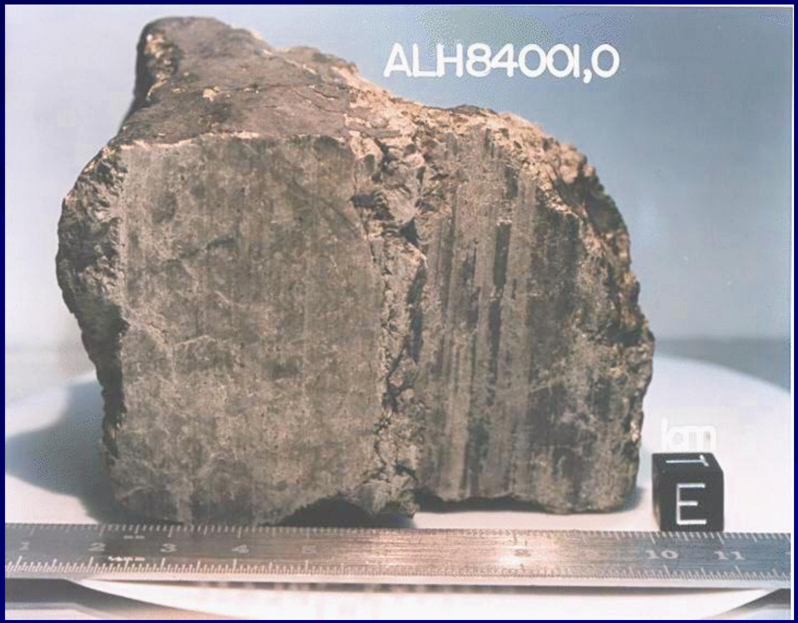
- In 1912 Edgar Rice Burroughs published a story entitled "Under the Moons of Mars" (printed in book form in 1917 as *A Princess of Mars*).

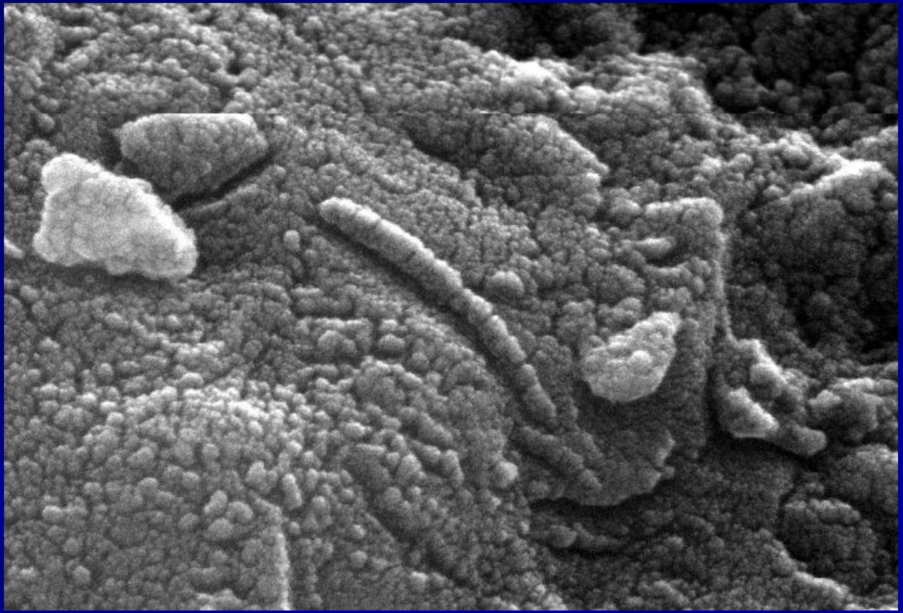
- In his story, he referred to the "hurtling moons of Barsoom" (Barsoom being the "native" word for Mars in the fictional account).

“Hurtling Moons of Mars”

- Burroughs had been inspired by the fact that Phobos, having an orbital period of slightly less than 8 hours, would appear from the surface of Mars to rise in the west and set in the east only five and a half hours later.
- Despite Burroughs' phrase, the outer moon, Deimos, doesn’t "hurtle”.
- Deimos takes nearly 60 hours to cross the sky from east to west, rising on one day and not setting again for over two more days.)
- Maybe he should have mentioned this “turtling” moon of Barsoom?

The Life on Mars Question





The conditions on early Mars were conducive to the origin of life.

Did life arise on Mars?

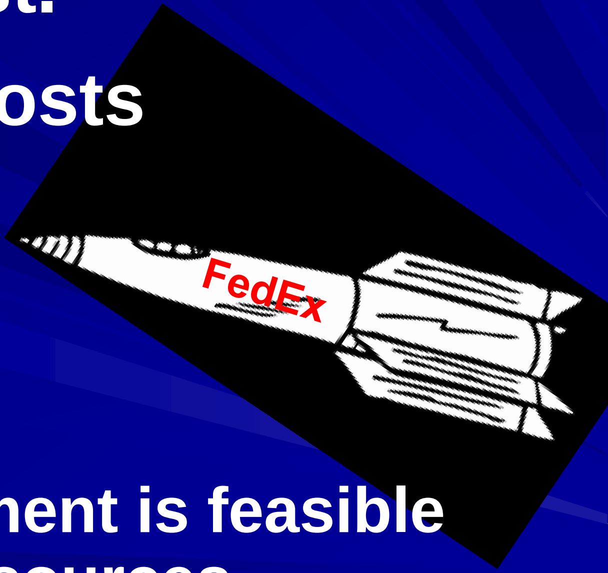
Does life survive on Mars today?

