7.3 Mars: A Victim of Planetary Freeze-Drying

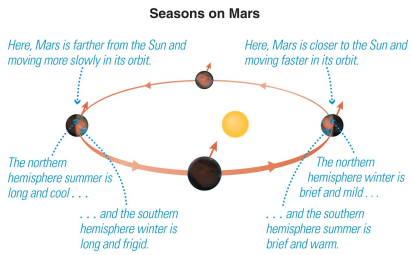
Our goals for learning:

- What geological features tell us that water once flowed on Mars?
- Why did Mars change?

Mars versus Earth

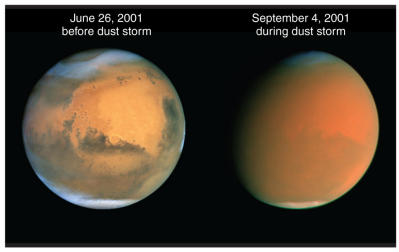
- 50% Earth's radius, 10% Earth's mass
- 1.5 AU from the Sun
- Axis tilt about the same as Earth
- Similar rotation period
- Thin CO_2 atmosphere: little greenhouse
- Main difference: Mars is SMALLER

Seasons on Mars



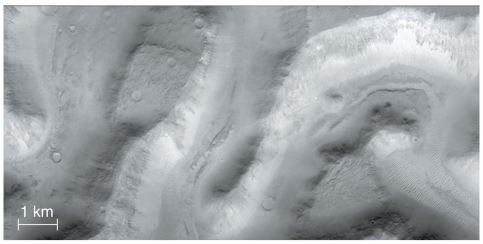
- Seasons on Mars are more extreme in the southern hemisphere because of its elliptical orbit.

Storms on Mars

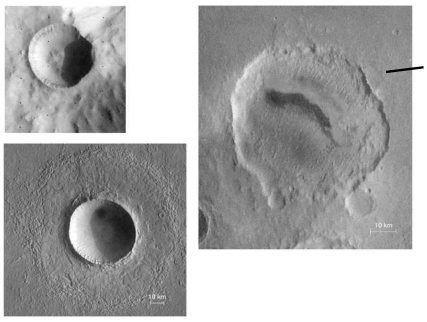


- Seasonal winds on Mars can drive huge dust storms.

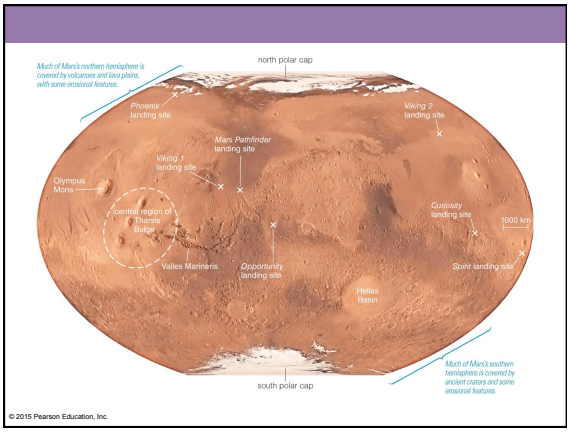
What geological features tell us that water once flowed on Mars?

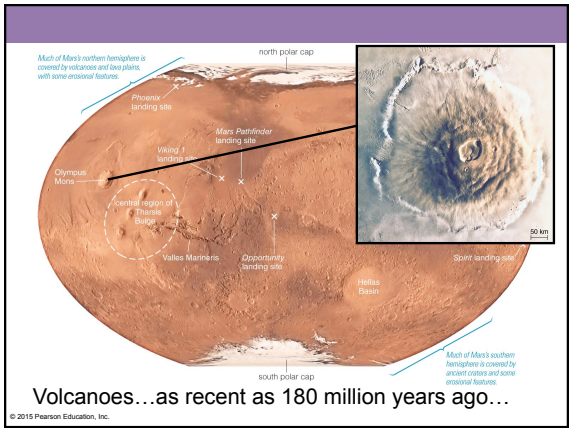


The surface of Mars appears to have ancient riverbeds.

