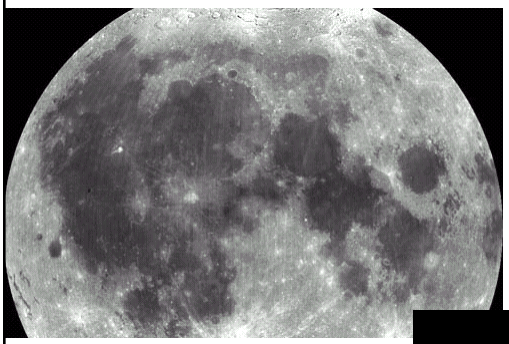
# The Moon and Mercury



The Moon

| | Moon | Mercury | Earth |
|---|---|---|---|
| Mass | 0.01 | 0.06 | 1 |
| Diameter | 0.27 | 0.38 | 1 |
| Density | 0.60 | 0.98 | 1 |

Mercury

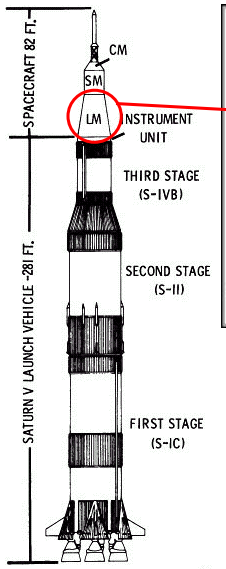
# The Lunar Surface

- Heavily Cratered Highlands
- Smooth Maria

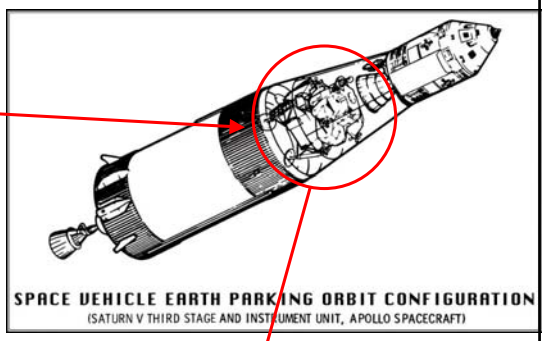
# Apollo --- Our Visit to the Moon

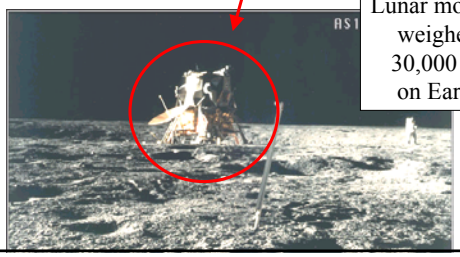
6 manned landings on Moon, 1969 - 1972

6,371,000 lbs total weight at liftoff




**Space shuttle to same scale**

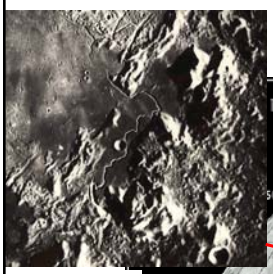


Lunar module weighed 30,000 lbs on Earth.

