Important Stuff (section 001, 9:45 am)

- The First Midterm is Tuesday, February 25
- The First Midterm will be given in a different room:
  - Willey 125 (West Bank)
  - Bring 2 pencils and a photo-id.
- In accordance with the syllabus (boldface), "You are allowed to bring in an 8.5x11 (inch) page of notes (one side) … no calculators".
- Test consists of 10 True/False and 50 Multiple Choice questions on Chapters 1 – 7.

1

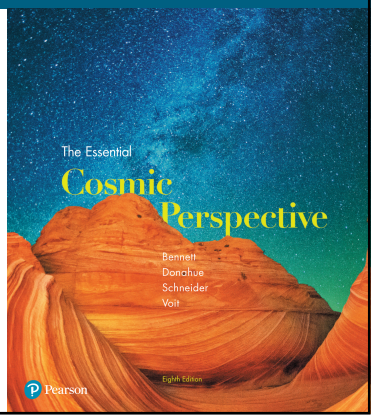
Important Stuff (section 002, 1:00 pm)

- The First Midterm is Tuesday, February 25
- The First Midterm will be given in two rooms:
  - Last Names starting A – I Tate B50 (This room)
  - Last Names starting J – Z Willey 125 (West Bank)
  - Bring 2 pencils and a photo-id.
- In accordance with the syllabus (boldface), "You are allowed to bring in an 8.5x11 (inch) page of notes (one side) … no calculators".
- Test consists of 10 True/False and 50 Multiple Choice questions on Chapters 1 – 7.

2

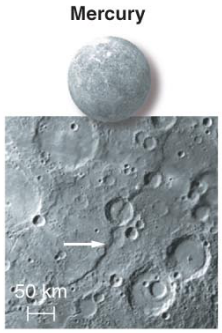
Lecture Outline

Chapter 7: Earth and the Terrestrial Worlds



3

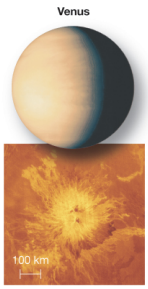
Mercury



Craters
Smooth plains
Cliffs

4

Venus



Cloud-penetrating radar revealed this twin-peaked volcano on Venus.

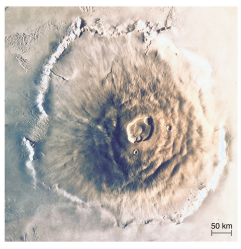
Volcanoes
Few craters

Radar view of a twin-peaked volcano

5

Mars

Some craters
Volcanoes
Riverbeds?



6

Moon

Craters
Smooth plains

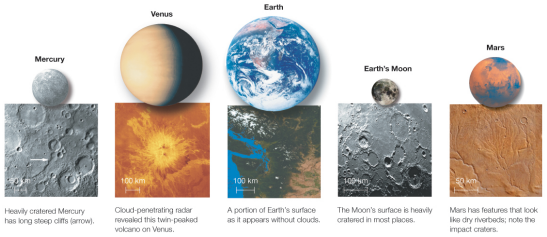
7

Earth

Volcanoes
Craters
Mountains
Riverbeds

8

Why have the planets turned out so differently, even though they formed at the same time from the same materials?



9

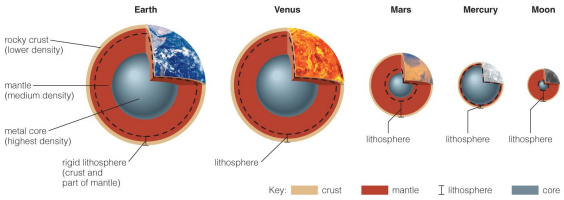
7.1 Earth as a Planet

Our goals for learning:

- Why is Earth geologically active?
- What processes shape Earth's surface?
- How does Earth's atmosphere affect the planet?

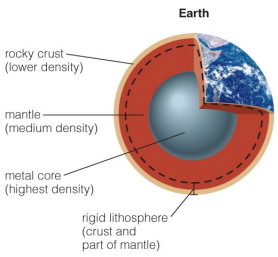
10

Why is Earth geologically active?



11

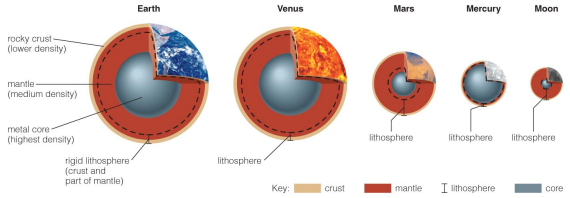
Earth's Interior



- **Core:** Highest density; nickel and iron
- **Mantle:** Moderate density; minerals with silicon, oxygen, etc.
- **Crust:** Lowest density; granite, basalt, etc.

12

Terrestrial Planet Interiors



- Applying what we have learned about Earth's interior to other planets tells us what their interiors are probably like.

13

Why do water and oil separate?

A. Water molecules repel oil molecules electrically.
B. Water is denser than oil, so oil floats on water.
C. Oil is more slippery than water, so it slides to the surface of the water.
D. Oil molecules are bigger than the spaces between water molecules.