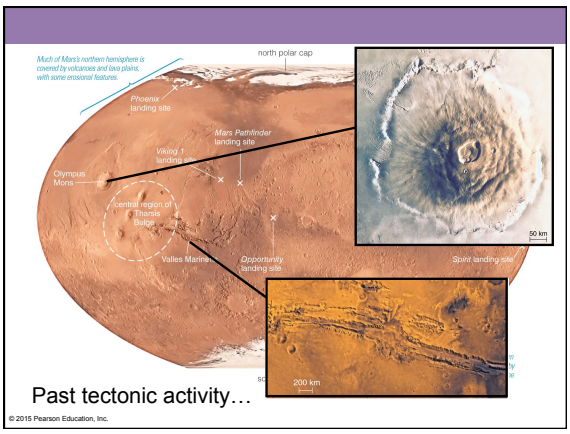


The condition of craters indicates surface history.

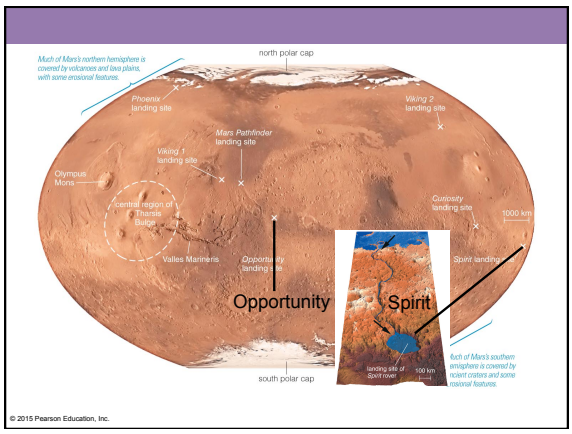


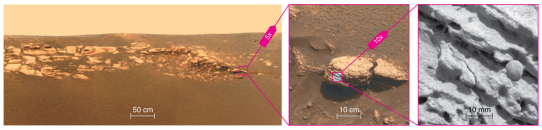


Volcanoes…as recent as 180 million years ago…

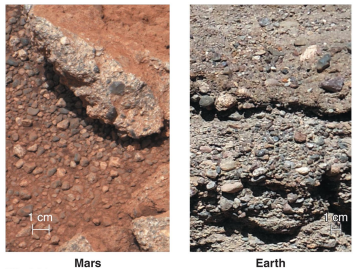


Past tectonic activity…





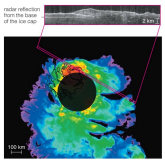
- 2004 *Opportunity* rover provided strong evidence for abundant liquid water on Mars in the distant past.
- How could Mars have been warmer and wetter in the past?



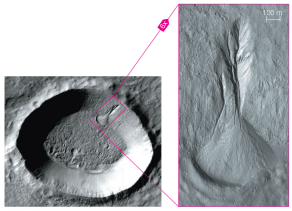
Mars Earth

Clumps of rounded pebbles discovered by the *Curiosity* rover compared with similar formations in Earth streambeds

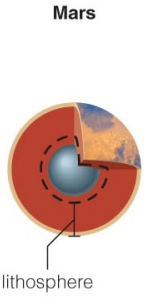
Today, most water lies frozen underground (blue regions).



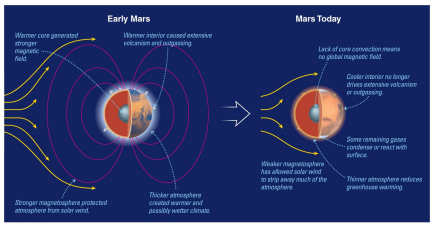
Some scientists believe accumulated snowpack melts carve gullies even today.



Why did Mars change?

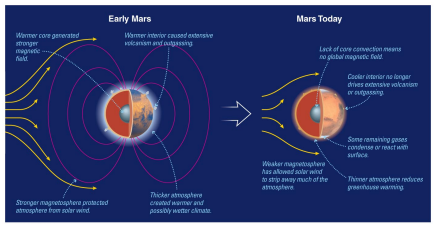


Climate Change on Mars



- Mars has not had widespread surface water for 3 billion years.
- The greenhouse effect probably kept the surface warmer before that.
- Somehow Mars lost most of its atmosphere.

Climate Change on Mars



- Magnetic field may have preserved early Martian atmosphere.
- Solar wind may have stripped atmosphere after field decreased because of interior cooling.

What have we learned?