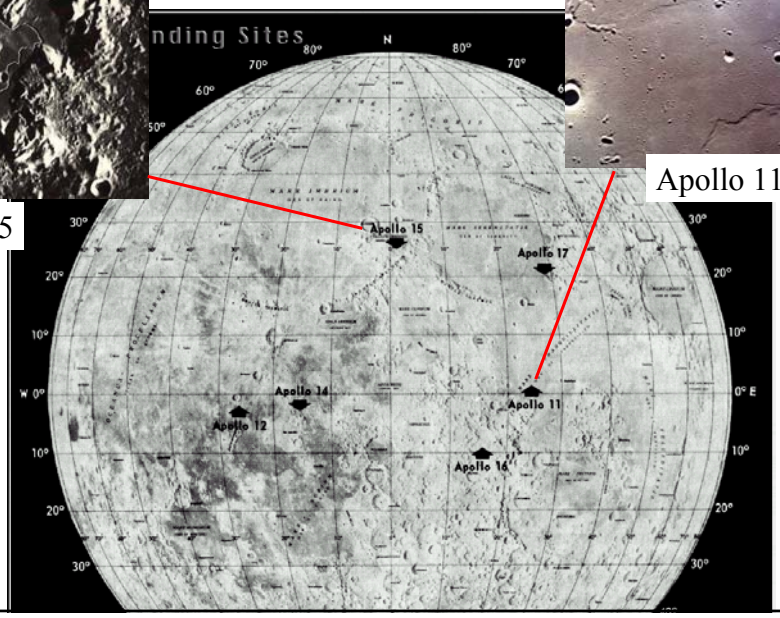
# Apollo Landing Sites

6 landings

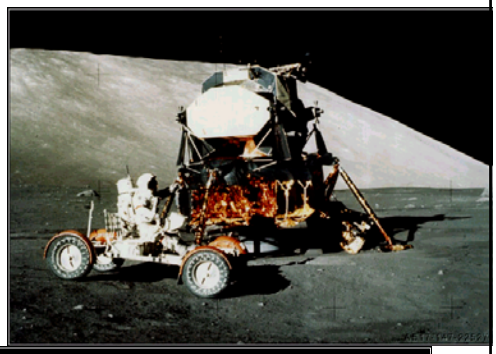


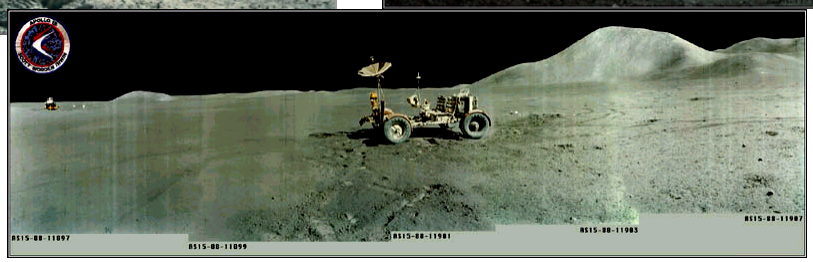
Apollo 15

Apollo 11



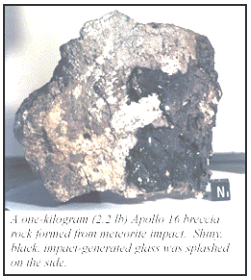
# Prospecting on the Moon

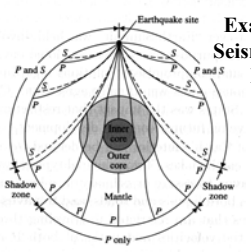



# Apollo's Accomplishments

- PR
  - beat Soviets to Moon
- Science
  - Brought back 400 kg of Lunar rocks
    - Composition
    - Age
  - Left behind seismographs and other instruments.
    - "Moonquakes" show internal structure of Moon
  - No life on Moon.



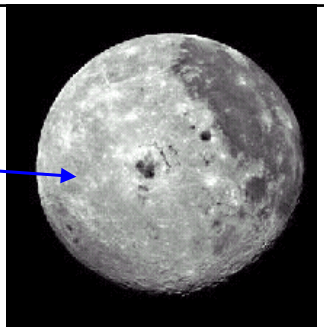
*A one-kilogram (2.2-lb) Apollo 16 breccia rock formed from meteorite impact. Shiny, black, impact-generated glass was splashed on the side.*




**Example: Seismology of Earth's interior**

# The Lunar Surface

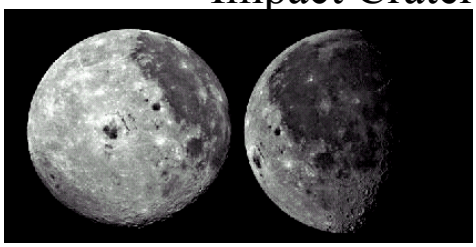
- Highlands
  - low density rocky slag formed on top of molten Moon
  - heavily cratered



## Maria

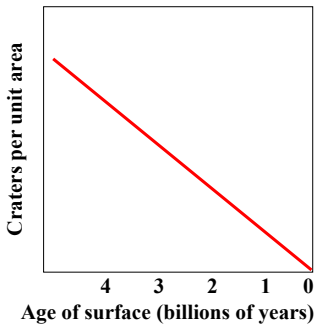
- 17% of Lunar surface
- Huge lava flows from volcanoes
- Basalts - similar to volcanic rock on Earth
  - but no water
  - fewer volatile (= easily melted) elements.
  - Much less iron.

# Impact Craters as Clocks



- Constant rain of meteors continuously makes craters
- Geologic activity
  - ➔ lava flows
    - ➔ covers over craters
- So number of craters per unit area proportional to time span since surface was last covered.

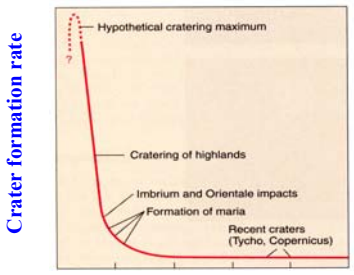
If craters form at constant rate:



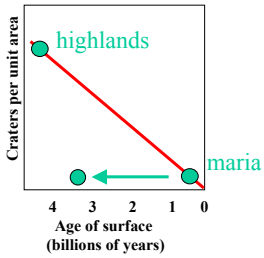
## Crater counts + Radioactive Dating of rock samples ➔ History

10x more craters per unit area on highlands than on maria.

➔ Highlands 10x older?




If craters form at constant rate:



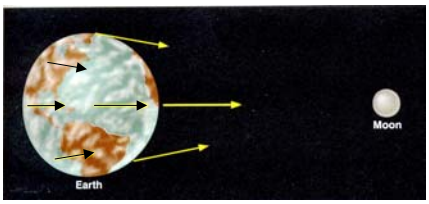

BUT:

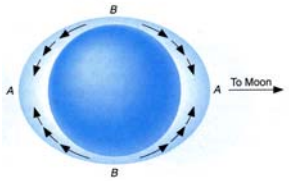
Highlands

- Rock samples ➔ 4.1 - 4.4 billion yrs old

- Maria
  - Rock samples ➔ 3.3 - 3.8 billion yrs old

## Tides [3.6]



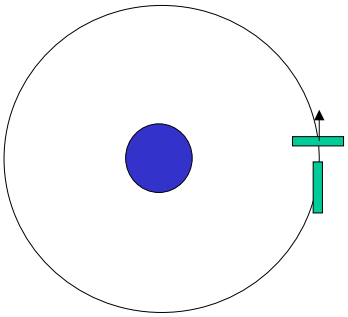



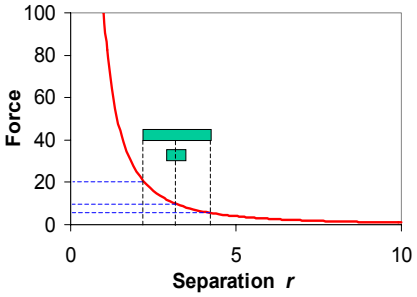

- Why do we always see same side of Moon?
  - Moon rotates in same period that it evolves around the Earth. *Why?*
  - Tidal locking.
- Moon is receding from Earth (see pg. 73)
  - Earth rotates faster than tides do.
  - Friction on tides slows Earth's rotation.
  - Conservation of angular momentum = mvr causes moon to move outwards.

