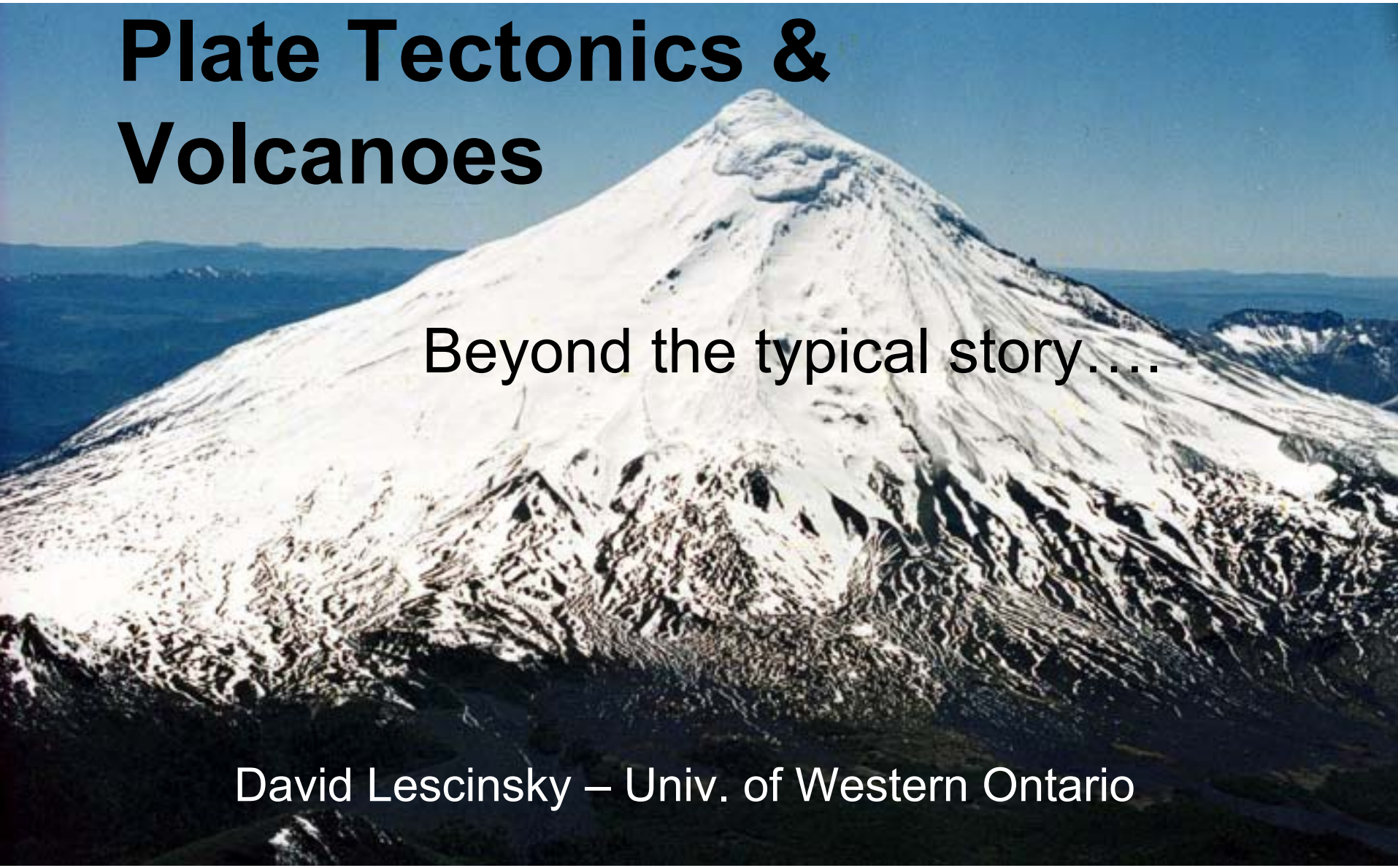


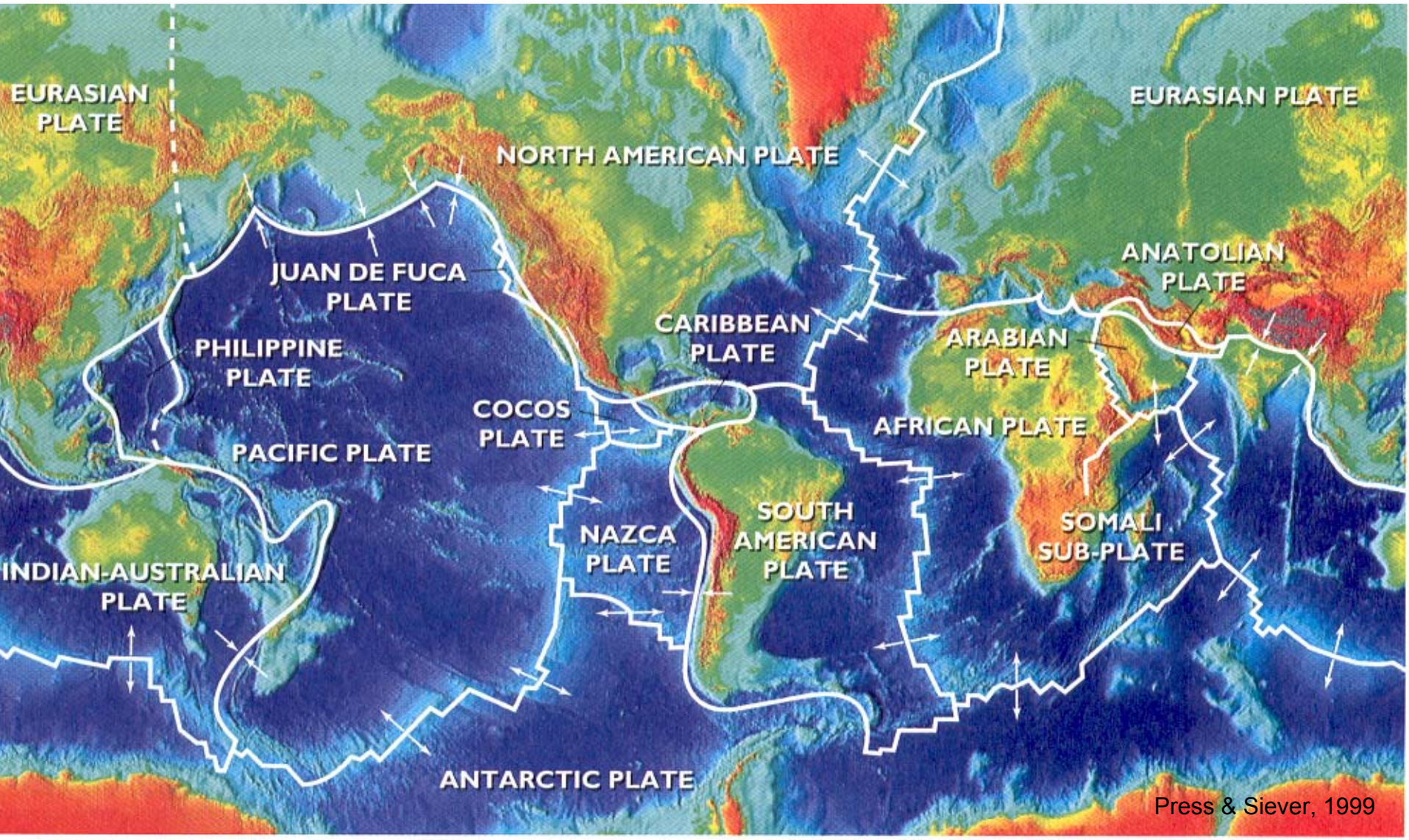
Plate Tectonics & Volcanoes

Beyond the typical story….