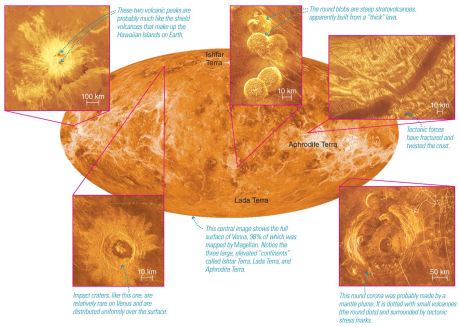
- What geological features tell us that water once flowed on Mars?
  - Dry riverbeds, eroded craters, and rock-strewn floodplains all show that water once flowed on Mars.
  - Mars today has ice, underground water ice, and perhaps pockets of underground liquid water.
- Why did Mars change?
  - Mars's atmosphere must have once been much thicker for its greenhouse effect to allow liquid water on the surface.
  - Somehow Mars lost most of its atmosphere, perhaps because of a declining magnetic field.

7.4 Venus: A Hothouse World

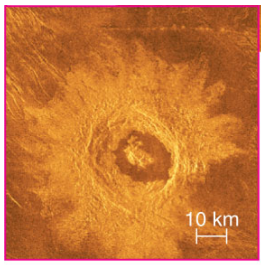
Our goals for learning:

- Is Venus geologically active?
- Why is Venus so hot?

Is Venus geologically active?

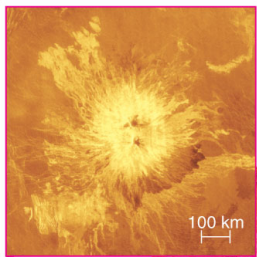


Cratering on Venus



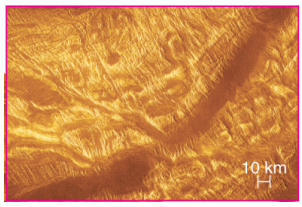
- Impact craters, but fewer than Moon, Mercury, Mars

Volcanoes on Venus



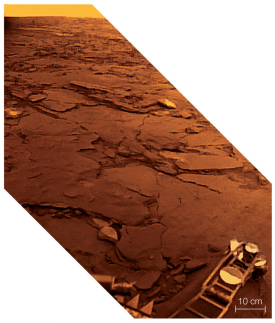
- Many volcanoes

Tectonics on Venus



- Fractured and contorted surface indicates tectonic stresses

Erosion on Venus



- Photos of rocks taken by lander show little erosion

Does Venus have plate tectonics?

- Most of Earth's major geological features can be attributed to plate tectonics, which gradually remakes Earth's surface.
- Venus does not appear to have plate tectonics, but its entire surface seems to have been "repaved" 750 million years ago.

Why is Venus so hot?

The greenhouse effect on Venus keeps its surface temperature at 470°C (about 900°F) .

But why is the greenhouse effect on Venus so much stronger than on Earth?

Atmosphere of Venus

- Venus has a very thick carbon dioxide atmosphere with a surface pressure 90 times that of Earth.

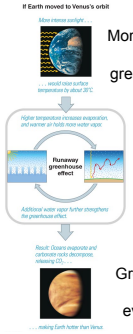
Greenhouse Effect on Venus

- Thick carbon dioxide atmosphere produces an extremely strong greenhouse effect.
- Earth escapes this fate because most of its carbon and water are in rocks and oceans.

Atmosphere of Venus

- Reflective clouds contain droplets of sulfuric acid.
- The upper atmosphere has fast winds that remain unexplained.

Runaway Greenhouse Effect



More evaporation, stronger greenhouse effect

Greater heat, more evaporation

- The runaway greenhouse effect would account for why Venus has so little water.

What have we learned?

- Is Venus geologically active?
  - Its surface shows evidence of major volcanism and tectonics during the last billion years.
  - There is no evidence for erosion or plate tectonics.
- Why is Venus so hot?
  - The runaway greenhouse effect made Venus too hot for liquid oceans.
  - All carbon dioxide remains in the atmosphere, leading to a huge greenhouse effect.

7.5 Earth as a Living Planet

Our goals for learning:

- ❑What unique features of Earth are important for human life?
- ❑How is human activity changing our planet?
- ❑What makes a planet habitable?

What unique features of Earth are important for life?

1. Surface liquid water
2. Atmospheric oxygen
3. Plate tectonics
4. Climate stability

What unique features of Earth are important for life?

