Planetary Geology (Chapter 9)

Part of Chapter 9:

General Processes Affecting the Terrestrial Planets (and the Moon)

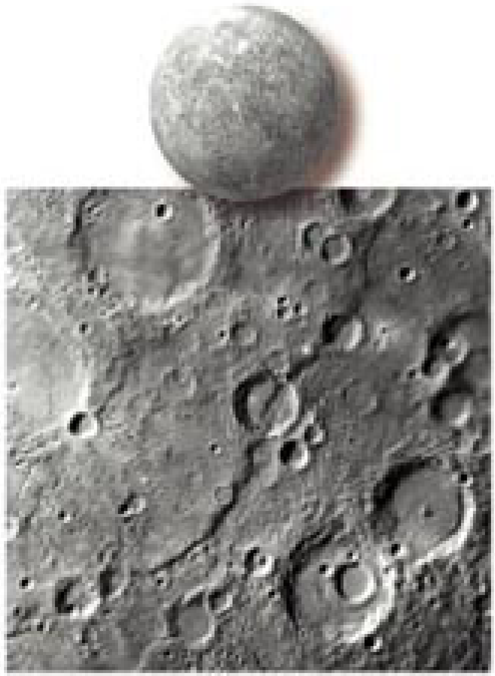
Based on part of Chapter 9

- This material will be useful for understanding Chapters 11 and 12 on “Jovian planet systems” and “Remnants of ice and rock”
- Chapters 4 and 8 on “Momentum, energy, and matter” and “Formation of the solar system” will be useful for understanding this chapter

Goals for Learning

- What are terrestrial planets like inside?
- What causes geological activity?
- What processes shape planetary surfaces?
- Why do the terrestrial planets have different geological histories?

Mercury



Mercury is heavily cratered, but also has long, steep cliffs—one is visible here as the long curve that passes through the center of the image.

Venus

The central structure is a tall, twin-peaked volcano on Venus. Both images are based on radar data from the Magellan space craft, because Venus's thick clouds prevent us from seeing the surface in visible light.

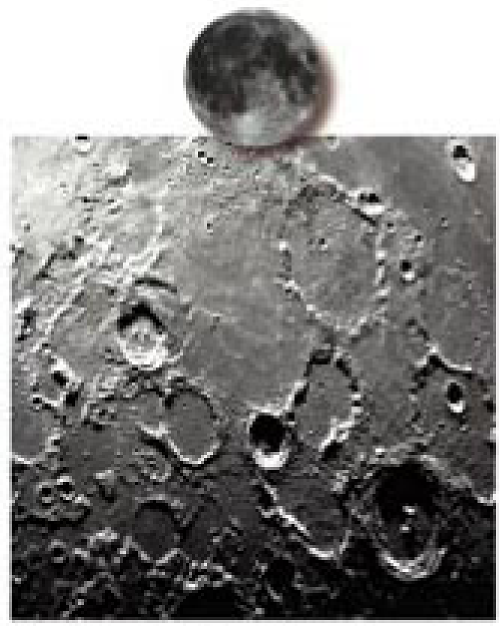
Earth

Earth has a variety of geological features visible in this photo from orbit.

Earth

Earth has a variety of geological features visible in this photo from orbit.

Earth's Moon



The Moon's surface is heavily cratered in most places.

Mars

Mars has impact craters like the one near the upper right, but it also has features that look much like dried up riverbeds.

Four Major Geological Processes

- Impact Cratering
  - Making big holes with impacting asteroids
- Volcanism
  - Erupting molten rock (lava) onto planet's surface
- Tectonism
  - Stretching or squashing of rock
- Erosion
  - Altering features by wind, water, ice, weather

Inside and Outside

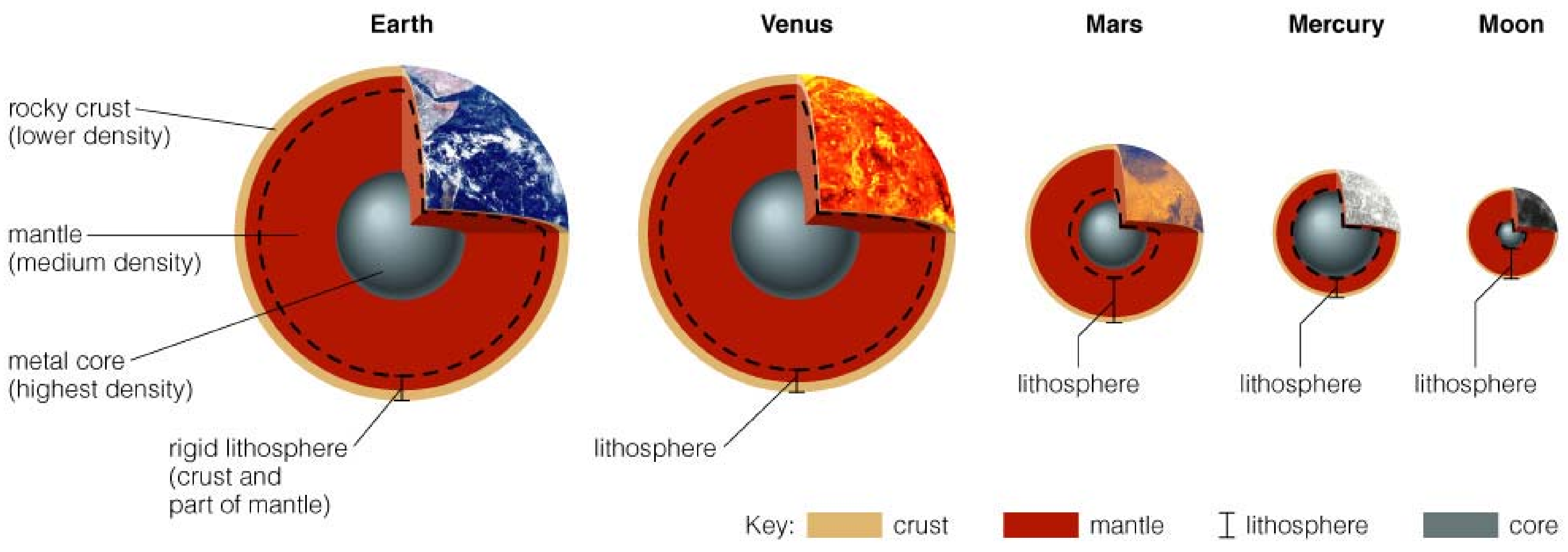
- Many surface geological features are shaped/influenced by processes deep within the planet
- Major differences between the surface geology of the terrestrial worlds can be related to differences in their interiors
- What are planetary interiors like?

Layering by Density

- Core – high density metals such as iron/nickel at the centre
  - Liquid or solid or both?
- Mantle – moderate density rocks, containing silicon, oxygen, other elements, forming a thick layer around the core
- Crust – lowest density rocks, such as granite and basalt, forming a thin, outermost layer above the mantle

Why layering?

- Gravity pulls dense stuff inwards, leaving less dense stuff at the top
- Requires a hot interior in the past so that rock and metal melt and flow past each other
- Layering by density leads to compositional layering



Mercury’s core is very large
Moon’s core is very small

Earth has a solid inner core and a liquid outer core
We know much less about the cores of the other worlds

Liquid Rock?

- Lava erupts as liquid
- Are we standing on a thin solid layer above a vast ocean of molten rock?
- No
- Earth’s crust and most of mantle are solid
- Only a thin layer near the top of the mantle is partially molten – where lava comes from

Flowing Rock

- Temperature increases inwards
- Pressure increases inwards
- Composition changes from crust to mantle to core
- These three factors affect the strength of rock
  - Rock can flow like a fluid over looong timescales, even though it behaves like a solid on short timescales

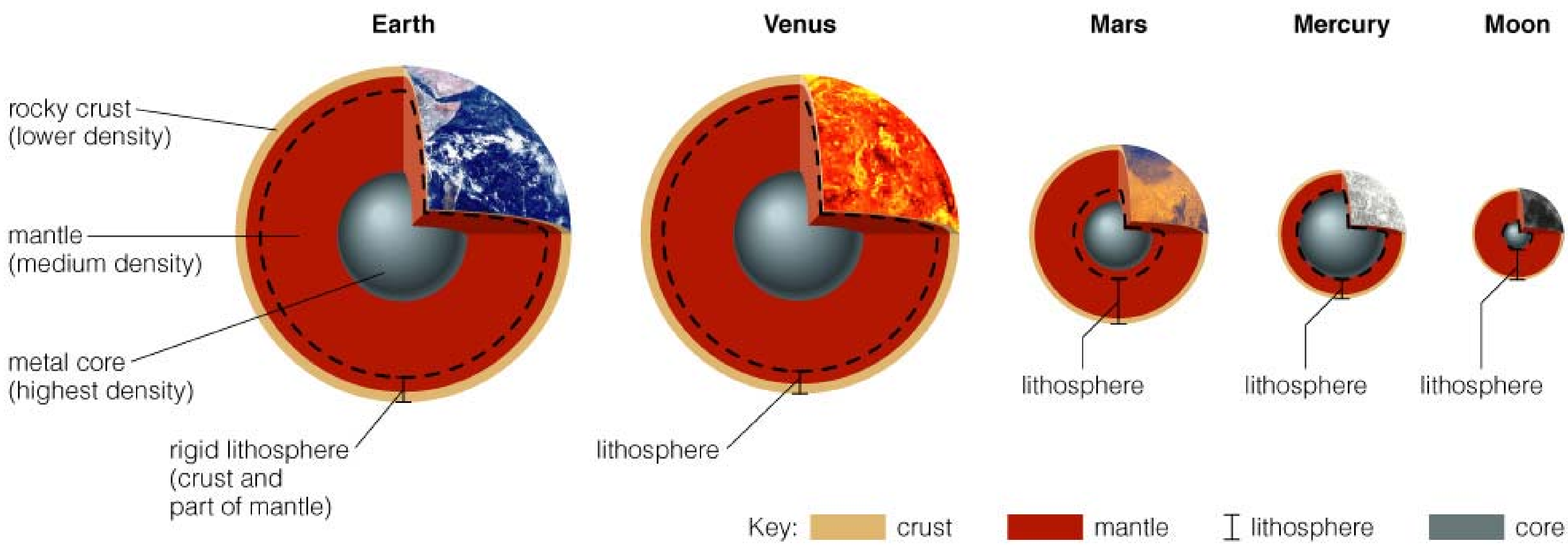
Asteroid Potatoes

- Big planets are round, small asteroids are shaped like potatoes
- Weak gravity on small, cold asteroids is not strong enough to slowly deform rocks and make them flow
- Without lumpy bits flowing “downhill”, asteroids don’t become round spheres
- Diameter of 500 km is needed to become round over ~1 billion years

