Global Tectonics
G404
Lecture-2

Instructor
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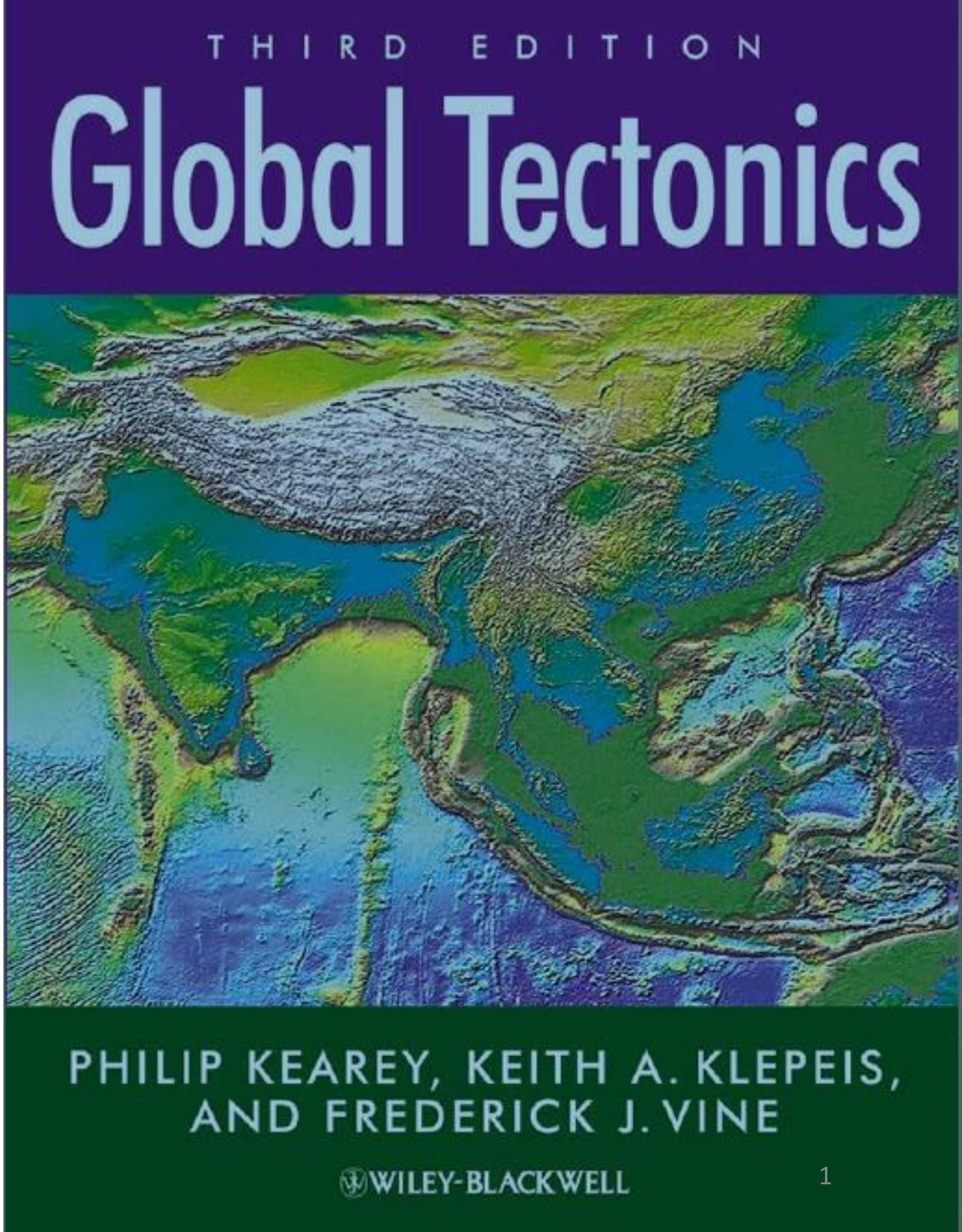


Chapter 2 – The Interior of the Earth (Detailed Summary)

2.1 Earthquake Seismology

Seismic Waves

- **Body Waves**:
  - **P-waves (Primary/Compressional)**:
    - Fastest (~6–8 km/s in crust, ~13 km/s in mantle).
    - Can travel through solids, liquids, and gases.
    - First to arrive at seismographs.
  - **S-waves (Secondary/Shear)**:
    - Slower (~3–5 km/s in crust, ~7 km/s in mantle).
    - Only travel through solids (absent in outer core, proving it's liquid).
- **Surface Waves**:
  - **Love waves**: Horizontally polarized, cause horizontal shaking.
  - **Rayleigh waves**: Elliptical ground motion, most destructive.