David Lescinsky – Univ. of Western Ontario

The talk is available at www.uwo.ca/earth/outreach/volcano.pdf

Plate tectonics are cool



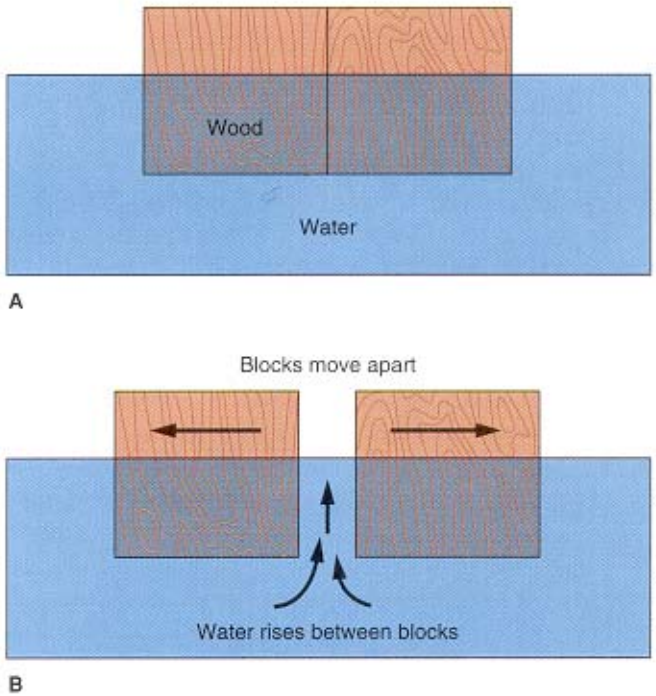
Press & Siever, 1999

Beyond the typical story

- Most often, just talk about:
  - the types of plate boundaries
  - how plates move
  - and where volcanoes are located
- We don't explain the "whys" and "hows"
- Today we will look at why volcanoes are found at plate boundaries

Summary of plate tectonics

- Explains a wide range of geological processes
- Layers of cold brittle rock on the surface of earth
- These “plates” slide on top of a warmer "fluid" layer of rock



like pieces of wood on top of a pond

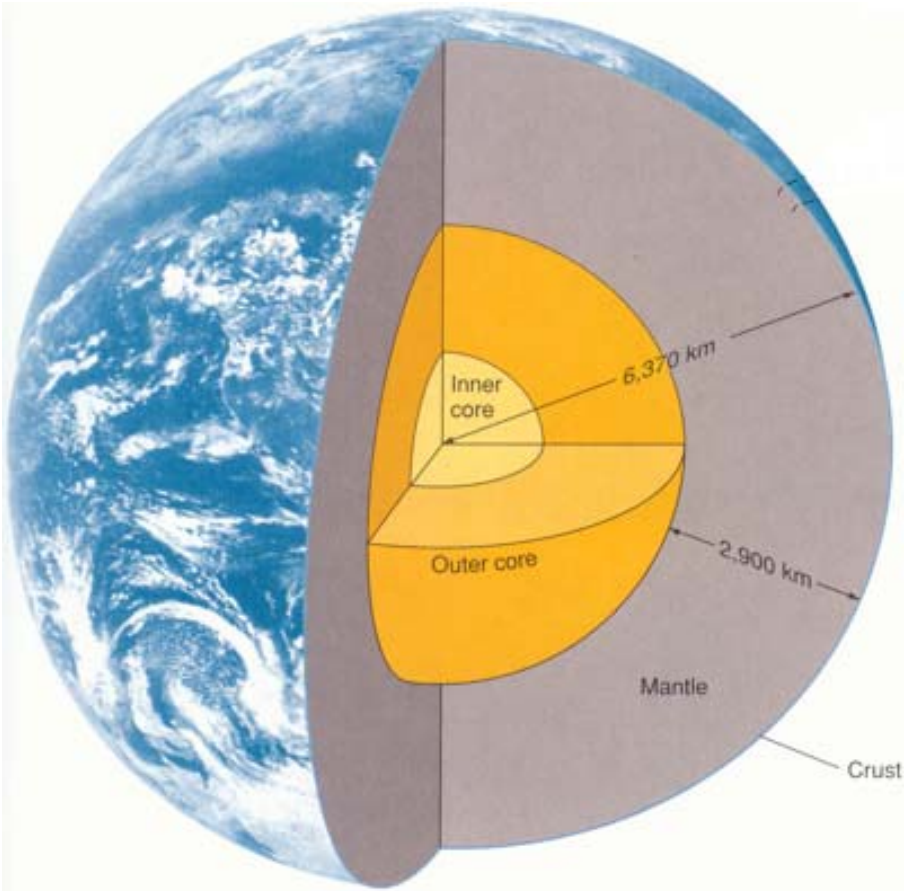
What are “Plates”?

- Cold brittle layers of rock at the surface of the earth are called the "lithosphere"
- “Fluid" ductile layer underneath is called the “asthenosphere”
  - This is not really a liquid

Interior of the earth

compositional divisions : crust, mantle, core

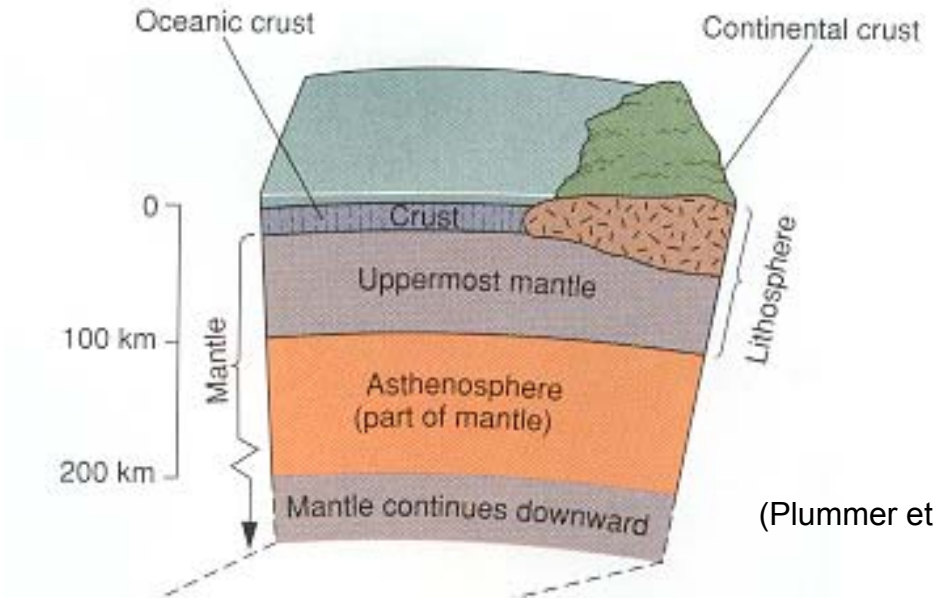
- Core - heavy iron
- Mantle - lighter silicic material; some iron and magnesium
- Crust - even lighter, more silica rich, little metal



(Plummer et al., 2003)

Lithosphere vs. crust

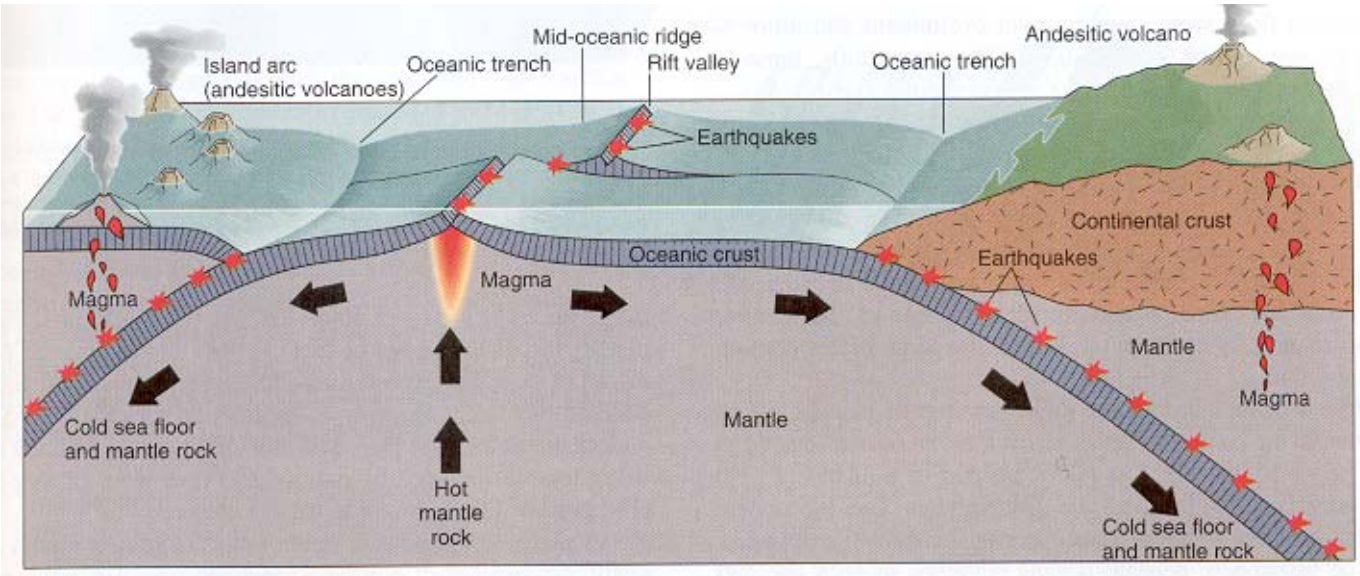
- The lithosphere includes all of the crust and part of the top of the mantle