# Tidal locking

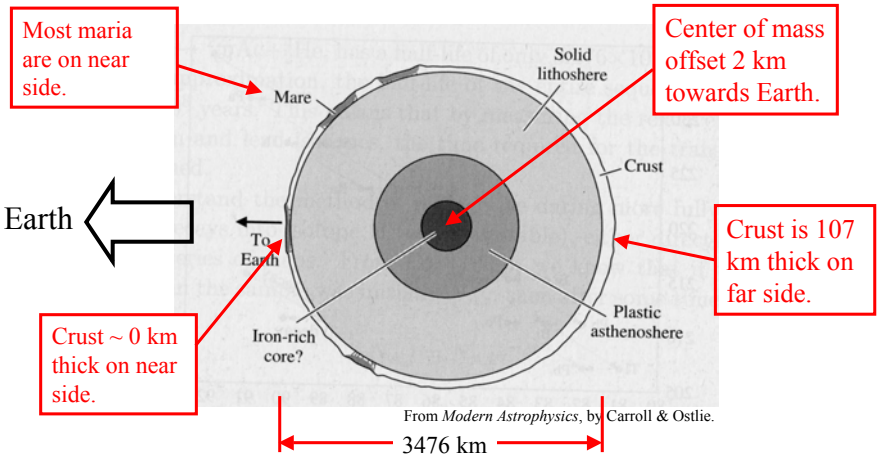
- Moon in it's orbit:

$$F_{gravity} = \frac{Gm_1m_2}{r^2}$$





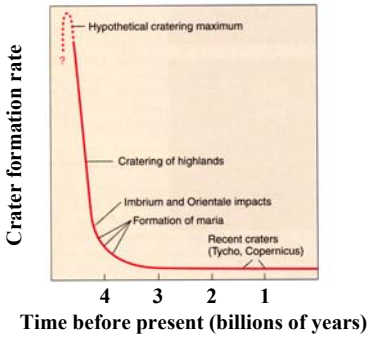

# The Interior of the Moon




- Geologically inactive.
- No magnetic field ➔ no molten core.

# The Early History of the Moon

- The Moon and Earth are genetically related .
  - formed from different proportions of a common reservoir of materials. Moon's composition is like Earth's mantle.
- Magma Ocean
  - Early in its history, the Moon was melted to great depths to form a "magma ocean."
  - The lunar highlands
    - early, low density rocks
    - floated to surface of magma ocean 4.1 - 4.4 billion yrs ago.
- Followed by a series of huge asteroid impacts
  - created basins (the maria)
  - Filled by lava flows 3.2 - 3.9 billion years ago.




# The Origin of the Moon

## Four theories

At least three wrong theories

- The Fission Theory --- Moon ejected from Earth.
  - But Moon's orbit is not in plane of Earth's rotation.
  - Why aren't Moon and Earth's composition *exactly* identical?
- The Sister Theory --- Moon and Earth formed side by side.
  - But why aren't compositions not *exactly* identical?
- Capture Theory --- Moon came in from other part of Solar System
  - No way for Moon to lose energy in order to go into orbit.
  - Why are compositions so similar?

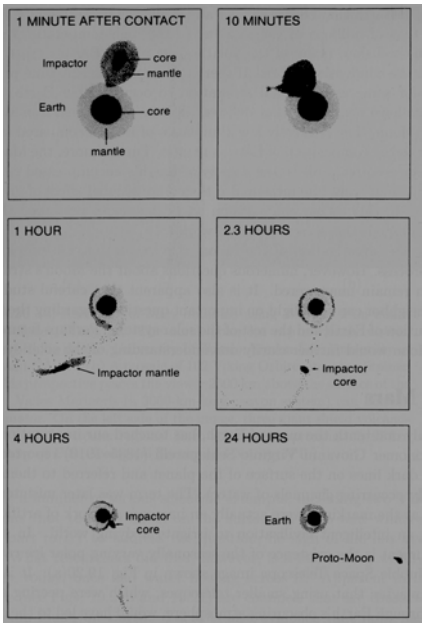
- The Current Theory --- the Giant Impact Theory

# The Giant Impact Theory

## The problem:

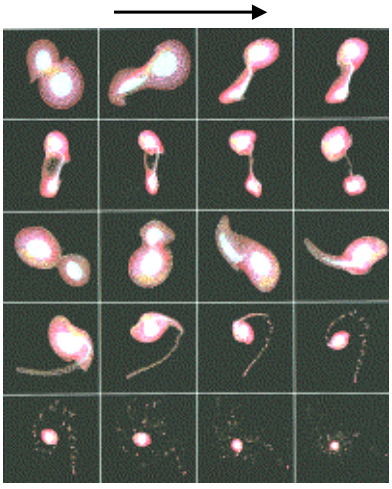
- The Moon is mostly made out of mantle material.
- Mantles are formed through *differentiation* of original mix of material.
- How do you get a mantle without having an iron core?

movie: (A. Cameron's simulations)




From *Modern Astrophysics*, by Carroll & Ostlie.