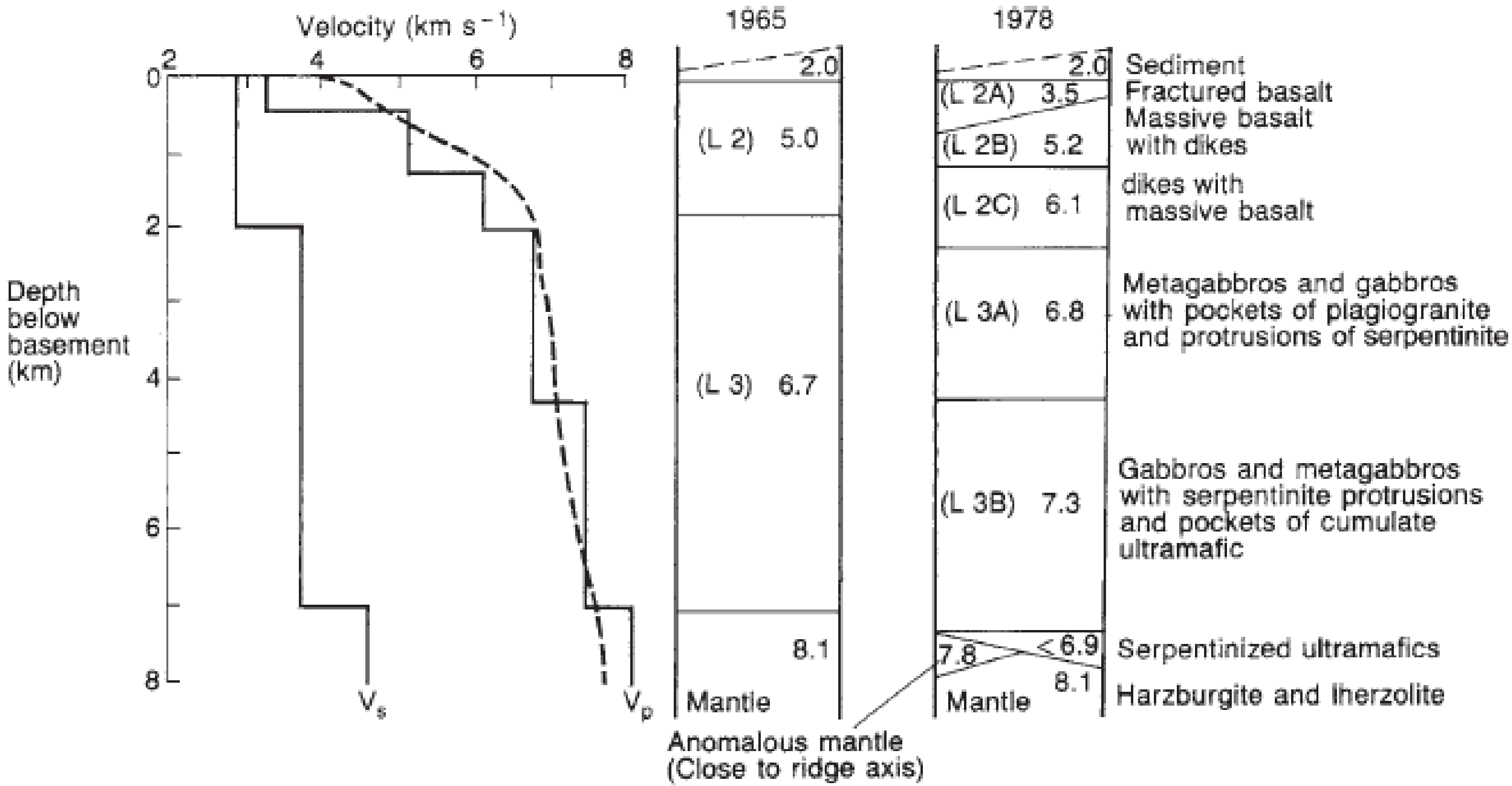
Earthquake Location & Focal Mechanisms

- **Epicenter vs. Hypocenter**:
  - *Hypocenter*: Actual rupture point underground.
  - *Epicenter*: Surface projection directly above the hypocenter.
- **Triangulation**: Uses P-S wave arrival time differences to locate earthquakes.
- **Focal Mechanism Solutions (Beachball Diagrams)**:
  - Used to determine fault type (normal, reverse, strike-slip).
  - **Ambiguity**: Cannot distinguish between the actual fault plane and the auxiliary plane.