(Plummer et al., 2003)

- continental crust has high silica content, forms thick layers that rise up high
- oceanic crust has low silica content, forms thin layers that sink low

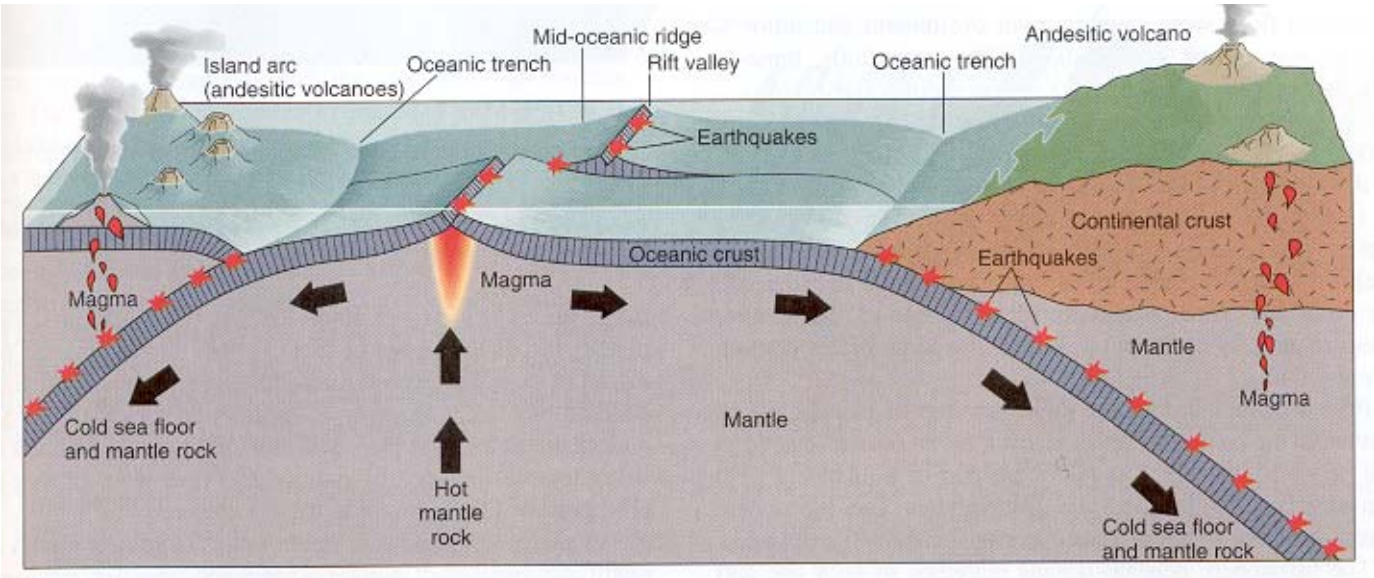
Plates move around



(Plummer et al., 2003)

- Plates move apart - called rifts or spreading centers
- Plates move past each other - called transform or strike-slip boundaries
- Plates collide…

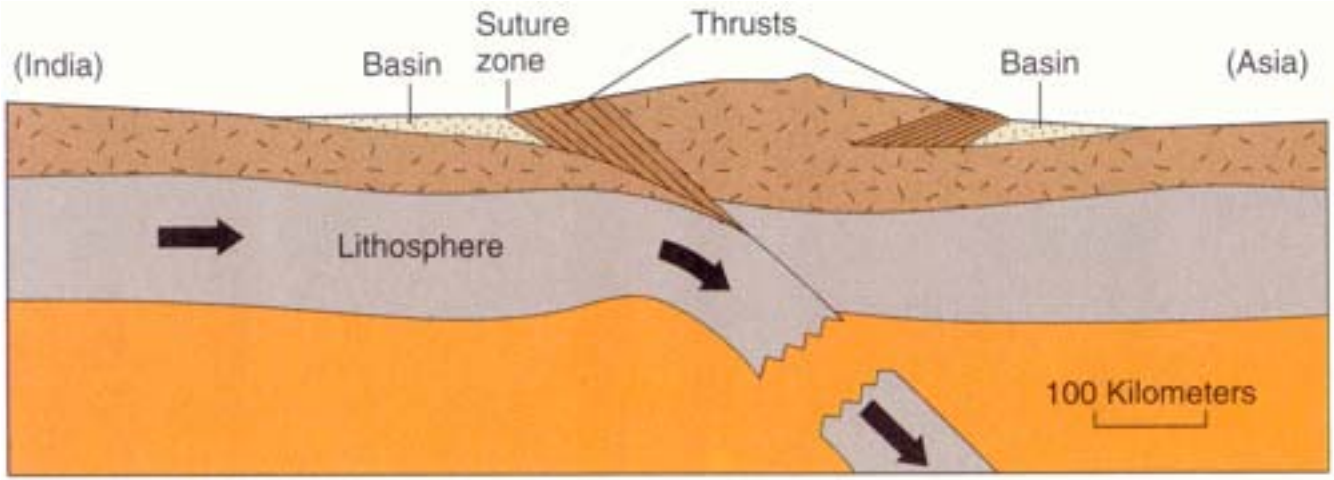
Collisional boundaries I



(Plummer et al., 2003)