14

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B. Water is denser than oil, so oil floats on water.
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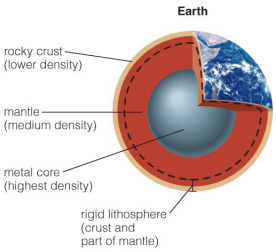
15

Differentiation



- Gravity pulls high-density material to center.
- Lower-density material rises to surface.
- Material ends up separated by density.

16

Thought Question

What is necessary for *differentiation* to occur in a planet?

A. It must have metal and rock in it.
B. It must be a mix of materials of different density.
C. Material inside must be able to flow.
D. All of the above
E. B and C

17

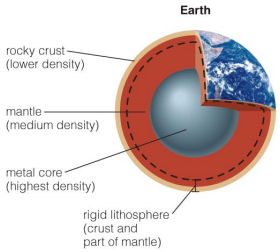
Thought Question

What is necessary for *differentiation* to occur in a planet?

A. It must have metal and rock in it.
B. It must be a mix of materials of different density.
C. Material inside must be able to flow.
D. All of the above
E. B and C

18

Lithosphere



- A planet's outer layer of cool, rigid rock is called the lithosphere.
- It "floats" on the warmer, softer rock that lies beneath.

19

Thought Question

Do rocks s-t-r-e-t-c-h?

A. No. Rock is rigid and cannot deform without breaking.
B. Yes, but only if it is molten rock.
C. Yes. Rock under strain may slowly deform.

20

Thought Question

Do rocks s-t-r-e-t-c-h?

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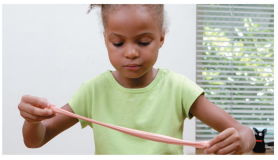
C. Yes. Rock under strain may slowly deform.

21

Strength of Rock



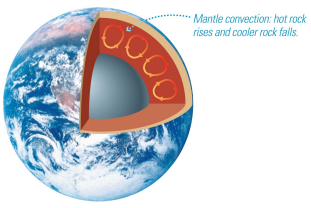
- Rock stretches when pulled slowly but breaks when pulled rapidly.
- The gravity of a large world pulls slowly on its rocky content, shaping the world into a sphere.

22

Heat Drives Geological Activity

Convection: Hot rock rises, cool rock falls.

One convection cycle takes 100 million years on Earth.



23

Sources of Internal Heat

1. Gravitational potential energy of accreting planetesimals
2. Differentiation
3. Radioactivity

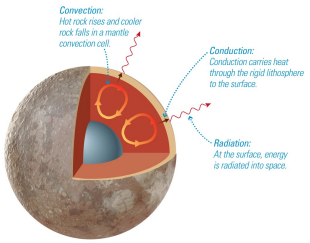
24

Heating of Interior over Time

- Accretion and differentiation when planets were young
- Radioactive decay is most important heat source today.

25

Cooling of Interior



- **Convection** transports heat as hot material rises and cool material falls.
- **Conduction** transfers heat from hot material to cool material.
- **Radiation** sends energy into space.

26

Thought Question

What cools off faster?

A. A grande-size cup of Starbucks coffee
B. A teaspoon of cappuccino in the same cup

27

Thought Question

What cools off faster?

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28

Thought Question

What cools off faster?

A. A big terrestrial planet
B. A tiny terrestrial planet

29

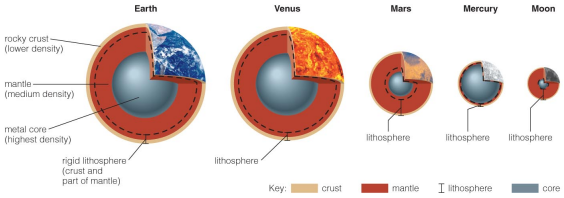
Thought Question

What cools off faster?

A. A big terrestrial planet
B. A tiny terrestrial planet

30

Role of Size



- Smaller worlds cool off faster and harden earlier.
- The Moon and Mercury are now geologically "dead."

31

Surface Area-to-Volume Ratio

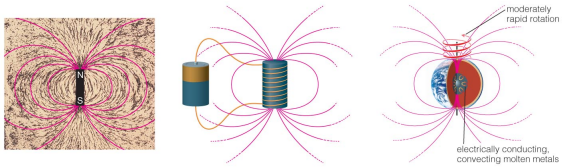
- Heat content depends on volume.
- Loss of heat through radiation depends on surface area.
- Time to cool depends on surface area divided by volume:

$$\text{Surface area-to-volume ratio} = \frac{4\pi r^2}{\frac{4}{3}\pi r^3} = \frac{3}{r}$$

- Larger objects have a smaller ratio and cool more slowly.

32

Planetary Magnetic Fields

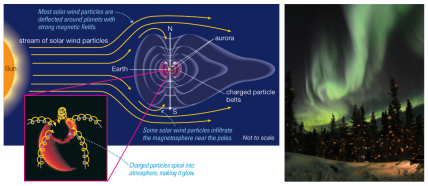


Moving charged particles create magnetic fields.
A planet's interior can create magnetic fields if its core is electrically conducting, convecting, and rotating.