Layering by Strength

- Lithosphere – Outermost layer of COOL strong rock, doesn't deform or flow easily, includes all of the crust and very top part of mantle
- Rock below the lithosphere is warmer and less strong, it can deform and flow when something stretches or compresses it

- Thin lithosphere cracks easily, letting lava erupt onto the surface, can be moved around to form mountains and plateaus
- Thick lithosphere prevents volcanic eruptions and formation of mountains
- Layering by strength has more effect on geology than crust/mantle/core layering does



Large planets have relatively thin cool lithospheres (and lots of geology)
Small planets have relatively thick cool lithospheres (and not much geology)

What causes this difference?

Which object has the most geological activity? The least?

- Mercury
- Venus
- Earth
- Moon
- Mars

- Why?

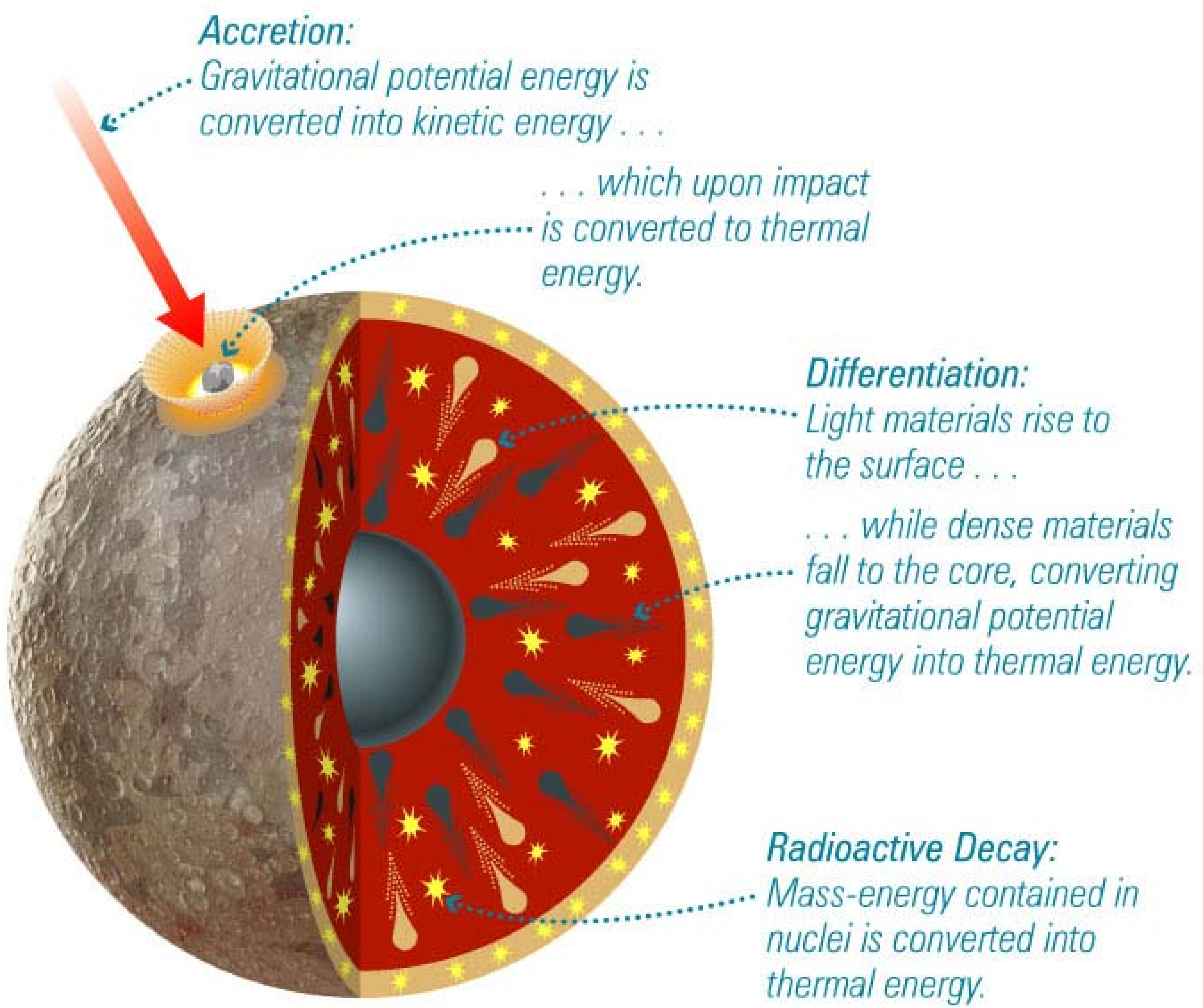
Geological Activity and Interior Heat

- Which planets are most/least geologically active?

- Interior heat is the driving force for most geological activity (except impact cratering)
- More heat, more activity
- Less heat, less activity

Why are planetary interiors hot?

- Heating by the Sun?
- Still hot from 4.5 billion years ago?
- Fires inside?
- Recent impacts?
- Volcanoes?
- Radioactivity?
- Space aliens?



A hot interior must have acquired its thermal energy from somewhere

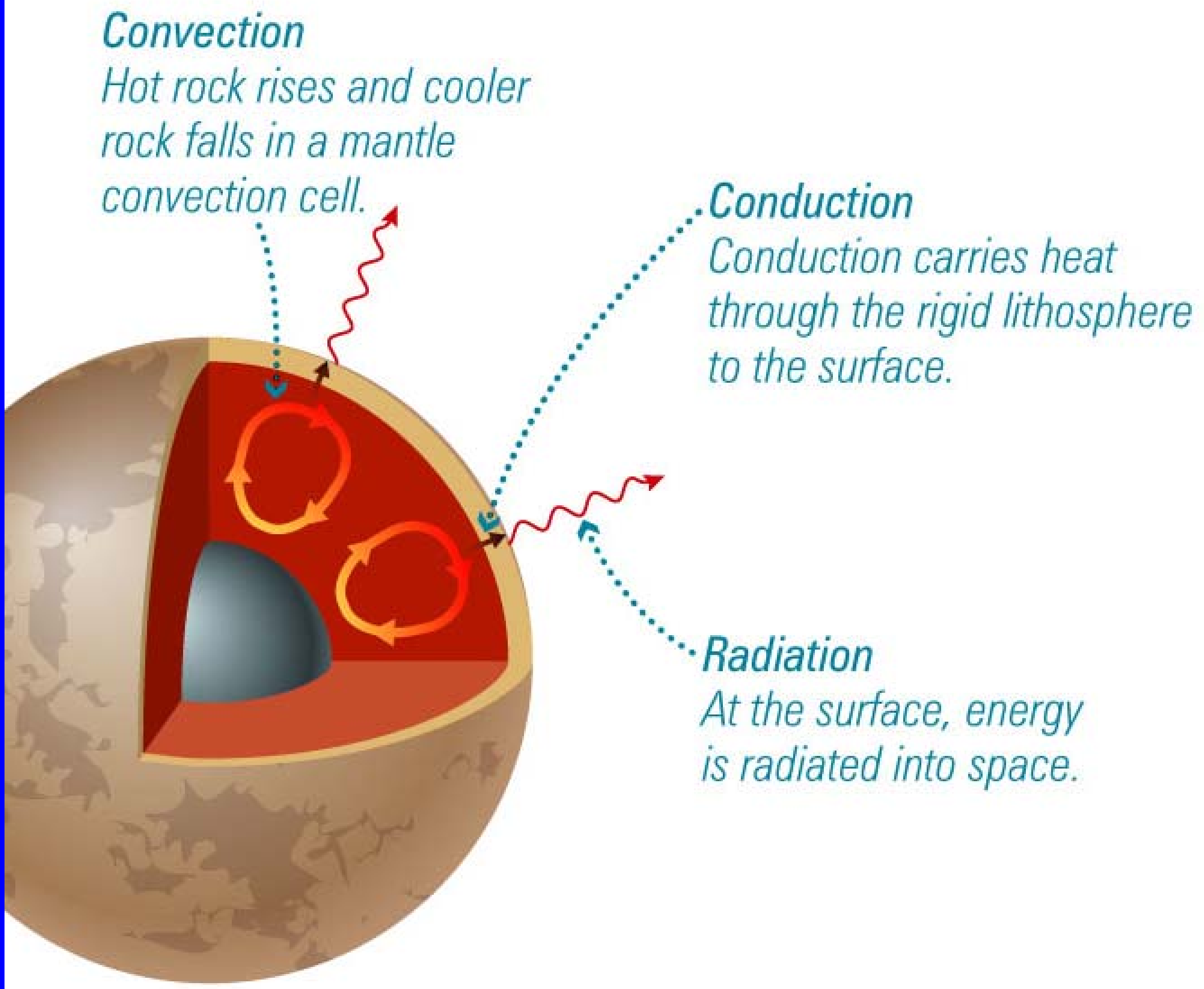
Interior heat does not come from the Sun