- Dense oceanic crust gets pushed down & sinks
- This is called subduction

Collisional boundaries II

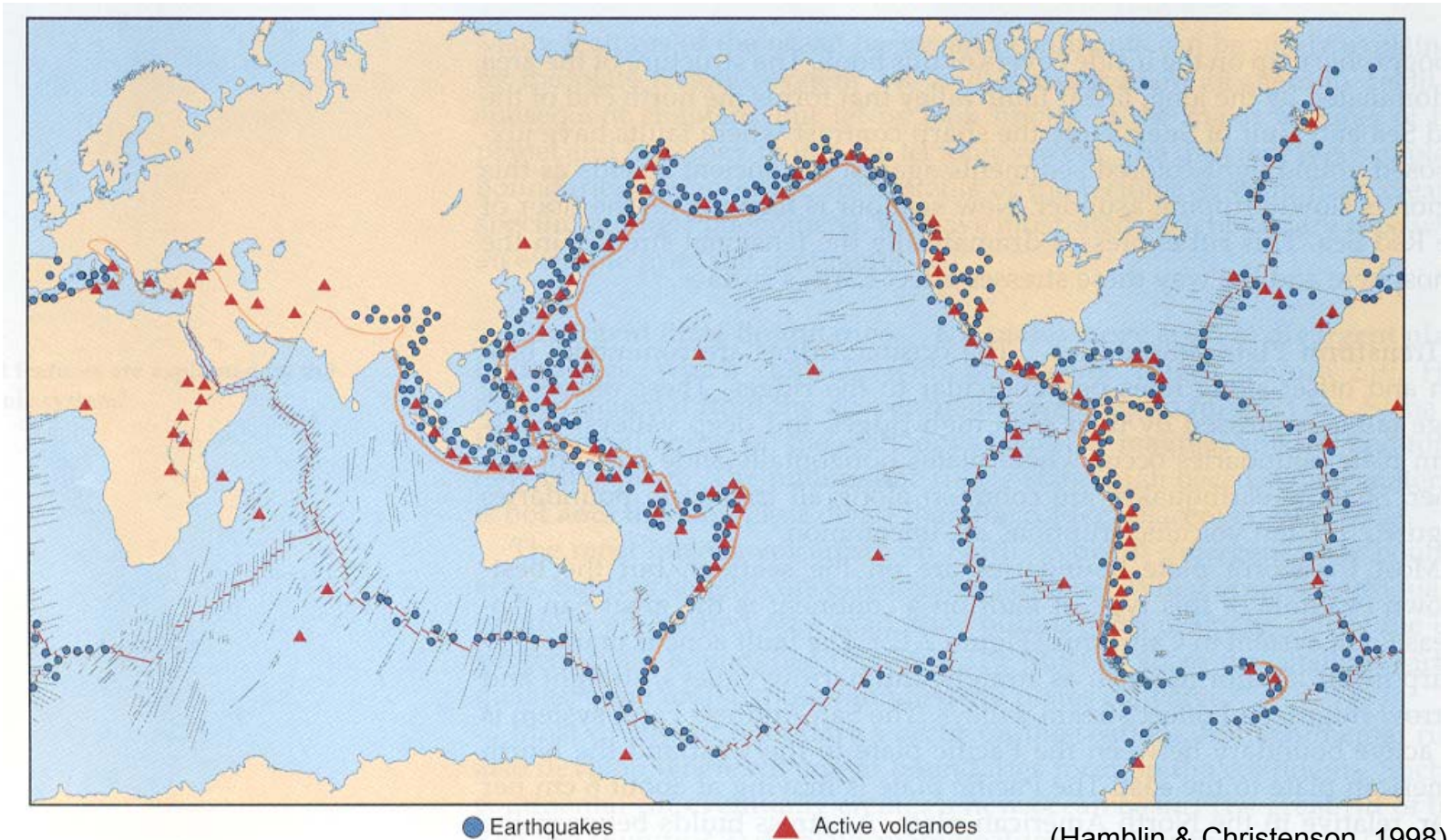


(Plummer et al., 2003)

- Light continental crust floats
- Where two collide - neither sinks
- Buckling and mountain formation (Himalayas)

Where do volcanoes fit in?

- Volcanoes are concentrated along plate boundaries - why?



(Hamblin & Christenson, 1998)

Volcanoes

http://www.ngdc.noaa.gov/seg/fliers/se-0801.shtml

- Where liquid rock erupts at surface of Earth
- Where does liquid rock come from?
- A zone of liquid rock inside of the earth?
- If true, volcanoes would be scattered
- Something special about plate boundaries – rock melts here rather than at other places

Why does rock melt?

- Things melt when they get hot enough – they “exceed their melting temperature”
- This is also called the “solidus” – the temperature at which things freeze
- Ice melts at 0°C and water freezes at 0°C

Rock melting temperatures

- Depends on the composition of the rock

Rock	Chemical Composition	Temp.
Basalt	45-55 SiO_2%, high in Fe, Mg, Ca, low in K, Na	1000 - 1200 ^oC
Andesite	55-65 SiO_2%, intermediate in Fe, Mg, Ca, Na, K	800 - 1000 ^oC
Rhyolite	65-75 SiO_2%, low in Fe, Mg, Ca, high K, Na	650 - 800 ^oC

Silica content is the most important

Let's consider pressure

- Overlying rocks push down creating pressure
- This is like in a swimming pool – as you go deeper in the water it pushes down more
- Rock weighs more than water –
  - water has a mass of 1000 kg/m^3
  - rock has a mass of ~3000 kg/m^3
- Under 1 km of rock we get:

3000 kg/m^3 * 1000 m = 3000000 Pa (Pascals) = 3 MPa

The effect of pressure

- We must consider the difference between liquid and solid material

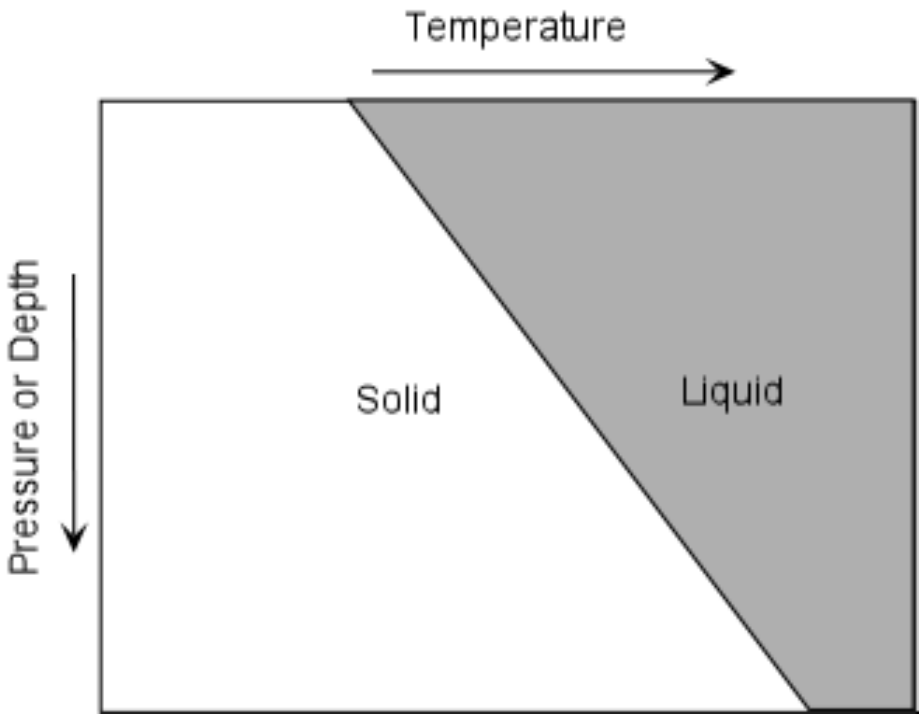
The molecular scale

- Solid:
  - atoms are bound & held fixed in place,
  - where these atoms have consistent composition and structure – we have crystals (minerals)
- As rock heats up, atoms start vibrating faster and eventually they break their bonds & move around
- Liquid:
  - Atoms move, but are still loosely bound
  - as a result gravity can still act on the group
- Gas:
  - Atoms no longer bound, they behave individually

Pressure effects vibration

- The pressure helps hold the atoms in place
- The more pressure,
  - the more tightly the atoms are held
  - greater temperature required to split them apart
- Therefore high pressure means high melting temperature

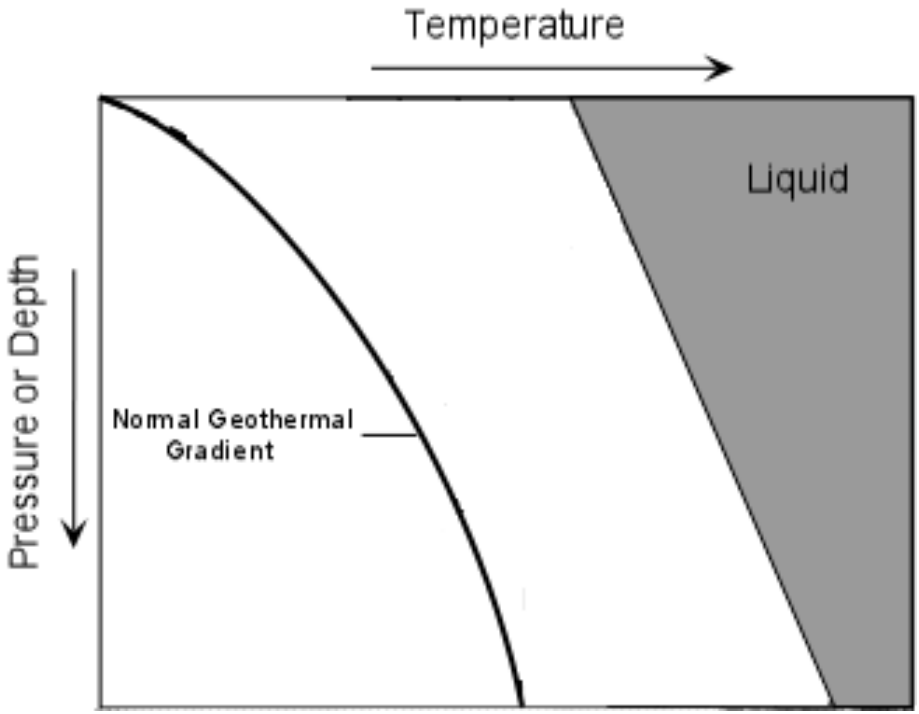
Plotting melting temperature



- Zone of melting (liquid)
- Zone of no melt (solid)

(Nelson, http://www.tulane.edu/~sanelson/geol204/volcan&magma.htm)

What temperature is it really?