Velocity Structure of the Earth

Crust

- **Continental Crust**:
  - Thickness: 20–80 km (thickest under mountains, thinnest under rifts).
  - Layers:
    - *Upper crust* (granodiorite, 5.6–6.3 km/s P-wave).
    - *Lower crust* (mafic, 6.8–7.7 km/s P-wave).
  - **Conrad Discontinuity**: Boundary between upper and lower crust (not always present).
- **Oceanic Crust**:
  - Thickness: ~7 km (uniform globally).
  - Layers:
    - **Layer 1**: Sediments (0–2 km).
    - **Layer 2**: Basalts & sheeted dikes (3.4–6.2 km/s).
    - **Layer 3**: Gabbro (6.4–7.0 km/s).



P and S wave velocity structure of the oceanic crust and its interpretation in terms of layered models proposed in 1965 and 1978. Numbers refer to velocities in km s 1. Dashed curve refers to gradational increase in velocity with depth deduced from more sophisticated inversion techniques (after Spudich & Orcutt, 1980 and Harrison & Bonatti, 1981).

Differences: Continental vs. Oceanic Crust

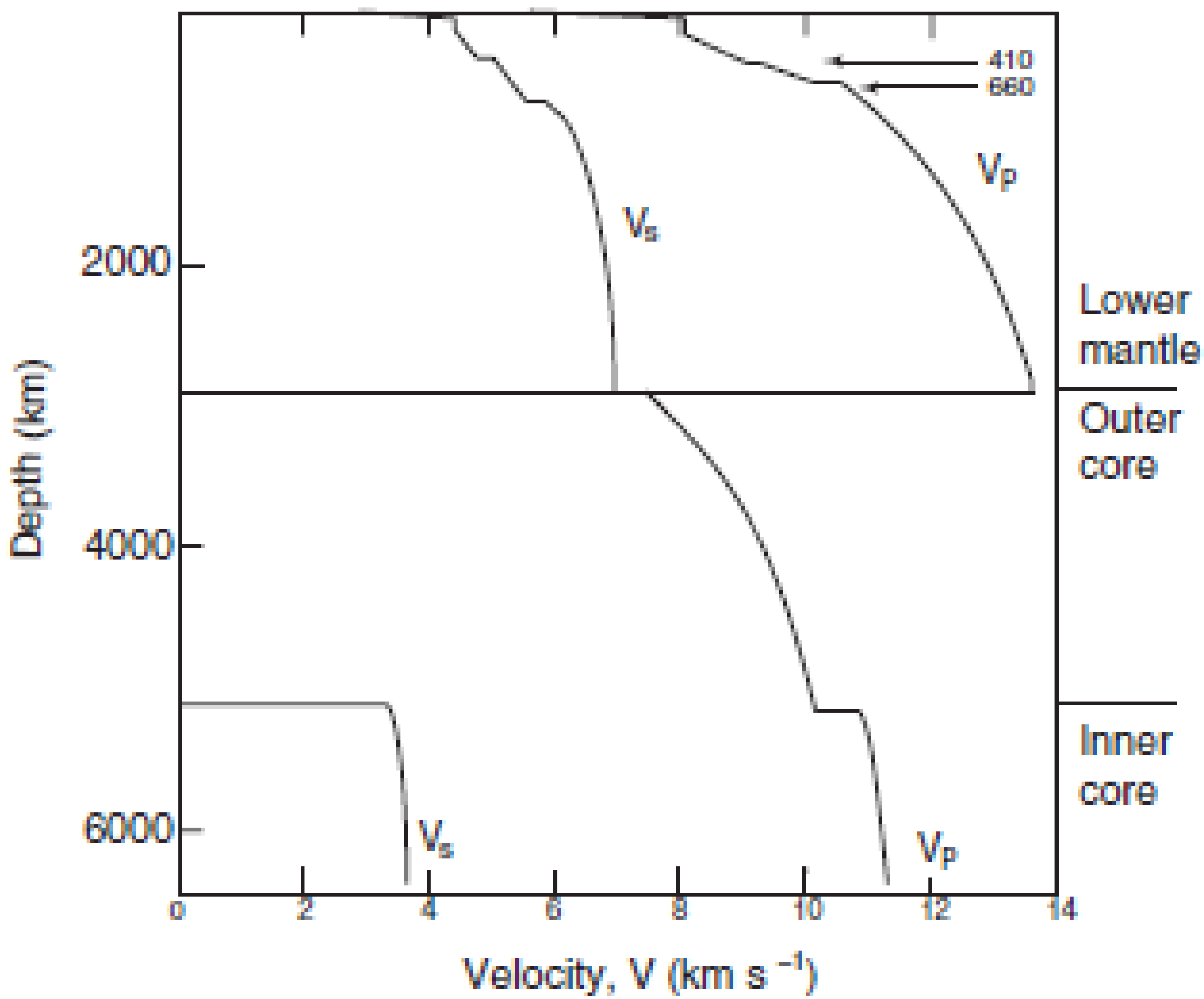
Feature	Continental Crust	Oceanic Crust
Thickness	20–80 km	~7 km
Age	Up to 4 Ga	<200 Ma
Composition	Felsic (granitic)	Mafic (basaltic)
Density	2.7 g/cm^3	3.0 g/cm^3

