10. Planetary Geology

Earth and the Other Terrestrial Worlds

"Nothing is rich but the inexhaustible wealth of nature. She shows us only surfaces, but she is a million fathoms deep."

Ralph Waldo Emerson (1803 – 1882)
American writer and poet

Agenda

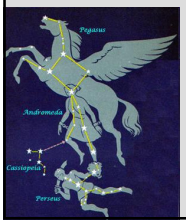
- How did Tuesday go?
- Astro news
- COTD: Pegasus
- Review of Ch. 9
- Start Ch. 10

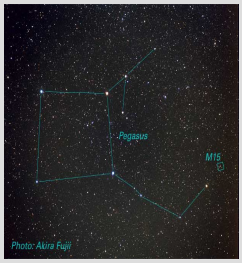
Astro News

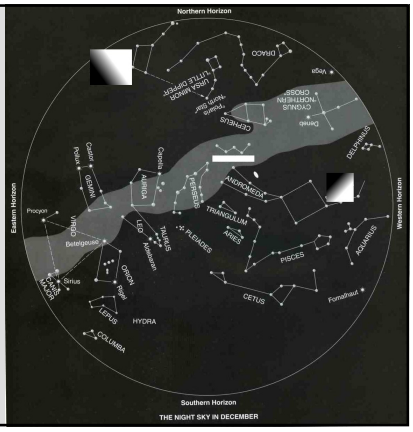
- two scientists at NASA are proposing using a 20-ton spacecraft to pull asteroids off a possible collision course with Earth, using the spacecraft's own gravity as an attractor
- ESA'a *Venus Express* launched ($258 million) to orbit twin planet and study atmosphere and greenhouse effect

COTD: Pegasus

- Resembles grazing horse
- Contains Great Square of Pegasus (asterism)







Ch. 9 Questions

- What must a theory of the formation of the solar system explain?

Ch. 9 Questions

- What evidence do we have that the nebular theory is correct? Incorrect?

Ch. 9 Questions

- Why are the inner planets made of rock and metal?

Ch. 9 Questions

- Where did leftover gas go?

Ch. 9 Questions

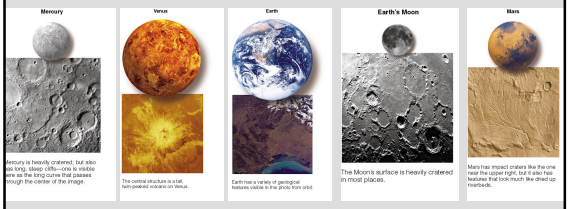
- How does radiometric dating work?

10.1 Planetary Surfaces

Our goals for learning:

- Briefly describe how the terrestrial surfaces differ from one another.

Terrestrial Planet Surfaces



How do they compare to one another?

Comparison of Planetary Surfaces

- Mercury & the Moon
  - heavily cratered {scars from the heavy bombardment}
  - some volcanic plains
- Venus
  - volcanoes and bizarre bulges
- Mars
  - volcanoes and canyons
  - apparently dry riverbeds {evidence for running water?}
- Earth
  - all of the above plus liquid water and life

10.2 Inside the Terrestrial Worlds

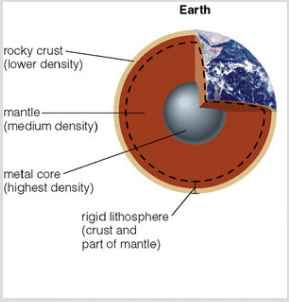
Our goals for learning:

- Describe the basic interior structures of the terrestrial worlds.
- How do interiors get hot?
- Why is planetary size so important to internal heat and geology?
- Why is Earth the only terrestrial world with a strong magnetic field?