33

Earth's Magnetosphere

- Earth's magnetic field protects us from charged particles from the Sun.
- The charged particles can create aurorae.



a This diagram shows how Earth's magnetosphere deflects solar wind particles. Some particles accumulate in charged particle belts encircling our planet. The inset is an ultraviolet image of a ring of auroras around the North Pole; the bright crescent at its left is part of the day side of Earth.

b This photograph shows the aurora near Yellowknife, Northwest Territories, Canada. In a video, you would see these lights dancing about in the sky.

34

Thought Question

If the planet core is cold, do you expect it to have magnetic fields?

A. Yes. Refrigerator magnets are cold, and they have magnetic fields.
B. No. Planetary magnetic fields are generated by moving charges around, and if the core is cold, nothing is moving.

35

Thought Question

If the planet core is cold, do you expect it to have magnetic fields?

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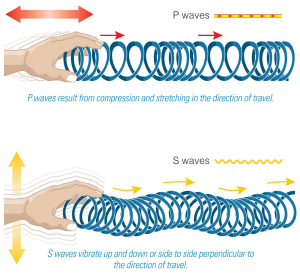
36

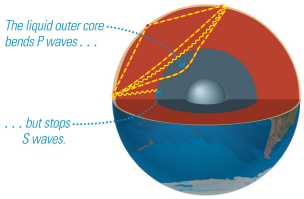
Special Topic: How do we know what's inside a planet?



- Earthquakes!
- P waves push matter back and forth.
- S waves shake matter side to side.

37

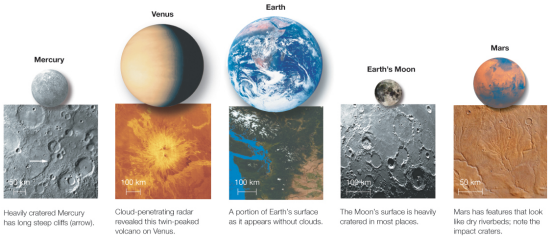
Special Topic: How do we know what's inside a planet?



- P waves go through Earth's core, but S waves do not.
- We conclude that Earth's core must have a liquid outer layer.

38

What processes shape Earth's surface?



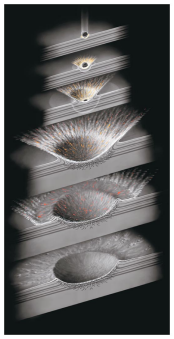
39

Geological Processes

- Impact cratering
  - Impacts by asteroids or comets
- Volcanism
  - Eruption of molten rock onto surface
- Tectonics
  - Disruption of a planet's surface by internal stresses
- Erosion
  - Surface changes made by wind, water, or ice

40

Impact Cratering



- Most cratering happened soon after the solar system formed.
- Craters are about 10 times wider than the objects that made them.
- Small craters greatly outnumber large ones.

41

Impact Craters

Meteor Crater (Arizona)

Tycho (Moon)

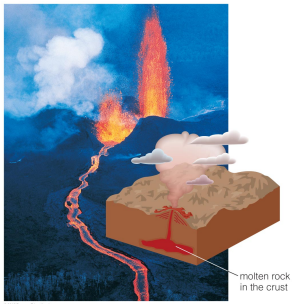
42

Impact Craters

Meteor Crater (Arizona)

43

Volcanism



- Volcanism happens when molten rock (magma) finds a path through lithosphere to the surface.
- Molten rock is called *lava* after it reaches the surface.

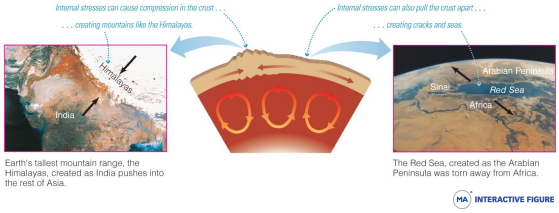
44

Outgassing

- Volcanism also releases gases from Earth's interior into the atmosphere.

45

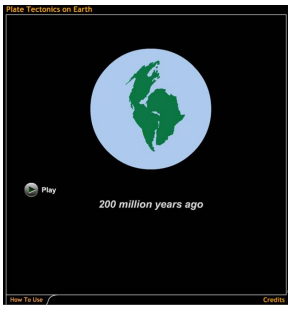
Tectonics



- Convection of the mantle creates stresses in the crust called tectonic forces.
- Compression forces make mountain ranges.
- A valley can form where the crust is pulled apart.

46

Plate Tectonics on Earth



- Earth's continents slide around on separate plates of crust.

PLAY Plate Tectonics on Earth

47

Erosion

- Erosion is a blanket term for weather-driven processes that break down or transport rock.
- Processes that cause erosion include
  - Glaciers
  - Rivers
  - Wind

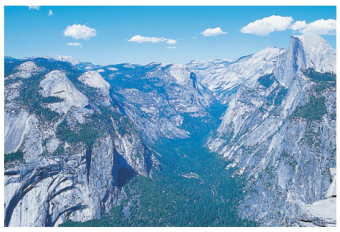
48

Erosion by Water

- The Colorado River continues to carve the Grand Canyon.

49

Erosion by Ice



- Glaciers carved the Yosemite Valley.

50

Erosion by Wind

- Wind wears away rock and builds up sand dunes.