1. **Surface liquid water**
2. Atmospheric oxygen
3. Plate tectonics
4. Climate stability

Earth's distance from the Sun and moderate greenhouse effect make liquid water possible.

What unique features of Earth are important for life?

1. Surface liquid water
2. **Atmospheric oxygen**
3. Plate tectonics
4. Climate stability

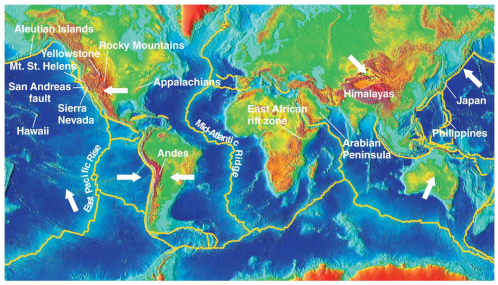
PHOTOSYNTHESIS (plant life) is required to make high concentrations of O_2, which produces the protective layer of O_3.

What unique features of Earth are important for life?

1. Surface liquid water
2. Atmospheric oxygen
3. **Plate tectonics**
4. Climate stability

Plate tectonics is an important step in the carbon dioxide cycle.

Continental Motion

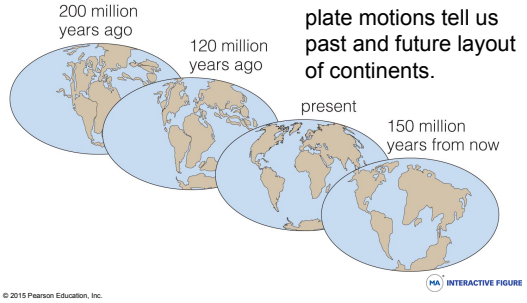


- ❑Motion of continents can be measured with GPS.

Continental Motion

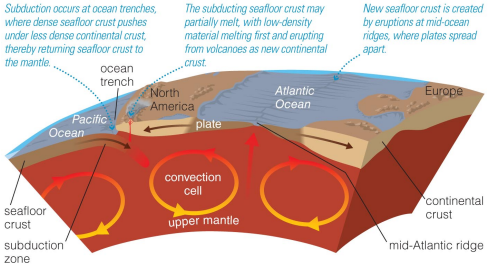
- Idea of continental drift was inspired by puzzle-like fit of continents.
- Mantle material erupts where seafloor spreads.

Plate Motions



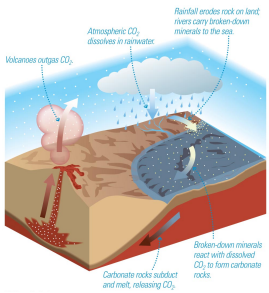
- Measurements of plate motions tell us past and future layout of continents.

Seafloor Recycling



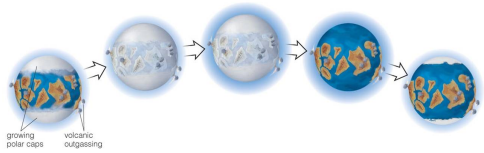
- Seafloor is recycled through a process known as subduction.

Carbon Dioxide Cycle



1. Atmospheric CO_2 dissolves in rainwater.
2. Rain erodes minerals that flow into the ocean.
3. Minerals combine with carbon to make rocks on ocean floor.
4. Subduction carries carbonate rocks down into the mantle.
5. Rock melts in mantle and outgases CO_2 back into atmosphere through volcanoes.

Long-Term Climate Change



- Changes in Earth's axis tilt might lead to *ice ages*.
- Widespread ice tends to lower global temperatures by increasing Earth's reflectivity.
- CO_2 from outgassing will build up if oceans are frozen, ultimately raising global temperatures again.

What unique features of Earth are important for life?

1. Surface liquid water
2. Atmospheric oxygen
3. Plate tectonics
4. **Climate stability**

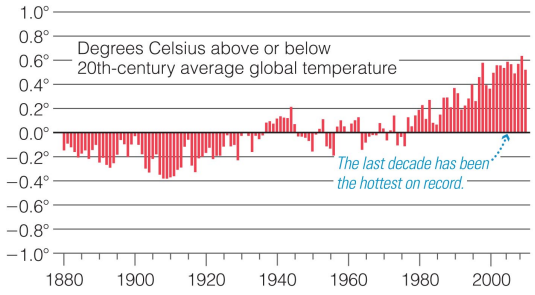
The CO_2 cycle acts like a thermostat for Earth's temperature.