# Computer simulation of formation of the Moon

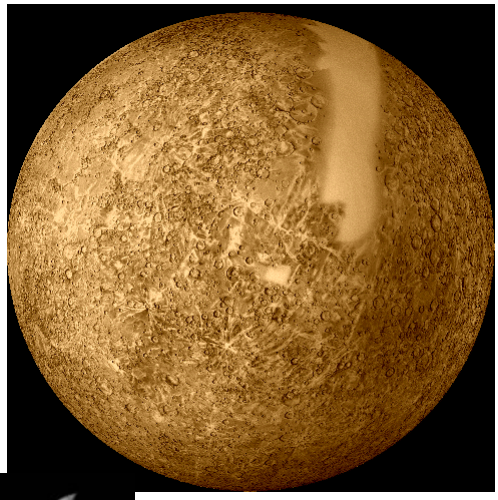


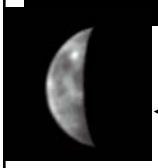
Red = mantle material
Orange = heated mantle
Blue = core material
Green = heated core

movie: //www.xtec.es/recursos/astronom/moon/camerone.htm (A. Cameron's simulations)

paintings: //www.psi.edu/projects/moon/moon.html paintings

# Mariner 10 Mosaic Image of Mercury





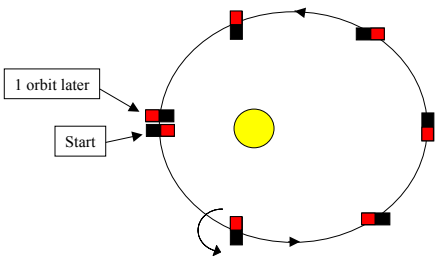
"High resolution" ground-based image.

- Semi-major axis = 0.39 au.
  = 58 million km
- But high eccentricity (0.2)
  - Distance from Sun varies between 46 and 58 million km.
- 88 day period of revolution about Sun.
- Only 1 visit: Mariner 10 (1974).
- Messenger orbiter planned
  - 2004 launch, 2009 arrival.

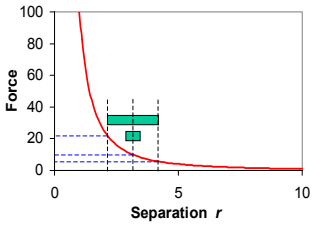
# Mercury's Rotation

- Tidal locking
- ...but Mercury rotates in 2/3 of its period of revolution around Sun. *Why?*
  - Orbit is elliptical (e = 0.2)
  - strongest tidal effect when closest to Sun
  - Another way to put it…. Mercury rotates 1.5 times per Mercury year, so elongation always points towards Sun at closest approach.

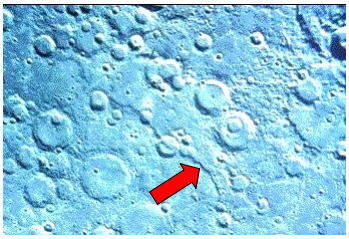
Kepler1 simulation



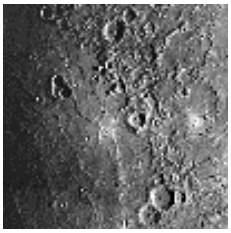

$$F_{gravity} = \frac{Gm_1m_2}{r^2}$$



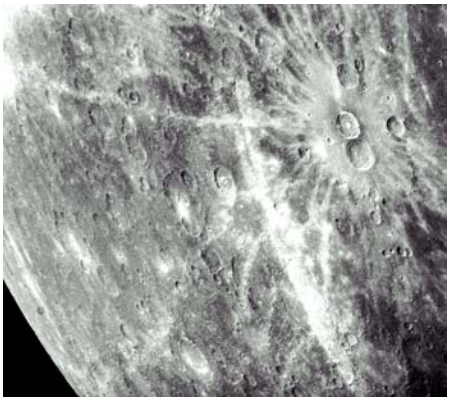
# Features on Mercury



Discovery Rupes
(1 km-high cliff)



Lava flows



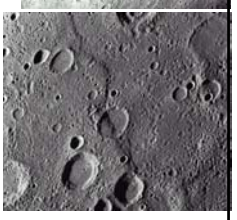
Rayed impact craters

# Structure of Mercury

- No seismological data… just educated guesses.
- Rocky mantle/crust
  - Perhaps 700 km thick.
- Metallic core
  - 75% of planet's radius
  - Weak magnetic field

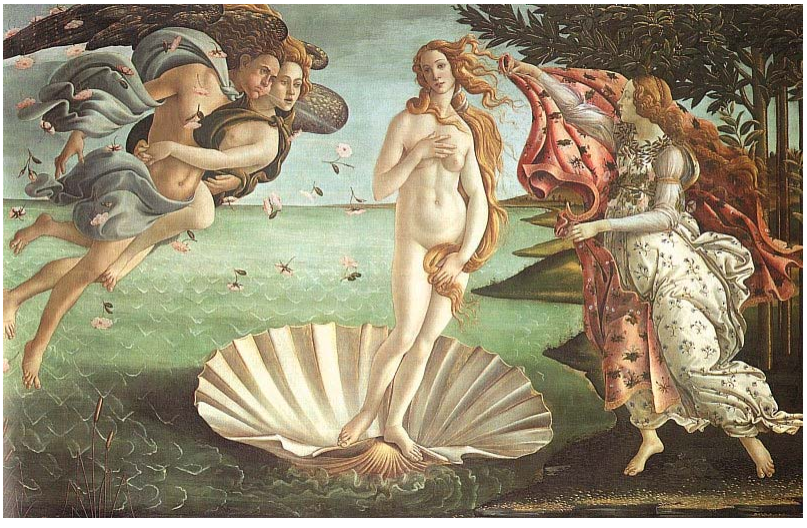
  ==> molten material in core.
- Faults & Ridges ➔Mercury shrank
  - by ~ 1-2 km as it cooled.
  - Crater counts
  - ➔ this happened after first 0.5 billion yrs.