Mantle

- **Low Velocity Zone (LVZ, 100–300 km)**:
  - Weak, partially molten (1% melt), allows lithospheric plate movement.
- **Transition Zone (410–660 km)**:
  - Phase changes:
    - 410 km: Olivine → Wadsleyite (β-spinel).
    - 660 km: Ringwoodite → Perovskite + Magnesiowüstite.
- **Lower Mantle (660–2891 km)**:
  - Mostly perovskite ($MgSiO_3$).
  - **D″ Layer (base of mantle)**:
    - Ultra-low velocity zones (ULVZs), possible plume sources.

Core

- **Outer Core (2891–5150 km)**:
  - Liquid iron-nickel alloy (no S-waves).
  - Generates Earth’s magnetic field via geodynamo effect.
- **Inner Core (5150–6371 km)**:
  - Solid iron-nickel (high pressure).
  - Anisotropic (faster P-waves along rotation axis).



Seismic wave velocities as a function of depth in the Earth showing the major discontinuities. AK 135 Earth model specifi ed by Kennett et al., *1995 (after Helffrich & Wood, 2001, with permission from* Nature ***412****, 501–7. Copyright © 2001 Macmillan Publishers Ltd.).*

Composition of the Earth

- **Bulk Earth Composition**:
  - **Core**: Fe-Ni alloy (+ lighter elements: S, O, Si).
  - **Mantle**: Peridotite (olivine + pyroxene + garnet).
  - **Crust**:
    - *Continental*: Felsic (Si, Al-rich).
    - *Oceanic*: Mafic (Fe, Mg-rich).
- **Meteorite Analogs**:
  - Chondrites (primitive mantle).

Iron meteorites (core analog).

Crust & Mantle Details

Ophiolites: Ancient Oceanic Crust

- **Sequence**: Sediments → Pillow lavas → Sheeted dikes → Gabbro → Peridotite.
- **Obduction**: Emplacement onto continents during collisions (e.g., Oman ophiolite).

Metamorphism of Oceanic Crust

- Hydrothermal alteration at mid-ocean ridges:
  - **Greenschist facies** (low-T alteration of basalt).
  - **Serpentinization** (hydration of peridotite).

Rheology of the Earth

Rheology is the study of how materials **deform and flow** under applied forces (stresses). It combines principles of **solid mechanics** (how solids bend or break) and **fluid dynamics** (how liquids/gases flow).