Three main sources

Accretion

Differentiation (layering by density)

Radioactive decay



Hot things always cool down

Convection occurs in a pot of soup and air

Hot things have lower densities than cool things. Hot things want to rise

Convection needs heating from below and gravity to define "below"

Conduction is a slower way to transport heat
Hot, fast molecules bump into cold, slow molecules
Fast ones slow down a bit, slow ones speed up
Heat is transferred

Only way to transfer heat to space is radiation, usually thermal radiation

Thermal radiation is often at infra-red wavelengths

Mantle Convection

- Controls a planet's interior temperature
- The flowing rock is solid, not liquid
- It flows slowly, 1 cm per year
- 100 million years to flow from core to crust
- Convection stops at the base of the lithosphere where the rock is too strong to flow very much
  - Volcanic eruptions transport some heat through the lithosphere, but conduction is more important

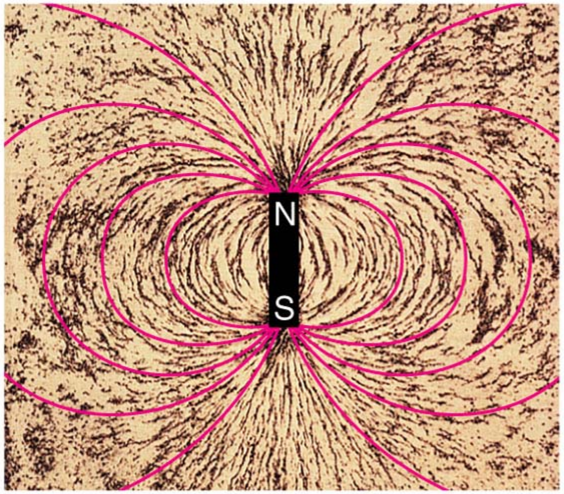
Size is Important

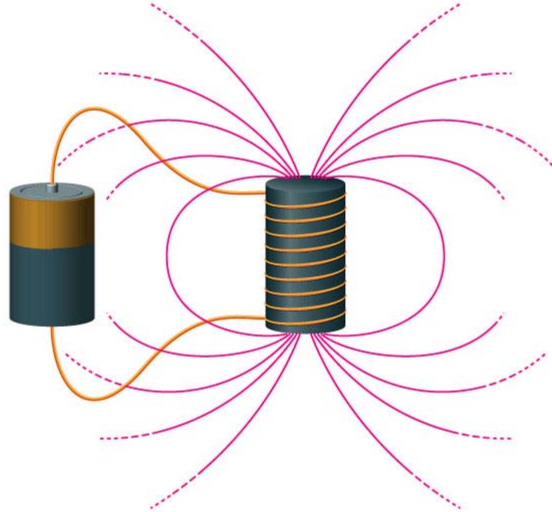
- Hot peas cool faster than hot potatoes
- Small planets cool faster than large planets
- It takes time for interior heat to move outwards. Longer distance, longer time
- Moon and Mercury are cold, so there is little heat flow to drive geological activity
- Venus and Earth are hot, so there is lots of heat flow to drive geological activity

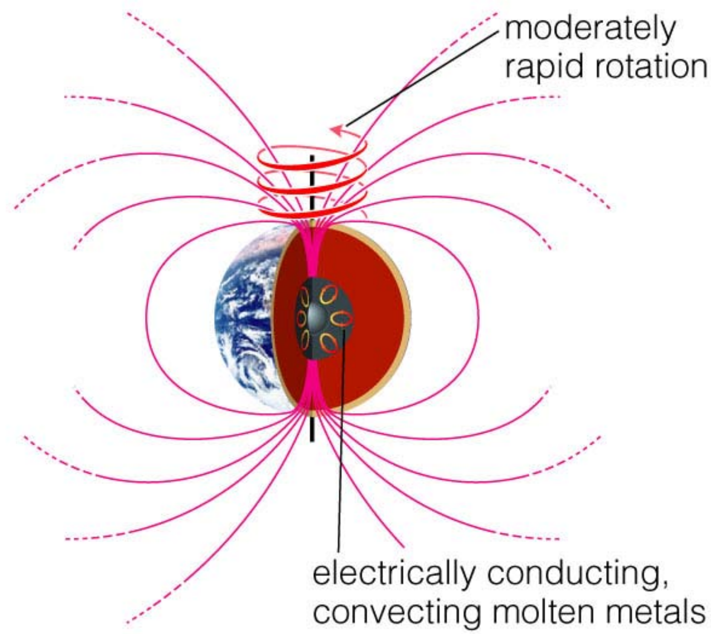
Magnetic Fields

- Earth and jovian planets have strong, global magnetic fields
- Venus and the Moon have no magnetic fields, Mercury has a weak global field, Mars has a weak localized field (Mars is awkward)
  - Magnetic fields affect charged particles, such as protons in the solar wind, and magnetized objects, like compass needles
- These magnetic fields are generated inside the respective planets – how?

Earth as a large bar magnet







Bar magnet influences iron filings
Iron filings line up with magnetic fieldlines (marked in red)

Battery forces electrons to move along wire wrapped around metal bar
This electromagnet generates a similar magnetic field

Charged particles move around in the convecting regions of Earth's outer core

Generating a Magnetic Field: Charged Particles in Motion

- An interior region of electrically conducting fluid, such as molten metal in Earth's outer core
- Convection in that fluid
- Rotation of that fluid (faster = better)
  - Mercury: Large core, partially molten? slow rotation
  - Venus: Large core, probably partially molten, slow rotation
  - Earth: Large molten outer core, rapid rotation
  - Moon: Small core or no core, solid if present
  - Mars: Small, probably solid, core, rapid rotation

Effects of Magnetic Fields

- None on the bulk of the planet
- Shield the planet from the solar wind, stop the solar wind from ripping the atmosphere off into space

- Navigation aid
- Presence and nature of planetary magnetic fields reveals a lot about the planetary interior

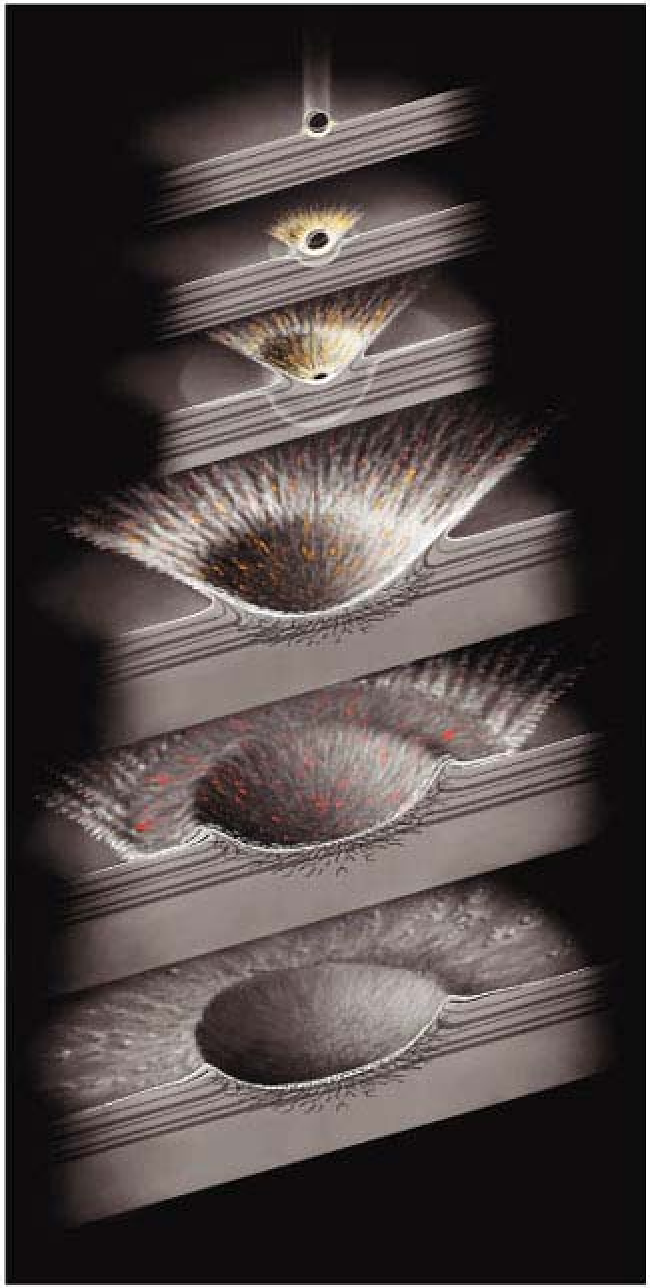
Four Major Geological Processes

- Impact Cratering
  - Making big holes with impacting asteroids
- Volcanism
  - Erupting molten rock (lava) onto planet's surface
- Tectonism
  - Stretching or squashing of rock
- Erosion
  - Altering features by wind, water, ice, weather

Which planets have been affected by which processes?