450 km-long ridge (rupes)



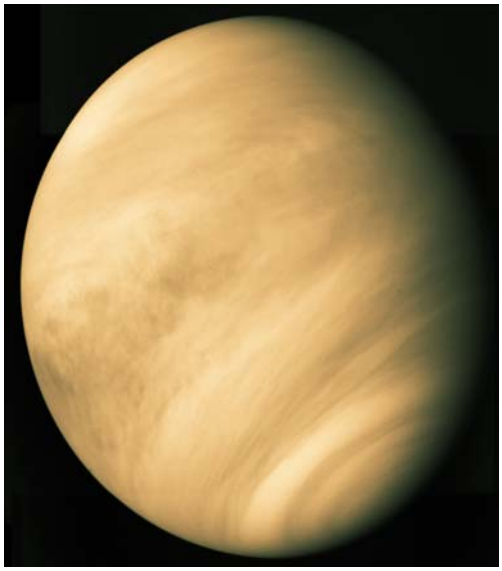
200 km-wide view showing Santa Maria Rupes.

Venus
(according to Botticelli)



# Venus
# (according to Galileo)

| | Venus | Earth |
|---|---|---|
| Diameter | 0.95 | 1 |
| Mass | 0.81 | 1 |
| Semi-major axis | 0.72 | 1 |
| Surface temperature | 480° C | 20° C |
| Surface Air Pressure | 92 | 1 |
| Atmosphere | $CO_2$ | $N_2$ |



Venera 7 (1970)
Venera 10,11 (1975)
Venera 11,12 (1978)
Venera 13,14 (1981)

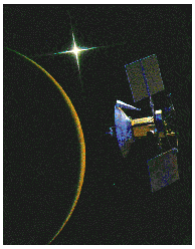
## Venera Landers
(USSR)

Venera 13, 14 soil samples: basalts


The view from Venera 14

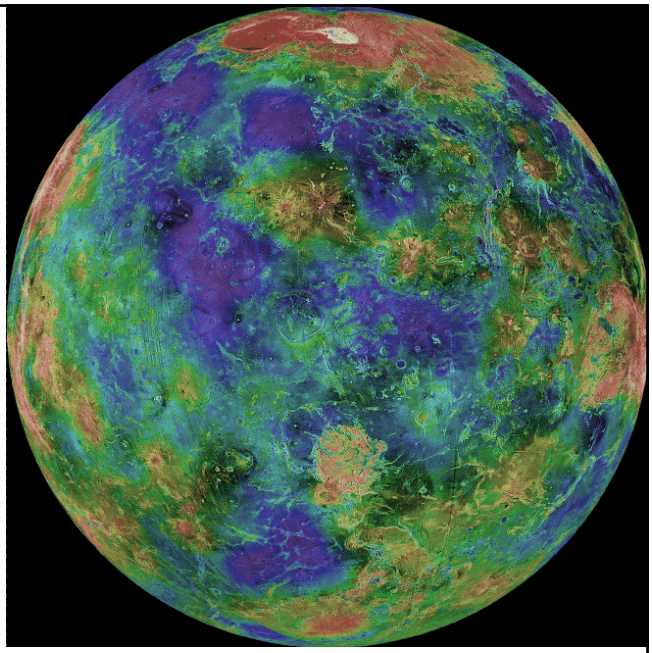
# Radar Map of Venus

Made by Magellan orbiter in 1991-93.



Blue = lower
Brown/red = higher.

Rotating Venus



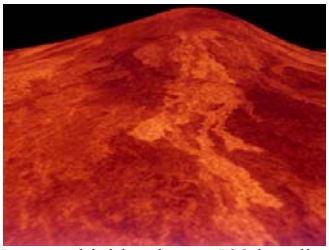
# The surface of Venus

- Impact craters
  - ➔ age dating of surface
  - only 15% as many craters as lunar maria.
- ➔Oldest terrain only 800 million yrs old
  - compare to 3.8 billion yrs on Earth
- Constant resurfacing by volcanic action.
  - but appears to have ceased ~ 500 million yrs ago

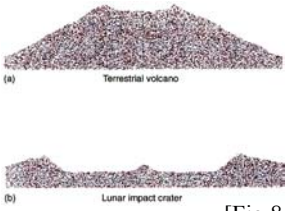
[Fig 9.5]
Magellan Radar Imaging.

# Volcanic Activity on Venus

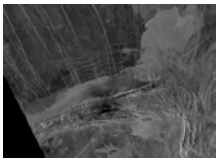
Radar Imaging: 100 m resolution



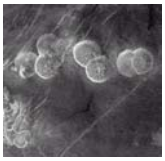
Sif Mons, a shield volcano 500 km diameter x 3 km high.



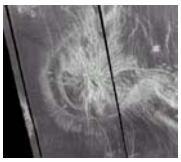

[Fig 8.13]



Lava flow



"Pancake" volcanoes, due to very thick lava.

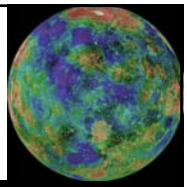


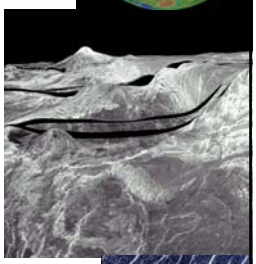
*Corona*: a collapsed dome over a magma chamber.