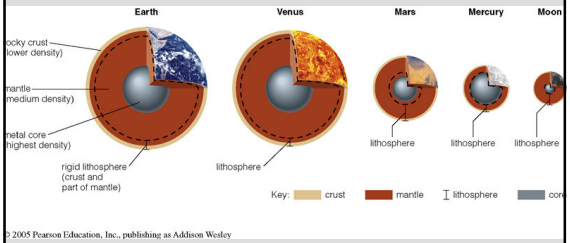
Inside the Terrestrial Worlds

- After they have formed, the molten planets differentiate into three zones:
  - core - made of metals
  - mantle - made of dense rock
  - crust - made of less dense rock
- Lithosphere - the rigid, outer layer of crust & part of the mantle which does not deform easily

Inside the Terrestrial Worlds



Inside the Terrestrial Worlds



active geology inactive geology

Heating the Terrestrial Worlds

- Planetary interiors heat up through:
  - accretion
  - differentiation

  } Supplies all the heat at the beginning

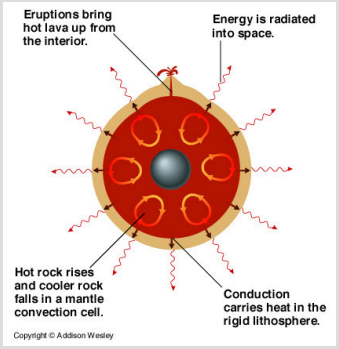
  - radioactivity

  } Supplies heat throughout the planet's life

Cooling the Terrestrial Worlds

- Planets cool off through:
  - conduction - heat flowing on the microscopic level
  - convection - heat flowing on the macroscopic level (bulk motions)
  - eruptions - hot lava bursts through crust
- the *larger* the planet, the *longer* it takes to cool off!

Cooling the Terrestrial Worlds



Magnetic Fields

- Electric charges moving via convection in a molten iron core and spinning acts like an electromagnet ⇒ magnetic field
  - Earth has a magnetic field
  - Venus, Mars, & the Moon do not
  - Mercury surprisingly has a weak magnetic field ??

10.3 Shaping Planetary Surfaces: The Four Basic Geological Processes

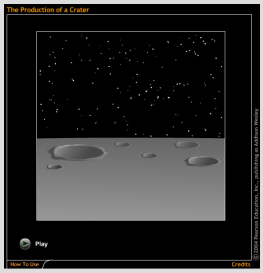
Our goals for learning:

- What are the four basic geological processes?
- Describe how each process is connected to fundamental planetary properties.

Shaping Planetary Surfaces

- Major geological processes that shape planetary surfaces:
  - impact cratering: excavation of surface by asteroids or comets striking the planet
  - volcanism: eruption of lava from interior
  - tectonics: disruption of lithosphere by internal stresses
  - erosion: wearing down by wind, water, ice

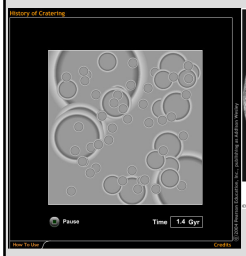
Impact Cratering

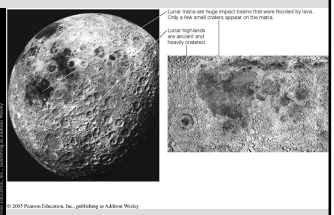


- objects hit planet at 10 – 70 km/s
  - solid rock is vaporized
  - a **crater** is excavated
- matter is ejected in all directions
  - craters are circular
  - large craters have a central peak

Counting Craters to find Surface Age

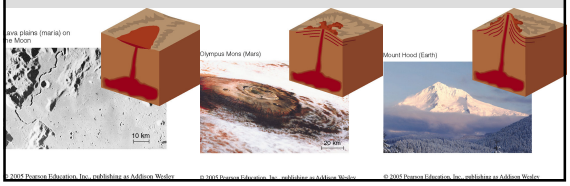
- Cratering rate decreased as Solar Systems aged.
- The older the surface, the more craters are present.