Mars Geology - Summary

- The Martian surface exhibits a wide range of terrain types and geologic features.
- Although volcanic activity has decreased, it is probable that some Martian volcanoes are dormant rather than extinct.
- The lack of craters on many surface regions indicate that these regions are undergoing active erosion or deposition.
- The possible presence of current or fossil life on Mars is a major driver & impediment to the Mars exploration program.

Human Missions / Settlements

- **We don't use the word "colonies" for the same reason that we don't – anymore - use the word "crusade" to describe American military policy in the middle East.**
- **Number 1 issue: Economics / Costs**
  - **Affordable**
  - **Political will and sustainability**
  - **International effort?**
  - **No human Mars mission or settlement is feasible without extensive use of *in situ* resources.**
    - **Best guessitimate? $200,000/kg from Earth-to-Mars**

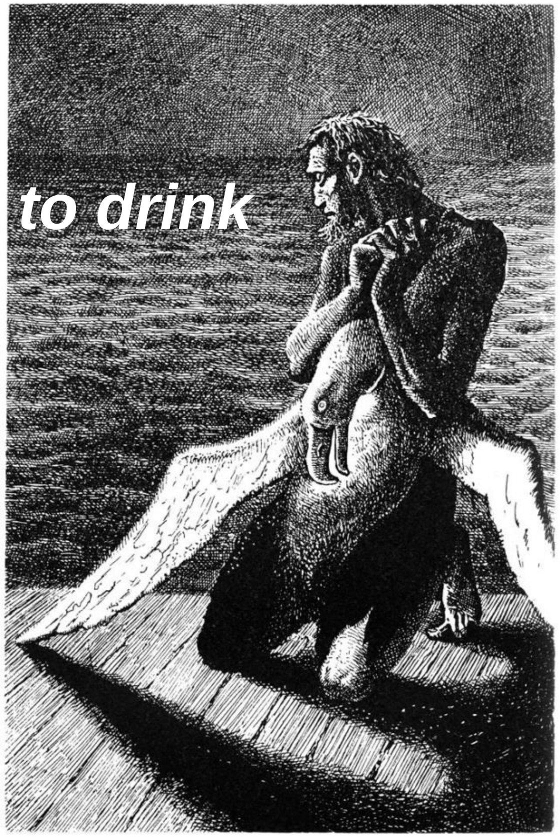


What is needed for a Human Mission / Settlement?

- **Human Life Support**
  - Food
  - Potable Water
  - Breathable atmosphere
  - Shelter & Radiation protection
- **Transportation**
  - Fuel for “surface↔orbit” & “orbit-to-orbit” vehicles
  - Surface transport

