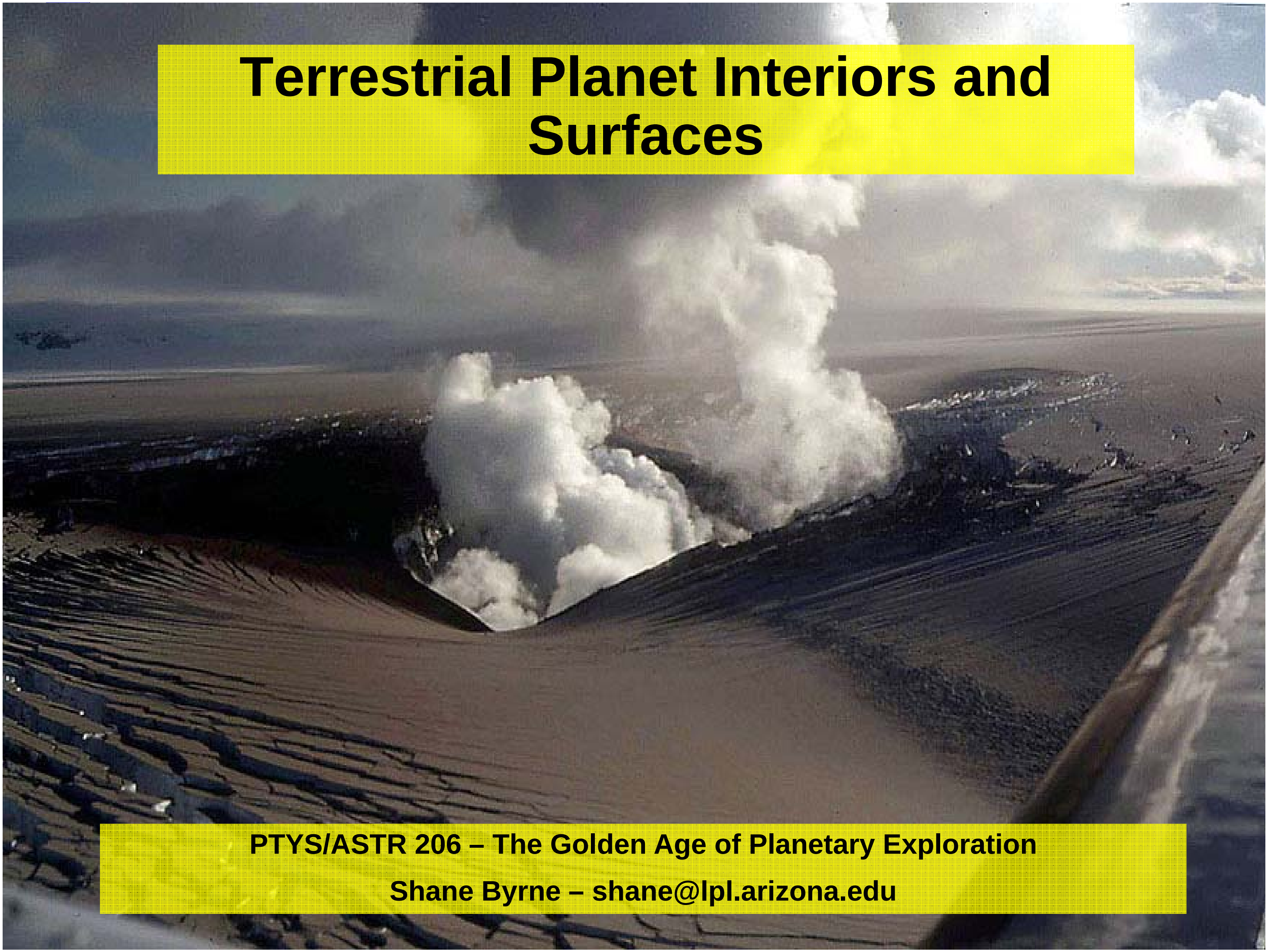
- **Announcements**
  - **Homework #2 due on Thursday**
  - **In-class assignment**
    - **You can answer the questions as we go along**
    - **There'll also be a few minutes at the end to fill this in**
    - **Save the last question for these final 5 minutes**
    - **Talk with your neighbors during these last few minutes but not during the lecture**
  - **Anyone missing a TI-30XA calculator?**

Terrestrial Planet Interiors and Surfaces



PTYS/ASTR 206 – The Golden Age of Planetary Exploration

Shane Byrne – shane@lpl.arizona.edu

In this lecture…

- **Internal structure of rocky planets**
- **Earthquakes and what they tell us**
- **Sources of heat**
- **How volcanoes work**
- **Wind-related (aeolian/eolian) processes**
- **Fluvial processes**

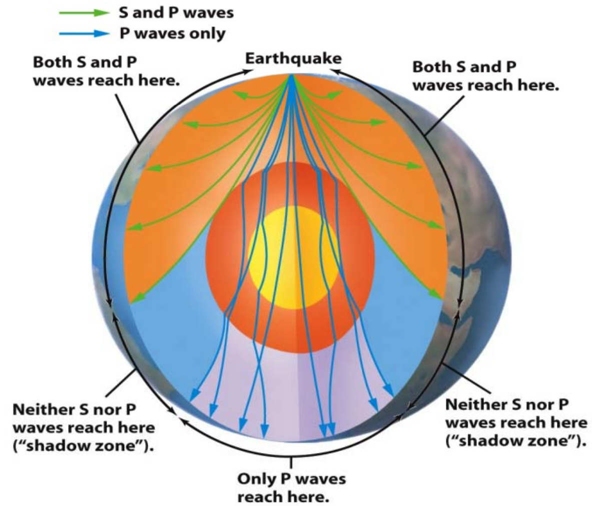


Figure 9-9
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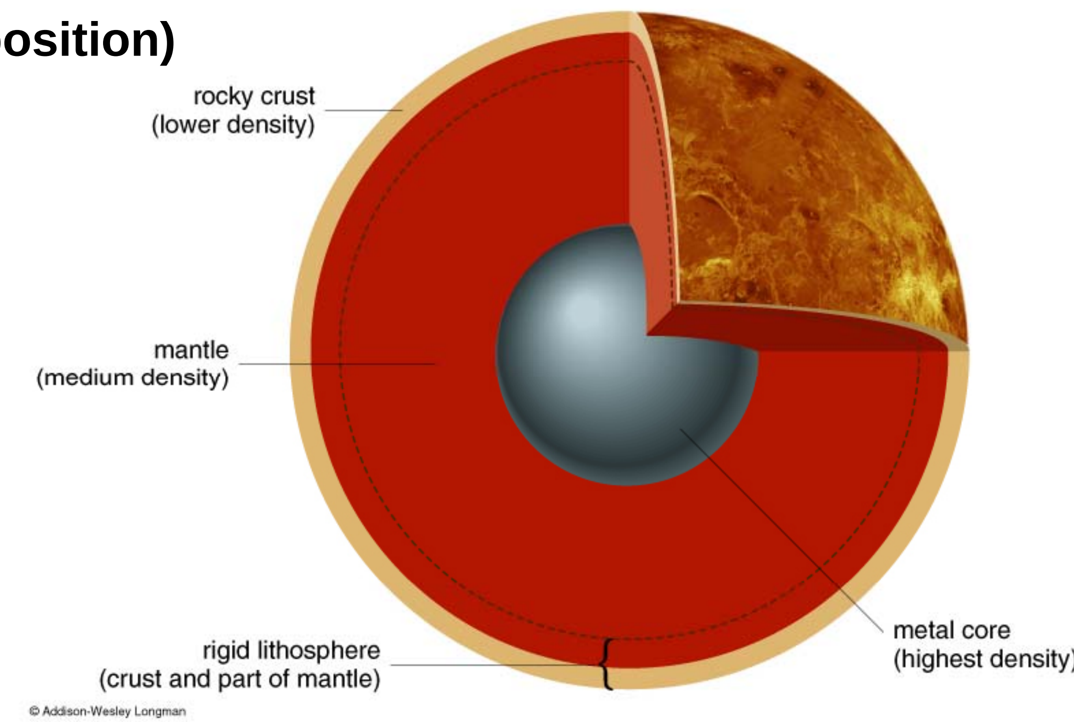
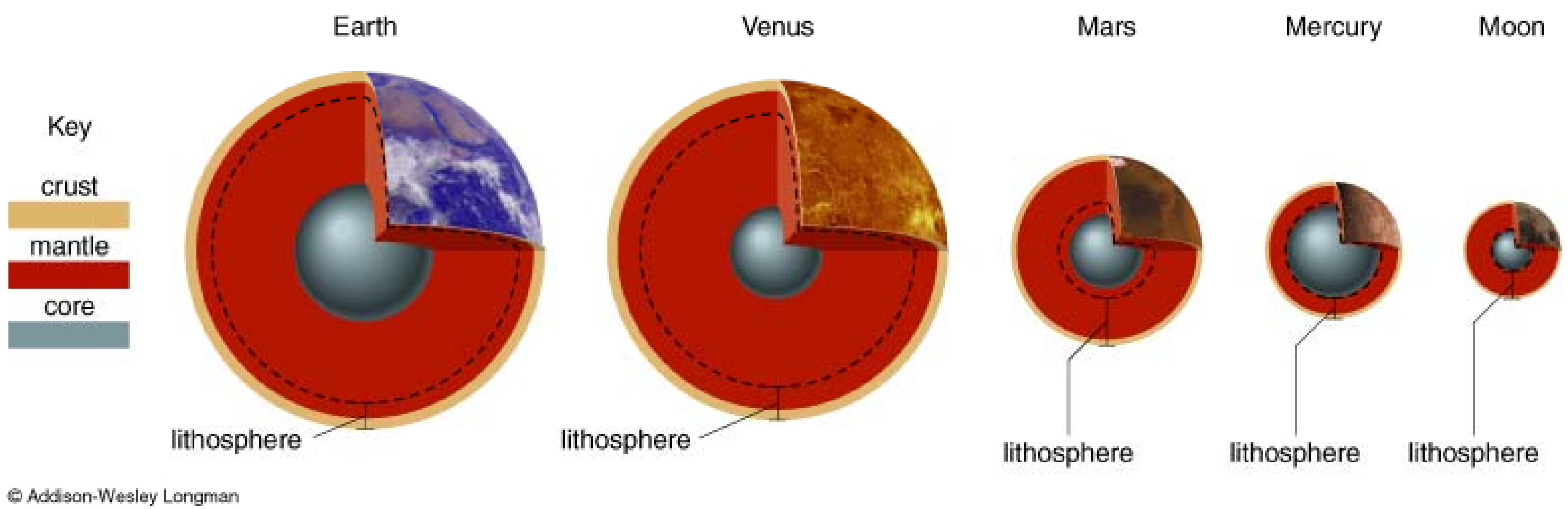
Internal structure

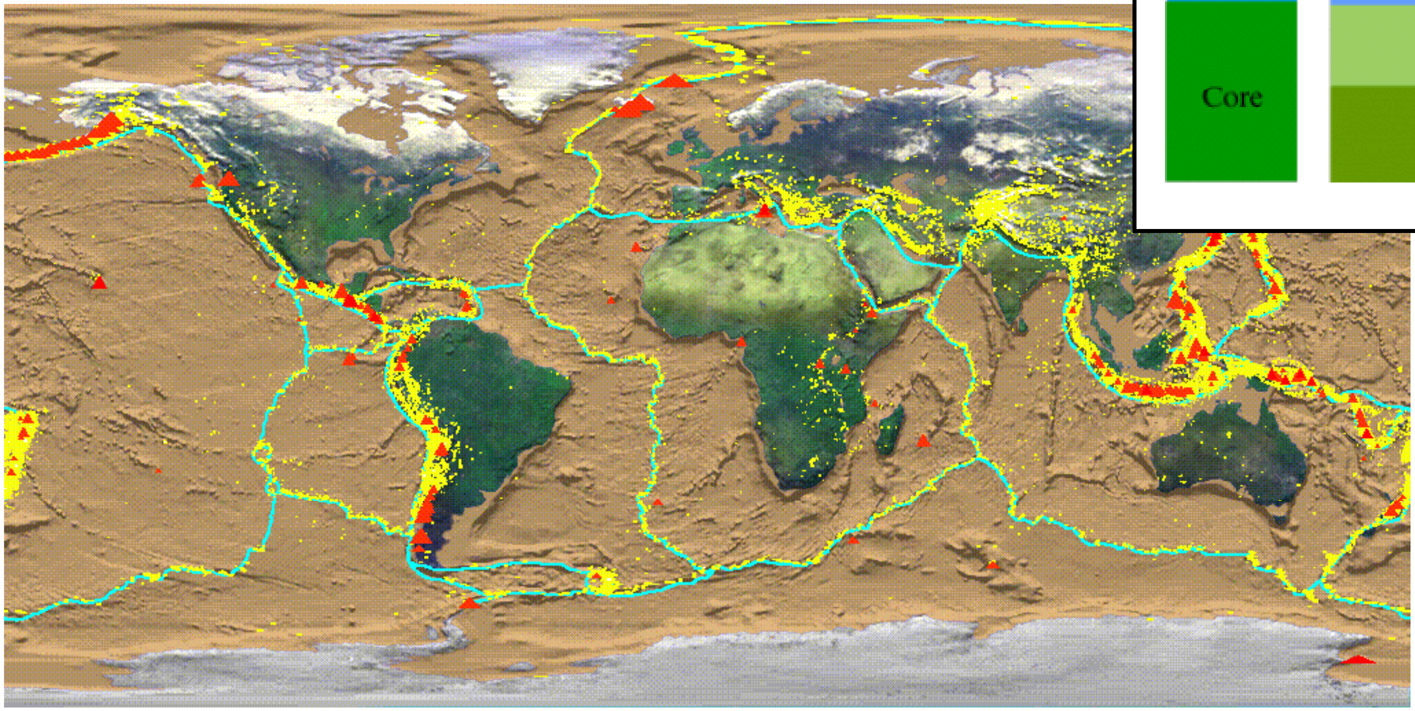
- Rocky planets have several parts
  - Core – Iron/Nickel
  - Mantle – Rocky
  - Crust – Rocky (different composition)
- Strong rocks near surface
  - Colder rocks = stronger rocks
  - Lithosphere
  - Rocks are brittle
- Weak rocks deeper
  - Hotter rocks = weaker rocks
  - Asthenosphere
  - Rocks flow
- Core
  - Solid in center – inner core
  - Surrounded by liquid iron – outer core