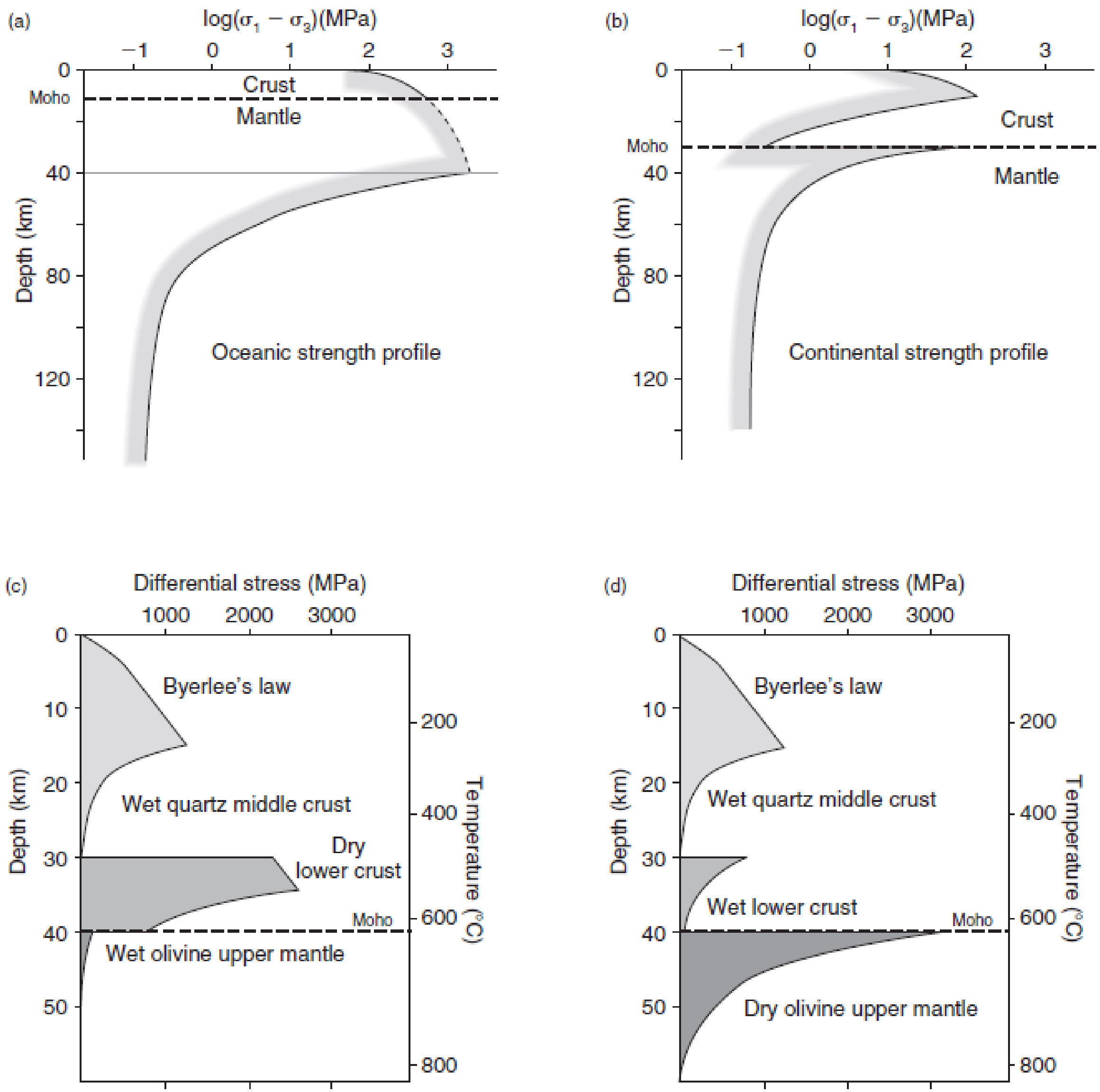
Brittle vs. Ductile Deformation

- **Brittle (Shallow Crust)**:
  - Faulting (Mohr-Coulomb criterion: $\tau = c + \mu\sigma_n$).
  - Earthquakes occur here (seismogenic zone: <25 km depth).
- **Ductile (Deep Crust/Mantle)**:
  - **Dislocation creep** (power-law, dominant in upper mantle).
  - **Diffusion creep** (lower mantle, grain-boundary sliding).

Lithospheric Strength Profiles

- **Oceanic Lithosphere**:
  - Strong upper mantle (olivine-dominated).
  - Thin crust (~7 km).
- **Continental Lithosphere**:
  - Weak lower crust (quartz-rich, ductile).
  - "Jelly sandwich" model:

Strong upper crust → Weak lower crust → Strong uppermost mantle.



Schematic strength profiles through (a) oceanic and (b) continental lithosphere (after Ranalli, 1995, fi g. 12.2. Copyright © 1995, with kind permission of Springer Science and Business Media). Profile in (a) shows a 10-km-thick mafi c crust and a 75-km-thick lithosphere. Profi le in (b) shows a 30-km-thick unlayered crust and a thin, 50-km-thick lithosphere. Profi les in (c) and (d) incorporate a wet middle crust and show a dry lower crust and a wet upper mantle, and a wet lower crust and dry upper mantle, respectively (modifi ed from Mackwell et al., 1998, by permission of the American Geophysical Union. Copyright © 1998 American Geophysical Union) See text for explanation.