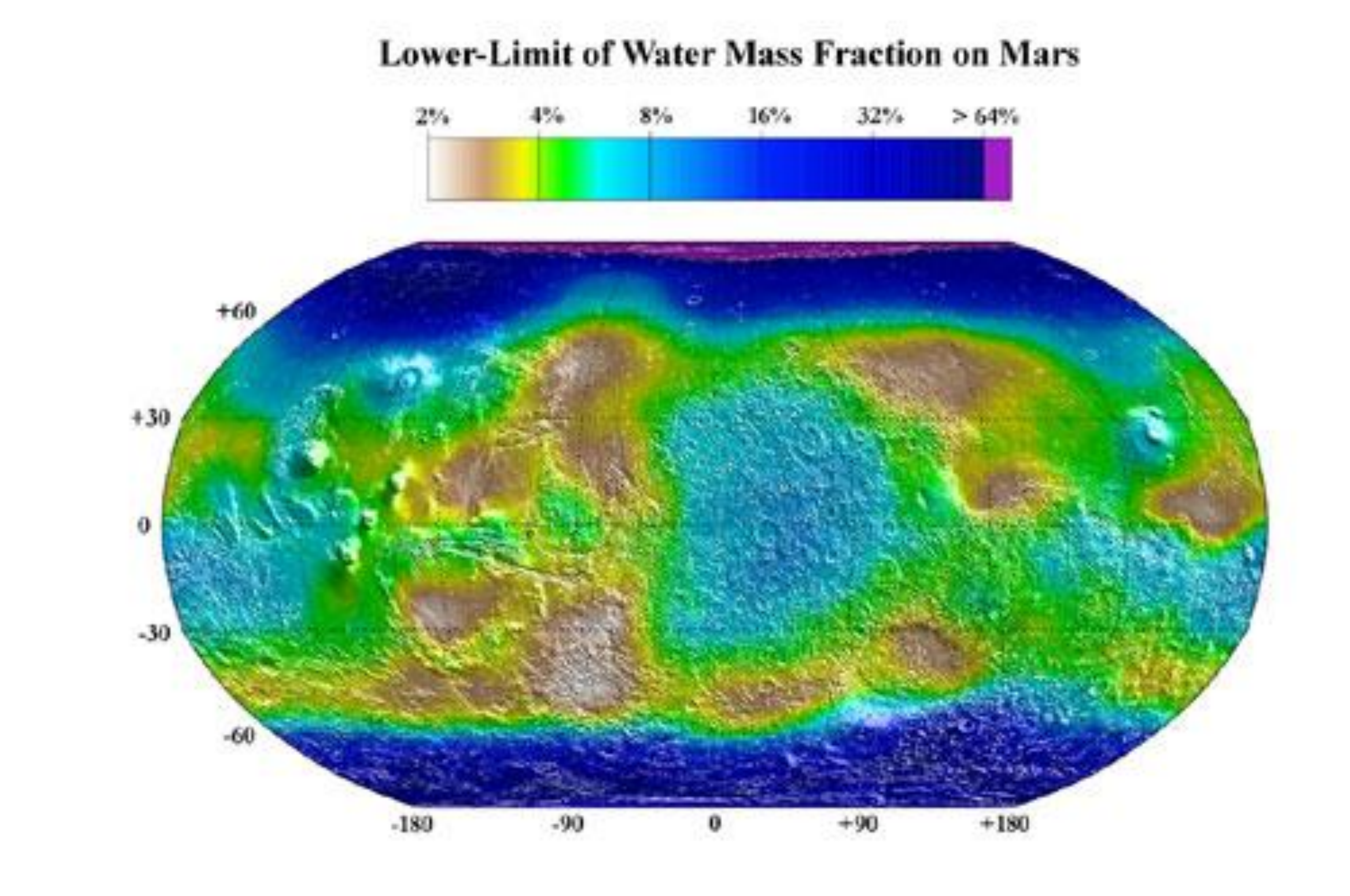
Water on Mars

Ice, ice everywhere & lots of drops to drink



- **Surface ice**
  - North polar cap
    - Primarily water ice
  - South polar cap
    - Dry ice (CO_2 ice) and water ice
- **Permafrost**
  - Present at shallow depth over most of surface (Odyssey mission)
  - Deep permafrost in many areas
- **Underground**
  - Liquid brines(?)

Water (Ice) in Upper Meter of Martian Surface



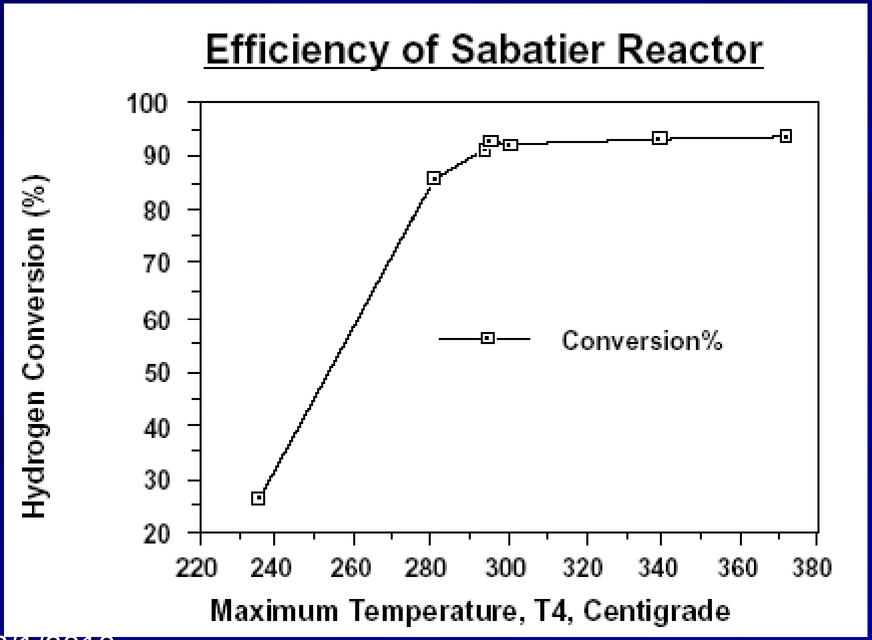
Mars Odyssey

If you can't figure out how to get pure water from soil ice ---

Of course, the "white lightning" folks weren't much interested in the water ---

Sabatier Reaction

- Carbon Dioxide & Hydrogen → Water & Methane
  - $CO_2 + 4H_2 \longrightarrow CH_4 + 2H_2O$
  - Exothermic and spontaneous with a nickel catalyst
  - >90% conversion on first pass
  - Oxygen can be produced and hydrogen recovered and recycled by electrolysis of the water



Atmospheric Resources

- "Nearly a vacuum" like the Moon
  - Very low pressure
    - Ave = 0.6 mbar (0.6% of Earth normal)
  - Enough for wind and dust to be an issue
- Abundant source of CO_2 & N_2 gas
  - 95% CO_2
  - 2.7% N_2
  - 1.6% Ar (*exclude from habitat atmosphere?*)

Producing a Breathable Atmosphere for a Habitat

- Easy to produce Earth-like atmosphere
  - 80% N_2
  - 20% O_2
- Can tolerate a "leaky" life support system
  - N_2 can be replenished from the atmosphere
  - O_2 can be produced by electrolysis of H_2O
    - H_2 to Sabatier reactor

Food Supply

- **The cost of delivering an entire mission's worth of even freeze dried food would be very expensive.**
- **Substantial benefits of local food production**
  - **Fresh food & morale**
  - **Psychological benefit of "green space"**
  - **Hands-on activities with tangible results**
- **Need:**
  - **Soil**
  - **Water ✓**
  - **Light ✓**