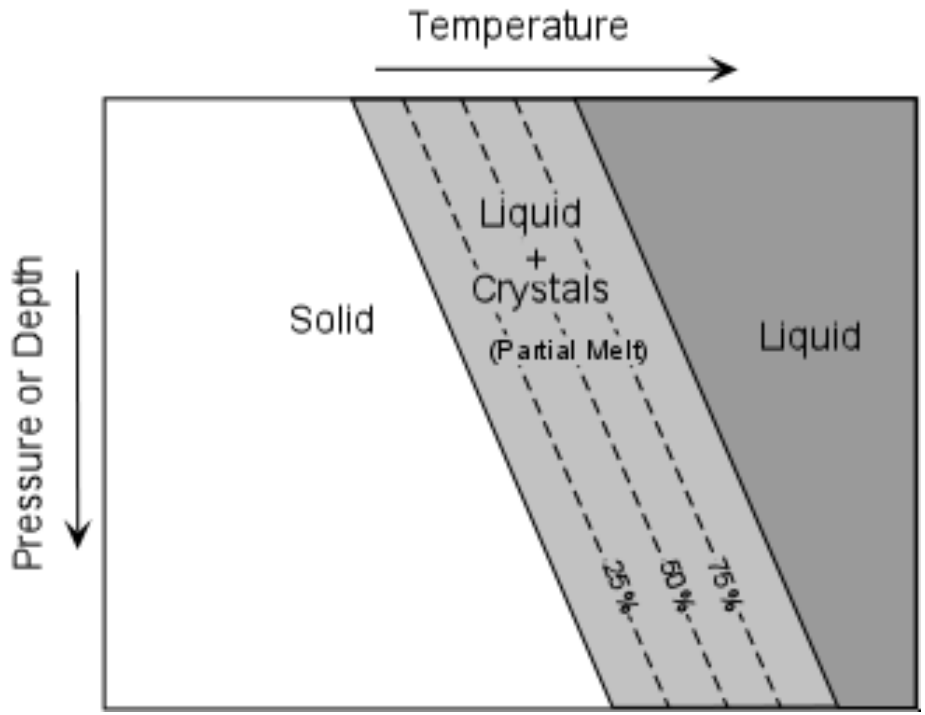


(Nelson, http://www.tulane.edu/~sanelson/geol204/volcan&magma.htm)

- It gets hotter, the deeper you go
- This is because the center of the earth is very hot - heat "leaks" out to the surface
- The geothermal gradient ~30°C/km

Rocks are mixtures

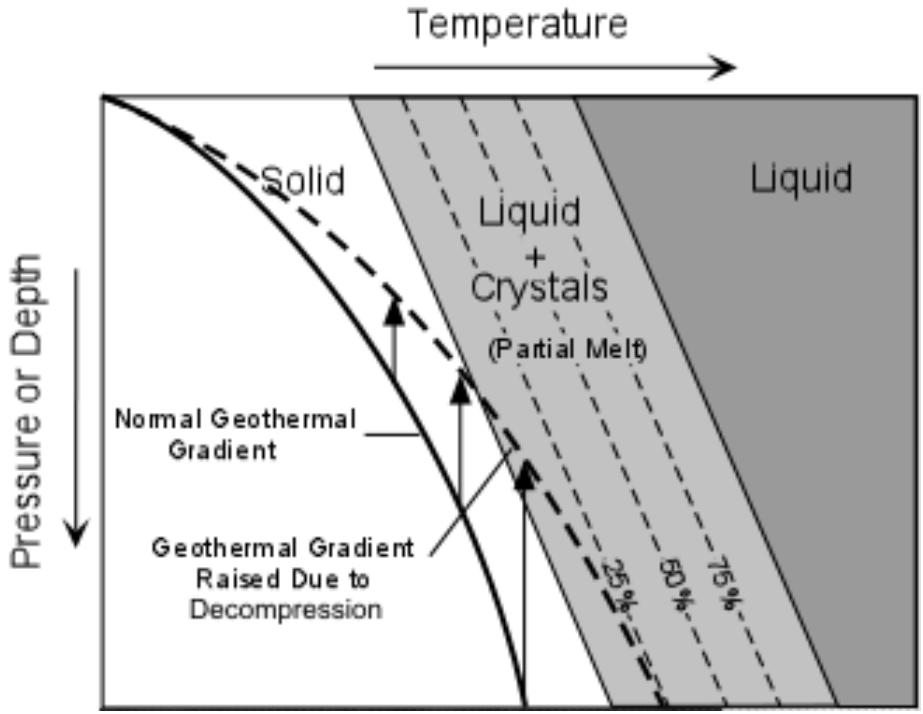
- Different minerals melt at different temperatures
  - Rock starts to melt at low temperature
  - Completely melted at high temperature
- However it still won't melt



(Nelson, http://www.tulane.edu/~sanelson/geol204/volcan&magma.htm)

How do we melt rock?

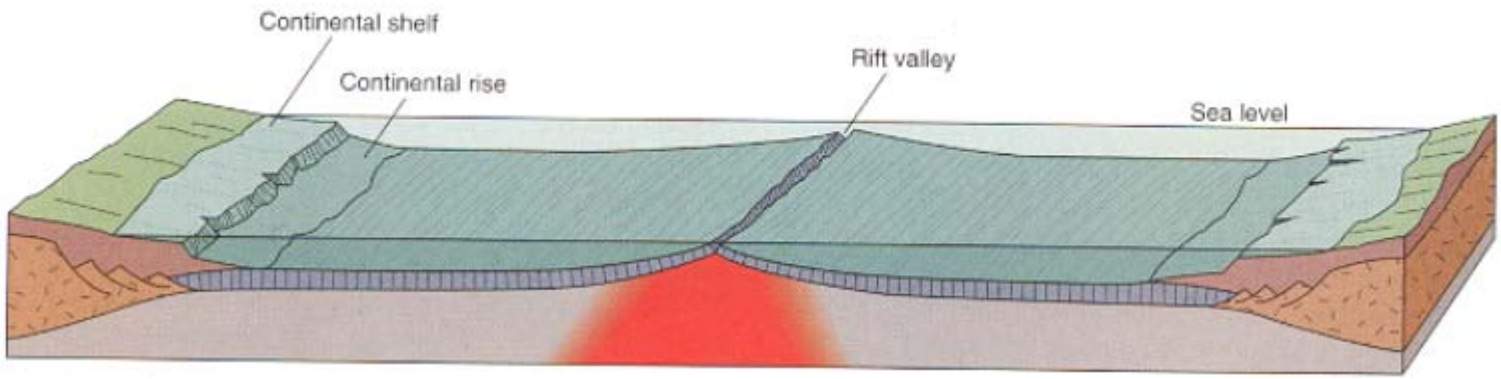
- Make the rock hotter
- Decrease the pressure
  - bring rock from deep in the earth to shallower level
- Is this possible?



(Nelson, http://www.tulane.edu/~sanelson/geol204/volcan&magma.htm)

Can we bring rock upward?

- Rift zones - warm rock rises up toward the surface of the earth



(Plummer et al., 2003)

Why?