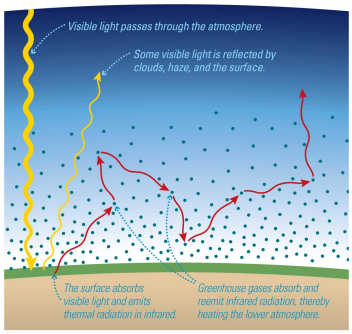
51

Erosional Debris

- Erosion can create new features by depositing debris.

52

How does Earth's atmosphere affect the planet?



53

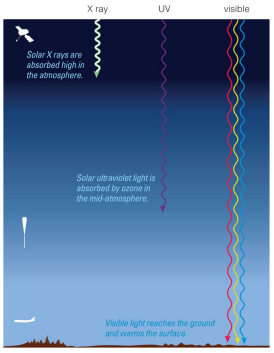
Effects of Atmosphere on Earth

1. Erosion
2. Radiation protection
3. Greenhouse effect
4. Makes the sky blue!

54

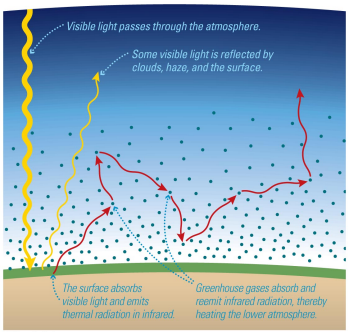
Radiation Protection

- All X-ray light is absorbed very high in the atmosphere.
- Ultraviolet light is absorbed by ozone (O_3).

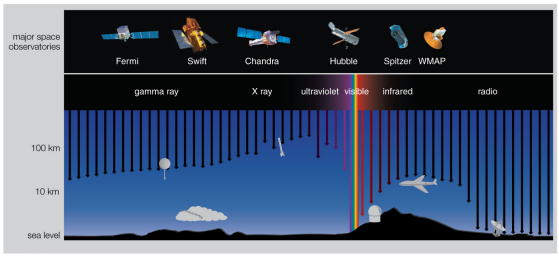


55

The Greenhouse Effect



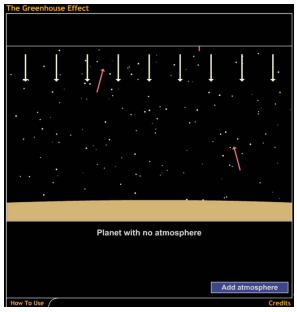
56



Earth's atmosphere absorbs light at most wavelengths.

57

Greenhouse effect:



Certain molecules let sunlight through but trap escaping infrared photons.

(H_2O, CO_2, CH_4)

PLAY The Greenhouse Effect

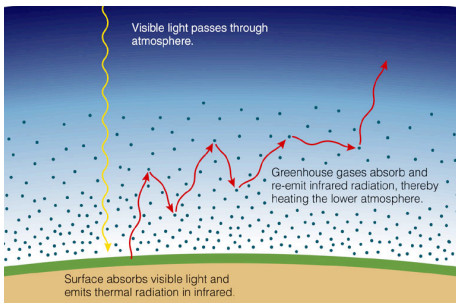
58

A Greenhouse Gas

- Any gas that absorbs infrared
- Greenhouse gas: molecules with two different types of elements (CO_2, H_2O, CH_4)
- Not a greenhouse gas: molecules with one or two atoms of the same element (O_2, N_2)

59

The Greenhouse Effect



PLAY Which Molecules are Greenhouse Gases?

60

Greenhouse Effect: Bad?

Because of the greenhouse effect, Earth is much warmer than it would be without an atmosphere…but so is Venus.

61

Thought Question

Why is the sky blue?

A. The sky reflects light from the oceans.
B. Oxygen atoms are blue.
C. Nitrogen atoms are blue.
D. Air molecules scatter blue light more than red light.
E. Air molecules absorb red light.

62

Thought Question

Why is the sky blue?

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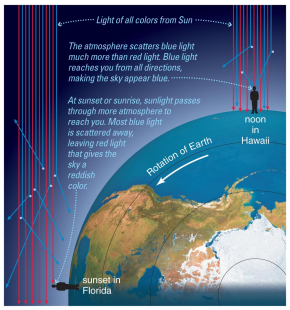
D. Air molecules scatter blue light more than red light.
E. Air molecules absorb red light.

63

Why the sky is blue



- Atmosphere scatters blue light from the Sun, making it appear to come from different directions.
- Sunsets are red because less of the red light from the Sun is scattered.

64

7.2 Mercury and the Moon: Geologically Dead

Our goals for learning:

- Was there ever geological activity on the Moon or Mercury?

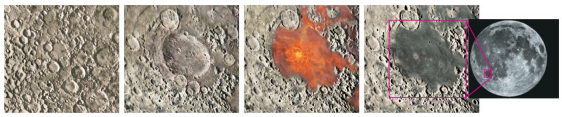
65

Was there ever geological activity on the Moon or Mercury?

Moon Mercury

66

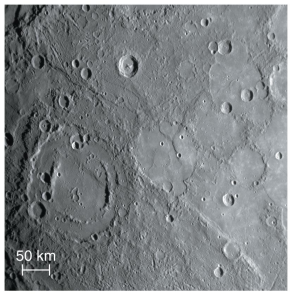
Moon



- Some volcanic activity 3 billion years ago must have flooded lunar craters, creating *lunar maria*.
- The Moon is now geologically dead.