Martian "Soils"

- **MER-B (Opportunity) Landing Site**
  - Basaltic sand
  - Hematite (iron oxide) spherules
  - Calcium and magnesium sulfates
  - Jarosite (Iron hydroxide sulfate)
  - Deposited in acid lake environment
- **MER-A (Spirit) Landing Site**
  - Olivine +/- pyroxene (basaltic sand)
  - Iron oxides (Hematite, Magnetite)
  - Largely unweathered basalt
  - Nearby Columbia Hills appear to be lake deposits

Soil at MER-B (Opportunity) Meridiani Planum Site

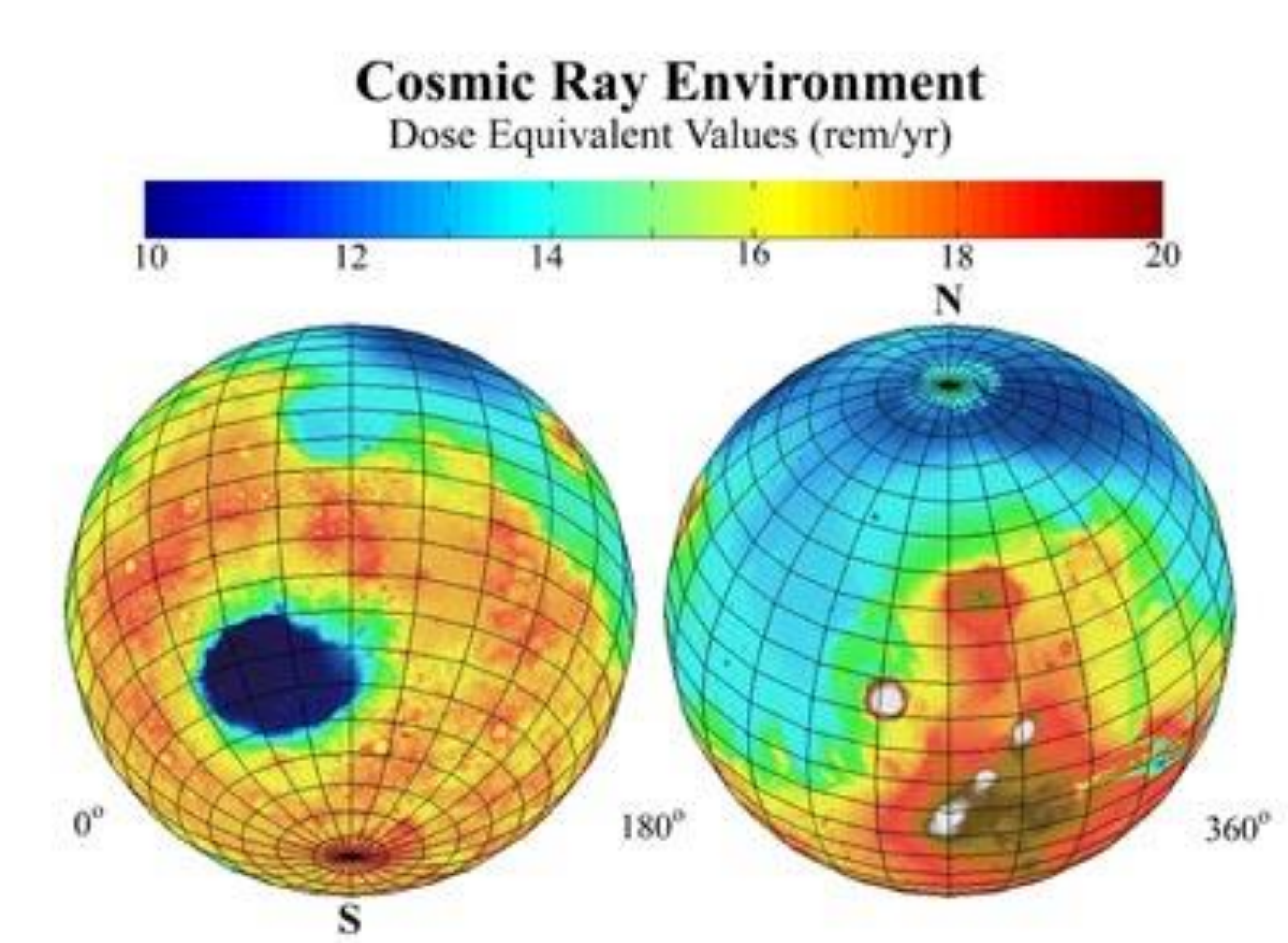
The patch of soil is 3 cm across. The spherical iron oxide grain in the lower left corner is ~3 mm in diameter.