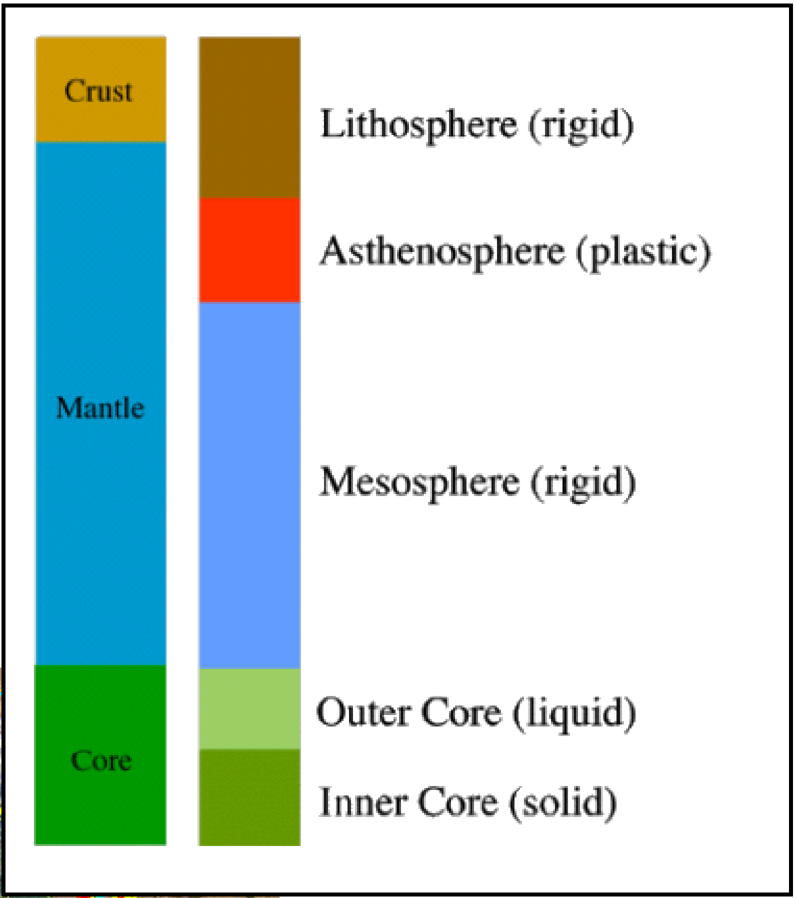


- **All rocky planets follow the same basic model**
  - **Differ in the details – like core size**
  - **Smaller bodies cool off faster – thicker lithospheres**
- **Details for later…**
  - **Earth has two separate types of crust and plate tectonics**
  - **The Moon may not have a core**
  - **Mercury's core is enormous compared to its size**

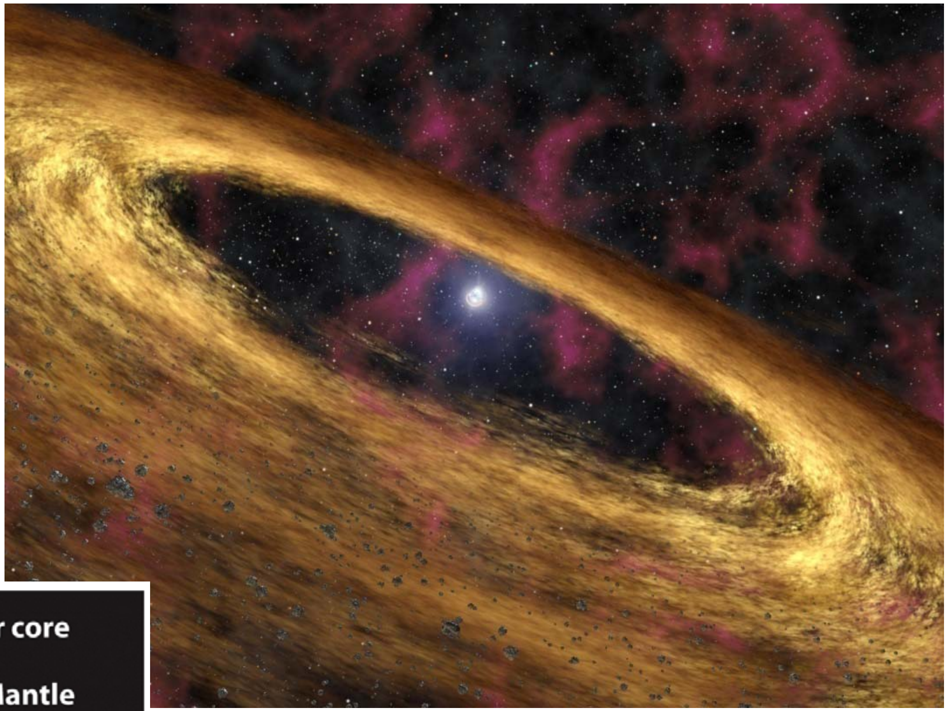


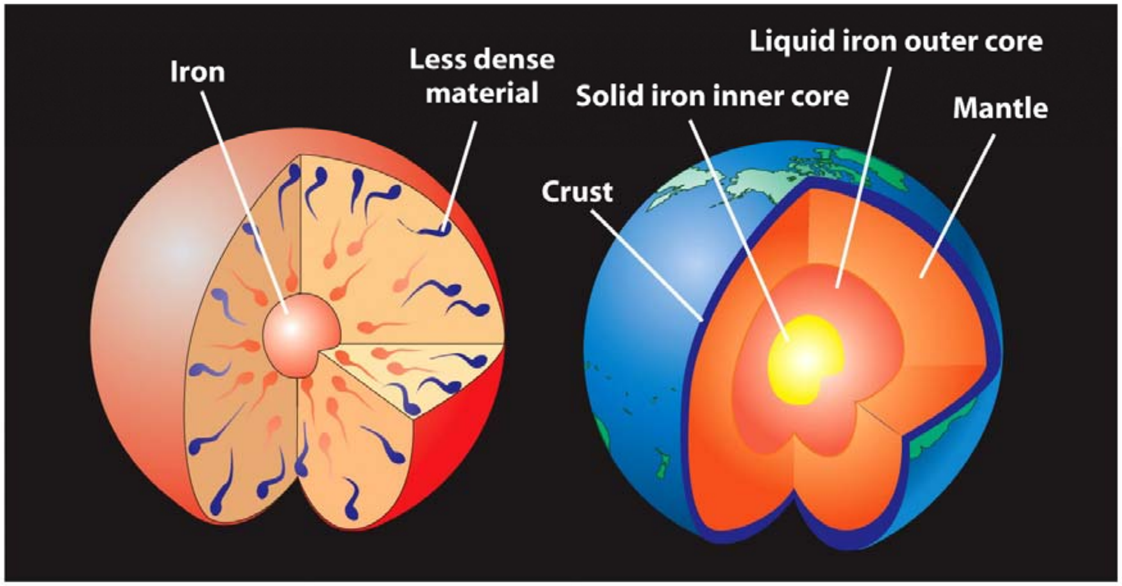
- **Compositional vs mechanical terms**
  - **Crust, mantle, core are compositionally different**
  - **Lithosphere, Asthenosphere, Mesosphere, Outer Core and Inner Core are mechanically different**
  - **Lithosphere is divided into plates…**
    - **More on this in the Earth lecture**





- **How did things get this way?**
  - **Planets formed from solar disk**
  - **Started as uniform lumps of rock and metal**
- **Proto-Earth was hot**
  - **Material could flow**
  - **Dense material (iron etc..) sinks**
  - **Lighter stuff (rocks) float**





(a) During differentiation, iron sank to the center and less dense material floated upward

(b) As a result of differentiation, the Earth has the layered structure that we see today

Figure 9-7
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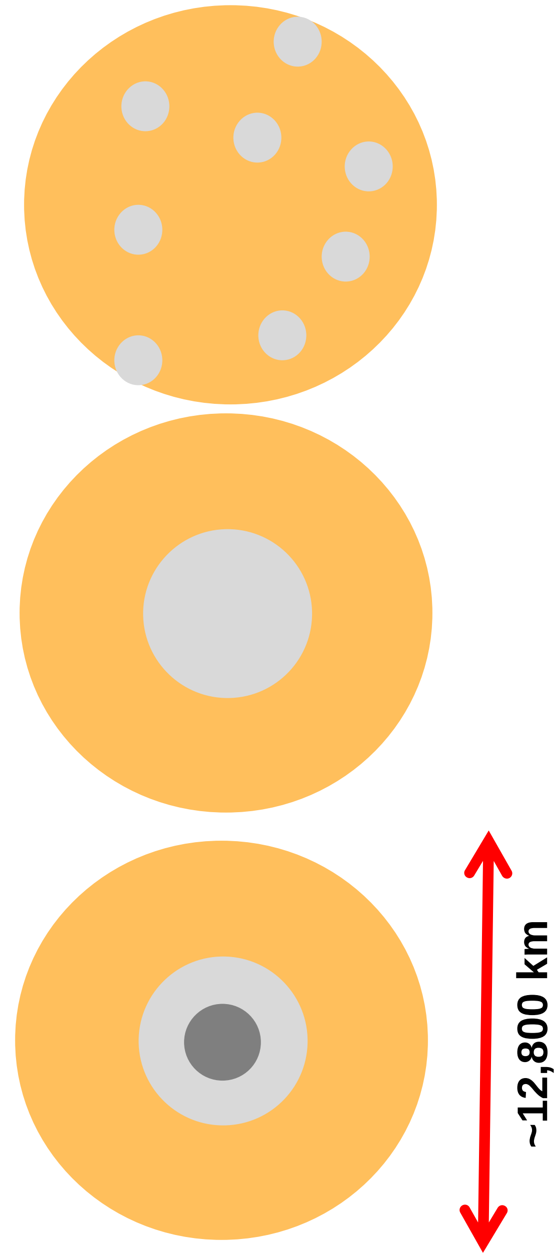
- Homogeneous mix of rock and metal

- Liquid metal core with rocky mantle
  - Takes only a few million years

- Core cools and solidifies from inside out
  - Takes billions of years
  - Some planets still have liquid outer cores
    - Earth and Mercury



- **Hot rock in mantle can convect!**
  - **Slowly…. ~1 cm/year – mantle material is very viscous**
  - **Mantle is heated from below by convection in the liquid outer core**
    - **Mantle also heated throughout by radioactivity**

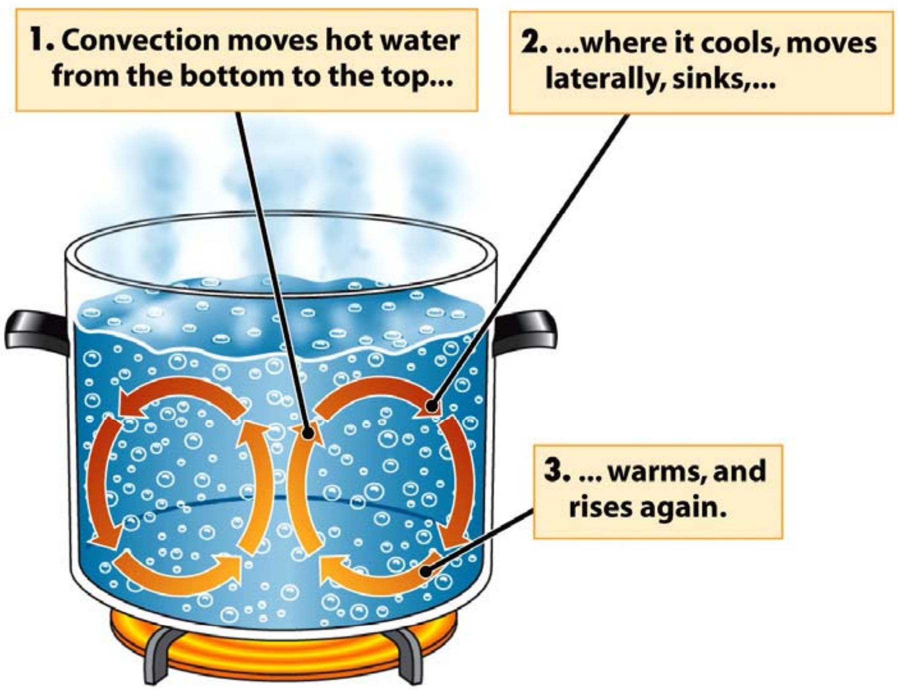


Figure 9-5
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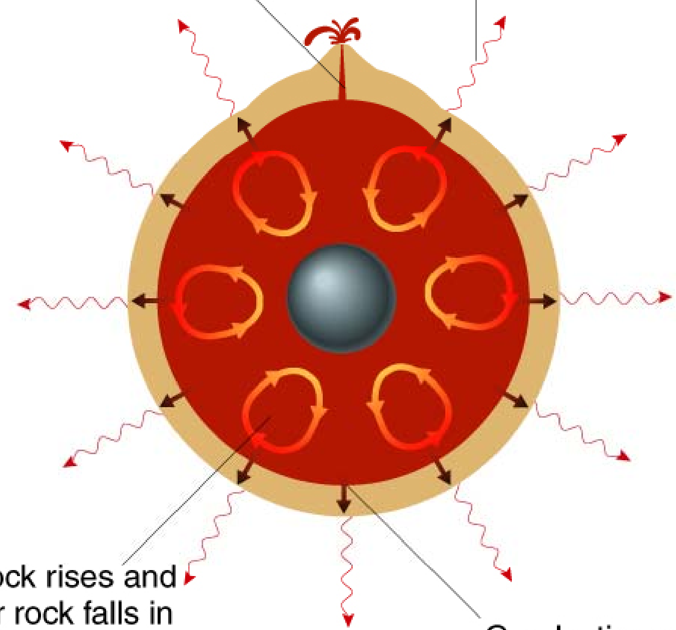

