Plate dynamics

- Kinematics = description of motion (rigid rotation or deformation)
- Dynamics = forces (stresses) responsible for these motions
- Rheology = mechanical properties of Earth’s material, determine their response to stress

⇒ “dynamics = kinematics + rheology”
Heat and its transport in the Earth

- The fundamental energy source within the Earth is heat, primarily provided by radioactive decay (U, Th).

- **Radiation**
  - Evacuation of heat by electromagnetic radiation
  - Ex. Lava flow looses heat by radiating ⇒ red color
  - Inside the Earth: pressure prevents radiation

- **Conduction**
  - Propagation of vibrations (= heat) inside crystals without radiation and without displacement of matter
  - Conduction is more efficient in some materials than others ⇒ conductivity (silver=$418$ W.m$^{-1}$.K$^{-1}$, wood $0.1$ W.m$^{-1}$.K$^{-1}$, granite $27$ W.m$^{-1}$.K$^{-1}$)
  - More efficient than conduction (function of conductivity), but less than convection

- **Convection**: if conduction not sufficient to evacuate heat:
  - Temperature increases
  - Mechanical properties change
  - Motion of the material itself towards colder region
  - Transport of heat by motion of matter
Convection

- 2 plates separated by distance $\Delta L$, with constant temperature difference $\Delta T$
- Temperature increase at the bottom $\Rightarrow$ density decrease $\Rightarrow$ buoyancy force
- Consequence: upward motion, but resisted by viscous drag, proportional to upward velocity
- “Intensity” of convection depends on Rayleigh number = ratio of buoyancy forces to viscous resistance
- Large $Ra \Rightarrow$ faster convection $\Rightarrow$ more efficient heat dissipation
Mantle convection

• 2 models:
  – Layered model: strong convection in upper mantle is decoupled from slow convection in the more rigid lower mantle (⇒ little or no mixing of material between upper and lower mantle)
  – Whole-mantle model: single cycle of convection reaches from the core-mantle boundary to the base of the lithosphere.
  – Modern tomographic images argue for whole mantle convection

• In both cases:
  – Updrafts below spreading centers
  – Downdrafts along subduction zones
The forces acting on plates

- Acting on their bottom surface: relative motion between plate and convecting mantle, can be resistive (drag) or active
- Body forces (gravity):
  - Slab pull: negative buoyancy of subducting slabs, resisted by slab resistance force due to mantle viscosity
  - Ridge push (= intrusion of magma + potential energy gradient)
- Acting on their edges:
  - At transform boundaries: frictional resistance to plate motion
  - At subduction boundaries: frictional contact, can be pushing or pulling ("trench suction")
  - At collisional boundaries: frictional contact, collision resistance force
The forces acting on plates

- Plate velocity independent of their surface but decrease with increase of continental area ⇒ significant role of mantle drag?

- Plate velocity increases with length of subduction boundaries ⇒ slab pull force important?

- Africa and Antarctica plates: spreading boundaries only and low velocity ⇒ ridge push force minor?
The forces acting on plates

- Direct measurements of these forces impossible ⇒ indirect assessment through models
- Most recent results:
  - Strongest driving force = pull of subducting slabs
  - Transform resistance, mantle drag under oceans, ridge push = negligible
  - Mantle drag under continents = significant

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