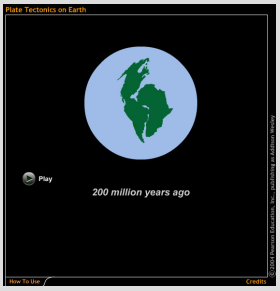
Volcanism

- Underground, molten rock, called **magma**, breaks through crack in the lithosphere.
- Trapped gases are released:
  - H_2O, CO_2, N_2
- Viscosity of **lava** (typically basalt) determines type of volcano →



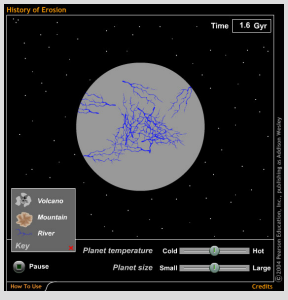
Tectonics

- convection cells in the mantle causes both:
  - compression in lithosphere
    - mountains are produced
  - extension in lithosphere
    - valleys are produced
- mountains & valleys appear on the surface



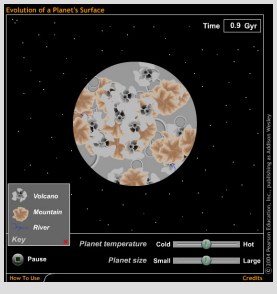
Erosion

- movement of rock by ice, liquid, or gas
  - valleys shaped by glaciers
  - canyons carved by rivers
  - sand blown by wind
- erosion not only wears down features, it also builds them:
  - sand dunes
  - river deltas
  - sedimentary rock



How Planetary Properties affect each Process

- impact cratering
  - # of impacts same for all planets
  - larger planets erase more craters
- volcanism & tectonics
  - requires interior heat
  - retained longer by large planets
- erosion
  - requires an atmosphere
  - large size for volcanic outgassing
  - moderate distance from Sun
  - fast rotation needed for wind

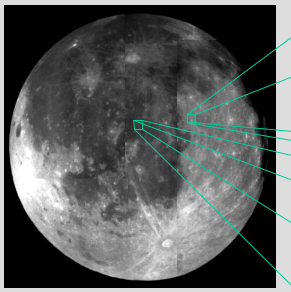


10.4 A Geological Tour: The Moon & Mercury

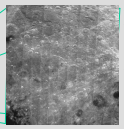
Our goals for learning:

- Describe the geology of the Moon & Mercury.
- How did the lunar *maria* form?
- Why do we think that Mercury shrank in size when it was young?

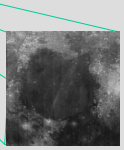
The Moon (☽)



heavily cratered, no atmosphere, geologically inactive



highlands
older surface
more craters



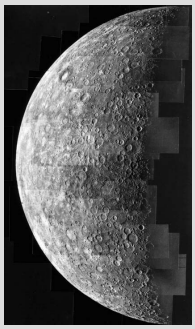
mare
younger surface
3 – 4 billion yrs
fewer craters
dark basalt

Formation of the *Maria*

- The Moon once had a molten interior.
- Several large impacts made huge crater basins.
  - left cracks in lithosphere below
  - at a later time, molten basalt leaked through the cracks
- This "runny" lava filled in the basins.

Mercury

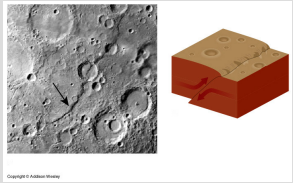
- dead planet with no atmosphere
- has no *maria*, but small lava plains
- has fewer craters than the Moon
- craters are shallower than Moon
  - due to higher gravity on Mercury
- evidence for tectonic processes
- evidence for ice at the N pole



Volcanism & Tectonics in Mercury's Past

Closeup view shows small lava plains that have covered up craters

- tectonic stresses
  - 3 km-high cliffs, 100s km long
  - formed when crust contracted
  - no evidence for expansion features
  - implies the entire planet shrunk!



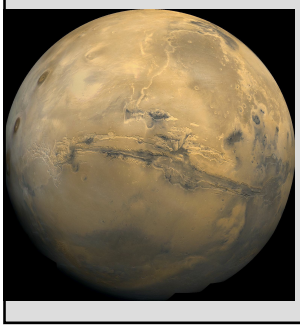
- volcanism
  - lava plains are small
  - but they are found all over the planet

10.5 A Geological Tour: Mars

Our goals for learning:

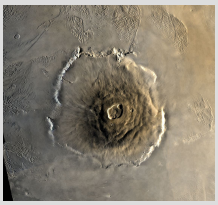
- Why did many people once believe that Mars had intelligent beings?
- Describe general features of the four geological processes on Mars.
- What evidence suggests a past warm and wet period on Mars?
- What evidence suggests more recent water flows on Mars?