- Moon, Mercury, Mars, Venus, Earth

- Impact cratering, volcanism, tectonics, erosion



Impact Cratering

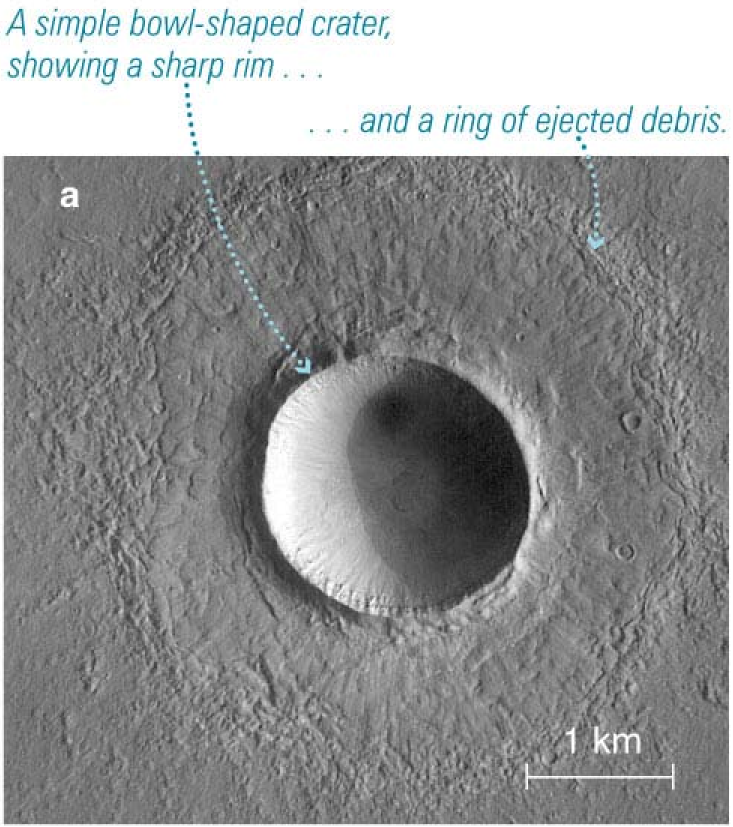
Asteroid/comet hits solid surface at 10-70 km / sec
More like an explosion than a car crash

Kinetic energy vaporizes/melts some rock and blasts debris everywhere

Amount of debris is much larger than size of impactor
Debris flies up and falls back down as a blanket of ejecta around the crater
Crater and surrounding debris blanket usually circular

Crater ~ 10x wider than impactor
Crater width ~ 5-10 x crater depth

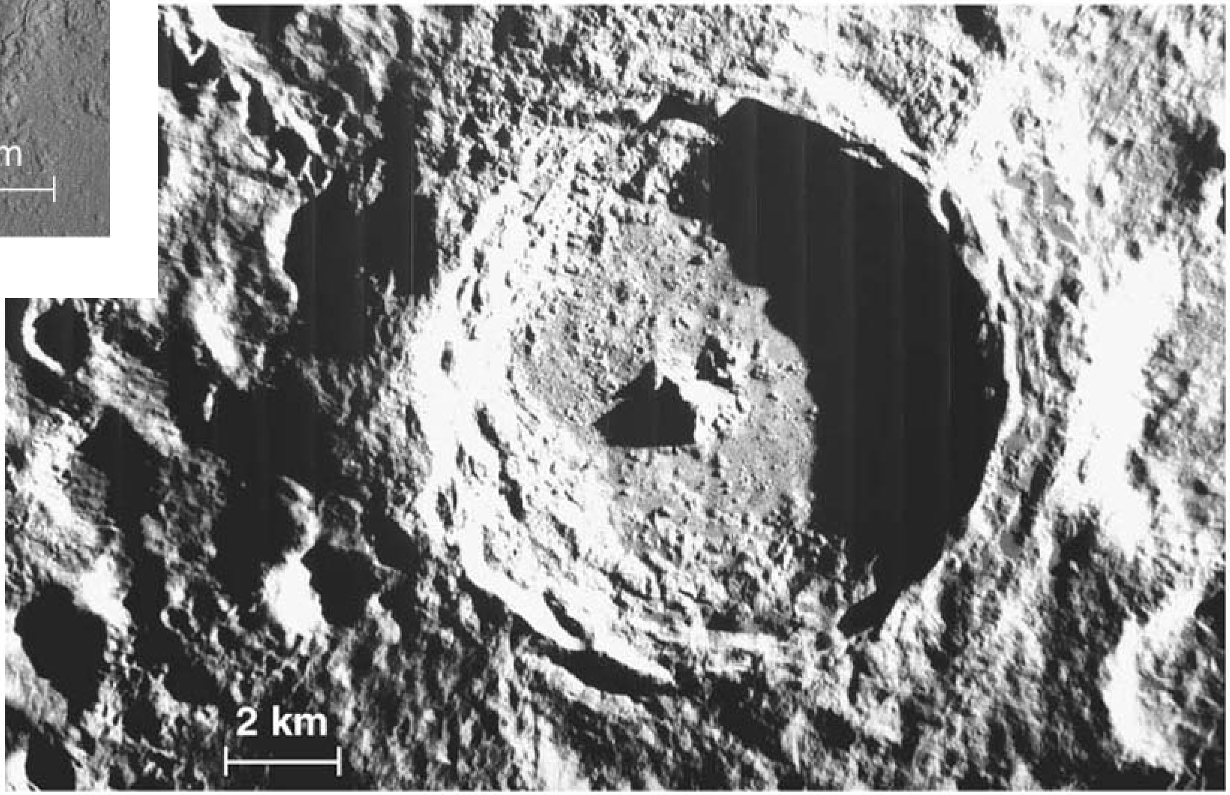
Craters formed by volcanoes are different from impact craters