## Interior Structure

- Similar to Earth
- Iron core 3000 km in radius
- Molten mantle
- Crust

Magellan Radar Images





Lakshmi Planum
Hilly area on Ishtar

## Tectonics

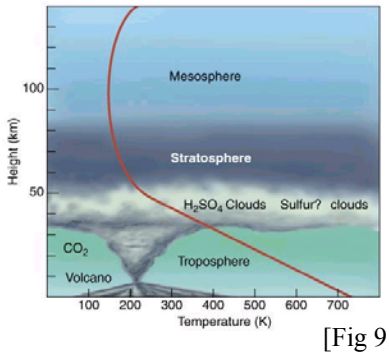
- No plates as on earth
- But much shearing, compression and stretching of crust by convection currents in mantle.
- Has pushed up "continents"
  - Aphrodite and Ishtar
- Rift valleys and cracks

[Fig 9.9]
Ridges & cracks

# The Atmosphere of Venus

- Surface Pressure = 92 x Earth's
- Surface Temperature = 482° C
  - melting point of lead: 327°
- Sulfuric acid cloud layer at 30-60 km

| | Venus | Earth |
|---|---|---|
| $CO_2$ | 96% | 0.03% |
| $N_2$ | 3.5 | 78.1 |
| Ar | 0.006 | 0.93 |
| $O_2$ | 0.003 | 21.0 |



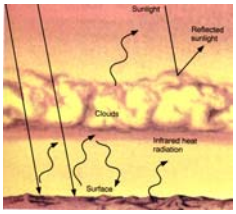

[Fig 9.11]

# Some Surface Temperatures in °F

- Mercury (Mariner 10) 800F
- Venus (Mariner 2; Venera landers) 900F
- Hell (Revelations 21:8) 832F
  - "But the fearful and unbelieving shall have their part in the lake which burneth with fire and brimstone"
  - boiling point of brimstone (sulfur); 832F

# The Runaway Greenhouse Effect

- Suppose Venus started out with Earth-like conditions
  - $CO_2$ originally dissolved in oceans or combined with rocks
- Modest extra heating




$CO_2$ blocks escape of infrared radiation

More $CO_2$ and $H_2O$ in air

More heating

- $H_2O$ then breaks down into hydrogen and oxygen.
- *Equipartition of energy*…
  - basketball - tennis ball collision: tennis ball flies off at high velocity
    - many such collisions ➔ all bodies have same kinetic energy = $\frac{mv^2}{2}$

➔light bodies (hydrogen atoms) move much faster and escape.

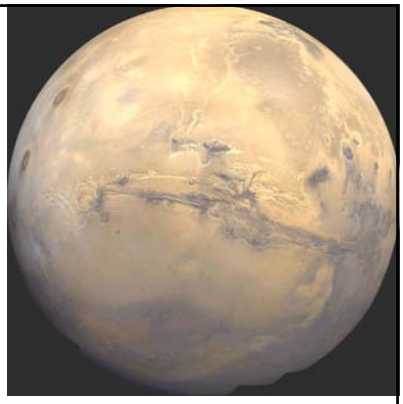
Atmosphere evolves… no going back.

# The Odd Rotation of Venus

- Slow rotation
  - 1 Venus day = 243 Earth days.
    - (not same as orbital period = 225 days)
- Retrograde (backwards) rotation
  - Conjectured to be due to massive impact during planet's formation.

# Mars

| | Venus | Earth | Mars |
|---|---|---|---|
| Diameter | 0.95 | 1 | 0.53 |
| Mass | 0.81 | 1 | 0.11 |
| Semi-major axis | 0.72 | 1 | 1.52 |
| Density | 0.96 | 1 | 0.71 |



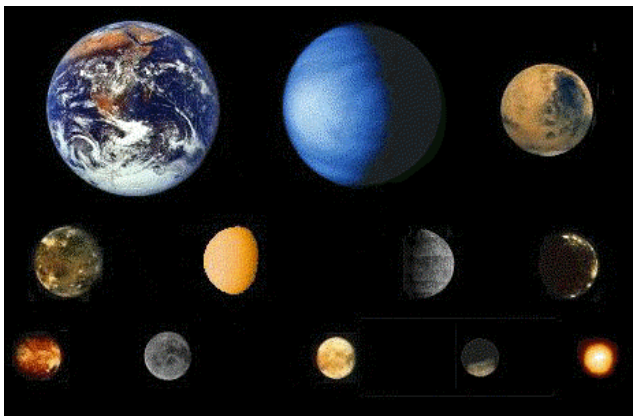
- Some of the 16 spacecraft that have gone to Mars:
  - **Mariner 9** orbiter (1971-72)
  - **Viking 1,2** landers (1976-80)
  - **Pathfinder** lander + rover (1997)
  - **Climate Orbitor**, **Polar lander** (crashed, 1999).
  - **Mars Global Surveyor**: orbiting Mars since March 1999.
  - **Odyssey**: orbiting Mars since October 2001.

Rotating Mars

# Some planets and moons

shown in correct relative sizes

Earth Venus Mars



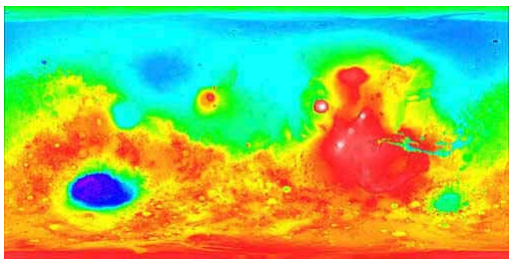
Ganymede Titan Mercury Callisto
Io Moon Europa Triton Pluto

# Geology

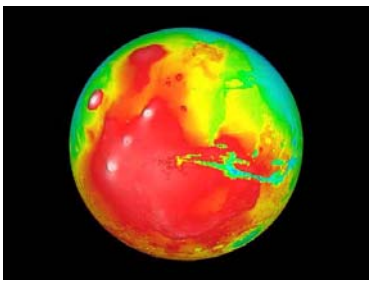
- Density suggests mostly silicates, but small metal core
- No detectable magnetic field
- Continental highlands
  - cover ~ 50% of planet.
- Low-lying lava plains
  - average of 4 km lower than continents.
  - Same age as lunar maria - 3-4 billion yrs old.