67

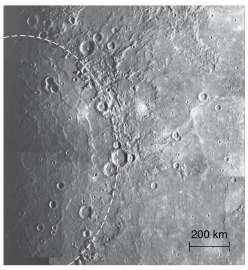
Cratering of Mercury



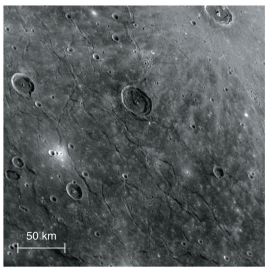
- Mercury has a mixture of heavily cratered and smooth regions like the Moon.
- The smooth regions are likely ancient lava flows.

68

Cratering of Mercury



The Caloris Basin is the largest impact crater on Mercury.

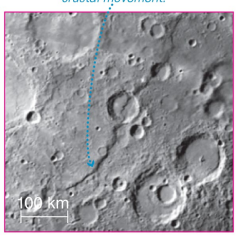


Region opposite the Caloris Basin is jumbled from seismic energy of impact.

69

Tectonics on Mercury

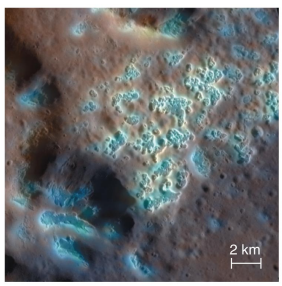
Today we see long, steep cliffs created by this crustal movement.



- Long cliffs indicate that Mercury shrank early in its history.

70

Recent Geology on Mercury



- Lighter areas (color enhanced) are thought to be "hollows" formed as easily vaporized minerals escape.

71

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?

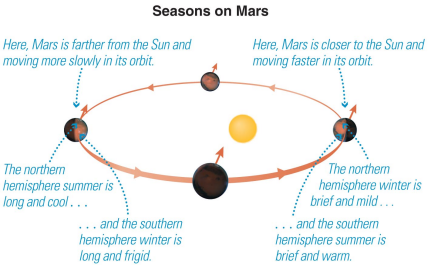
72

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

73

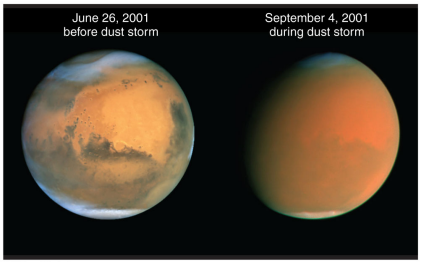
Seasons on Mars



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

74

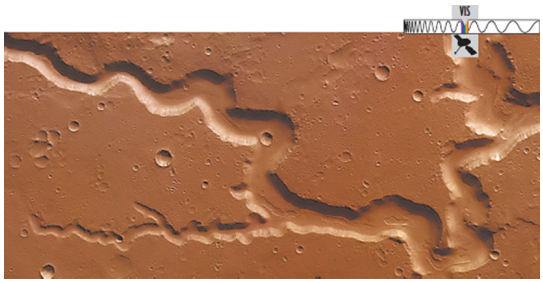
Storms on Mars



- Seasonal winds on Mars can drive huge dust storms.

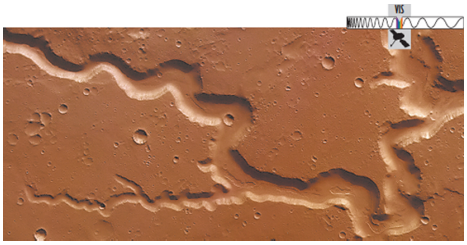
75

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



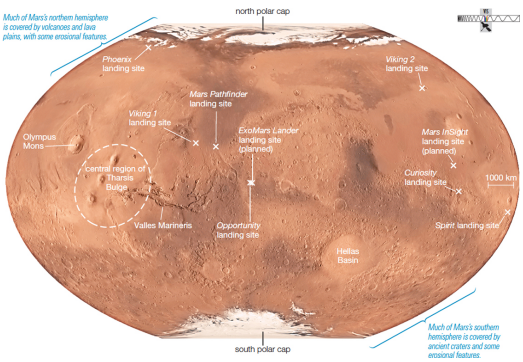
76

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

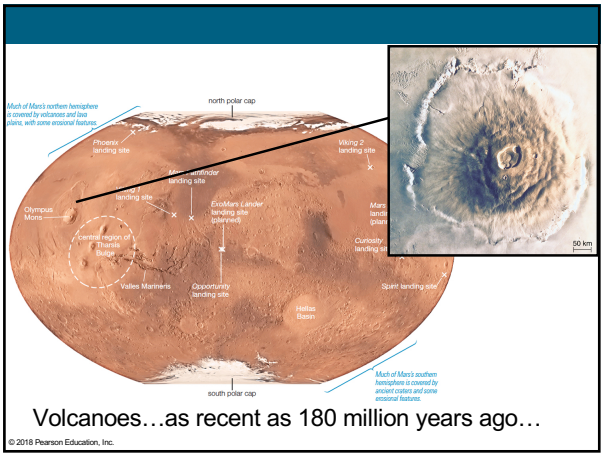


The surface of Mars appears to have ancient riverbeds.