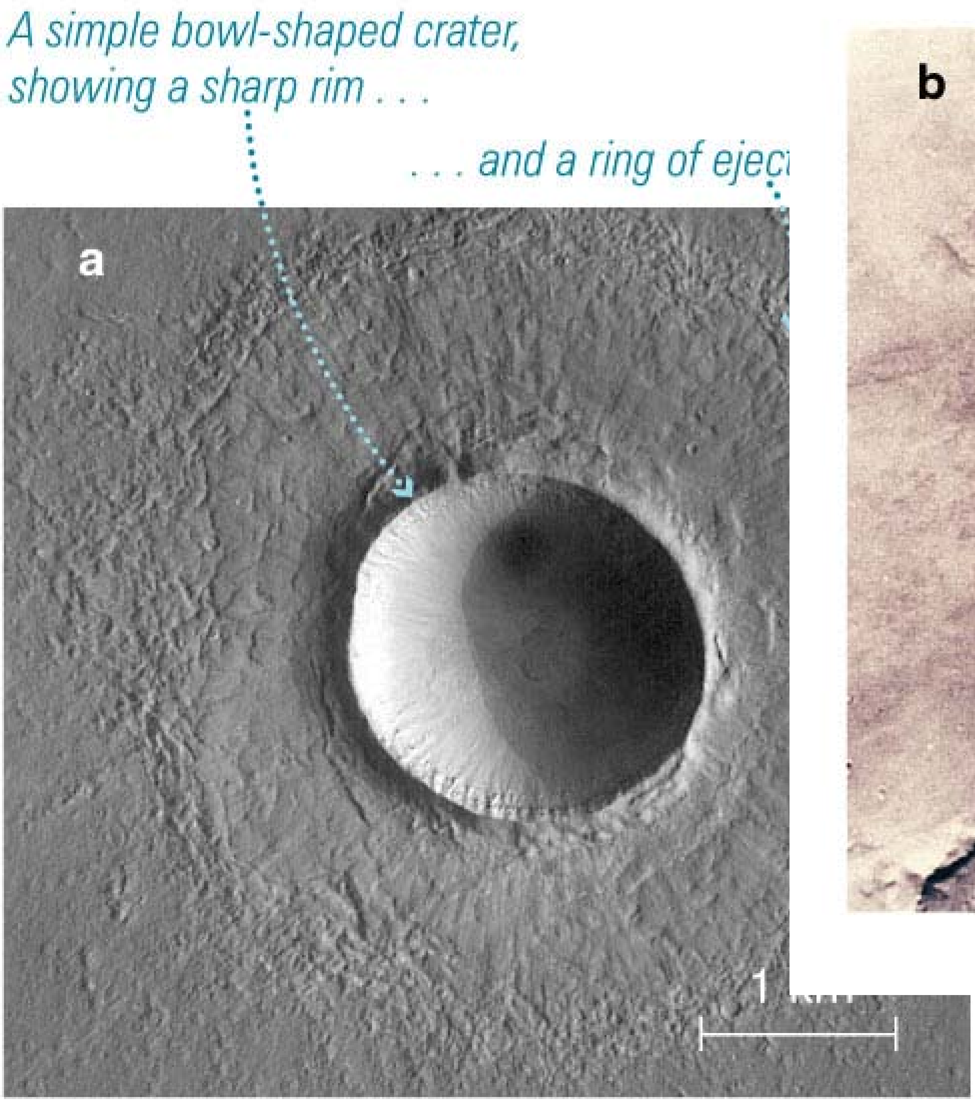
Small craters have simple bowl shapes

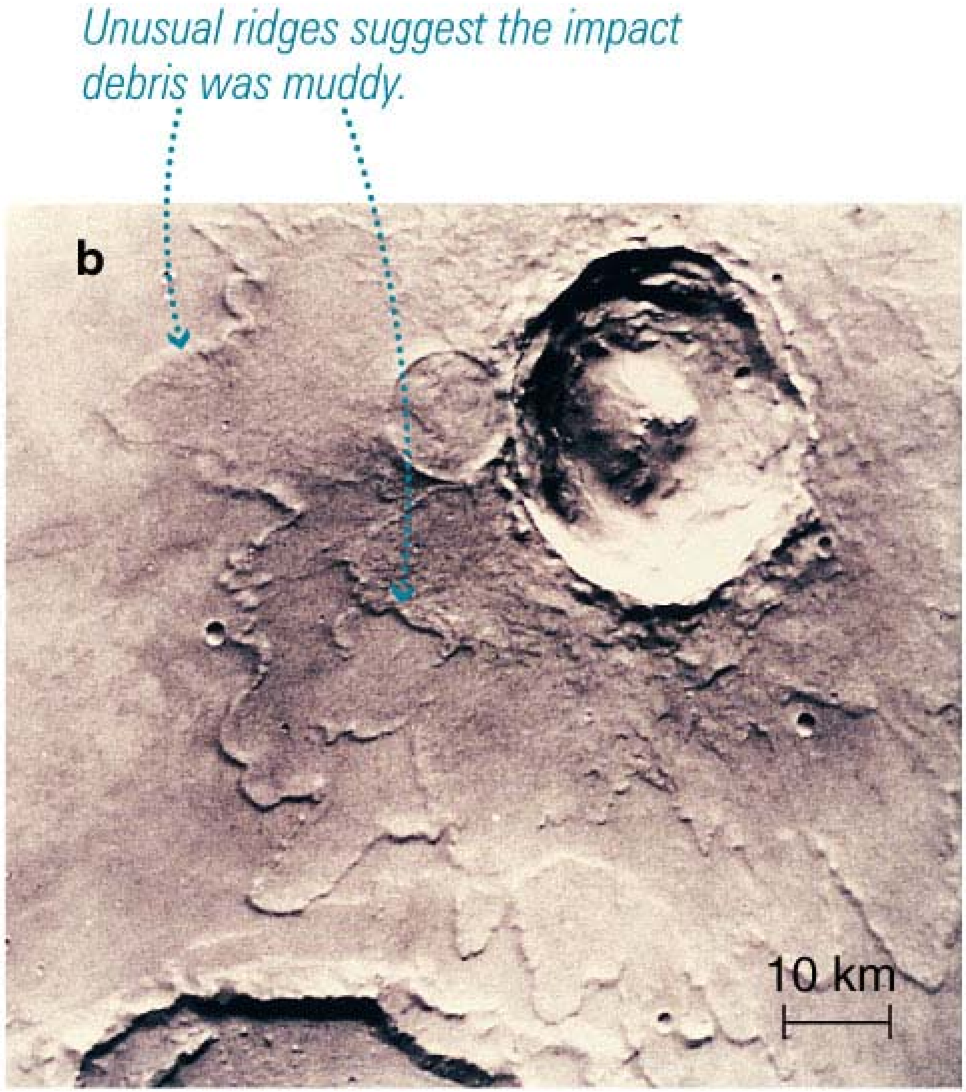
Medium craters have central peaks (imagine dropping a pebble into thick mud)

Very large craters have more complex structure (multi-ring basin)



Craters are affected by the ground they form in





Crater above was formed in water-rich (icy?) ground

Impact Cratering

More small craters than large craters

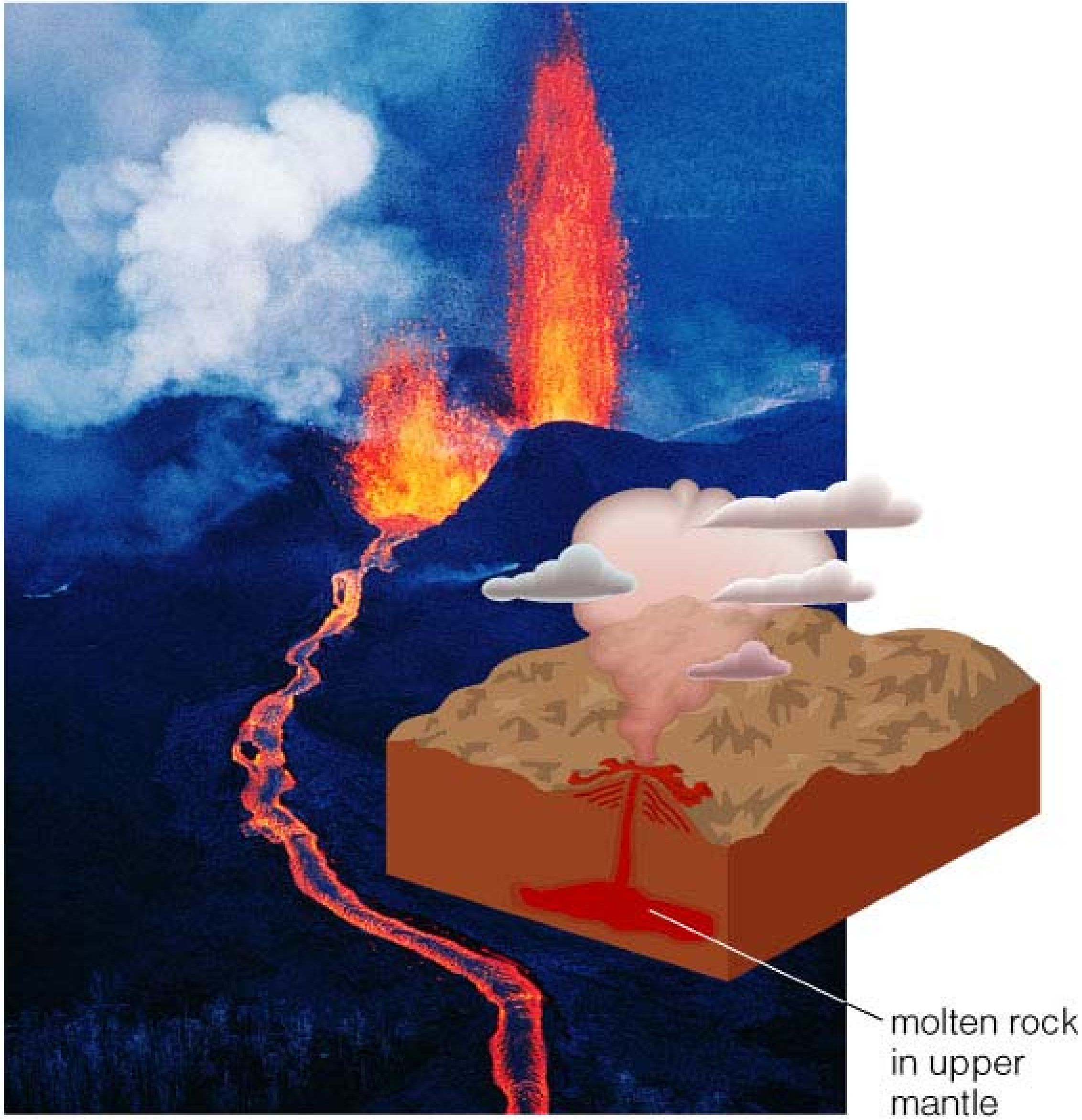
Because there are more small asteroids than large asteroids

Moon and Mercury are covered in impact craters

Why do Venus and Earth have so few craters?

Impact Lab – Tues 20 June

- How do speed and size of steel balls affect size and shape of craters in bucket of sand?
- Does an impact from an angle make an elongated, not round, crater?
- How many craters are seen on surfaces of different planets?



Volcanism = any eruption of molten lava onto the surface

Don't care whether it comes out of a tall mountain or just oozes out of the ground

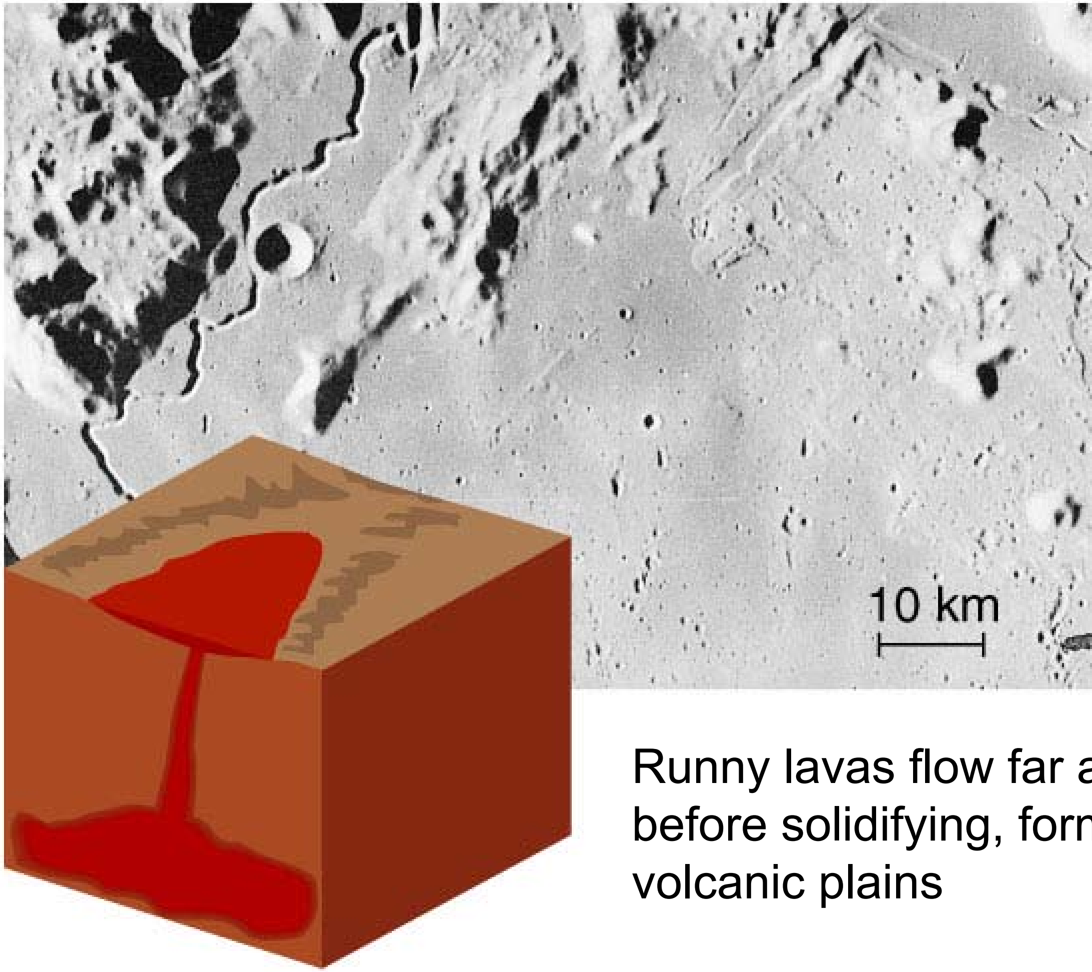
Molten rock underground is called magma
It changes its name to lava when it reaches the surface