Rock layers with a plethora of iron oxide spherules weathered out

Soils for Greenhouses

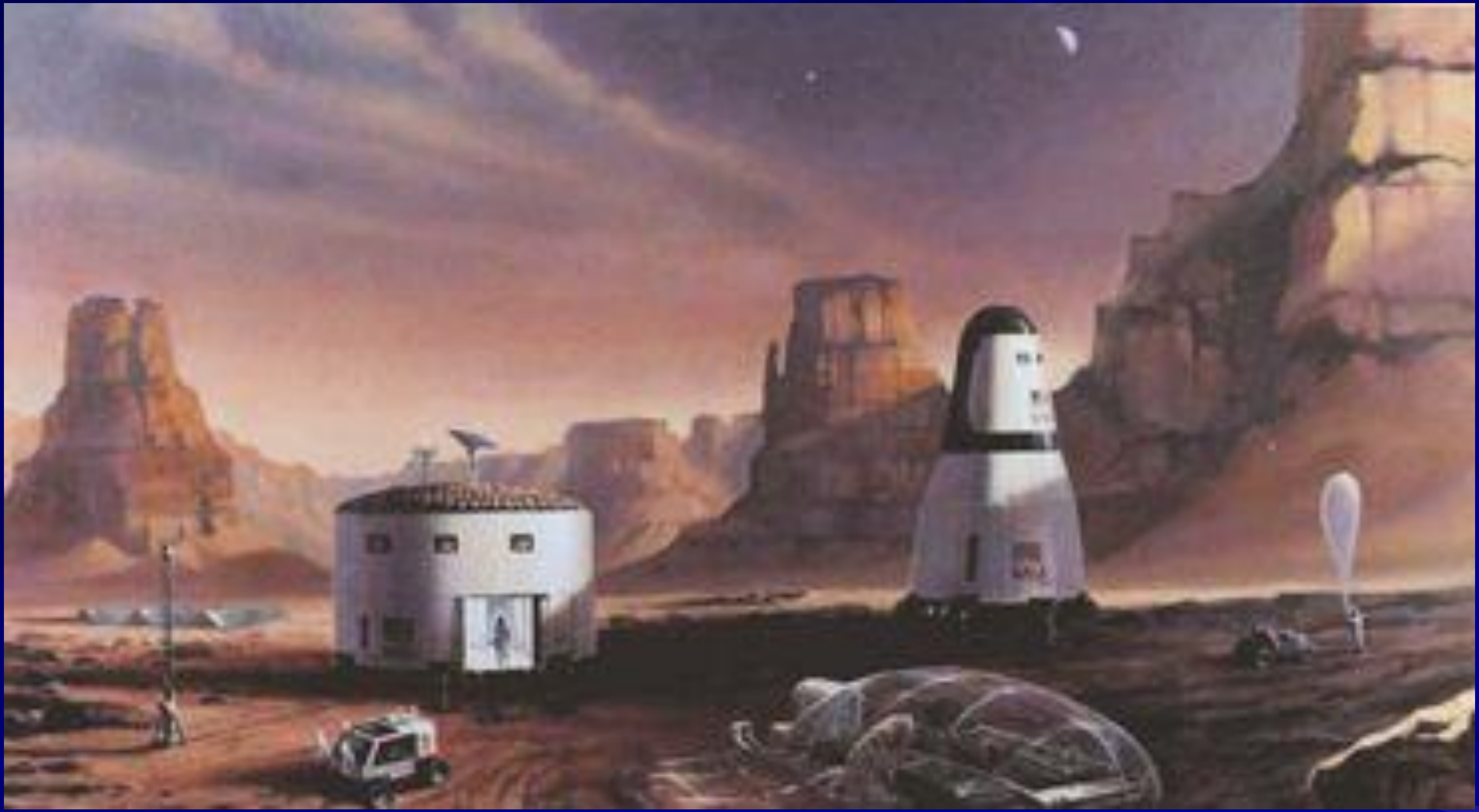
- The basaltic sand and fragments eroded from the bedrock resemble volcanic ash and glacial loess deposits
  - Both contain most of the essential nutrients for plants
  - Lack nitrates(?) and carbonaceous material (humus)
- Contain toxic levels of sulfates and peroxides
  - Toxics would be leached from soil prior to use
- Martian soils can be readily processed for use in agriculture

A significant cosmic ray flux reaches the surface



Current NASA Limits: 50 rem/yr   Lifetime = 100 rem

Lab/Habitat & Mars Ascent Vehicle



Although very scenic, the real landing site would probably be flat and featureless. And the habitats buried!

Mars Fuel Option - Rationale

- **Propellant is the largest single commodity that must be delivered to Mars for any round-trip mission.**
  - **Von Braun (1962) designed a mission using 10 ships each with an initial mass of 3700 tons. 3 ships (50 tons / each) returned. Initially each had 3600 tons of fuel**

- ***In situ* propellant production significantly reduces the initial mass that must be delivered to Mars.**

Strawman Calculation

- Consider a bare-bones Mars Mission Return Vehicle based around 3 CEVs
  - Six crew on a Hohmann Transfer Trajectory
  - Dry mass ~ 50,000 kg
  - Supplies
    - Expendables ~ 2500 kg
      - Food: 0.5 kg/day/person
      - Oxygen: 1 kg/day/person
    - Margins & Non-expendables ~2500 kg
- Total Mass ~55,000 Kg + Fuel

ΔV Requirement for Return

- Get approximate ΔV from three equations:
  - Vis-Viva Equation: $v^2 = GM(2/r - 1/a)$
  - Escape Velocity: $v^2 = 2GM/r$
  - Circular Orbital Velocity: $v^2 = GM/r$
- Assume single engine burn from Phobos orbit to Hohmann Transfer Orbit
  - Enter Earth's atmosphere on a ballistic trajectory
- ΔV ~5600 m/sec