77

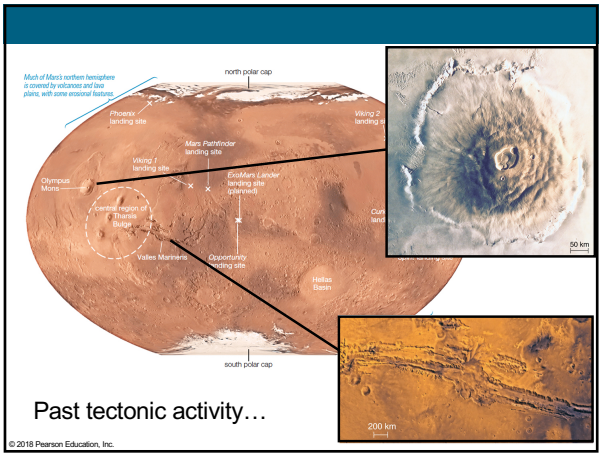


78



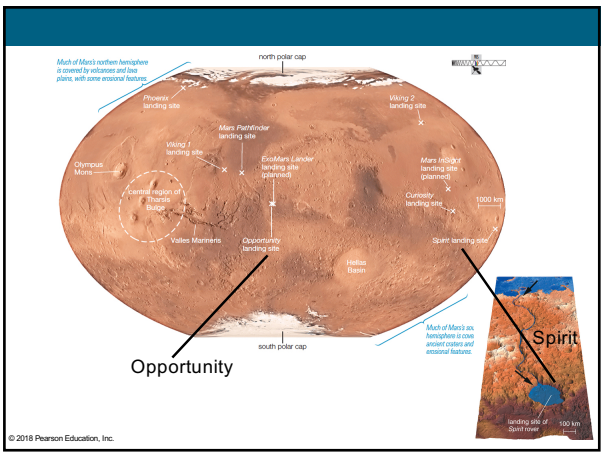
Volcanoes…as recent as 180 million years ago…

79

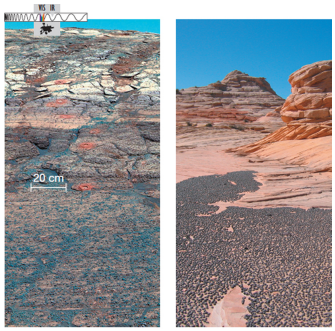


Past tectonic activity…

80



81



Mars (Endurance Crater) Earth (northern Arizona)

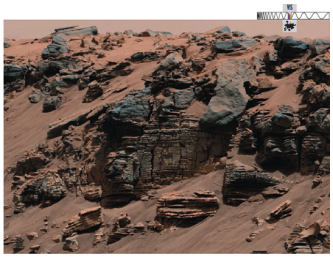
- 2004 *Opportunity* rover provided strong evidence for abundant liquid water on Mars in the distant past.
- The mineral hematite, typically formed in a salty water environment.

82

Mars Earth

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

83



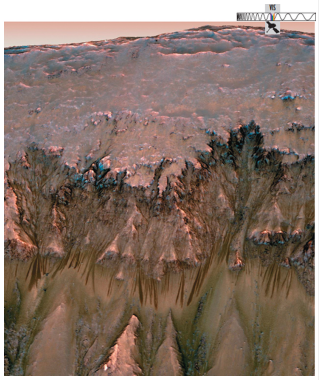
b The even layers of the foreground rocks in this image from *Curiosity* are characteristic of sediment deposited over time in the delta of a river that emptied into a lake.

Curiosity also found these layered rocks, characteristic of sedimentation by water.

84

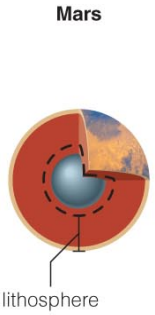
Today, most water lies frozen underground.

Recent evidence does suggest small-scale flow of salty water at or near the surface—here seen as seasonally changing dark streaks.



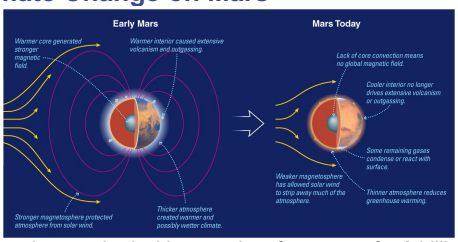
85

Why did Mars change?



86

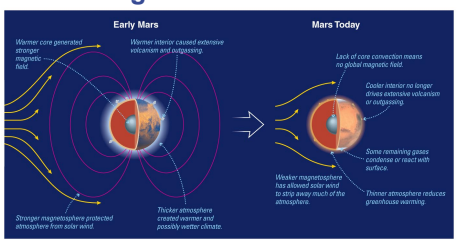
Climate Change on Mars



- 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.

87

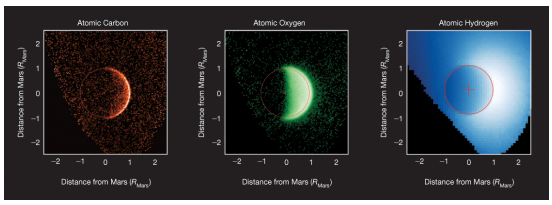
Climate Change on Mars



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

88

Climate Change on Mars



- The *MAVEN* spacecraft is measuring the loss of Mars' atmosphere today.