Volcanism occurs when molten rock is forced upwards through the lithosphere and out onto the surface

Why does the molten rock rise upwards?
[Three reasons in book]

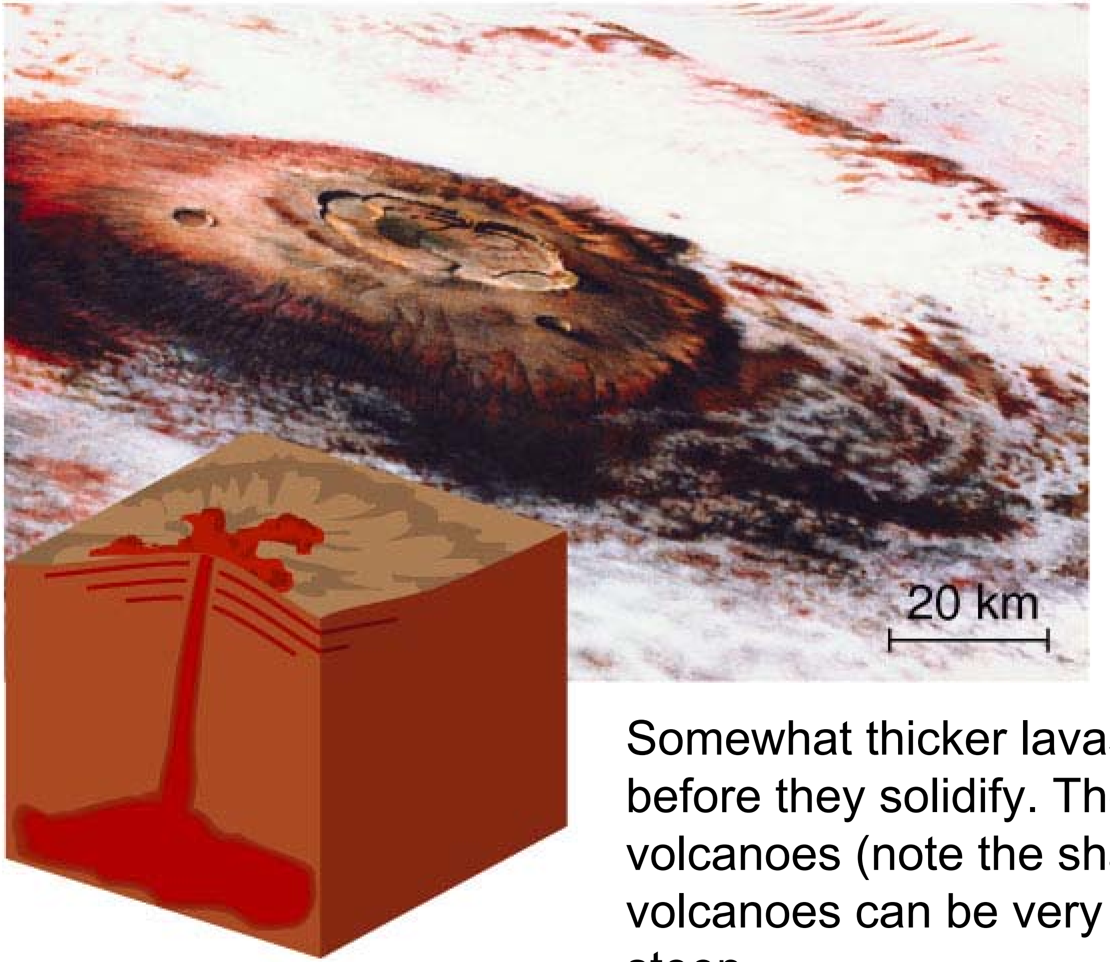
Chemical composition of lava is important - runniness

Lava plains (maria) on the Moon



Runny lavas flow far and flatten out before solidifying, forming vast volcanic plains

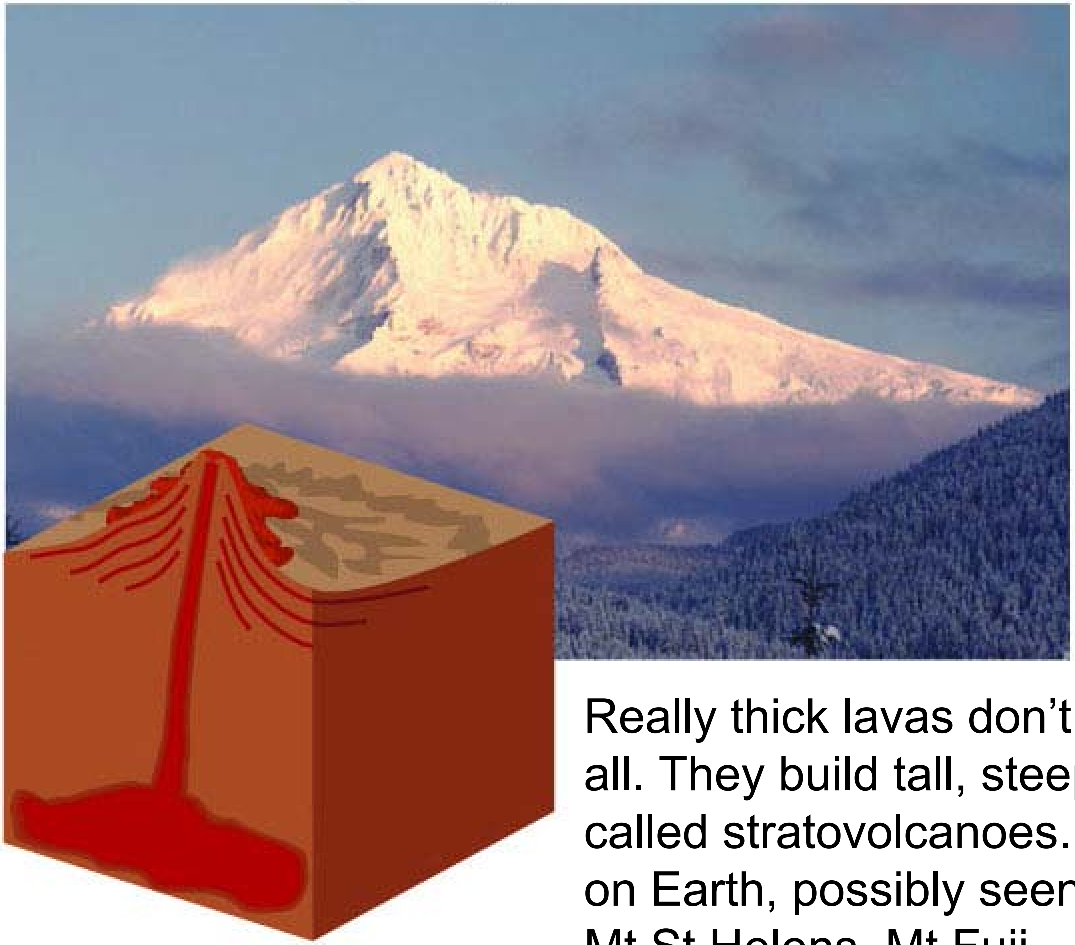
Olympus Mons (Mars)



Somewhat thicker lavas don't flow as far before they solidify. They form shield volcanoes (note the shape). Shield volcanoes can be very tall, but not very steep

Hawaiian Islands on Earth

Mount Hood (Earth)