Rocket Equation

$$M_O/M_F = e^{(\Delta V / Ve\ )} = e^{(\Delta V / g\ \ Isp)}$$

Where

M_O = Mass of Vehicle + Fuel (*original mass*)

M_F = Mass of Vehicle (*after fuel is burned*)

ΔV = Velocity Change

V_e = Exhaust velocity

G = Acceleration of gravity = 9.8 m/sec^2

I_{SP} = Specific Impulse

Fuel Requirement for Return

- Use Rocket Equation:

$$M_O/M_F = e^{(\Delta V\ /\ g\ \ Isp)}$$

$$\Delta V = 5600 \text{ m/sec}$$

$$I_{sp} = 450 \text{ sec}$$

$$g = 9.8 \text{ m/sec}^2$$

$$M_O/M_F = 1.27$$

$$M_O = 1.27 * M_F = 1.27 * 55{,}000 \text{ kg} = 69{,}800 \text{ kg}$$

$$\text{Fuel Mass} = M_O - M_F = \sim 15{,}000 \text{ kg}$$

- @ $200,000 / kg = $3 billion

Fuel Requirement for Return

- Assumes long flight time is acceptable
- Assumes high specific impulse (LH_2/LOX)
  - Frozen hydrogen fuel? ($T \leq 14$ K)
- To cut flight time → ΔV increases
- A more storable fuel → I_{SP} decreases
- Try ΔV = 8 km/sec & ethanol (I_{SP} = 330 sec)
- $M_O/M_F = 2.5$
- Fuel Mass ~ 82,500 kg
  - @ $200,000 kg = $16.5 billion

Kerosene
Not just for lamps!

- **Kerosene has a long history as rocket fuel.**
  - **Highly refined kerosene called RP-1 (refined petroleum).**
  - **It is used in combination with liquid oxygen as the oxidizer.**
- **RP-1 and liquid oxygen are/were used in the first-stage boosters of:**
  - **Atlas/Centaur launch vehicles**
  - **Delta launch vehicles.**
  - **Saturn 1B rockets**
  - **Saturn V rockets**