89

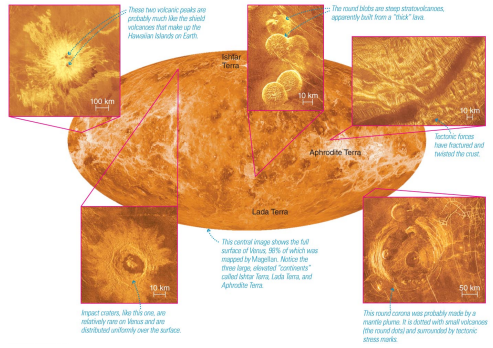
7.4 Venus: A Hothouse World

Our goals for learning:

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

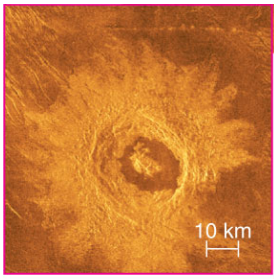
90

Is Venus geologically active?



91

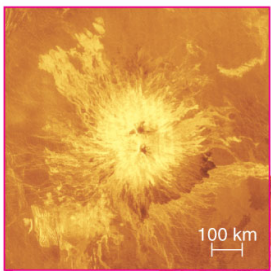
Cratering on Venus



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

92

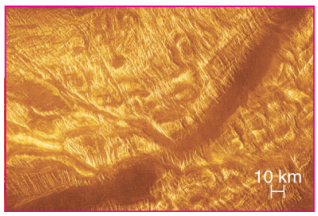
Volcanoes on Venus



- Many volcanoes

93

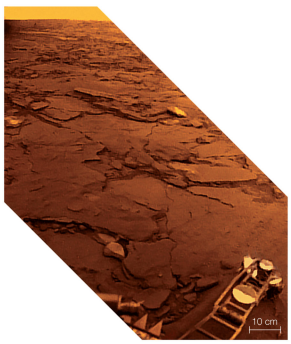
Tectonics on Venus



- Fractured and contorted surface indicates tectonic stresses

94

Erosion on Venus



- Photos of rocks taken by lander show little erosion

95

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.

96

Why is Venus so hot?

97

Why is Venus so hot?

The greenhouse effect on Venus keeps its surface temperature at 470°C.

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

98

Atmosphere of Venus

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

99

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.

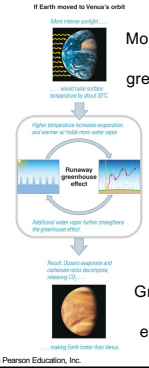
100

Atmosphere of Venus

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

101

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.

102

Thought Question

What is the main reason Venus is hotter than Earth?

A. Venus is closer to the Sun than Earth.
B. Venus is more reflective than Earth.
C. Venus is less reflective than Earth.
D. The greenhouse effect is much stronger on Venus than on Earth.
E. Human activity has led to declining temperatures on Earth.

103

Thought Question

What is the main reason Venus is hotter than Earth?

A. Venus is closer to the Sun than Earth.
B. Venus is more reflective than Earth.
C. Venus is less reflective than Earth.
D. The greenhouse effect is much stronger on Venus than on Earth.
E. Human activity has led to declining temperatures on Earth.

104

7.5 Earth as a Living Planet

Our goals for learning:

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

105

What unique features of Earth are important for life?

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

106

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.

107

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.

108

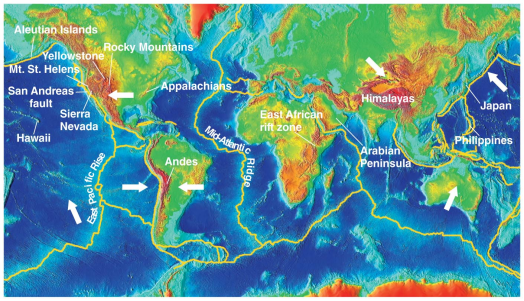
What unique features of Earth are important for life?

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

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

109

Continental Motion



- Motion of continents can be measured with GPS.

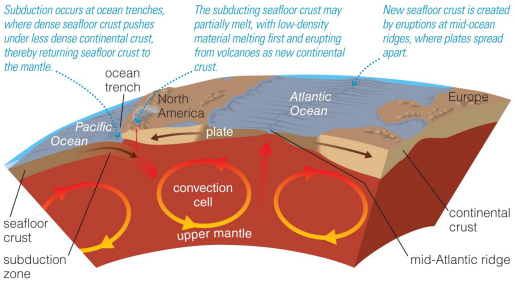
110

Continental Motion

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

111

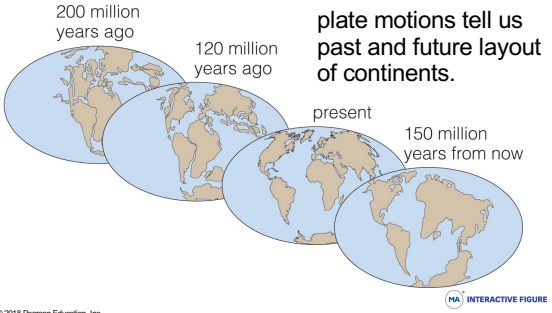
Seafloor Recycling



- Seafloor is recycled through a process known as subduction.