Mars



- mountains & canyons
  - *Valles Marineris*
- volcanoes
- thin atmosphere (CO_2)
- no plate tectonics --- volcanoes are higher
- evidence for water erosion

Mars

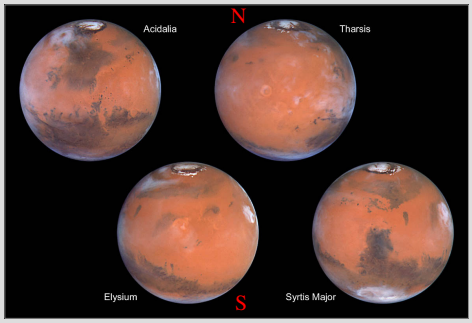


- *Olympus Mons*
  - the largest volcano in our Solar System
  - it is located atop the *Tharsis Bulge* along with several other volcanoes

•Mars has a rotation period & axis tilt almost identical to Earth's

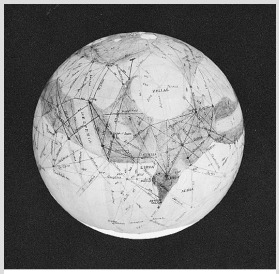
- this implies that Mars has seasons
- look at the ice caps (CO_2 & H_2O)

Four images of Mars in one Martian Day
Summer in North, Winter in South



Where are the Martians?

- These seasonal similarities fuelled speculation that Mars could be habitable.
- In 1877, Schiaparelli sketched a series of lines on Mars which he called *canali*.
- In the 1890s, Percival Lowell sketched a network of canals.
  - Lowell published speculations about a Martian civilization
  - early 20th Century conventional wisdom held that Mars was inhabited
  - space probes sent to Mars in 1960s, 70s, 90s have shown this to be false



Ancient Water on Mars

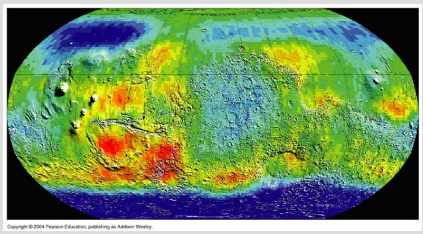
- Liquid water can not exist on Mars today.
  - temperatures below freezing
  - air pressure too low
- Dry river channels in southern highlands
  - heavily cratered terrain (> 3 billion years old)

- Some craters are eroded.
  - implies rainfall
  - crater lakes
- Mars was warm & wet over 3 billion years ago.

Recent Water on Mars?

- Liquid water could exist temporarily with today's temperatures and air pressures…in a flash flood!
- Underground water seeps out to form erosion gullies
  - these gullies were observed on a crater wall
  - at their size, sandstorms would cover them in few million yrs
  - such floods have occurred within the last few million years

Water on Mars?



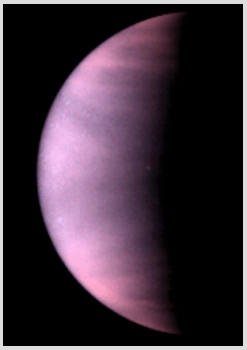
- Recent results from the *Mars Odyssey* mission
  - evidence for (frozen) water within 1 meter under the surface
  - this underground water is found all over the planet

10.6 A Geological Tour: Venus

Our goals for learning:

- How do we study the surface of Venus?
- What happened to Venus about a billion years ago?
- Why isn't there much erosion on Venus?
- Is Venus still geologically active?