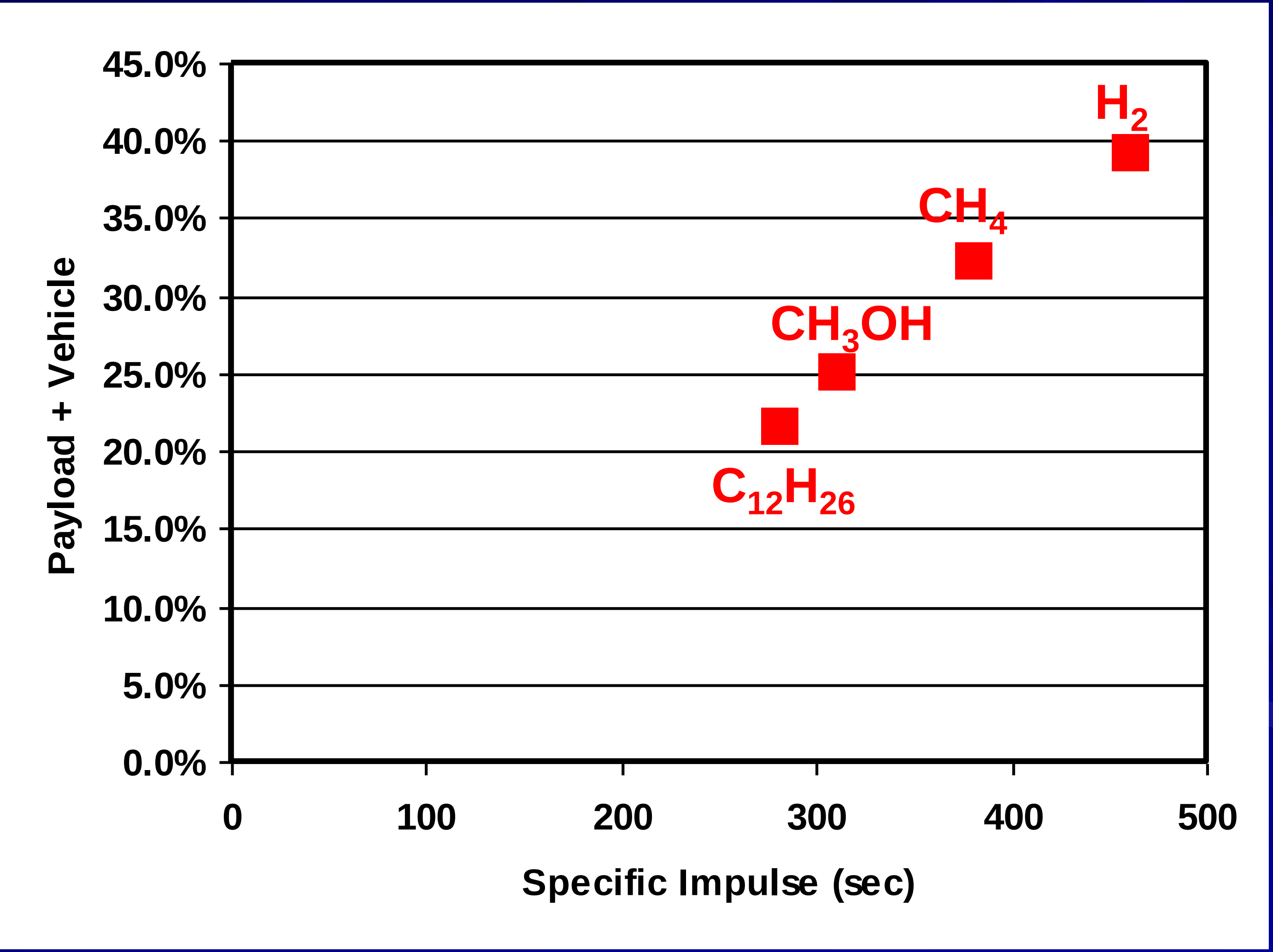
Hydrocarbon Fuels

Fuel	I_{SP}	Storage
Hydrogen - H_2	460	Cryogenic: -253°C [20K]
Methane - CH_4	380	Cryogenic: -162°C [111K]
Ethanol - C_2H_5OH	330	Non-Cryo.
Methanol - CH_3OH	310	Non-Cryo.
Kerosene ~$C_{12}H_{26}$	280	Non-Cryo.
Oxygen – LOX/LO_2	N.A.	Cryogenic: -183°C [90K]

Manufacturing Fuel on Mars

- **Sabatier reactor**
  - Water + energy → Hydrogen (H_2) + Oxygen (O)
  - $4H_2$ + CO_2 → CH_4 (methane) + $2H_2O$
  - CH_4 + energy → heavier hydrocarbon
    - CH_3OH – Methanol (Methyl alcohol)
    - C_2H_3OH – Ethanol (Ethanol alcohol)
    - ~$C_{6-8}H_{14-18}$ – "Gasoline"
    - ~$C_{12}H_{26}$ - Kerosene
    - Etc.

Vehicle + Payload Fraction to LMO
ΔV = 4200 m/sec



Phobos Option

- **Phobos as a staging area**
  - Natural space station – Docking Earth Return craft
  - Radiation shielding by burrowing into surface
  - No orbital adjustments needed
- **Phobos is not good as a fuel supply**
  - Water appears to be absent
  - Carbon? Possibly synthesize solid propellants?
  - Oxygen available in silicates
  - Mars methane/ethanol/kerosene + Phobos oxygen?

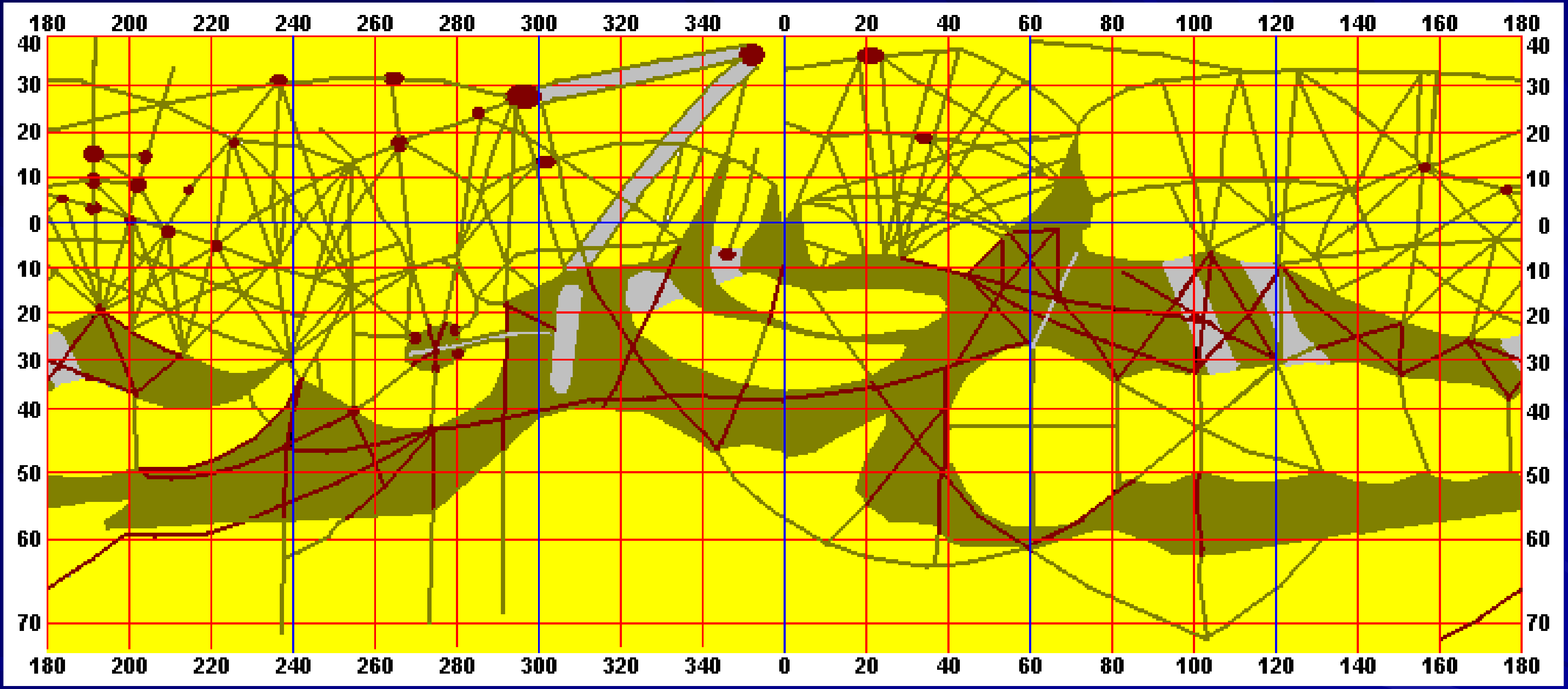
Human Habitation

- If long-term human habitation is the goal:
  - Most materials must be derived locally
  - Simple and easily maintainable MAVs (Surface-to-orbit vehicles)
  - Local smart manufacturing capabilities
  - Large-scale, self-sufficient agriculture
  - Identify export products
    - Information – Scientific, medical, ecological
    - Specialty items – Mars rocks, ?
    - High value items – Gems, precious metals, ?