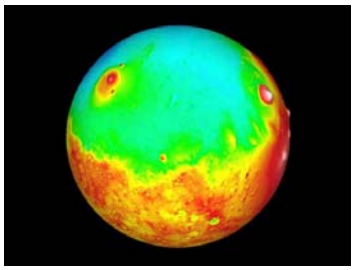
# Topographic Map

From Mars Global Surveyor orbiter



Red = high areas.
Blue = low areas.

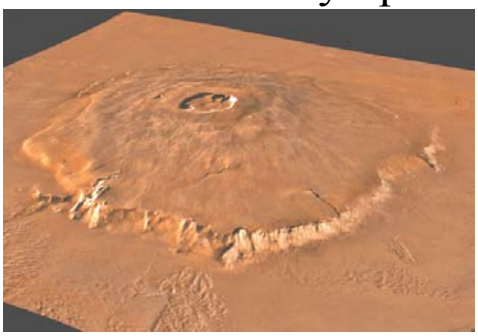




Tharsis bulge

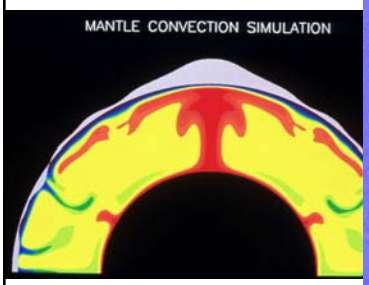
- uplifted continent 10 km high.
- has 4 huge volcanoes, 15 km high.

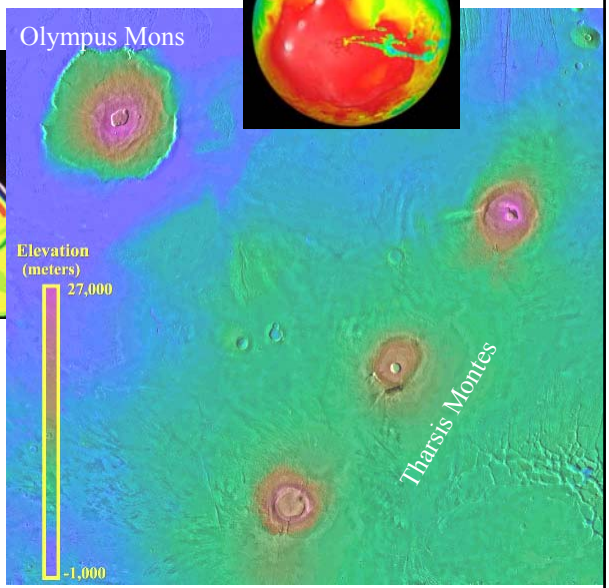
# Olympus Mons



- 500 km diameter
  - would cover MI lower penninsula
- 25 km above surrounding plains
- largest mountain in Solar System.
  - 100 x volume of Mauna Loa
- < 100 million yrs old (impact crater counts)
  - so Mars is still geologically active.

# Tharsis Montes

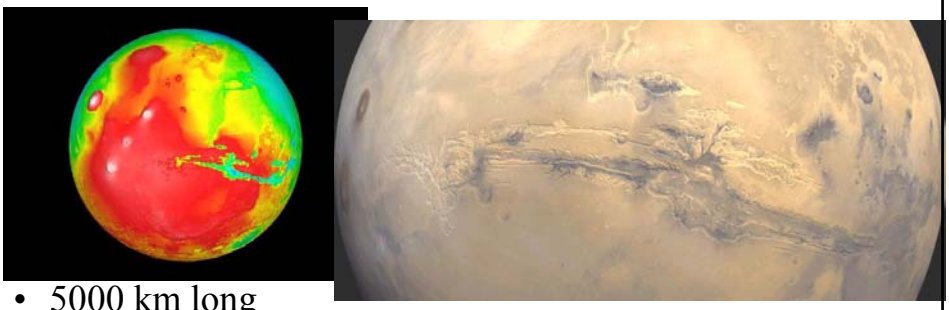



- Three shield volcanoes along crest of Tharsis bulge.

- Reach same height as Olympus Mons, but start out at higher elevation.

# Valles Marineris



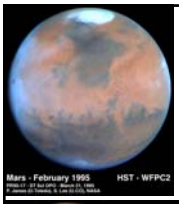
- 5000 km long
  - 1/4 way around Mars
  - would stretch clear across US.
- Huge tectonic crack in Tharsis bulge
  - no outlet for water
    - but some minor role of water erosion in side canyons.

# The Martian Atmosphere

| | Venus | Earth | Mars |
|---|---|---|---|
| Surface temperature | 482° C | 20° C | -100° C |
| Surface Air Pressure | 92 | 1 | 0.007 |
| $CO_2$ | 96% | 0.03% | 95% |
| $N_2$ | 3.5% | 78% | 2.7% |

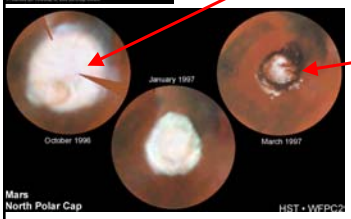
- Little air
- Very cold
- (almost) no liquid water.
  - At Mars' low atmospheric pressure, water should go straight from ice to vapor.
- No Greenhouse effect because there is so little atmosphere.