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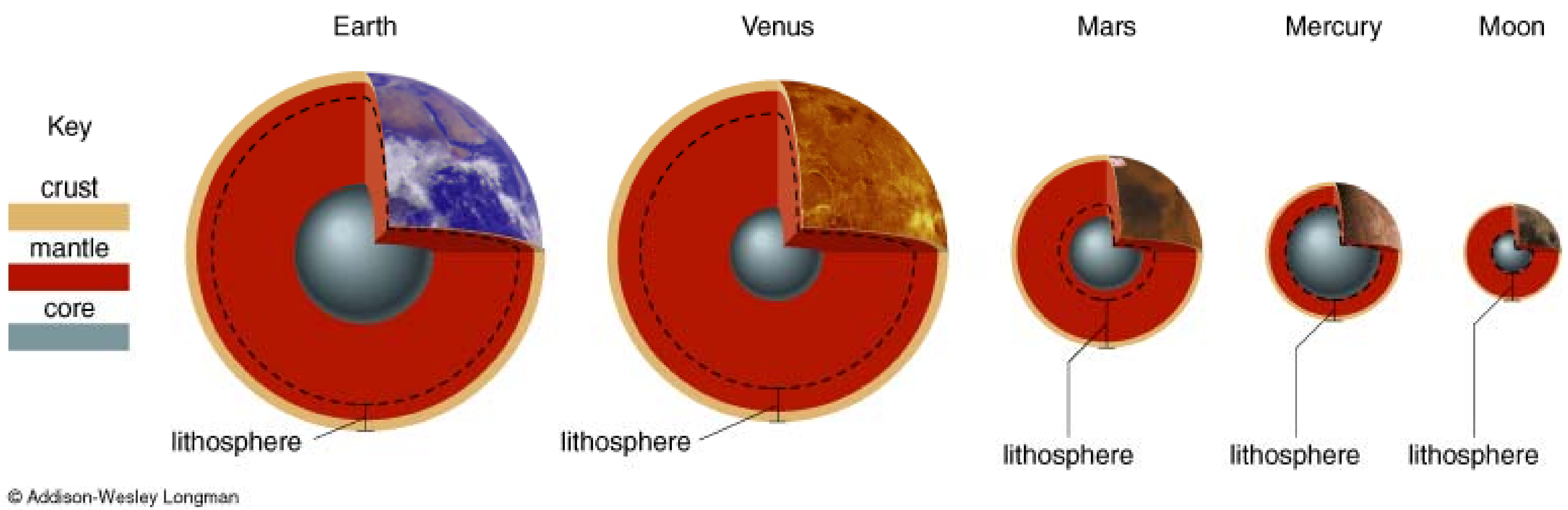
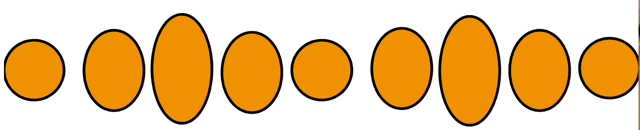
- Cooling is through the surface
  - Surface area is proportional to R^2
- Amount of initial heat and generated heat is proportional to volume, R^3
- If you double the size of the planet
  - Cooling is 4 times faster
  - …but amount of heat is 8 times as much
- Bigger planets stay hotter longer

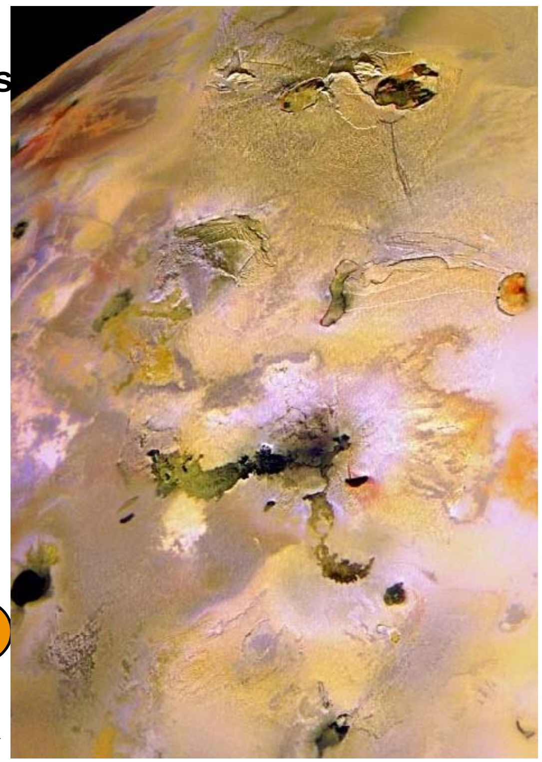


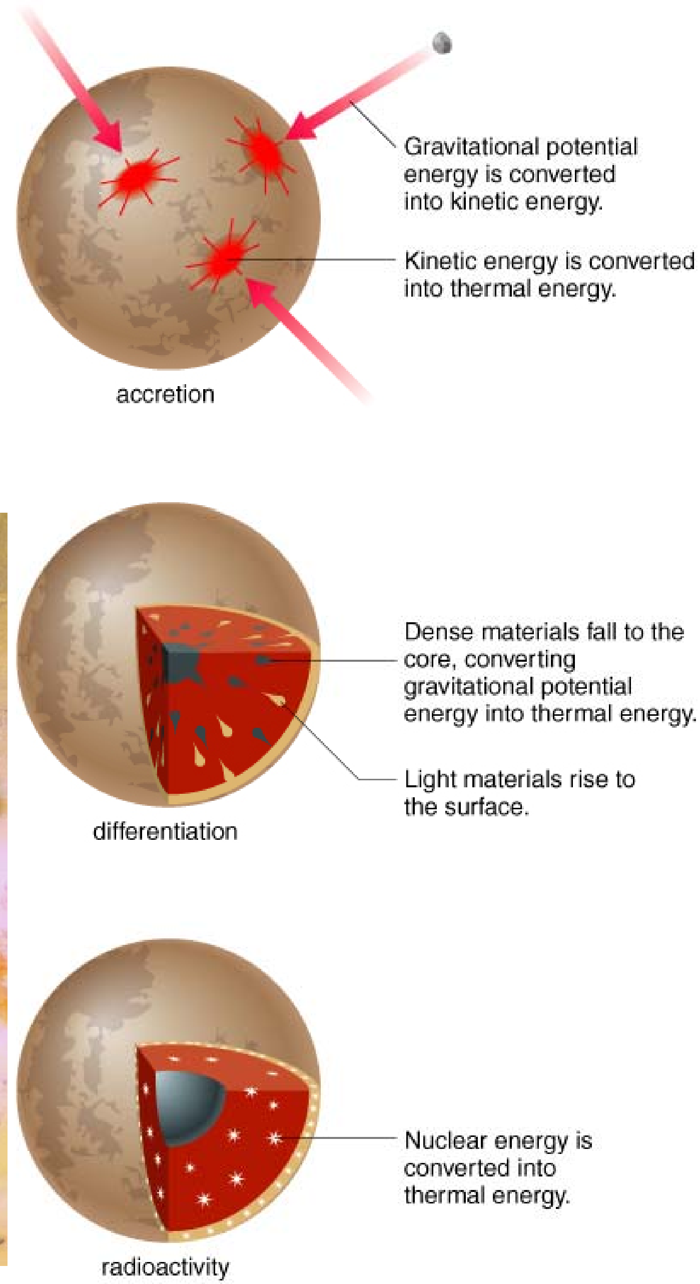
Why do we still have a liquid core?

- **Sources of heat for planetary interiors**
  - **Original heat of formation**
    - **Accretion**
      - **Impacting objects transfer heat to the proto-Earth**
    - **Differentiation**
      - **Differentiated object has lower potential energy**
      - **Energy difference goes into heat**
  - **Radioactivity**
    - **Long lived radioisotopes**
    - **Uranium**
    - **Thorium**
    - **Potassium**
  - **Tidal forces**
    - **Usually inefficient**
    - **Io is an exception**
    - **Io is stretched when near Jupiter**



Io's shape - 2 orbits





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- **Melting temperature depends on pressure**
- **Material temperature depends on**
  - **Rate of heat production**
  - **Rate of heat release**