Venus

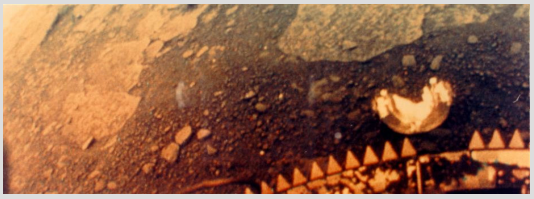


- Has a thick, cloudy atmosphere -- you can not visually see the surface
- we must image the surface using radar
- smooth plains with few mountain ranges
- few craters
- many volcanoes and domes of lava (*corona*)
- Venus is very active with tectonics & volcanism

Venus

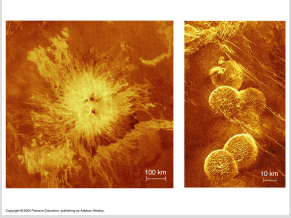
Searing heat, heavy pressure, clouds of sulfuric acid, frequent volcanic eruptions; as Carl Sagan said:

Venus is the planet most like hell!



Volcanism & Tectonics on Venus

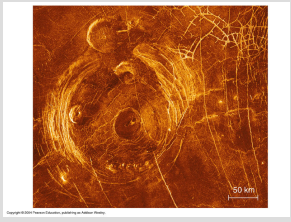
- Impact craters are evenly spread over Venusian surface.
  - implies that the planet's entire surface is the same age
  - crater counting suggests an age of 1 billion years old
- Volcanism "paved over" the surface 1 billion years ago.



- Two types of volcanism are observed
  - shield volcanoes
  - stratovolcanoes

Volcanism & Tectonics on Venus

- The *corona* is a tectonic feature.
  - rising plume in mantle pushes crust up
  - cause circular stretch marks
- Plume forces magma to the surface.
  - volcanoes are found nearby



Lack of Erosion on Venus

- No erosion features are seen on Venus. (so far)
- This means no wind, rain, or ice on the surface.
- Such a lack of weather can be explained:
  - the surface of Venus is very hot (430 C)… too hot for liquid or ice to exist
  - Venus rotates very slowly (P = 243 days), so no wind is generated

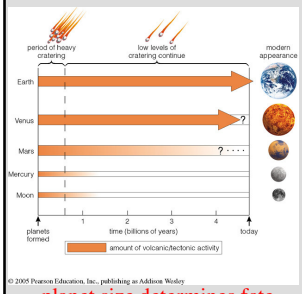
10.7 Earth and Geological Destiny

Our goals for learning:

- In what sense was the geology of each terrestrial world destined from birth?
- In our Solar System, what geological features are unique to Earth?

Geological Destiny

A planet's fundamental properties determine its geological fate.



planet size determines fate

- Impact cratering
  - important early on
  - affects all planets equally
- Volcanism & Tectonics
  - become dominant later on
  - require internal heat
  - **size** determines how long a planet remains hot
- Erosion
  - ultimately dominant
  - requires volcanism for outgassing of atmosphere

Earth

- most active geology
- volcanoes & tectonics
  - ongoing plate tectonics
- moderate atmosphere
  - N_2 O_2 H_2O
- H_2O exists in **liquid** state
  - rampant erosion
  - few craters
- life

What have we learned?

- Briefly describe how the terrestrial surfaces differ from one another.
  - Mercury and the Moon are heavily cratered with some volcanic plains. Venus has volcanoes and other, stranger features. Mars shows a varied geology, including volcanoes and evidence of running water. Earth shows features similar to all the others, and more.
- Describe the basic interior structures of the terrestrial worlds.
  - By density: core-mantle-crust. By rock strength, the crust and part of the mantle together make up the rigid lithosphere.

What have we learned?

- How do interiors get hot?
  - Sources of heat at birth are accretion and differentiation. Radio-active decay deposits heat over longer times, though more at early times.
- Why is planetary size so important to internal heat and geology?
  - Size determines how fast a hot interior cools. Only large planets can maintain significant heat and mantle convection for billions of years.
- Why is Earth the only terrestrial world with a strong magnetic field?
  - A planetary magnetic field requires an interior layer of electrically conducting fluid, convection of that fluid, and rapid rotation. Only Earth has all three among the terrestrial planets.

What have we learned?

- What are the four basic geological processes?
  - Impact cratering, volcanism, tectonics, and erosion.
- Describe how each process is connected to fundamental planetary properties.
  - Impact cratering: larger planets more likely to have craters erased by other geological processes. Volcanism and tectonics: require interior heat, retained only by larger planets. Erosion: requires large size before outgassing by volcanism and a mild temperature. A fast rotation can make winds to cause erosion.