# Polar Ice Caps




Frozen $CO_2$ layer in winter

Only underlying $H_2O$ ice left in summer, 3 km thick



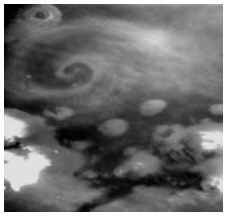

Northern Cap

Southern Cap

- Always below 150° K (-279°F), so $CO_2$ frozen all year.
- Unknown mix of $CO_2$ and $H_2O$ ice.

# Clouds

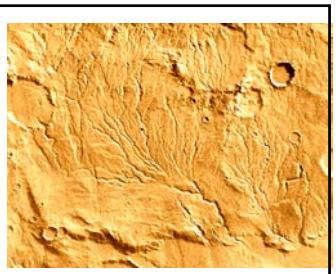
Cyclonic storm near North Polar ice cap
(+ some frozen $CO_2$ on ground)



Rotating Mars

Giant dust storm


# Climate change

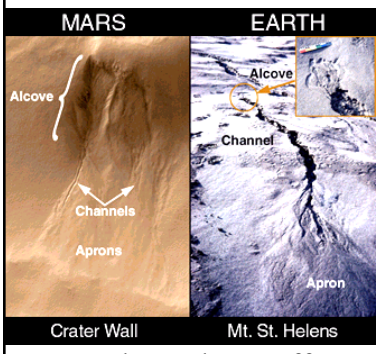


- Used to be *lots* of running water
  - Runoff channels.
    - From rainstorms billions of years ago.
  - Outflow channels.
    - From more recent meltings of huge volumes of permafrost.

- Loss of atmosphere
  - due to low escape velocity.
  - Low air pressure, then water freeze-out
    ==> cannot retain heat.
  - "runaway refrigerator effect"

| | Venus | Earth | Mars |
|---|---|---|---|
| Escape velocity | 0.93 | 1 | 0.45 |
| Surface temperature | 482° C | 20° C | -100° C |
| Surface Air Pressure | 92 | 1 | 0.007 |

# Sub-surface Water

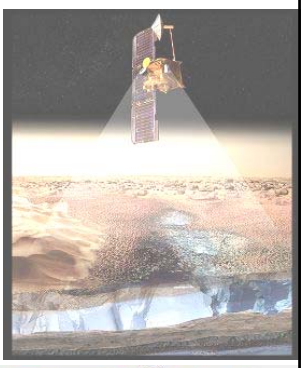


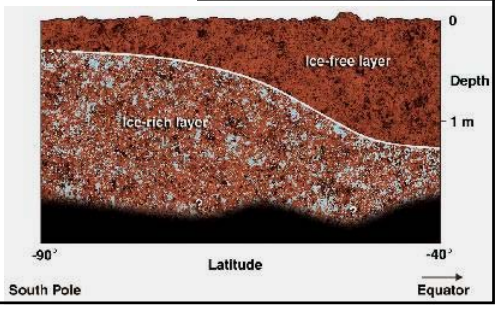

Recently made runoff channels,

seen by Mars Global Surveyor.

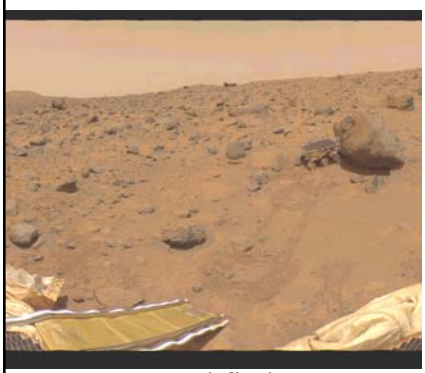
… but these features are very rare.

Mars Odyssey is finding lots of water just below surface.






# Results from the Landers



Mars Pathfinder

Soil analysis: clays & iron oxides.
Weather stations: -33° to -100° C.

Search for life.

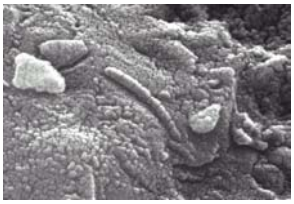
# Life on Mars?

Meteorite from Mars.

- Formed on Mars 4.5 billion yrs ago.
- Ejected from Mars by meteor impact 15 million yrs ago.
- Eventually captured by Earth (!!)
- Found in Antarctica.

Viking landers analyzed soil samples:

- Extremely sensitive search.
- No signs of life.
- But they only measured in 2 locations.

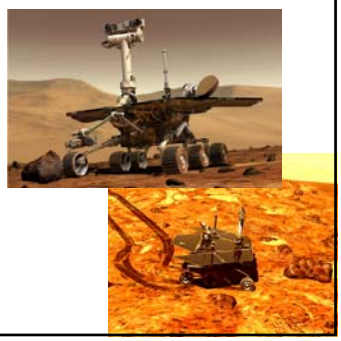


Possible discovery of organic compounds in Martian meteorites, and even a possible (micro) fossil.

- *Unclear!* Considerable skepticism among many scientists.
- Occam's Razor: Extraordinary claims require extraordinary proof.

# Coming soon… to a planet near you:

- Beagle 2
  - Launch: June 2, 2003; Landing: Dec 24, 2003
  - Robot arm:
    - Grinder, drill, "mole", microscope, spectrometer (measure chemical composition).
    - Gas analyzer to search for life
      - $C^{12}/C^{13}$ ratio?
      - Methane from bacteria?



- MER A, B
  - Two separate missions, to different parts of Mars:
    - Launch: June 8, 2003; Landing: Jan 6, 2004
    - Launch: June 25, 2003; Landing: Jan 24, 2003
  - Will travel 40 meters/day, for 3 months.
  - Carries cameras, spectrometers, alpha-particle detector, grinder.
  - Will determine history of climate & water.