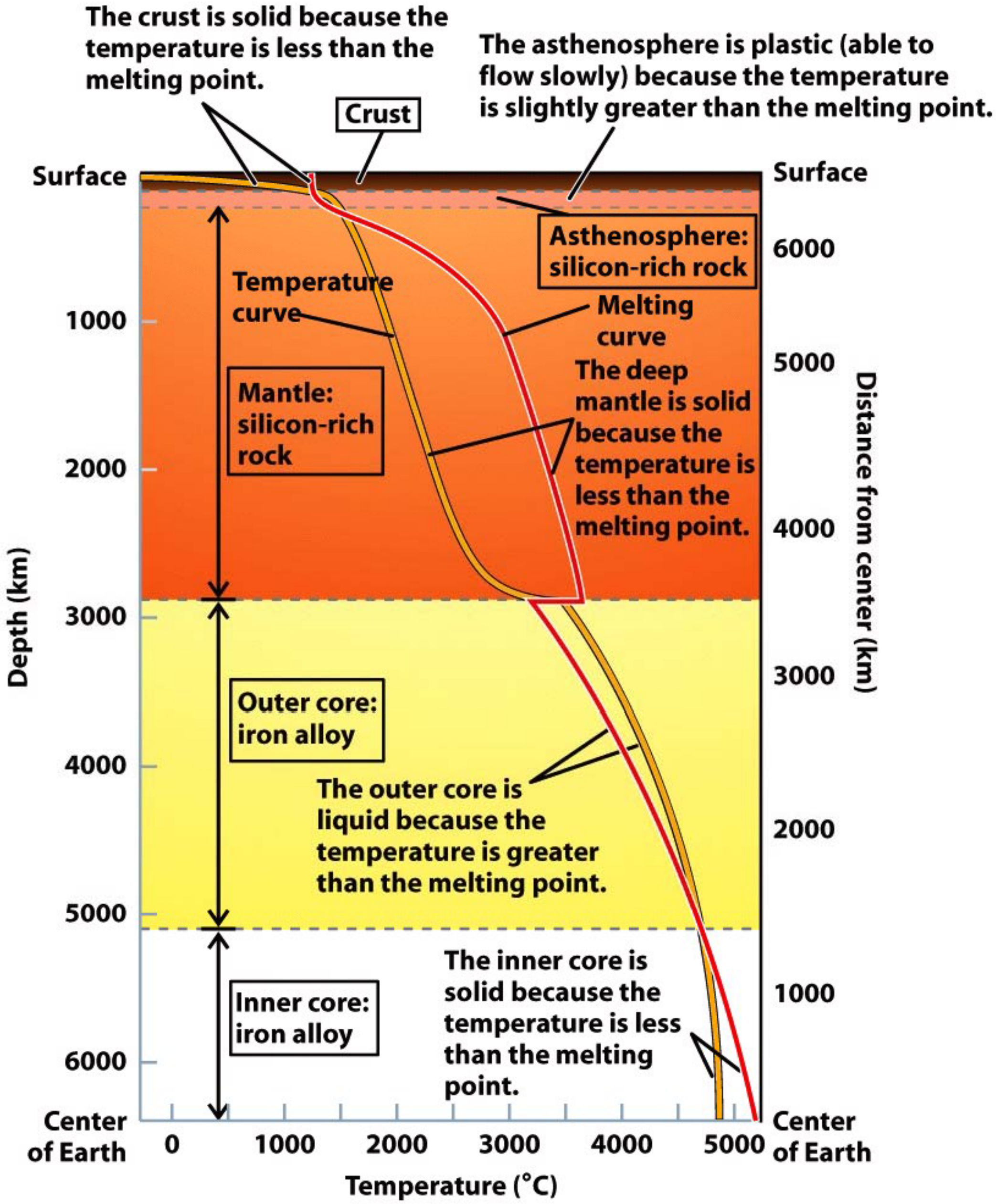

Figure 9-10
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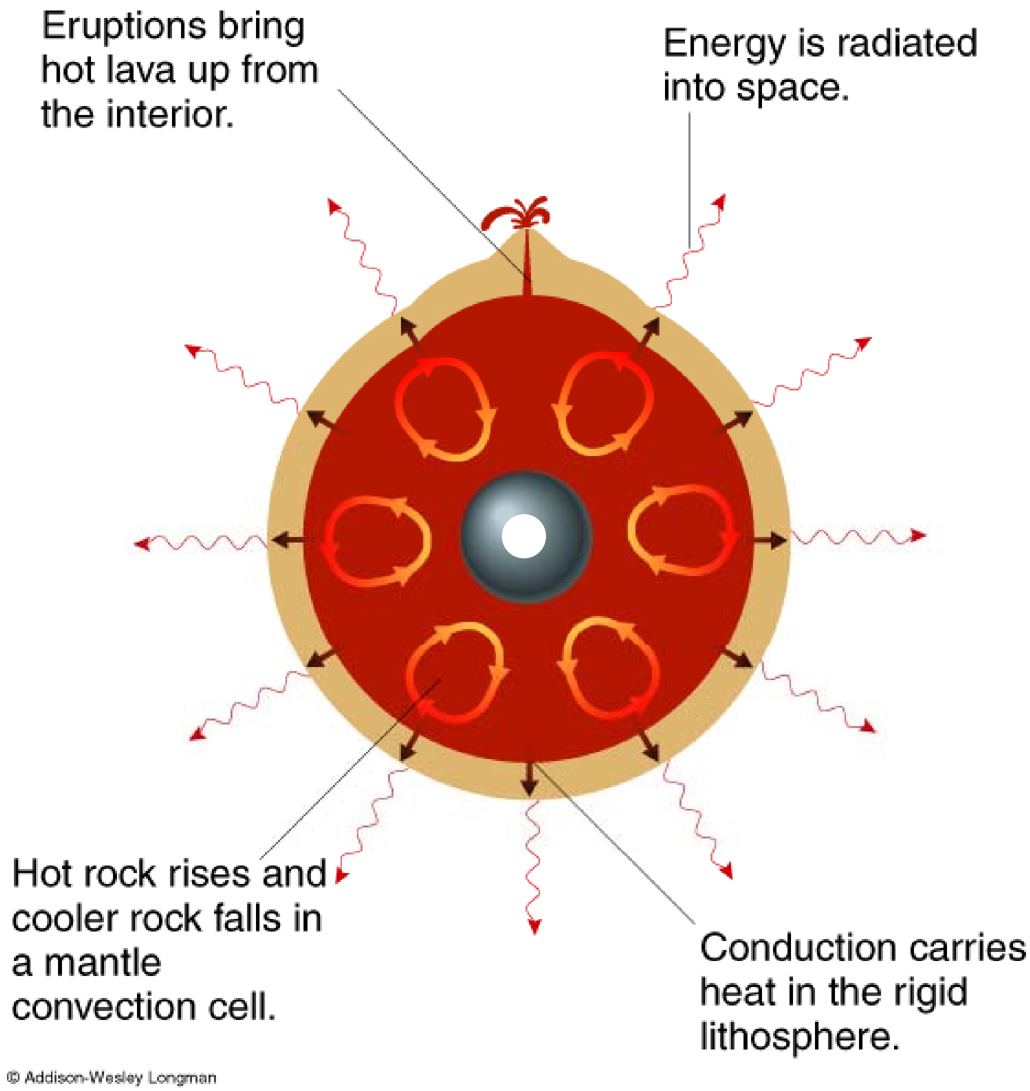
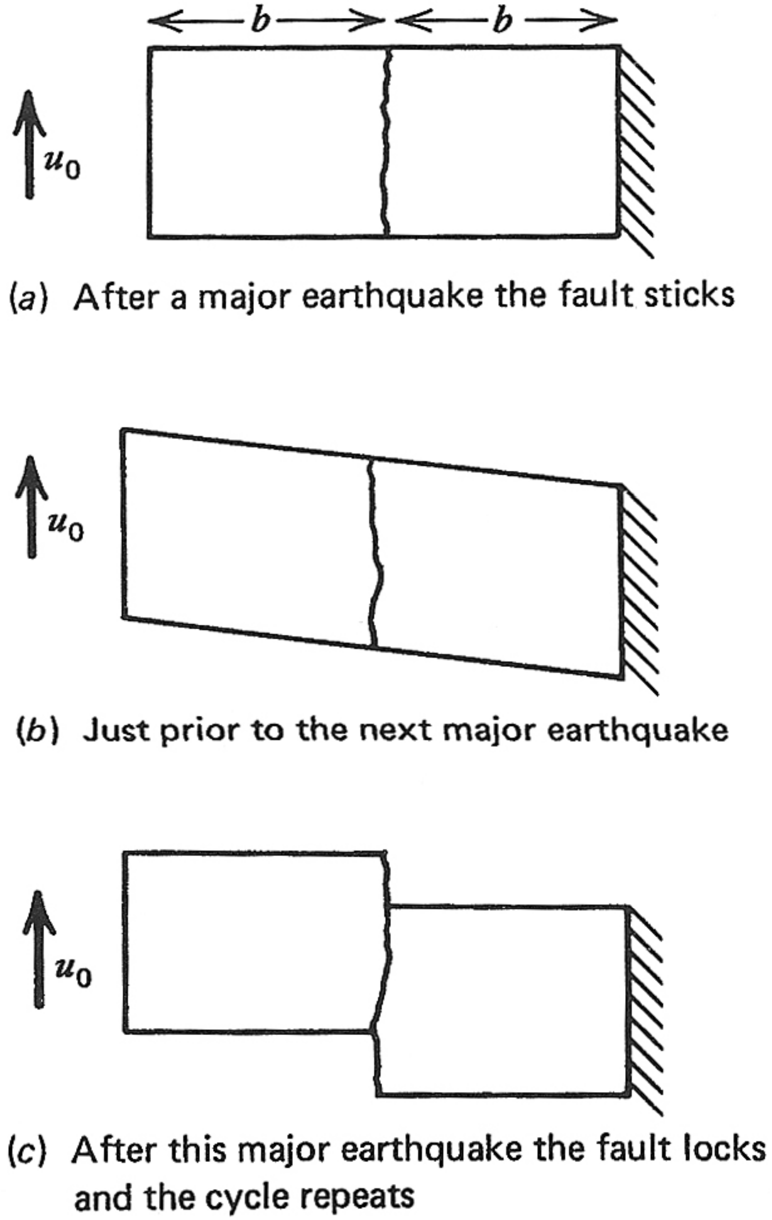
- **Earth is still cooling off**
  - **Takes billions of years**
  - **Freezing iron**
  - **Solid inner core growing**
- **Convection**
  - **Liquid outer core**
  - **Mantle (asthenosphere) rocks**
- **Conduction**
  - **Rigid lithosphere**
  - **Earth's heat flow ~ 0.08 Wm^{-2}**
- **Volcanoes**
  - **Transport hot material to the surface to cool off**

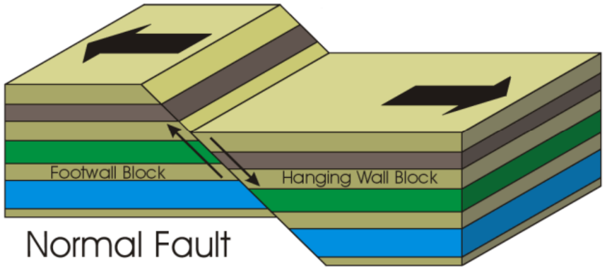


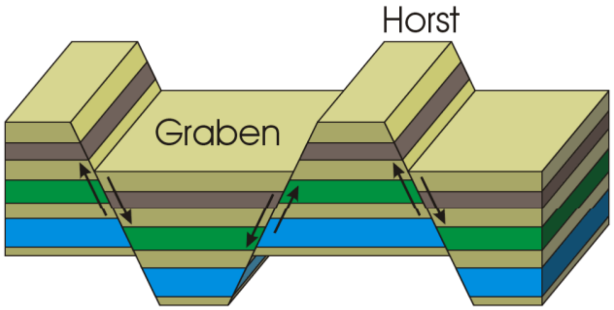
How do we know all this? - Earthquakes

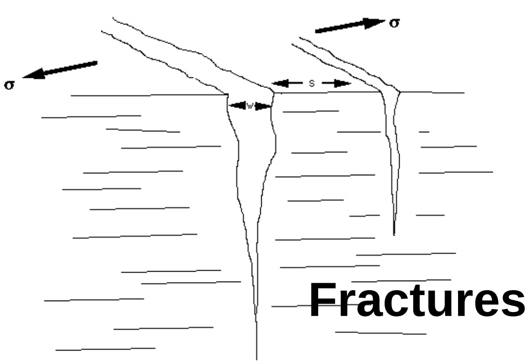
- How do Earthquakes work?
  - Near-surface rocks are brittle and get pushed around by flow of the mantle rocks
  - Faults in rock can break when stresses get too large
  - Termed "Tectonic activity"

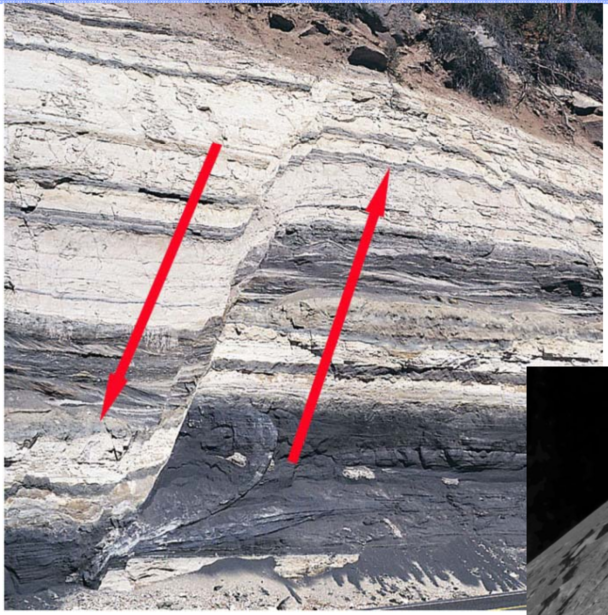


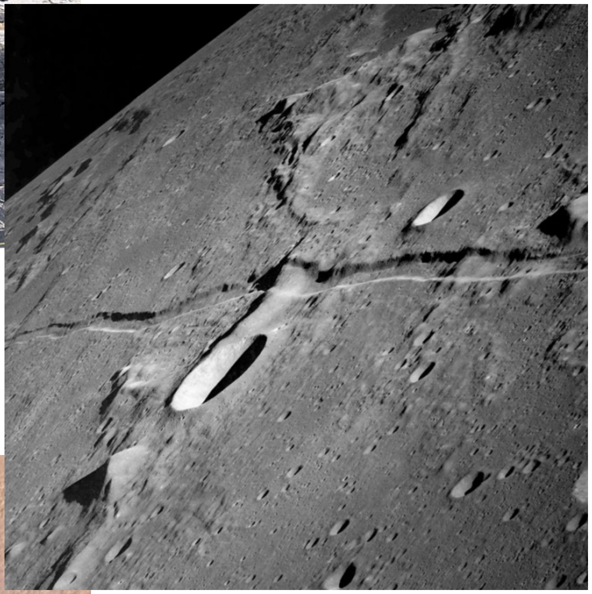
- **Difference kinds of tectonic activity – extensional faults**