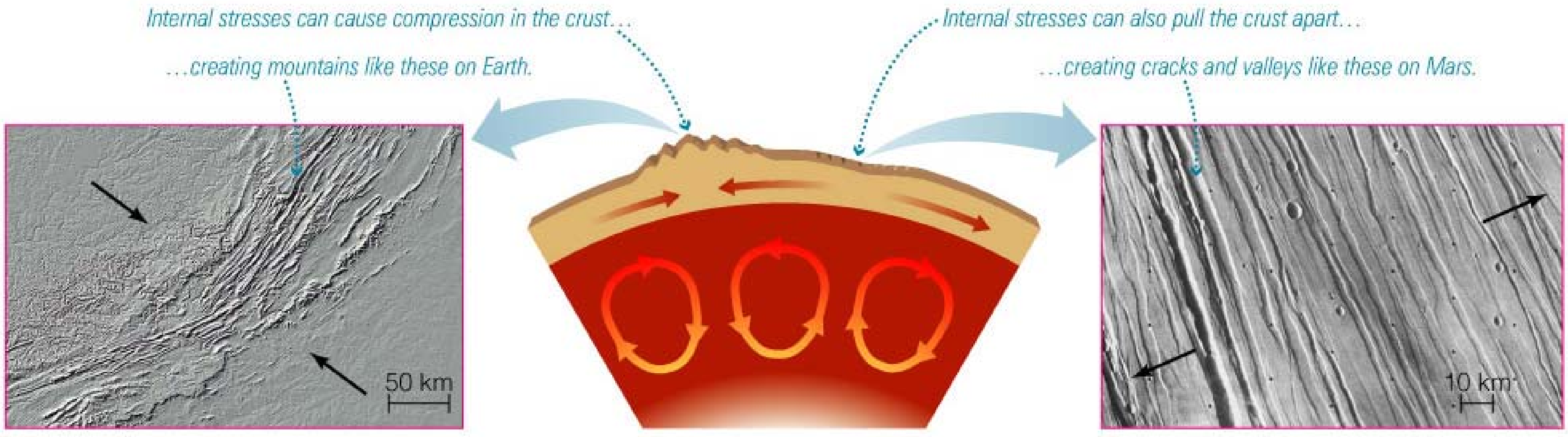
Really thick lavas don't flow very far at all. They build tall, steep mountains called stratovolcanoes. Only common on Earth, possibly seen on Venus
Mt St Helens, Mt Fuji
A "classical" volcano

Volcanism

- Volcanic plains and shield volcanoes are found on all terrestrial worlds. Runny lava is common in the solar system
- Stratovolcanoes are common on Earth, but not elsewhere. Thick lava is common only on Earth
- Accretion left lots of water and gases inside planets. Volcanism spews them out again, leading to atmospheres and oceans

Tectonism

- Stretching/compressing the lithosphere can create geological features
- Weight of a volcano can stretch the lithosphere beneath
- Force of an upwelling mantle plume can push up and stretch lithosphere above
- Convection cells can stretch or compress the lithosphere
  - Interactive Figure 9.13



Appalachian Mountains in eastern United States

Ceraunius Valleys on Mars

Compression (squashing) and extension (stretching)

Examples: Himalaya mountains and Appalachian mountains
Rio Grande Rift and Red Sea

Earth has experienced a unique form of tectonism called “plate tectonics” that we’ll talk about later

Erosion

- A collection of different processes, rather than one process
- Processes that fragment or transport rock through the action of ice, liquids (water), or gas (atmosphere)
- Can break down existing features
- Can also build up new features

Find three examples of erosion

- In groups

Making Rocks by Erosion

- Erosion can fragment large rocks into tiny pieces (sand)
- These fragments get transported by flowing water into the ocean
- They settle to the bottom of the ocean
- They pile up in layers and layers
- They get compressed into sedimentary rock
  - Can also build sand dunes and river deltas

Planetary Properties Controlling Volcanism and Tectonism

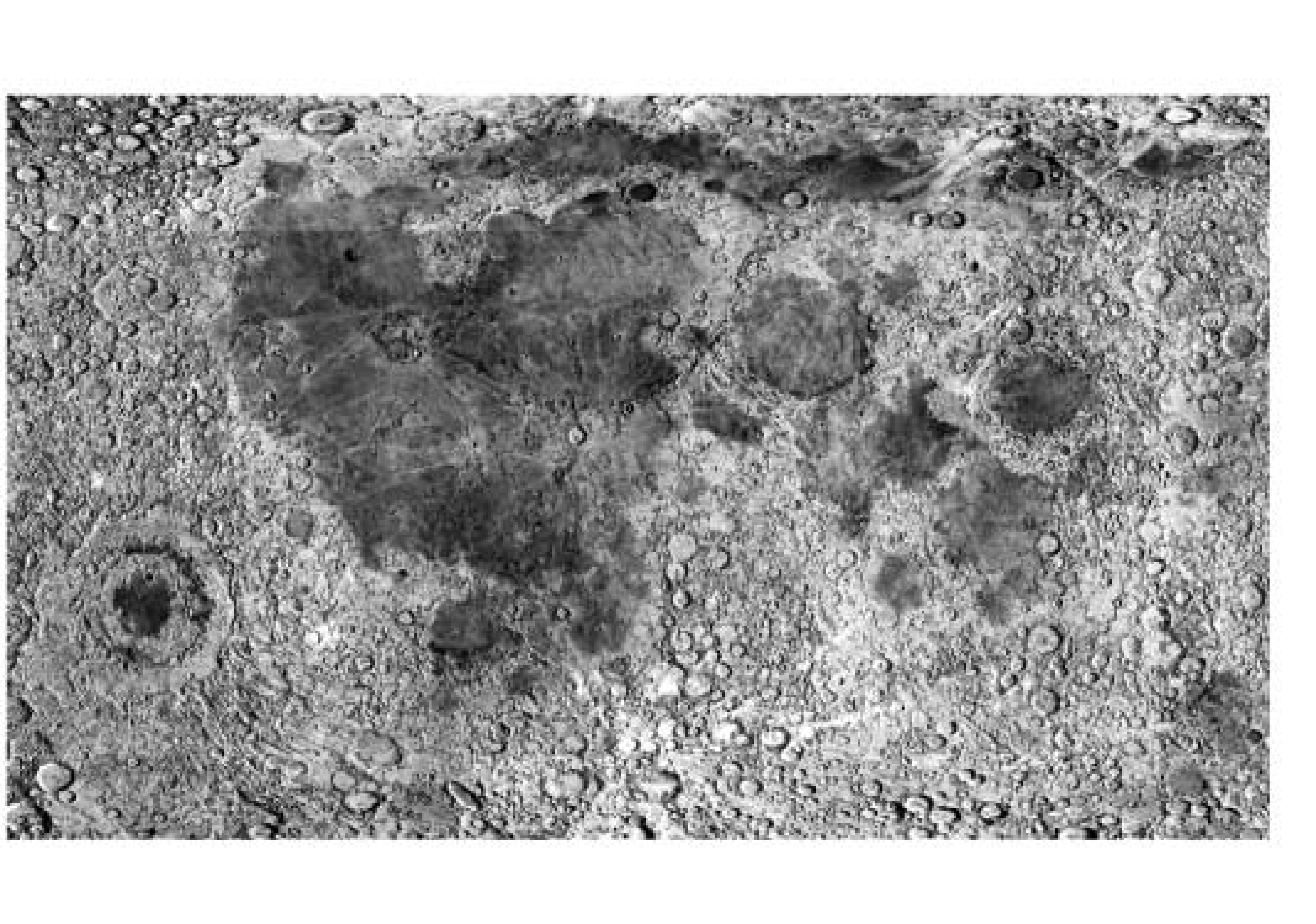
- Both require internal heat, which makes them influenced by planetary size
- All the terrestrial worlds once had some volcanism/tectonism when they were young and hot inside
  - Volc/Tect stopped on Mercury and Moon because their interiors cooled
  - Volc/Tect are still active on Venus (probably) and Earth
  - Volc/Tect may still be weakly active on Mars, but were much more active in the past

Planetary Properties Controlling Erosion

- Erosion needs an atmosphere
  - Surface liquids, wind, climate changes
- A stationary atmosphere doesn’t cause any erosion
- Erosion needs weather
  - Processes such as wind, rain (these all involve motion, momentum, energy)
- Large size means lots of outgassing
- Distance from the Sun affects whether water is gas, liquid, solid
- Planetary rotation drives winds and weather

Planetary Properties Controlling Impact Cratering

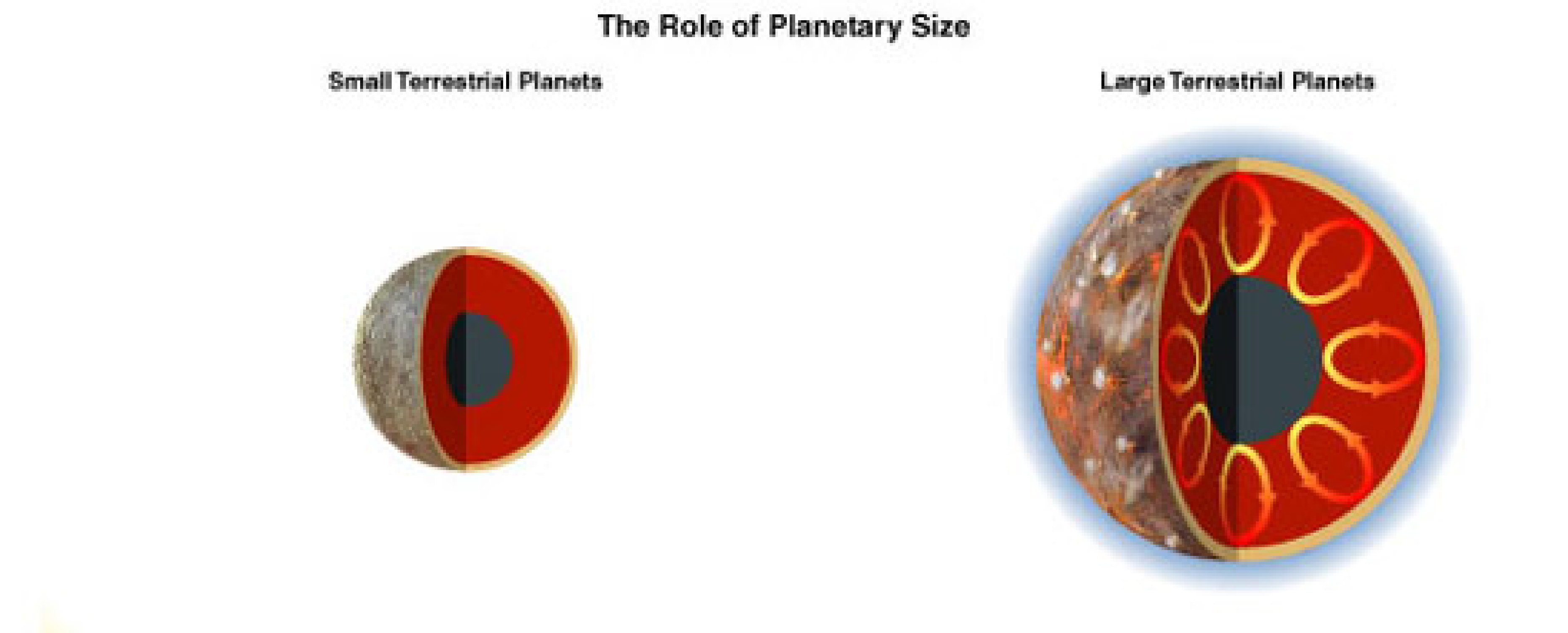
- None control formation of impact craters, but lots control removal of impact craters
- Tectonism, volcanism, and erosion all remove impact craters from the landscape
- More impact craters on a surface means a longer time since other geological processes affected that surface
- Can provide an “age” for the surface