What have we learned?

- Describe the geology of the Moon & Mercury.
  - Both are heavily cratered. The Moon's lava plains are large and localized in the *maria*, while Mercury's lava plains are small and globally distributed. Mercury has more tectonic features. Many large cliffs on Mercury appear tectonic in origin.
- How did the lunar *maria* form?
  - Large impacts during the heavy bombardment fractured the lithosphere beneath the huge craters they created. A few hundred million years later, heat from radioactive decay melted mantle material, which welled up through the fractures and flooded the craters.
- Why do we think that Mercury shrank in size when it was young?
  - Long, high cliffs show that Mercury's surface was compressed, but there are no features to suggest surface expansion.

What have we learned?

- Why did many people once believe that Mars had intelligent beings?
  - Percival Lowell claimed to see canals and popularized the idea they were made by intelligent beings. The canals do not really exist.
- Describe general features of the four geological processes on Mars.
  - A dramatic difference in crater crowding on different parts of the surface. Numerous tall volcanoes, and the large *Tharsis Bulge*. The huge canyon of *Valles Marineris*, shaped at least in part by tectonics. Abundant evidence of water erosion.
- What evidence suggests a past warm and wet period on Mars?
  - Surfaces dating to older than 3 billion years appear to have been eroded by rainfall.

What have we learned?

- What evidence suggests more recent water flows on Mars?
  - Some younger regions of Mars appear to have suffered catastrophic floods between 1 to 3 billion years ago small. Small gullies suggest far more recent water flows at or near the surface.
- How do we study the surface of Venus?
  - Radar observations from spacecraft.
- What happened to Venus about a billion years ago?
  - Its entire surface was apparently repaved by some combination of volcanism and tectonics.

What have we learned?

- Why isn't there much erosion on Venus?
  - Its rotation is too slow to produce weather, despite its thick atmosphere.
- Is Venus still geologically active?
  - Probably, but we have no direct proof.
- In our Solar System, what geological features are unique to Earth?
  - Plate tectonics and rampant, ongoing erosion.

What have we learned?

- In what sense was the geology of each terrestrial world destined from birth?
  - Size is the key factor, as it determines how long volcanism and tectonics continue. Size is also necessary to erosion, since terrestrial atmospheres come from volcanic outgassing.

The interior of the Earth consists of

1. a metallic core and solid rock outer shell.
2. a rocky core and metallic outer shell.
3. a metallic core and liquid rock outer shell.
4. a liquid rocky inner core and solid rock outer shell.
5. a mixture of rock and metals throughout.

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The Earth's interior is hot mostly because of

1. high pressure (i.e. the weight of the surface layers).
2. the insulation of the outer surface (i.e. it can't cool down).
3. radioactive decay.
4. tidal heating from the Moon-Earth interaction.
5. heating from the Sun.

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4. tidal heating from the Moon-Earth interaction.
5. heating from the Sun.

In general, what kind of planet would you expect to have the thickest lithosphere?

1. The largest planet because the lithosphere scales with planet size.
2. The smallest planet because it has lost the most interior heat and thus its lithosphere has thickened the most.
3. The closest planet to the Sun since it will be mostly metallic and metals don't have as many radioactive elements to maintain the heat in their interior.
4. The furthest planet since it will be coolest.
5. There is no simple reason but rather it is a combination of factors intricately linked with the formation of the solar system.

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Why does Mercury have a more heavily cratered surface than Venus?

1. Mercury formed before Venus and therefore has an older surface.
2. Mercury is closer to the Sun than Venus and therefore experienced many more impacts during the early solar system.
3. Geological processes have erased old craters on Venus.
4. The volcanoes on Mercury has given the appearance of a highly cratered surface.
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Suppose Venus rotated as fast as Earth. How would this change its relative levels of volcanism, tectonics, and erosion?

1. All would remain the same - independent of rotation.
2. Higher levels of all three.
3. Lower levels of all three.
4. The same levels of volcanism and tectonics, and a higher level of erosion.
5. Higher levels of volcanism and tectonics, and the same level of erosion.

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