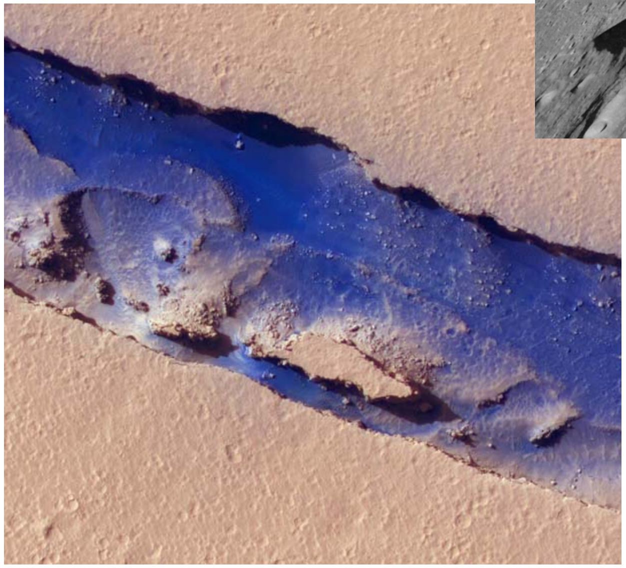




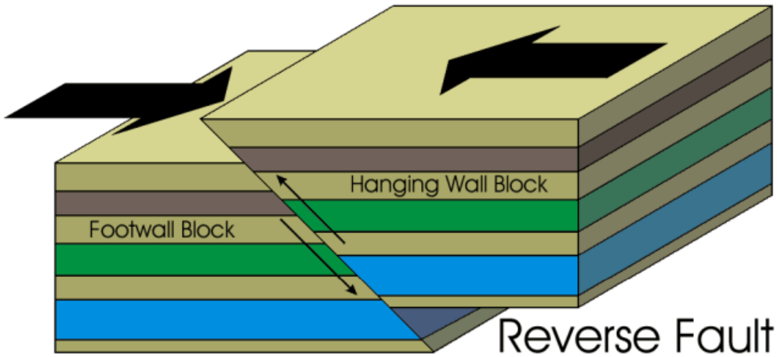


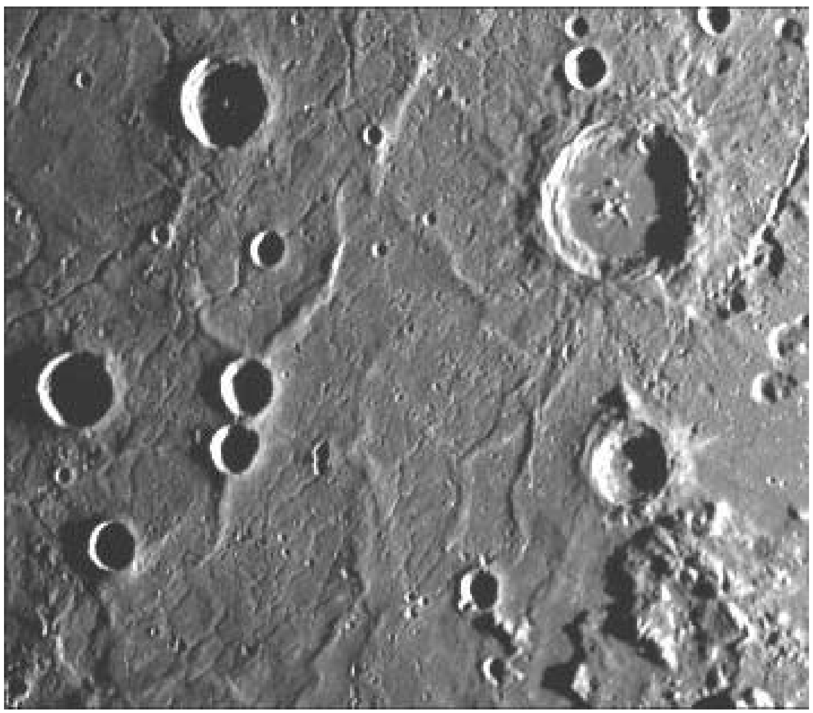




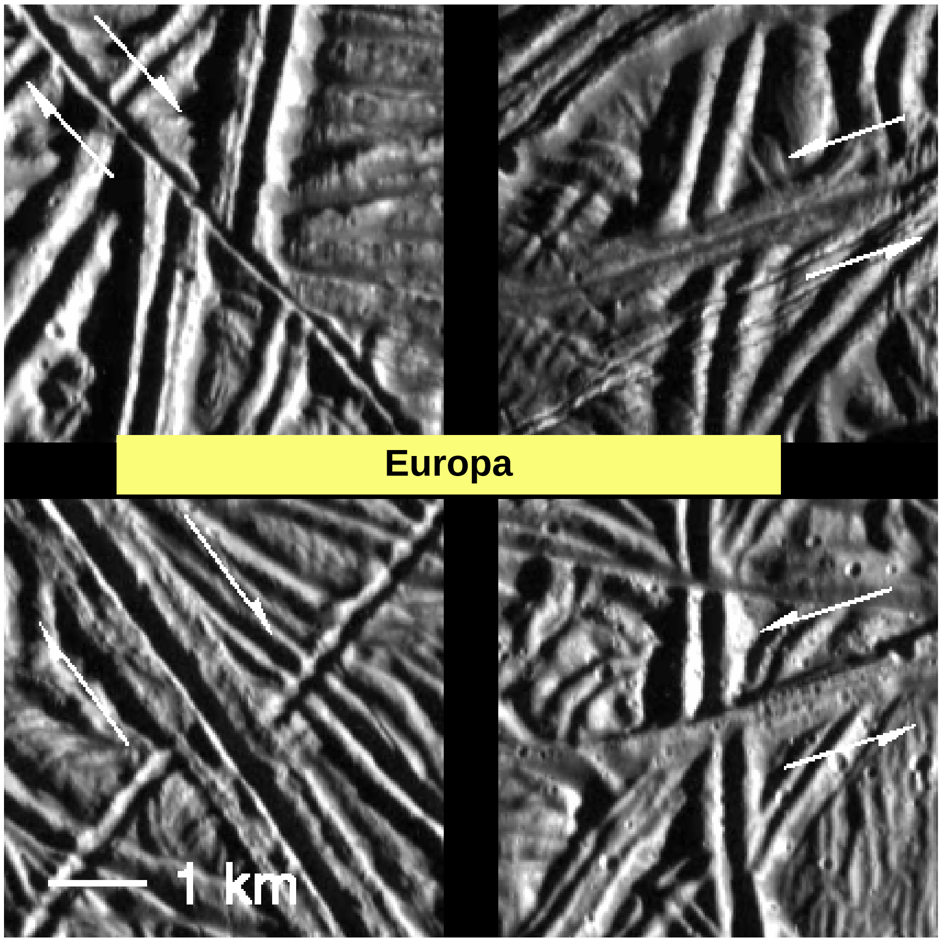


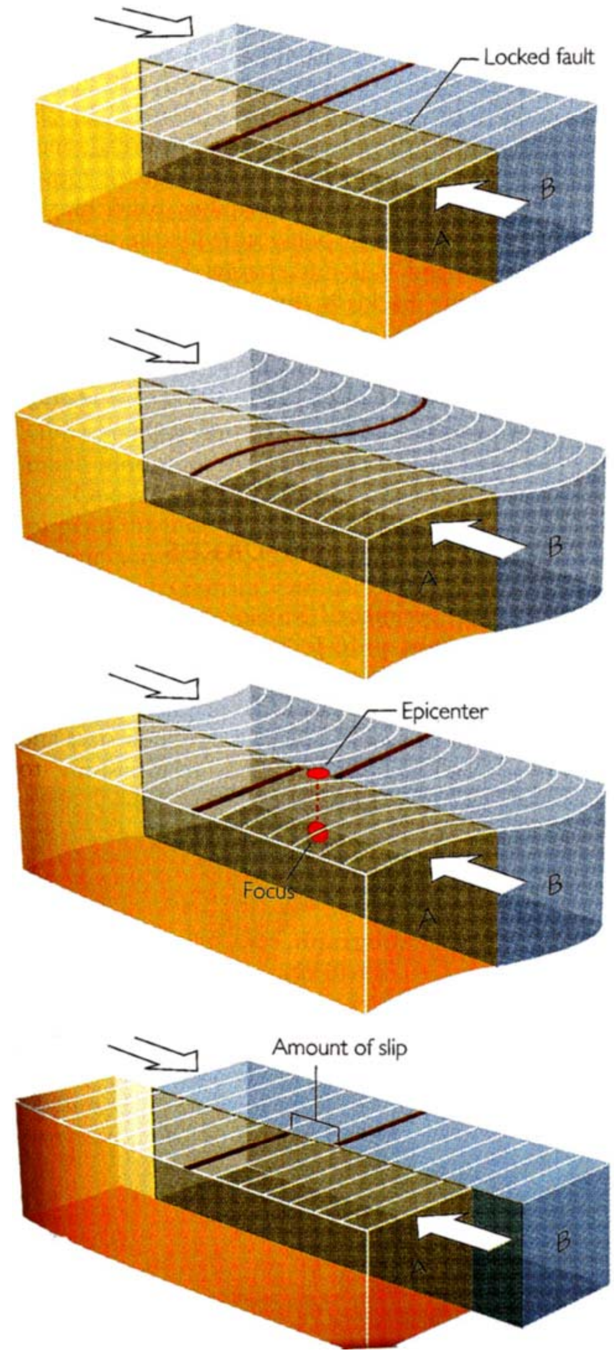
- **Difference kinds of tectonic activity – compressive faults**



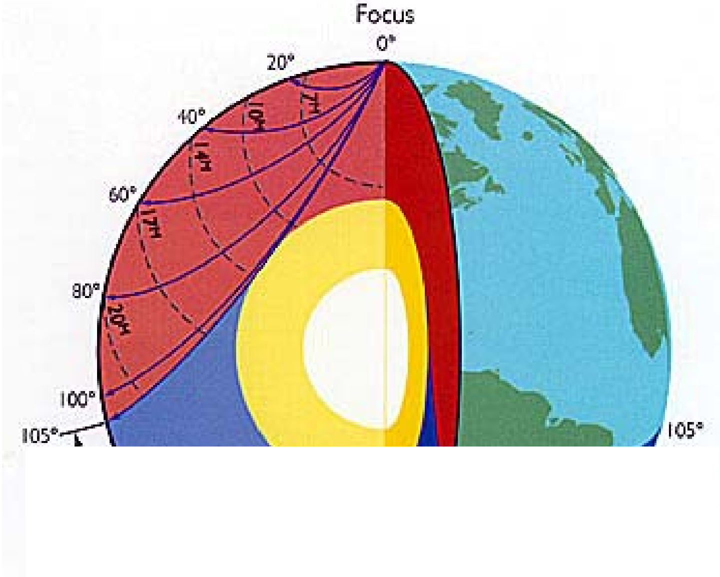


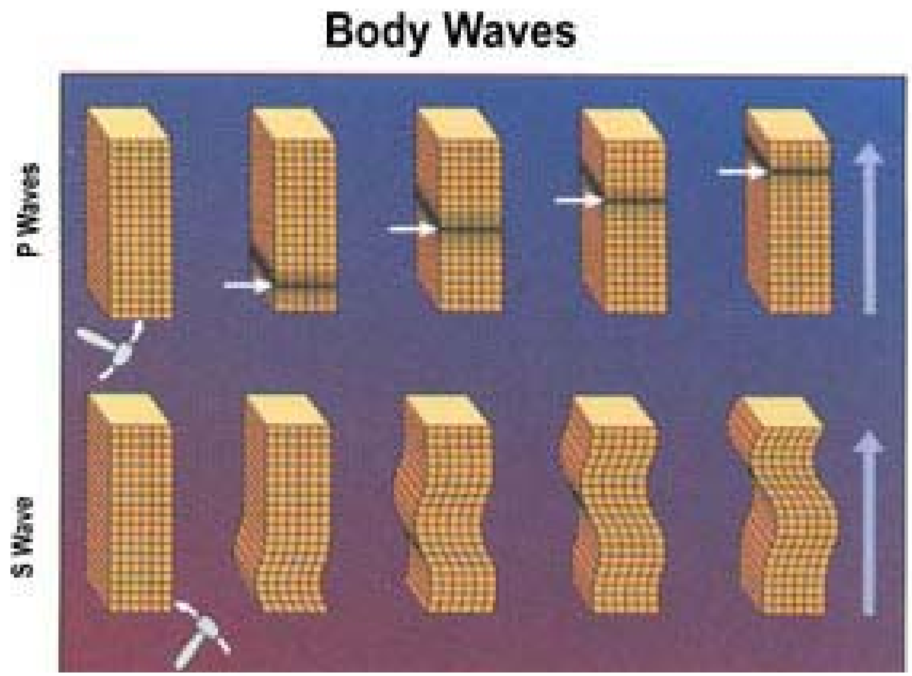
- **Difference kinds of tectonic activity – strike-slip faults**





- Breaking faults releases seismic energy
  - Travels in waves
- Surface waves cause motion in Earthquakes
- Body waves travel inside the Earth
  - ‘P’ waves and ‘S’ waves
    - Behave differently
  - Waves curve back towards the surface
    - Wave speed depends on rock density





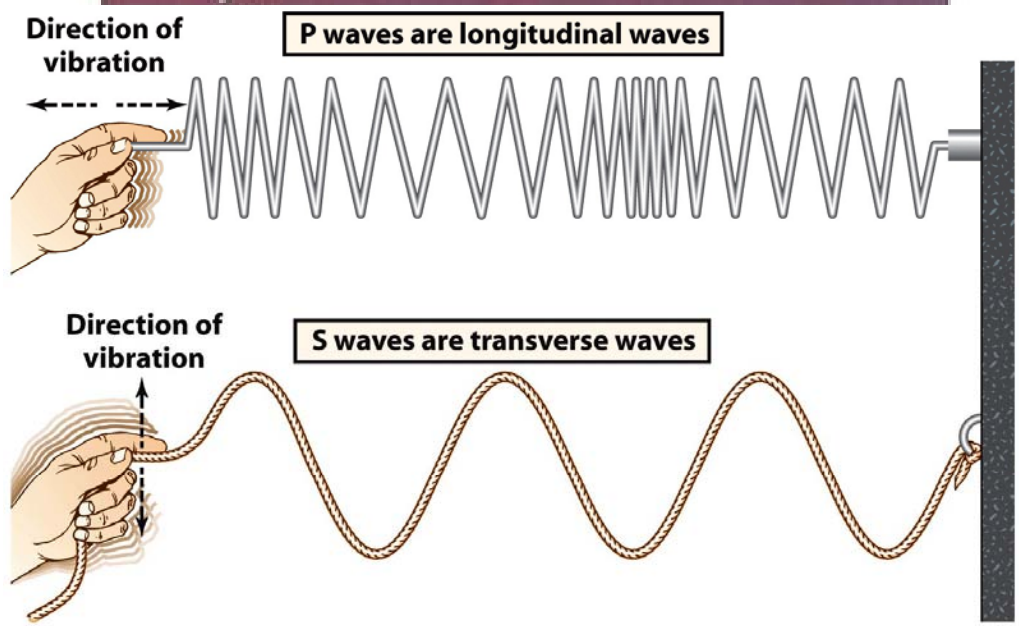


Figure 9-8
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- **So… how does that help?**
  - **We can time when waves arrive at different places**
  - **Later waves sample deeper depths**
  - **Build up a map of density variations in the mantle**