These unique features are intertwined:

- Plate tectonics creates climate stability.
- Climate stability allows liquid water.
- Liquid water is necessary for life.
- Life is necessary for atmospheric oxygen.

How many other connections between these can you think of?

How is human activity changing our planet?



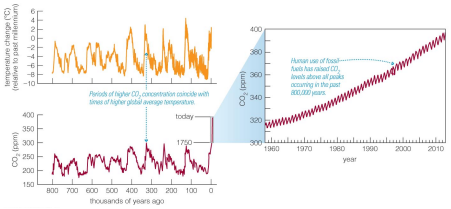
Dangers of Human Activity

- Human-made CFCs in the atmosphere destroy ozone, reducing protection from UV radiation.
- Human activity is driving many other species to extinction.
- Human use of fossil fuels produces greenhouse gases that can cause global warming.

Global Warming

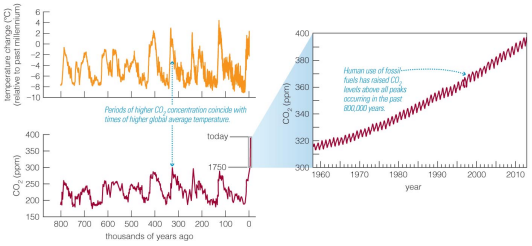
- Earth's average temperature has increased by 0.5°C in the past 50 years.
- The concentration of CO_2 is rising rapidly.
- An unchecked rise in greenhouse gases will eventually lead to global warming.

CO_2 Concentration



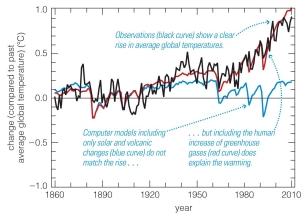
- Global temperatures have tracked CO_2 concentration for the last 500,000 years.
- Antarctic air bubbles indicate the current CO_2 concentration is at its highest level in at least 500,000 years.

CO_2 Concentration



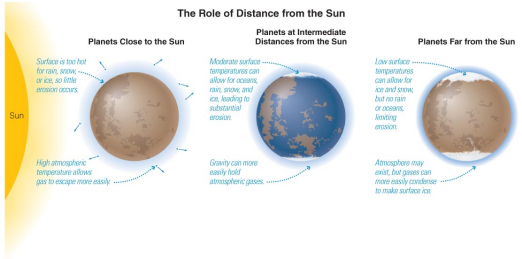
- Most of the CO_2 increase has happened in the last 50 years!

Modeling of Climate Change



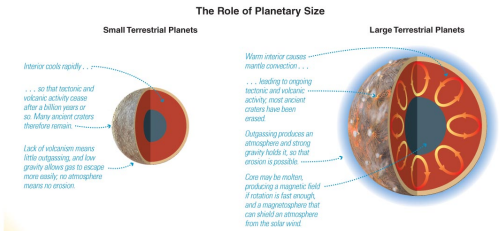
- Models of global warming that include human production of greenhouse gases are a better match to the global temperature rise.

What makes a planet habitable?



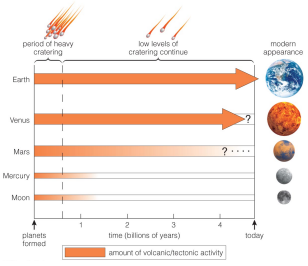
- Located at an optimal distance from the Sun for liquid water to exist

What makes a planet habitable?



- Large enough for geological activity to release and retain water and atmosphere

Planetary Destiny



Earth is habitable because it is large enough to remain geologically active, and it is at the right distance from the Sun so oceans could form.

What have we learned?

- What unique features of Earth are important for life?
  - Surface liquid water
  - Atmospheric oxygen
  - Plate tectonics
  - Climate stability

What have we learned?

- How is human activity changing our planet?
  - Human activity is releasing carbon dioxide into Earth's atmosphere, increasing the greenhouse effect and producing global warming.
- What makes a planet habitable?
  - Earth's distance from the Sun allows for liquid water on Earth's surface.
  - Earth's size allows it to retain an atmosphere and enough internal heat to drive geological activity.