112

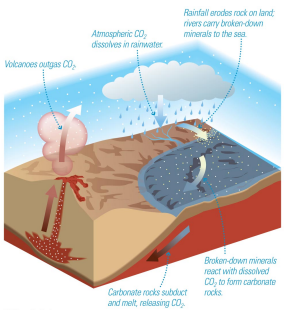
Plate Motions



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

113

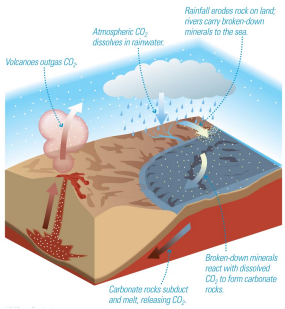
Carbon Dioxide Cycle



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.

114

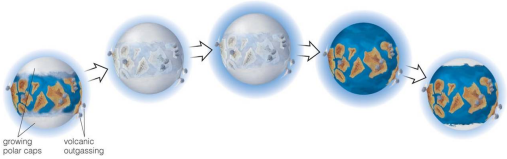
Carbon Dioxide Cycle



4. Subduction carries carbonate rocks down into the mantle.
5. Rock melts in mantle and outgases CO_2 back into atmosphere through volcanoes.

115

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.

116

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.

117

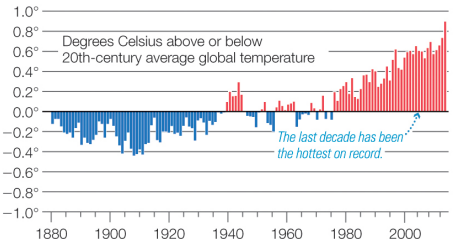
These unique features are intertwined:

- 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?

118

How is human activity changing our planet?



119

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 cause global warming.

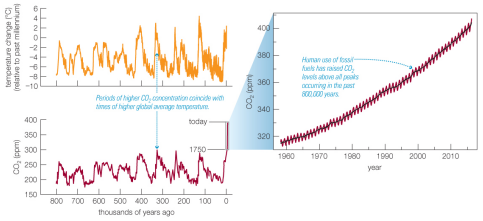
120

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.

121

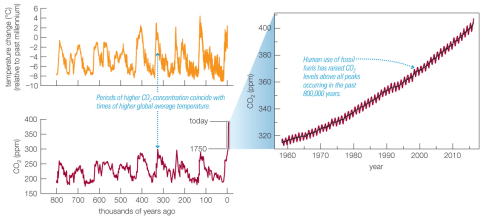
CO_2 Concentration



- 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.

122

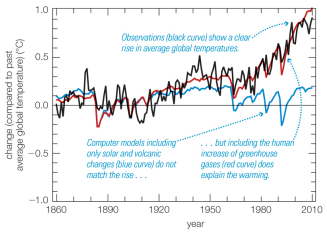
CO_2 Concentration



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

123

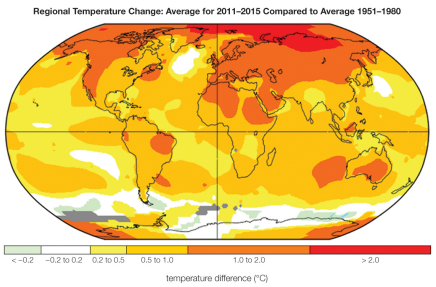
Modeling of Climate Change



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

124

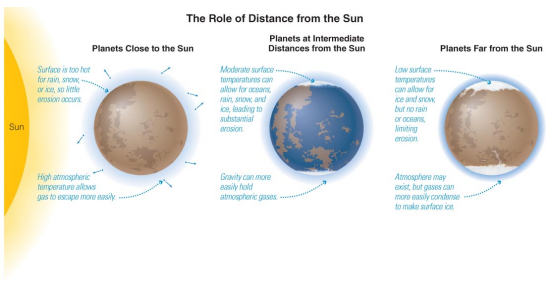
Consequences of Climate Change



- Increases in temperature vary from place to place, and the effects on weather patterns are quite complex.

125

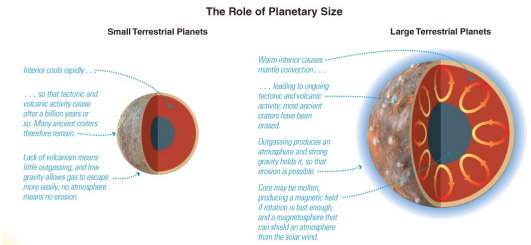
What makes a planet habitable?



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

126

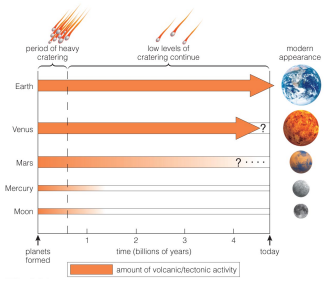
What makes a planet habitable?



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

127

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.

128