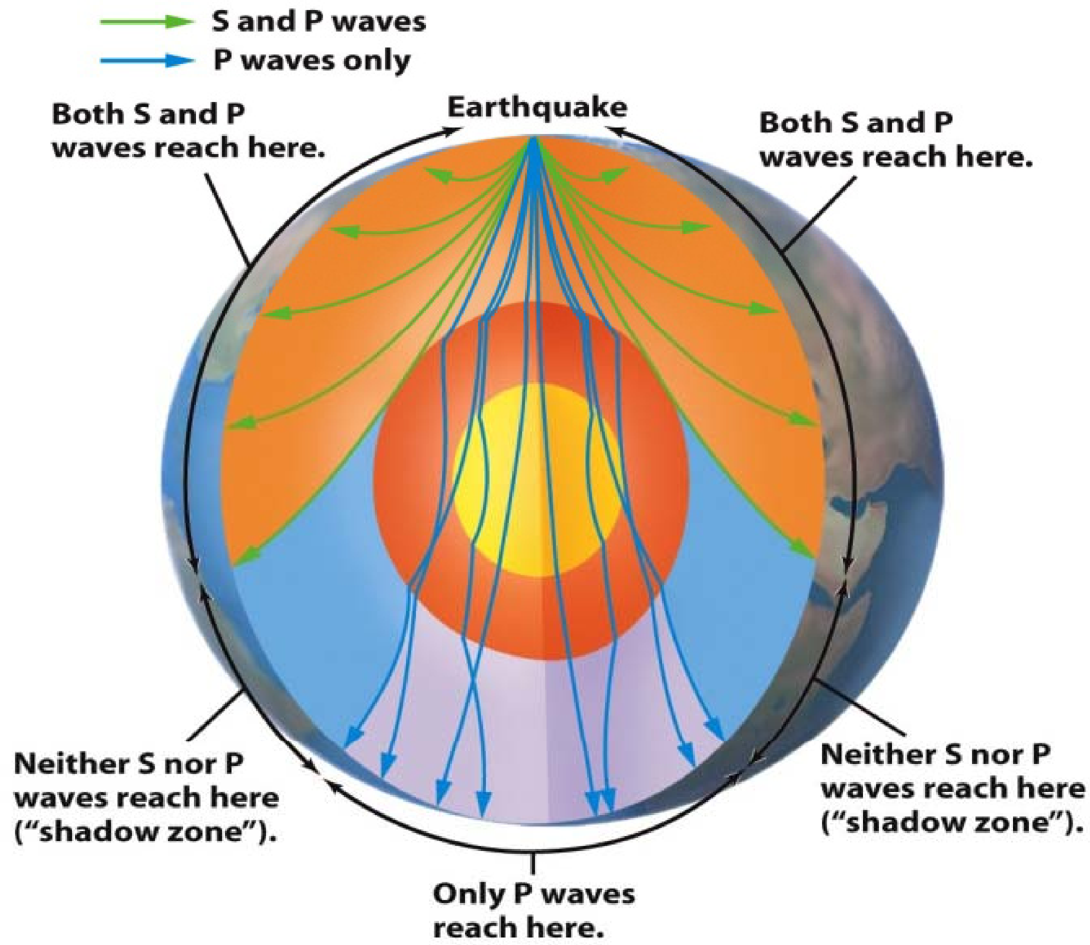

Figure 9-9
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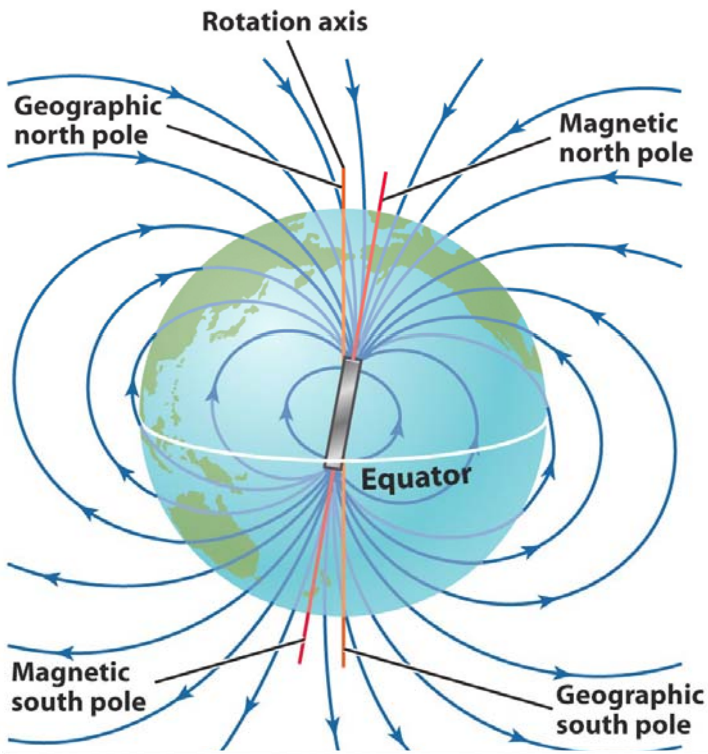
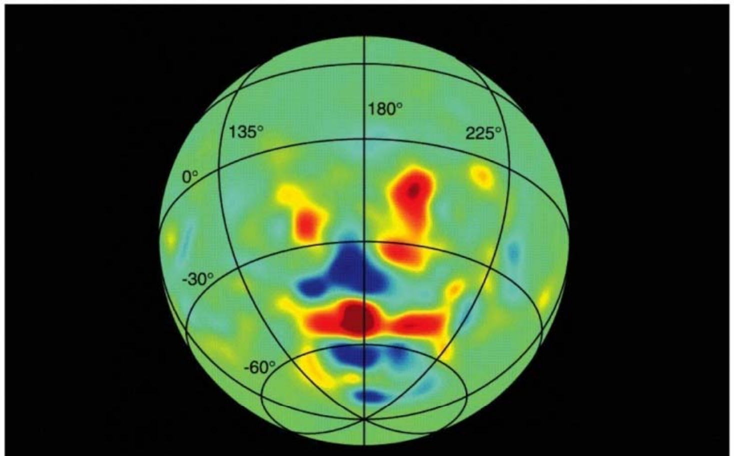
- **S-waves can't travel through liquids**
  - **Liquid outer core leaves a shadow zone with no s-waves**

- **Other evidence for a liquid outer core**
  - **Earth's magnetic field – internally generated**

- **A liquid outer core generates dipole magnetic fields**
  - **Earth's magnetic field**
  - **Mercury's magnetic field**

  - **Rotation and convection of liquid iron**
  - **Moving charges generate magnetic field**
- **Venus has no magnetic field**
  - **Hardly any rotation**
- **Mars has no magnetic field**
  - **Rotation rate is similar to the Earth**
  - **But has old rocks that are magnetized**
  - **Core convection in the past**
  - **Present core probably entirely solid**

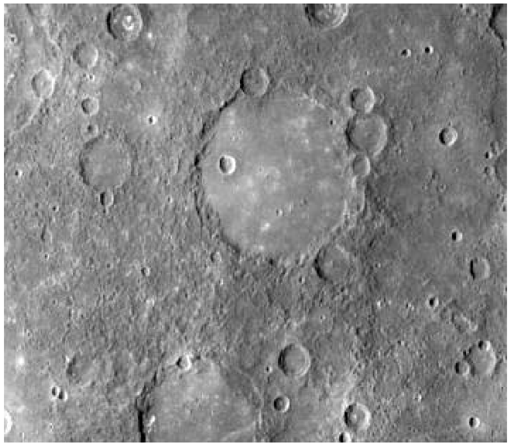




RED: magnetic field points upward from surface
BLUE: magnetic field points downward into surface
GREEN: no magnetic field

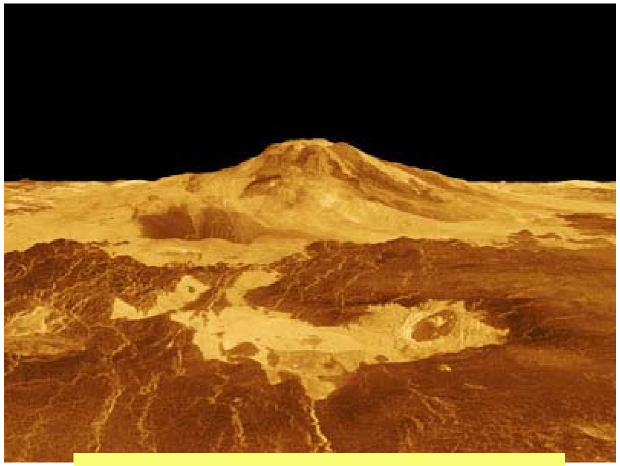
Volcanoes

- **On all the terrestrial planets (and then some)**



Mercury – Smooth plains

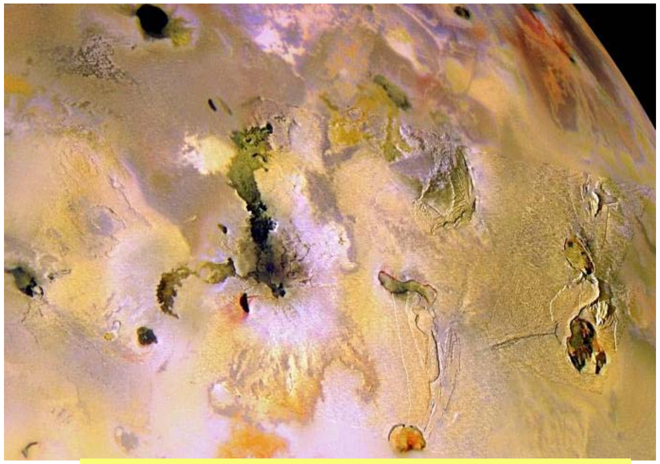
Moon – Maria



Venus – Maat Mons

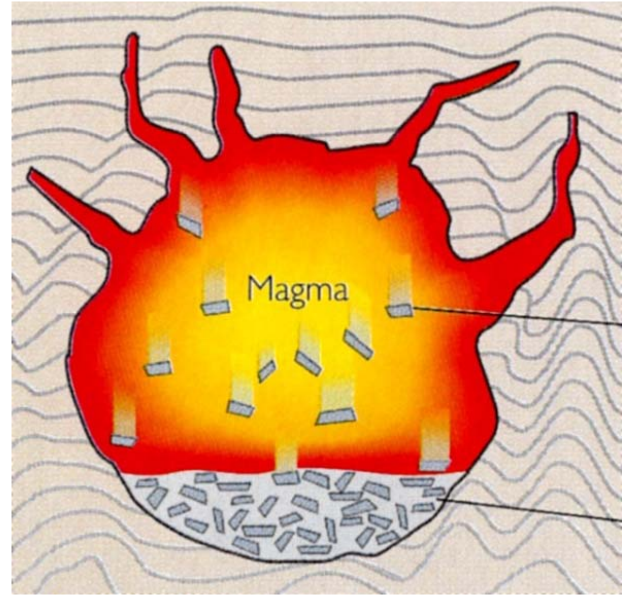
Earth – Mount Augustine

Mars – Olympus Mons



Io – just about everywhere

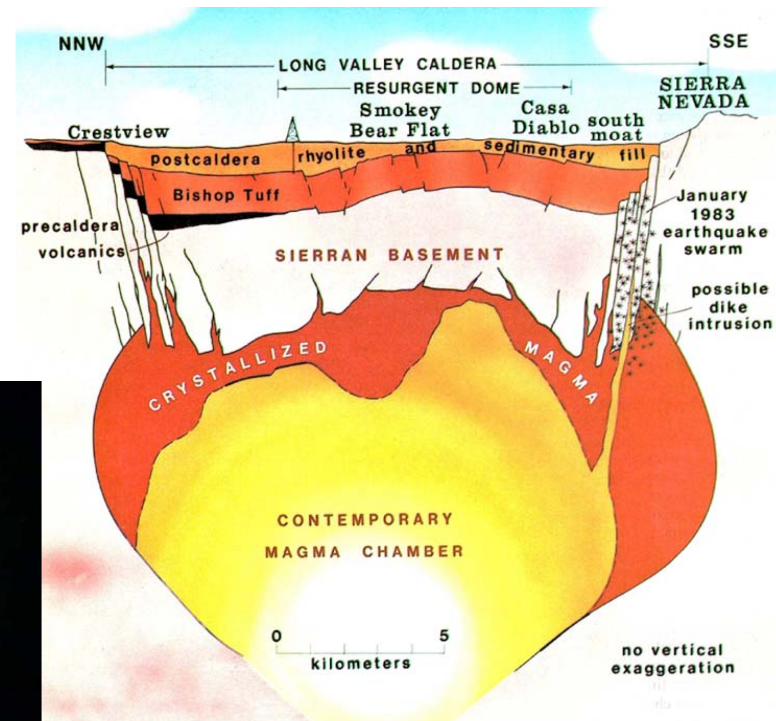
- **What causes volcanism?**
  - **Material in mantle rises**
  - **Decompression causes partial melting**
  - **Droplets of molten rock migrate upwards**
  - **Collect in magma chambers**
    - **Rock density decreases as the magma moves towards the surface**
    - **Magma stops when neutrally buoyant**



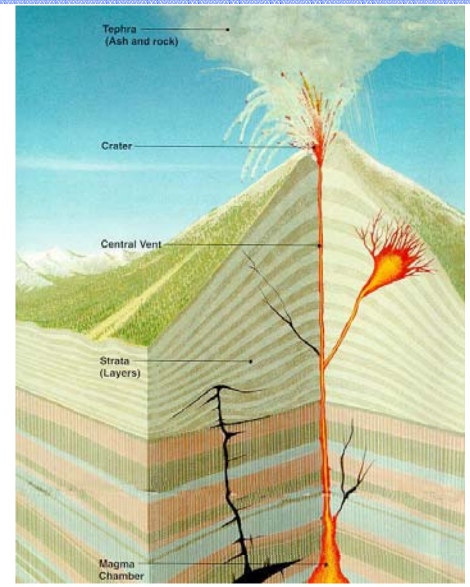
  - **Magma chambers can either:**
    - **cool off underground**
    - **Forms intrusive rock (Pluton) – like granite**
    - **Slow cooling – big crystals**

or

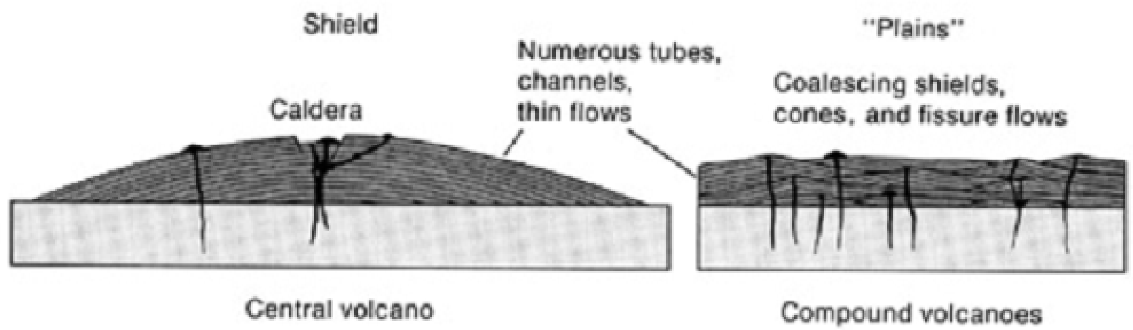
    - **Erupt onto surface to make volcanoes**
    - **Forms extrusive rock – like basalt**
    - **Quick cooling – tiny crystals**