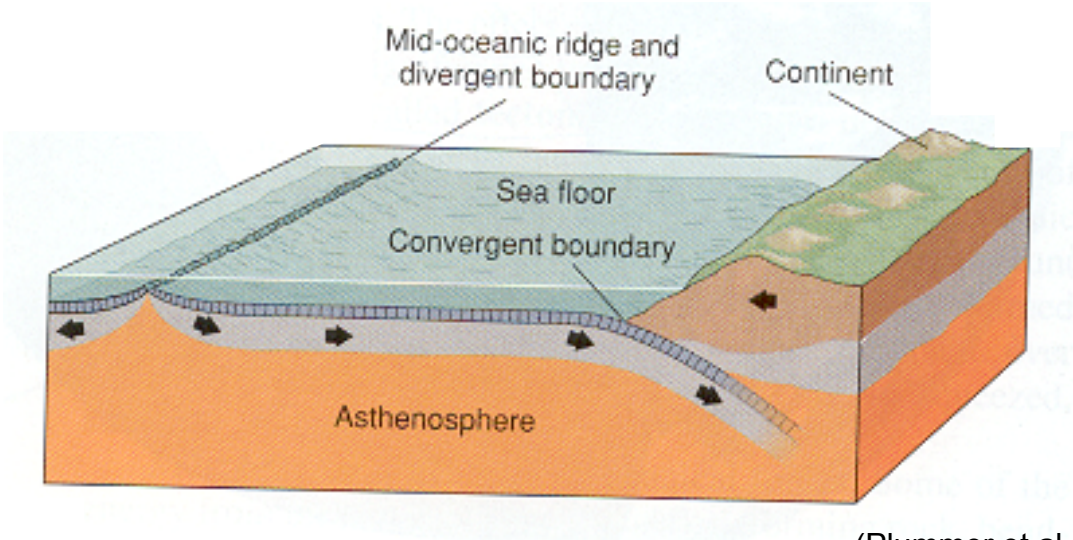
- Rock is warmer than surrounding due to heterogeneities in the earth's crust
  - possibly due to pockets of radioactivity
  - possibly due to magnetic forces
  - uncertain
- Warm rock is less dense than cold – will float
- As it rises the pressure decreases
  - temperature will decrease a little - it takes longer to cool than to rise
- Get a zone of melting – process called decompression melting

Rift zone volcanoes

http://www.mbari.org/volcanism/

http://www.uwo.ca/earth/outreach/volcano.pdf

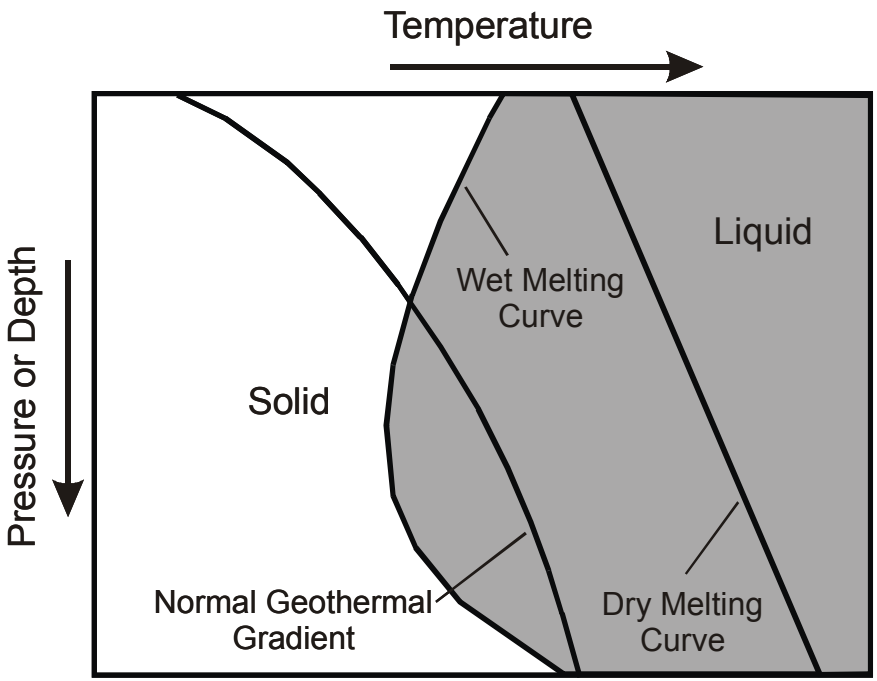
What about subduction zones?



(Plummer et al., 2003)

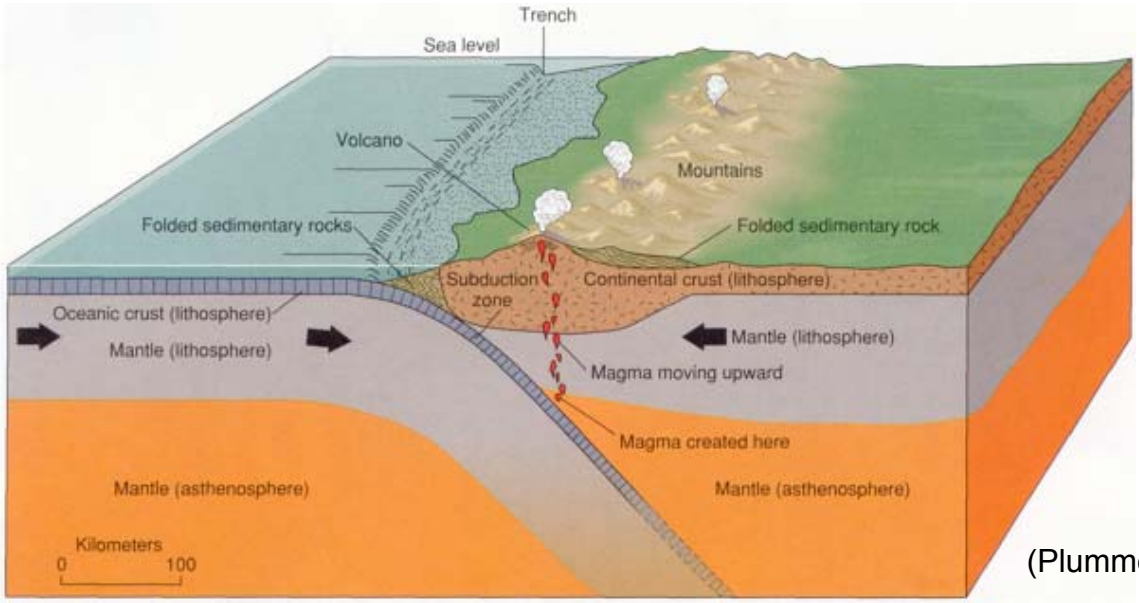
- Here rocks are going down
- How do we explain this?

Is there some other way?



- Melting line is “dry” rock
- What about “wet” rock?
- Water pushes atoms apart - easier to melt rock
- Curve for wet rock is different
- Can melt rock by adding water
- How do we add water?

How to add water



(Plummer et al., 2003)