Planetary Protection – The Final Frontier

- The return of a **self-replicating Martian organism** to Earth would likely to produce significant adverse effects.
- While the probability is considered low and the risk of pathogenic or ecological effects is lower still, **the risk is not zero**.
- NASA has adopted a planetary protection policy to deal with organisms at least as capable of surviving extreme conditions as the **toughest organisms** found on Earth.

Lowell's Martian "Canals"



Spacecraft imaging of Mars showed the "canals" to have been optical illusions.

Why are we concerned?

- History!
- A long and very bleak record of consequences that result from the intentional or unintentional introduction of organisms into new environments.
  - Invasive species
  - Epidemics
  - Extinctions

Exotic / Invasive Species

Impacts of Exotic/Invasive/Alien Species

- In new environments, exotic species commonly lack natural biological controls (e.g., predators, etc.)
- In the absence of such controls, invasive species can rapidly overwhelm an ecosystem.
  - Extinction of native species
  - Economic damage
  - Transmission of new diseases
- Introduction of new pathogenic organisms can decimate susceptible populations.
  - Measles, Smallpox, Bubonic plague, SARS, Ebola

Exotic Species – A “Bad” Example

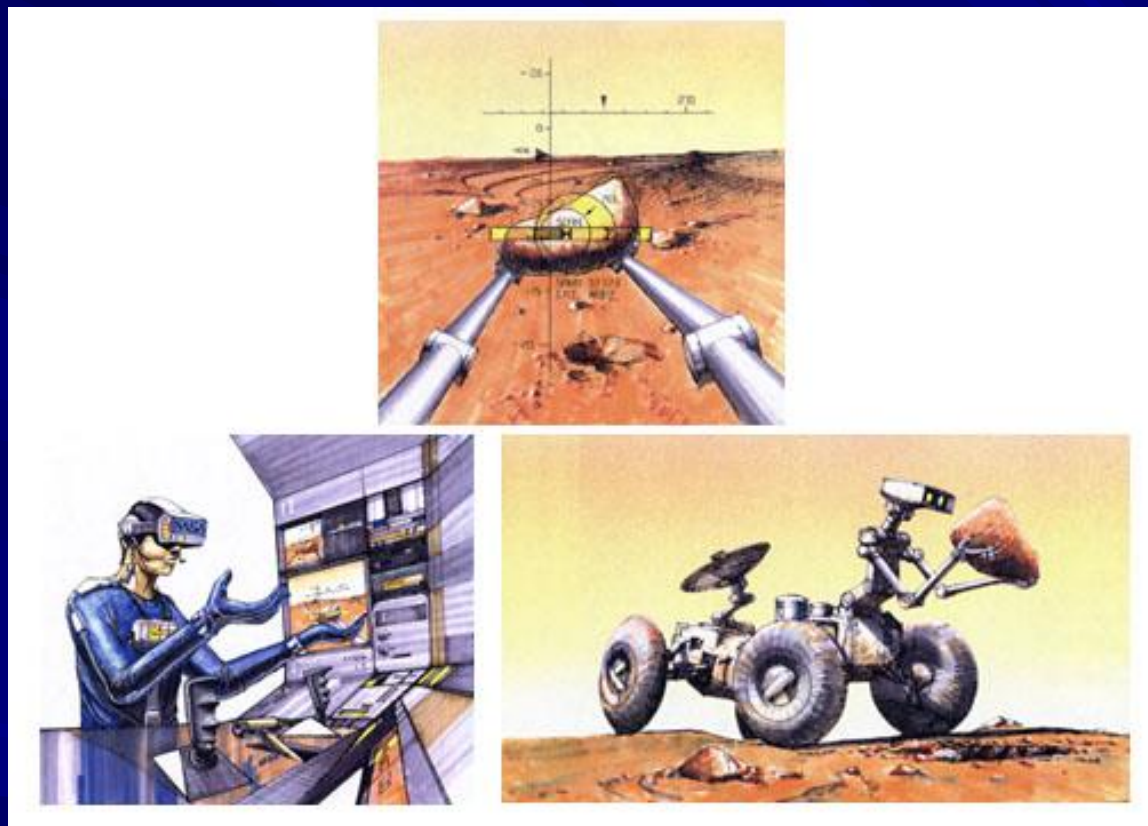
Brown Tree Snake - Guam

Accidentally introduced to Guam between 1945 and 1952.

Population density is now 20 or more snakes per acre.

That’s about 1 snake in the area of this room.

The First Step to Actual Manned Missions?



Tele-presence on the Martian Surface