Dark areas of the Moon (few craters) have been resurfaced by some process more recently than the bright areas (many craters)

Fundamental Properties Controlling a Planet's Geological History

- Planetary size
- Distance from the Sun
- Planetary rotation



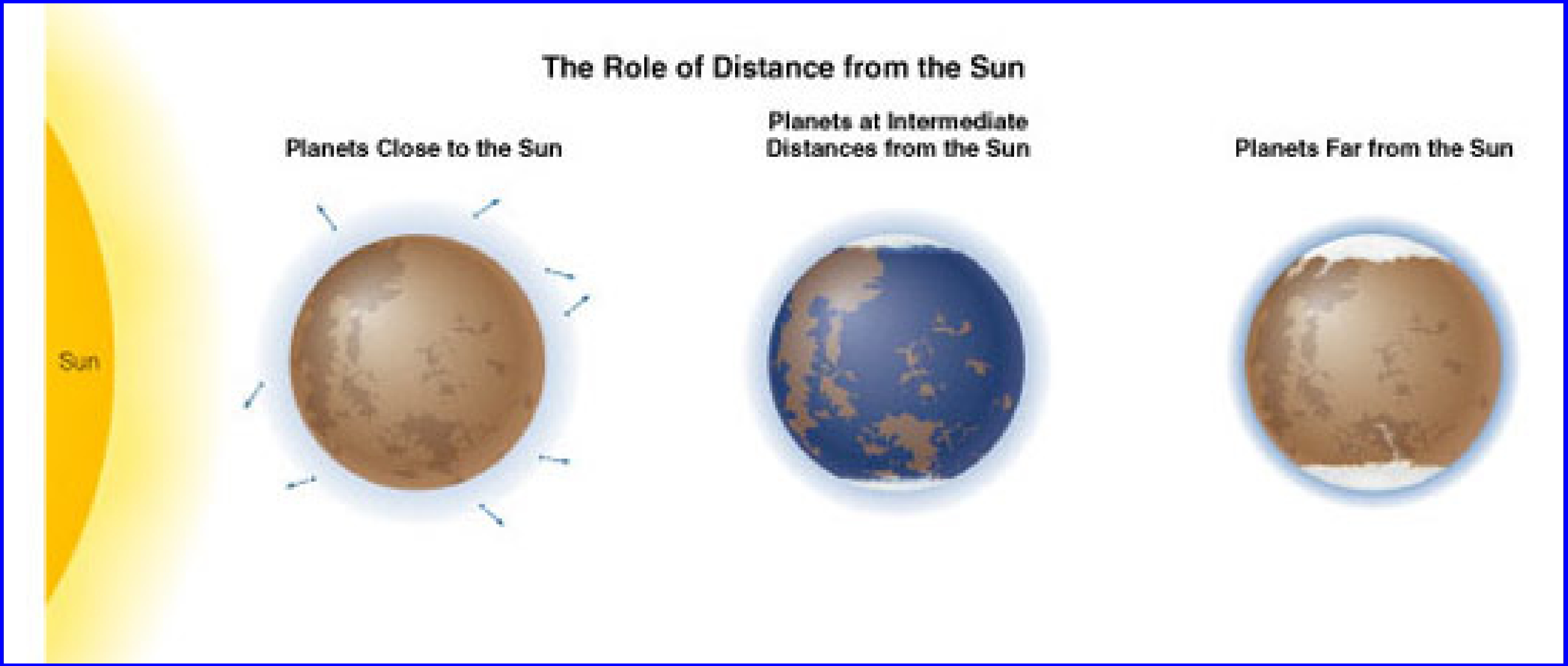
Interior cools rapidly
Tectonic and volcanic activity cease after about one billion years
Many ancient impact craters remain

Lack of volcanism means little outgassing
Low gravity allows gas to escape easily
No atmosphere means no erosion

Hot interior causes mantle convection, leading to ongoing tectonic and volcanic activity
Most ancient craters have been erased

Outgassing produces an atmosphere and strong gravity holds it, so erosion is possible

Core may be molten and producing a magnetic field



Surface is too hot for rain, snow, or ice, so little erosion occurs

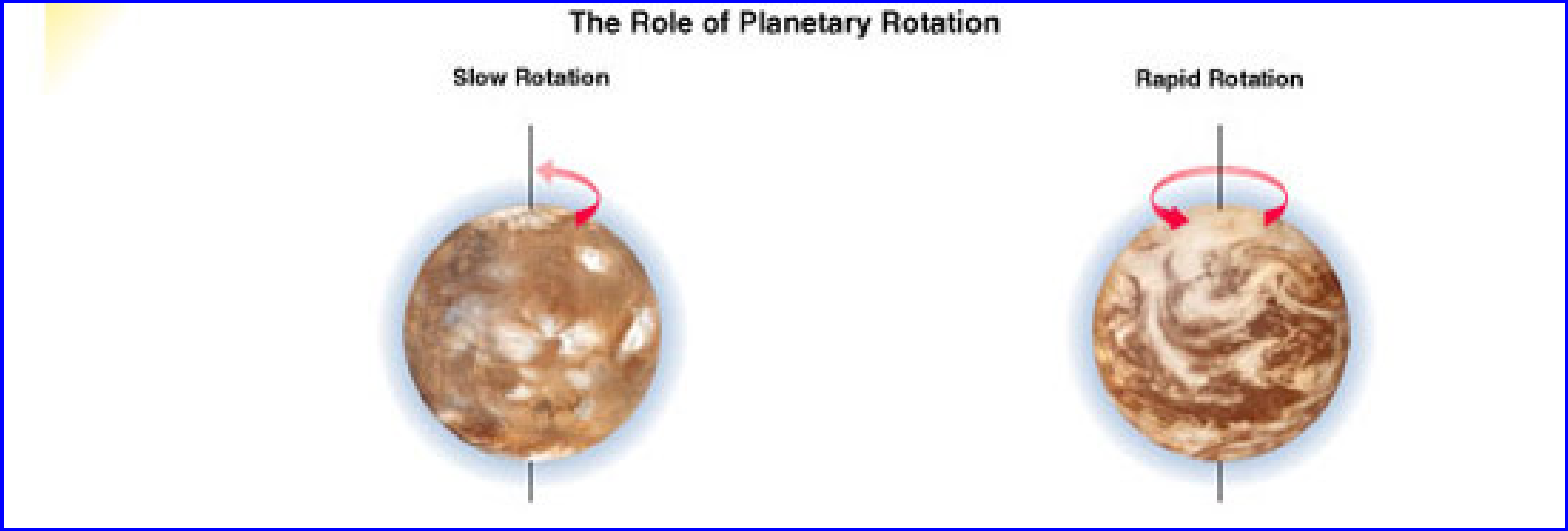
Moderate surface temperatures can allow for oceans, rain, snow, and ice, leading to lots of erosion

Low surface temperatures can allow for ice and snow, but no rain or oceans, limiting erosions

High atmospheric temperature allows gas to escape more easily

Moderate atmospheric temperature allows gravity to hold atmospheric gases more easily

Atmosphere may exist, but gases can more easily condense to make surface ice



Less wind and weather means less erosion, even with a substantial atmosphere

More wind and weather means more erosion

Slow rotation means weak magnetic field, even with a molten core

Rapid rotation is necessary for a global magnetic field

Goals for Learning

- What are terrestrial planets like inside?
- What causes geological activity?
- What processes shape planetary surfaces?
- Why do the terrestrial planets have different geological histories?

Goals for Learning

- What are terrestrial planets like inside?
  - Metal (iron-rich) core
  - Rock mantle (high-density rocks)
  - Rock crust (low density rocks)
  - Also layered by strength, with a strong lithosphere above a weaker interior
  - Terrestrial planet interiors have been heated by accretion, differentiation, and radioactivity. They are now cooling

Goals for Learning

- What causes geological activity?
  - Interior heat
  - Heat can be transported by convection, conduction, and radiation

Goals for Learning

- What processes shape planetary surfaces?
  - Impact cratering
  - Volcanism
  - Tectonism
  - Erosion

Goals for Learning

- Why do the terrestrial planets have different geological histories?
  - The terrestrial planets have different sizes, distances from the Sun, and rotation rates
  - Size is the most important factor influencing geological history