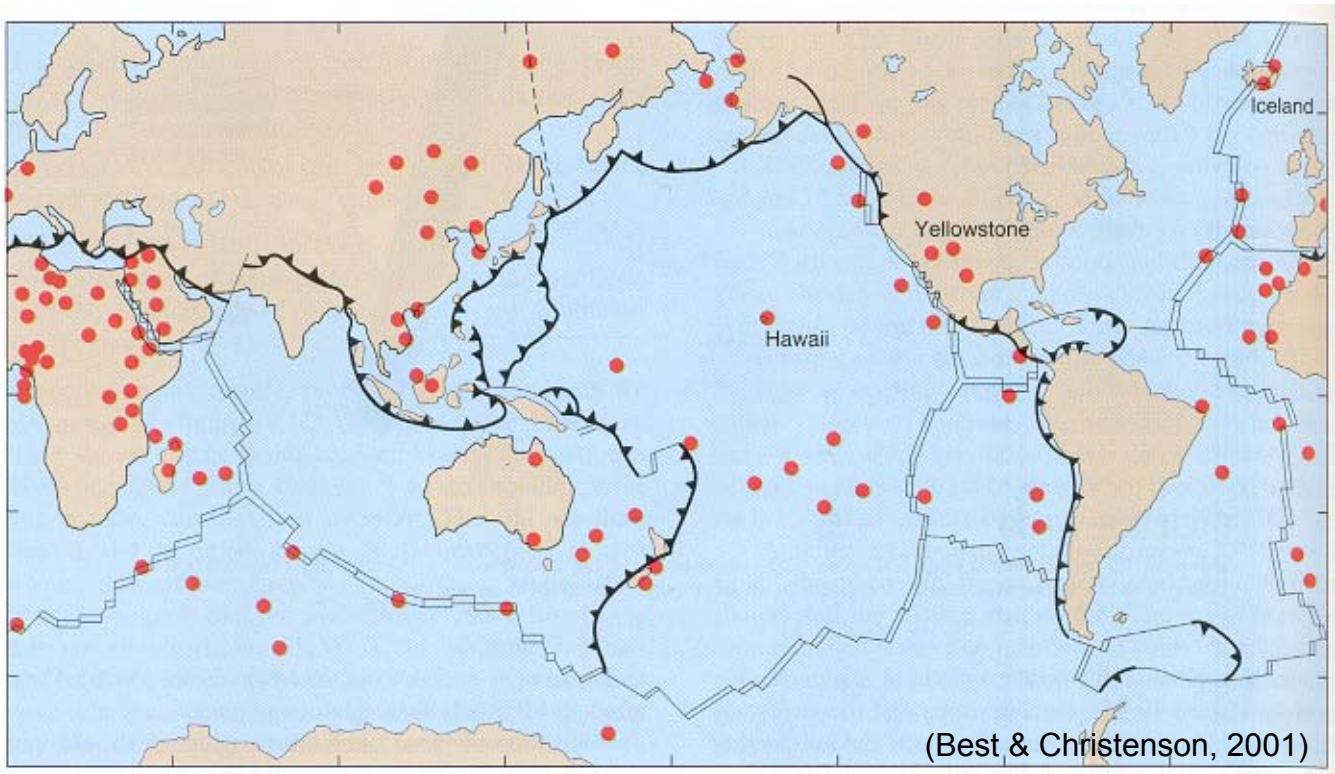
- Rock moves down in subduction zones
- Carries sea water
- At high pressure:
  - water is squeezed out
  - rises upward to hotter rocks
  - and causes melting

Subduction zone volcanoes

http://volcanoes.usgs.gov/Hazards/What/Landslides/RainierSlides.html

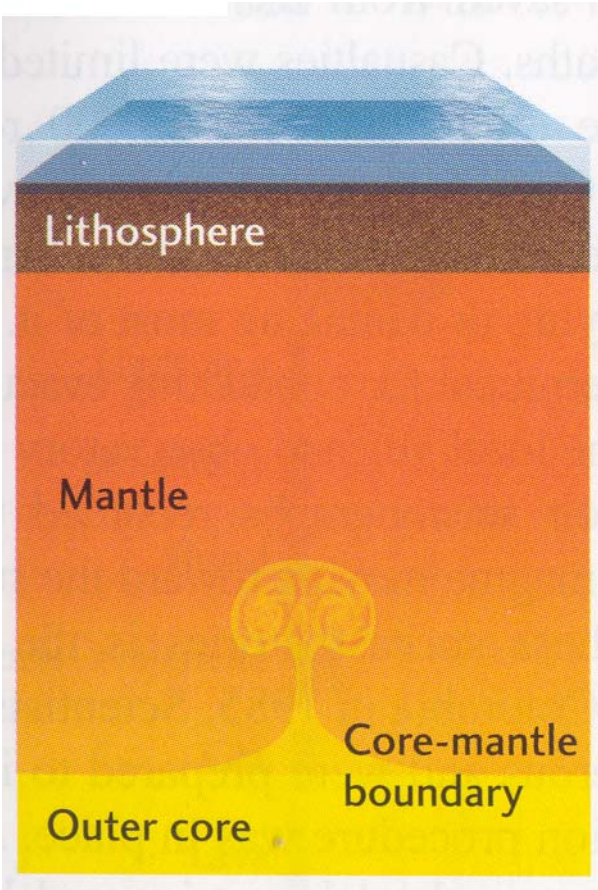
What about Hawaii?

- Not on a plate boundary



- This is a “hotspot” volcano

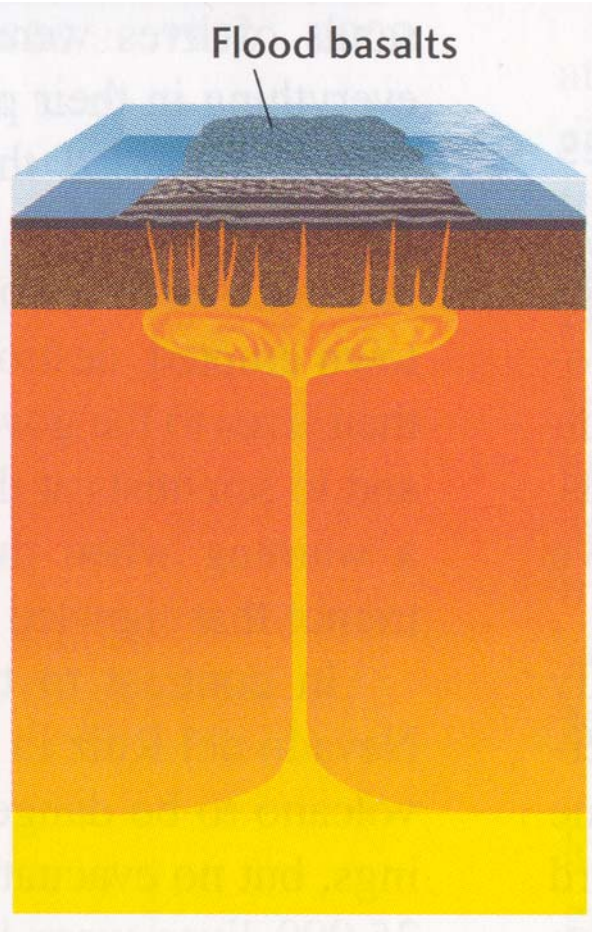
Hotspots



(Press et al., 2003)

- Starts near core-mantle boundary
- For some reason an area of rock heats up
- Warm rock rises like a plume toward surface - 2900 km above