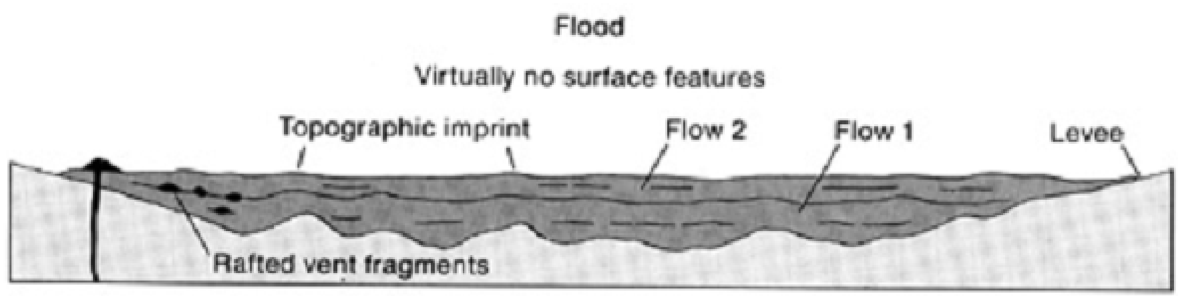
- **Different types of volcano**
  - **Stratovolcanoes**
    - **Steep-sided**
    - **Layered ash and lava**
    - **Found only on the Earth**



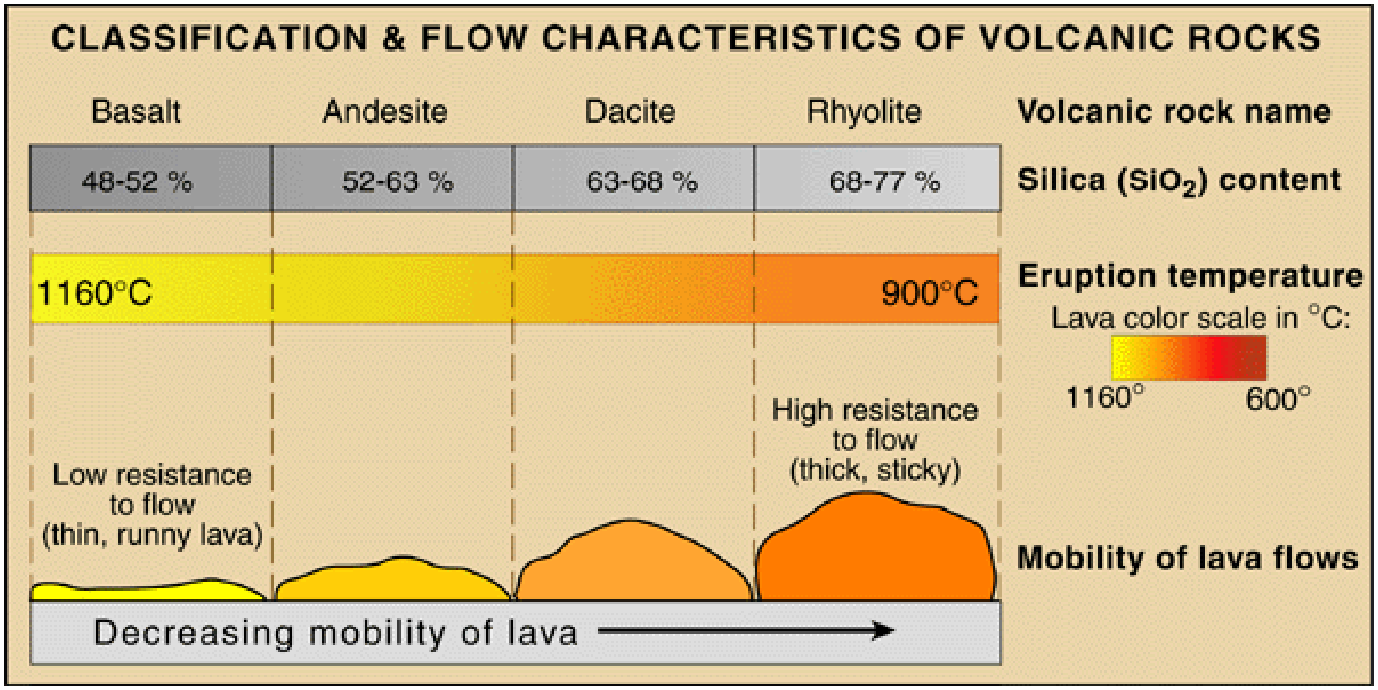
  - **Shield Volcanoes**
    - **Low slopes**
    - **Layered lava**
    - **Coalescing shields called plains volcanism**
    - **Common throughout the solar system**



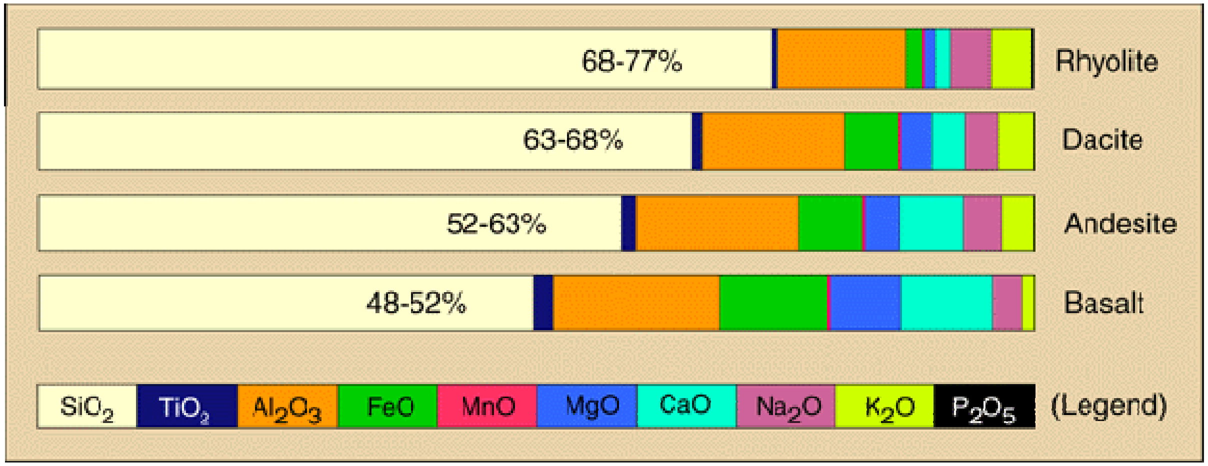
  - **Flood Volcanism**
    - **Common on Venus & Moon**
    - **Rare on Earth**



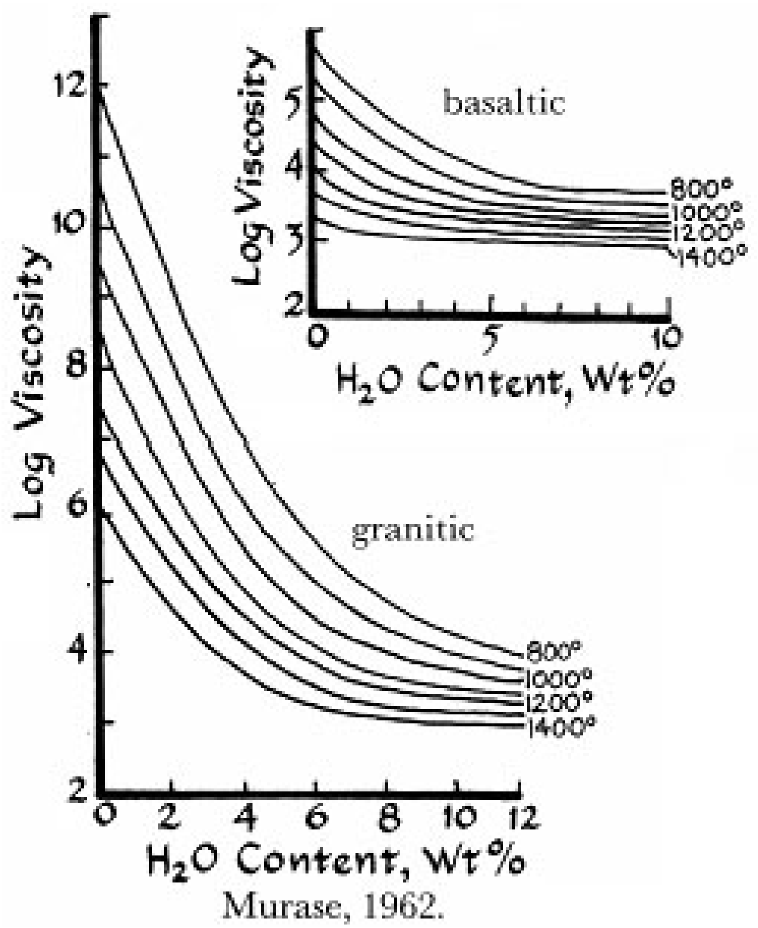
- **Why the different types?**
  - **All depends on the composition of the lava – silica (Si O_2) content**

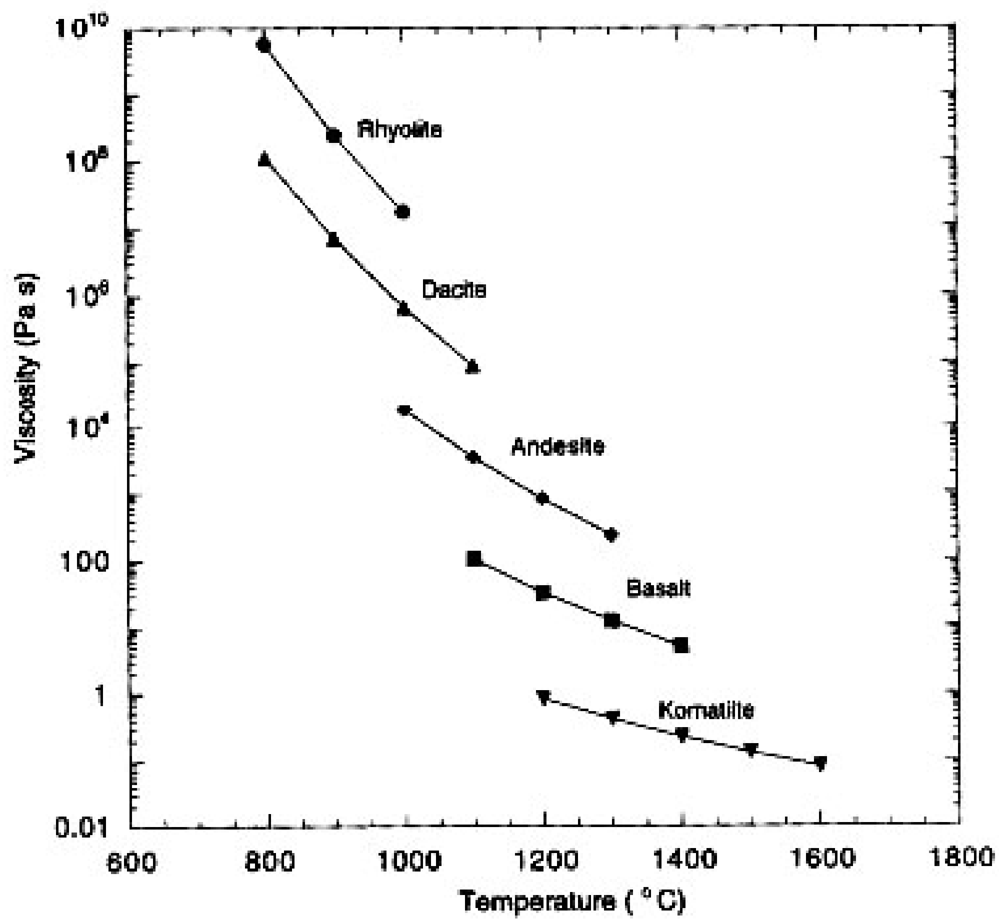


- **High silica means high viscosity**

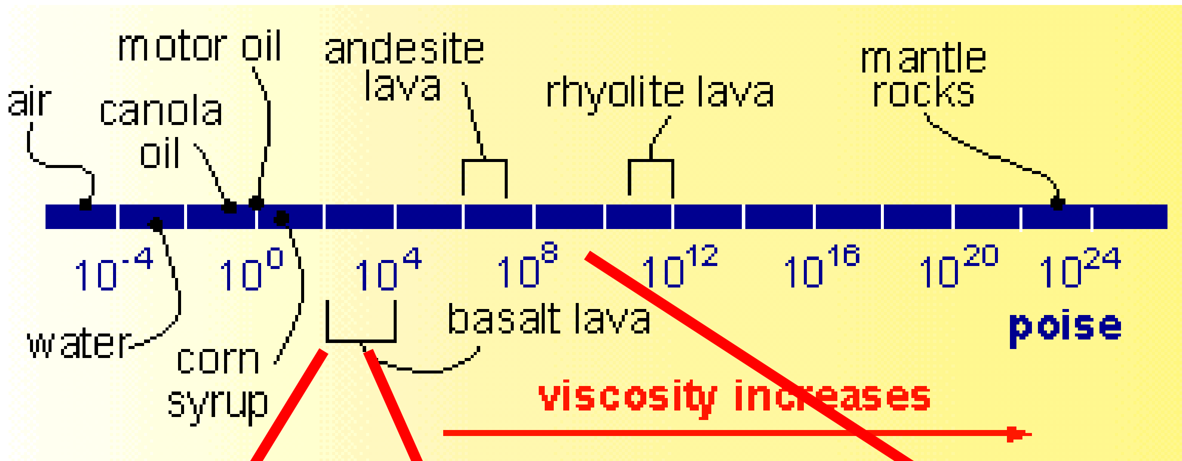


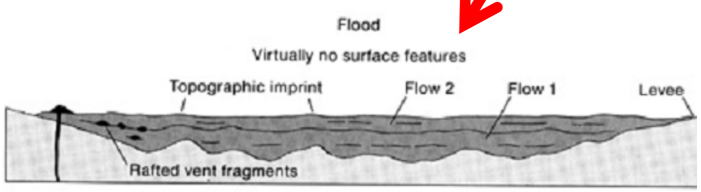
- **Different magmas melt at different temperatures**
  - **Alters viscosity**
  - **Adding water lowers viscosity**