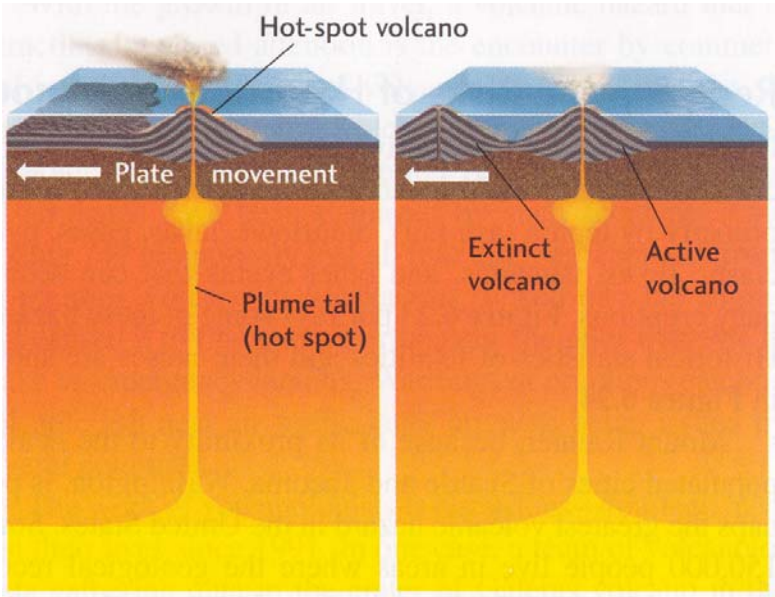
Hotspots



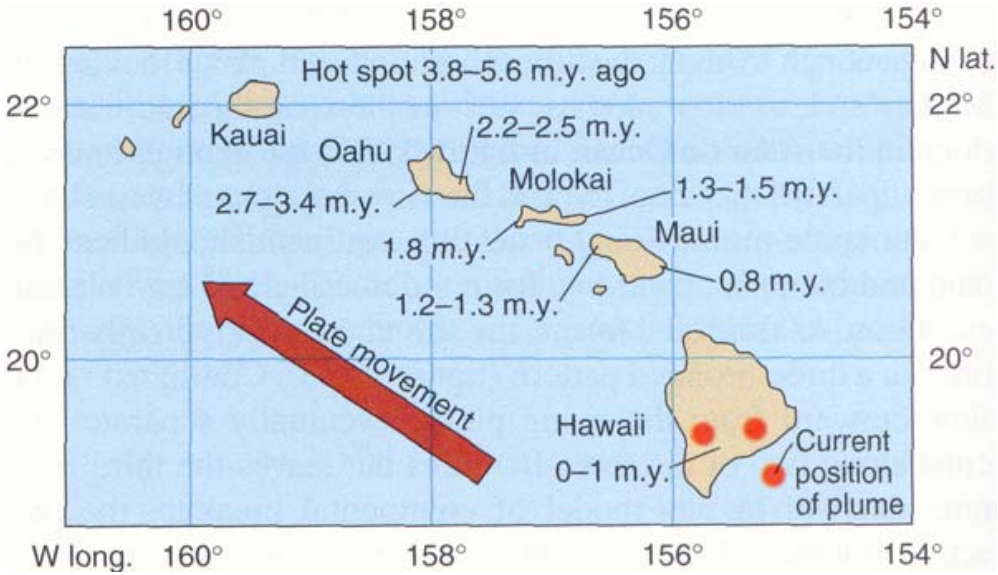
(Press et al., 2003)

- Near surface, large volume of rock melts
- Molten rock erupts onto surface
  - Covers huge area – like a “flood”
  - Major portion of Washington & Oregon covered by the "Columbia River basalts"
- Process continues for tens to hundreds of million years

Lines of volcanoes



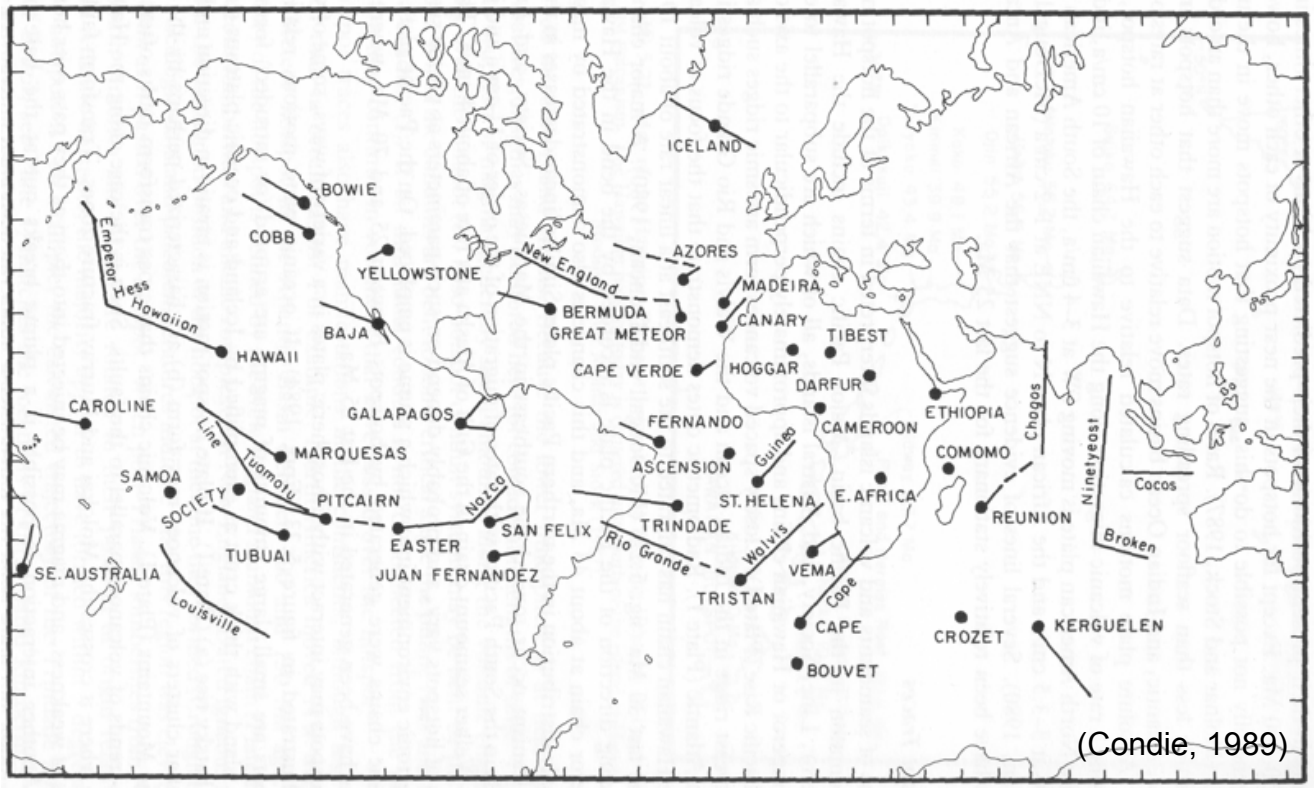
(Press et al., 2003)



(Plummer et al., 2003)

- Plume always rises in the same place
- Plate keeps moving
- Volcanoes form directly over the plume
- As they move away they stop erupting
- A new volcano forms over the plume

Hotspots found around the world



- Include the Galapagos & Yellowstone

Hot spot volcanoes

http://www.uwo.ca/earth/outreach/volcano.pdf

Tectonics & volcano type

- Volcanoes erupt:

  - explosively

  - and non-explosively

http://www.ngdc.noaa.gov/seg/fliers/se-0801.shtml

http://www.geo.aau.dk/palstrat/tom/santorini_homepage/volcanoes/etna0501_3.htm

Why do some explode and others don't?

- Let’s find out
- Pressure from expanding gas causes explosion

What kind of gas is in lava?

- Mostly water, some carbon dioxide & sulfur gases
- Where does it come from?
- The ocean in subduction zones!
- Ridges & hot spots are dry

http://www.uwo.ca/earth/outreach/volcano.pdf

It's more than just gas

- Lava viscosity (sticky vs. runny)
- Gas escapes from runny lava
  - just like gas out of soda
- Gas has harder time escaping from sticky lava

Viscosity

- Function of:
  - Composition
  - Temperature

- Cold lava & high-silica content both result in high viscosities
- Hot lava & low-silica content result in low viscosities

Viscosity & lava flows

- Runny lavas
  - Thin and long (several meters thick and 5-20 km long)

http://www.uwo.ca/earth/outreach/volcano.pdf

- Sticky lavas
  - Thick and short (hundred meters thick and 1-2 km long)

http://volcanoes.usgs.gov/Products/Pglossary/LavaDome.html

Different composition lavas?

- Mostly related to type of rock melted
- Melt rock with low-silica content – usually get low-silica magma
- Melt rock with high-silica content – usually get high-silica magma
- Mantle has low-silica content - produces low-silica melts
- Continental crust has high-silica content (granite, sandstone) - produces higher-silica melts

Rock compositions

Rock	Silica Content	Tectonic Environment
Basalt	Low – 45-55 SiO_2%	Ridges and hot spots
Andesite	Intermed. - 55-65 SiO_2%	Subduction zones, rare ridges & hot spots
Rhyolite	High – 65-75 SiO_2%	Subduction zones

Hot spots and ridges: dry melting of low-silica mantle

- Non-explosive eruptions of thin runny lava flows

http://hvo.wr.usgs.gov/kilauea/update/archive/2002/Nov/3-15.html

- Low angle "shield" volcanoes

http://www.uwo.ca/earth/outreach/volcano.pdf

Subduction zones: wet melting of low-silica mantle

- Weakly explosive eruptions
- Long thin lava flows

http://www.geo.mtu.edu/~boris/SECconephoto.html

http://www.ngdc.noaa.gov/seg/fliers/se-0801.shtml

Subduction zones: Wet melting of high-silica rock

- Explosive eruptions
- Short thick lava flows

http://volcanoes.usgs.gov/Hazards/Effects/SoufriereHills_PFeffects.html

http://volcanoes.usgs.gov/Hazards/What/PF/PFMSH.html

Where would you rather live?

http://volcanoes.usgs.gov/Products/Pglossary/effusive.html)

http://www.ngdc.noaa.gov/seg/fliers/se-0801.shtml