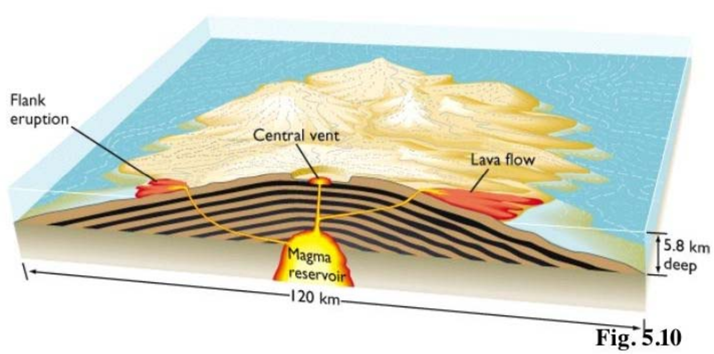


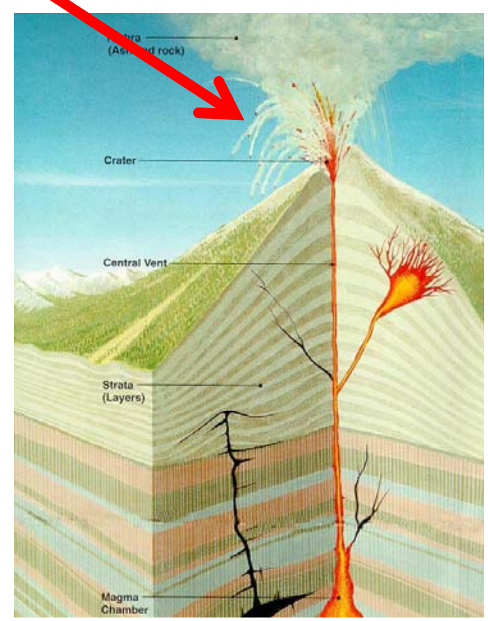
- **Silica content determines viscosity**
  - **Temperature and water-content also play a role**



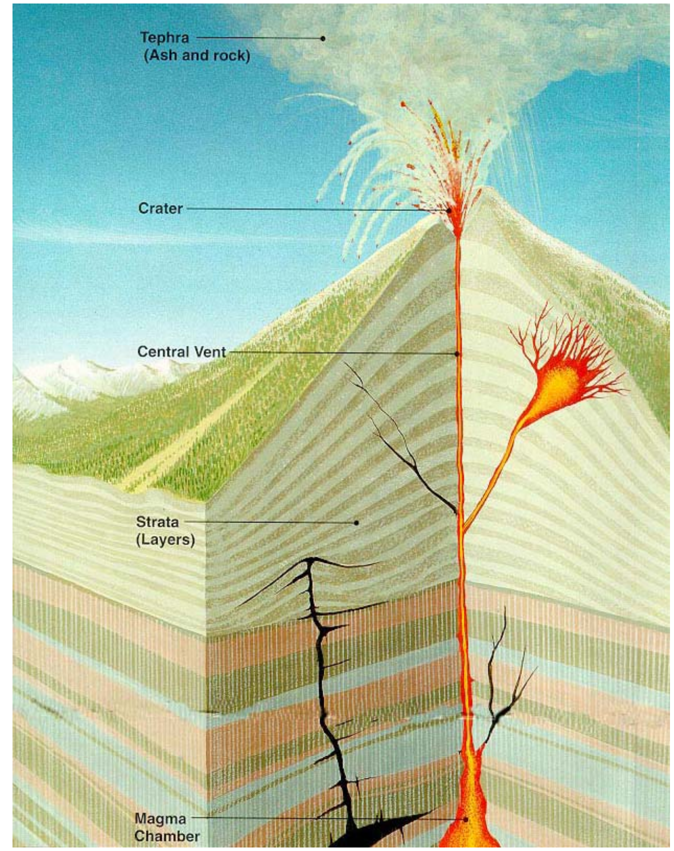


Shield Volcano

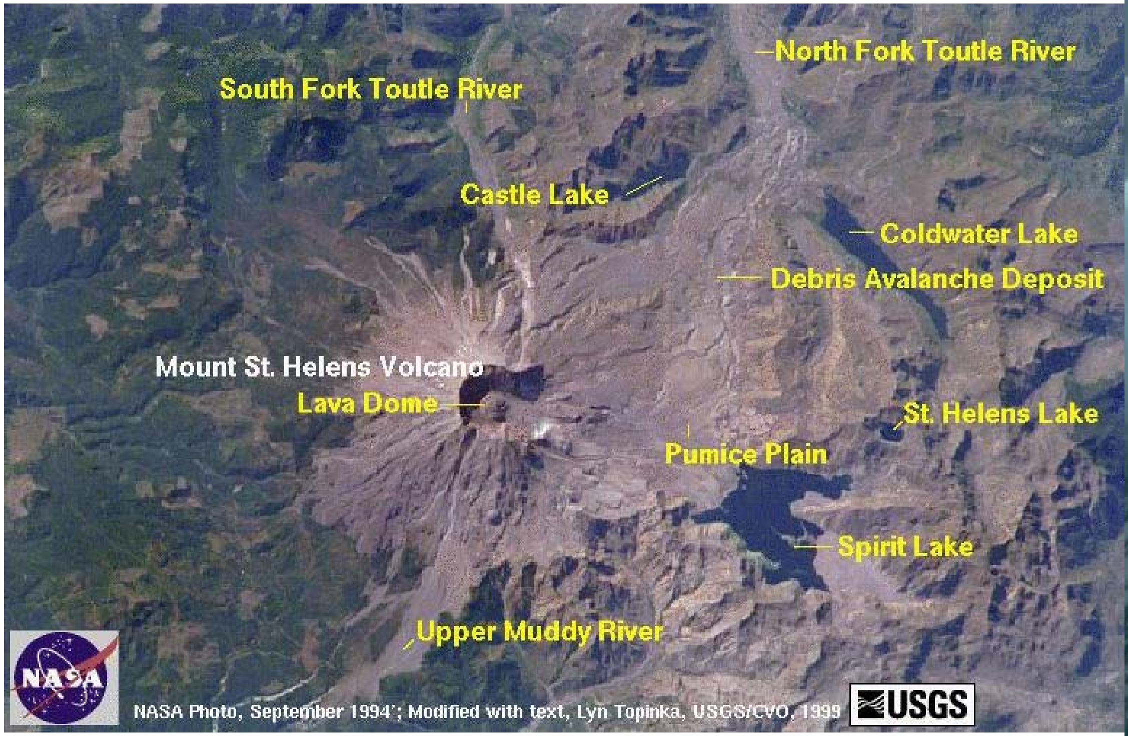




- **Stratovolcanoes**
  - **Lots of silica chains – very viscous magmas**
  - **Gases trapped in the magma – bubbles can't rise**
  - **Explosive eruptions**
  - **Ash clouds can collapse to form pyroclastic flows**
  - **Volcano made from stratified ash and lava layers**



- **Mount St. Helens is a famous example**



- **Splatter cones and cinder cones**
  - **Lots of gas struggling to escape the magma**
  - **Leads to fire fountains and cinders**

- **Shield volcanoes**
  - **Less silica chains – non-viscous magmas**
  - **Runny magma travels far**
  - **Builds low-slope structures**
  - **Non-violent eruptions**
    - **E.g. Hawaii**

Shield Volcano

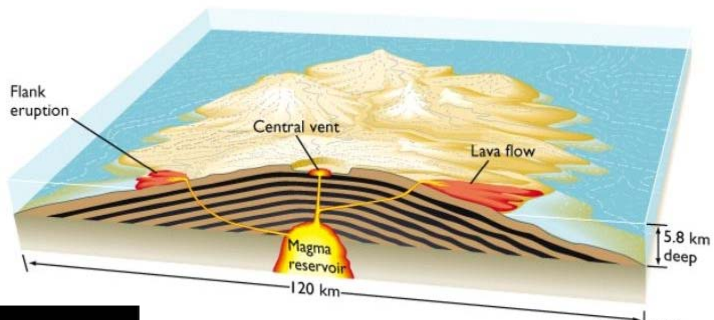
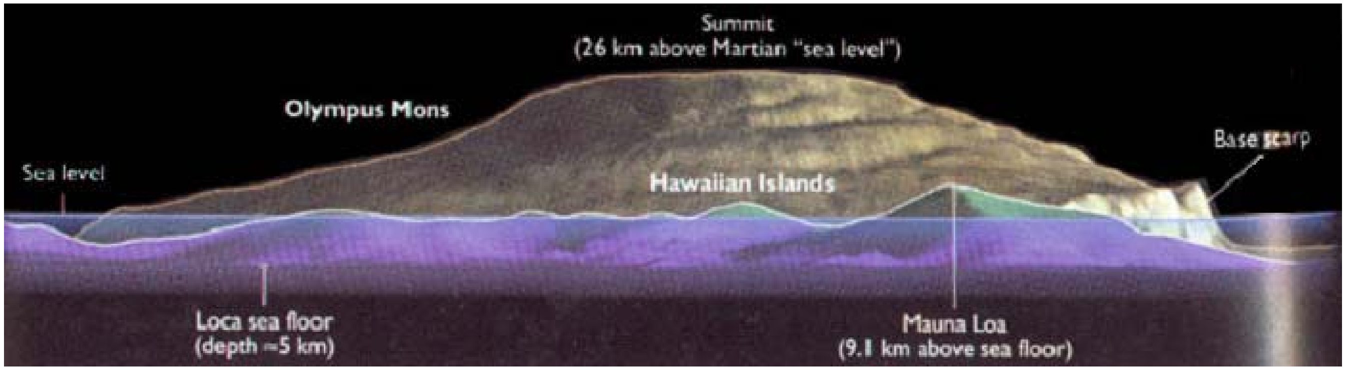
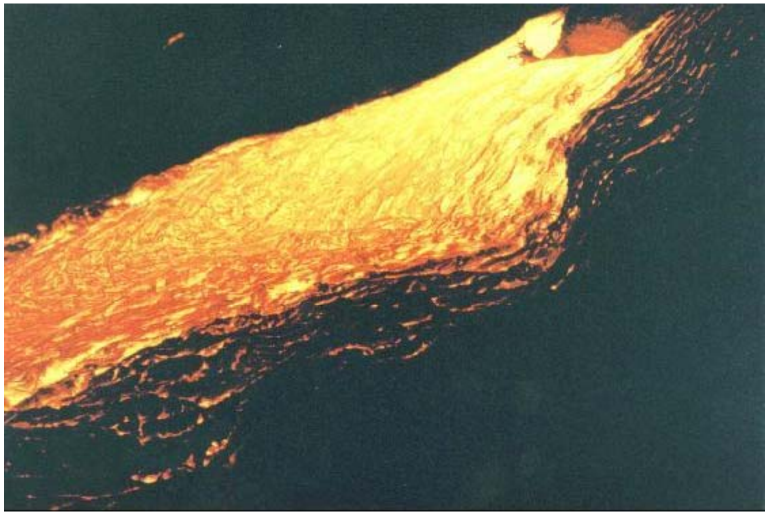


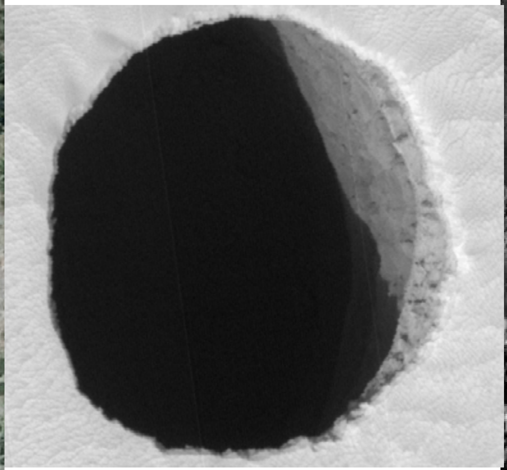
Fig. 5.10





Volcanic Collapse features

- Volcanic calderas
  - Collapse pits
  - Withdrawal of magma from the subsurface
    Magma chamber collapses
  - Multiple collapses indicate magma chamber filled and emptied several times
- Lava tubes
  - Sinuous rilles on the Moon and Venus
  - Run for 100's of km
  - Collapsed lava tubes
  - Sometimes just portions of the tube collapse



- **The big picture…**
  - **Earth's core is still cooling off – drives all the following steps**
    - **Liquid core shrinking – solid inner core growing**
  - **This escaping heat drives convection in the mantle**
  - **Rising rock can partially melt due to pressure changes**
  - **Molten droplets are less dense and rise above rocks**
  - **Molten material collects at the depth where it's no longer less dense**
  - **These magma chambers can erupt molten rock onto the surface**
  - **Type of volcano depends on the viscosity of the rock**
    - **Mostly determined by its silica content**

In this lecture…

- Internal structure of rocky planets
- Earthquakes and what they tell us
- Sources of heat
- How volcanoes work
- Wind-related (aeolian/eolian) processes
- Fluvial processes

Next: Craters

- Reading
    - Chapter 9.2 to revise this lecture
    - Chapter 10 for next lecture