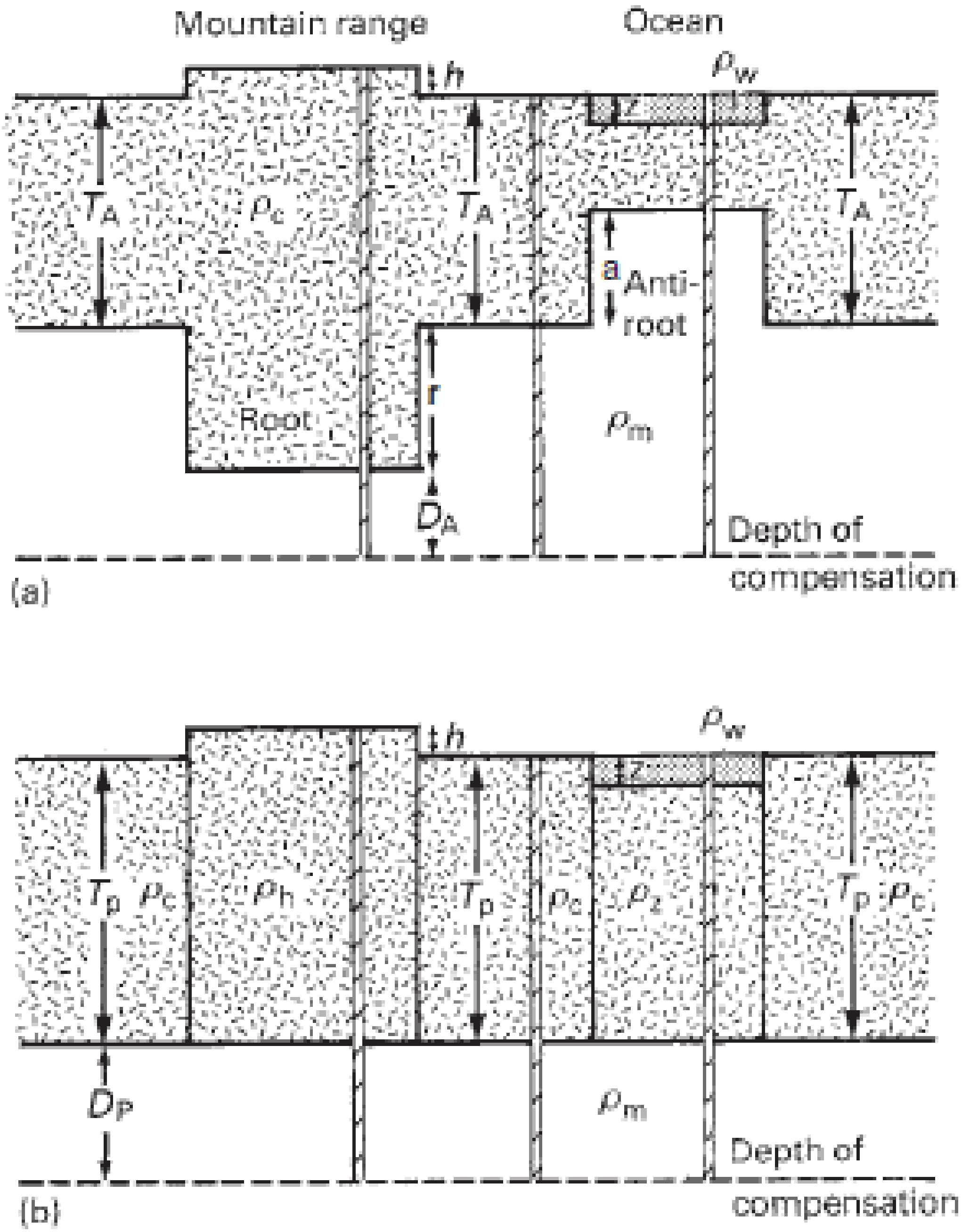
Isostasy

Compensation Mechanisms

1. **Airy Isostasy**:
   - Mountains have deep roots (like icebergs).
   - *Example*: Himalayas (70 km crustal root).
2. **Pratt Isostasy**:
   - Density variations support topography.
   - *Example*: Ocean ridges (low-density mantle beneath).
3. **Flexural Isostasy**:
   - Lithosphere bends under loads (e.g., seamounts, ice sheets).
   - *Example*: Hawaiian Islands (~100 km flexural bulge).

Post-Glacial Rebound

- **Fennoscandia & Canada**:
  - Uplift rates ~10 mm/yr after ice sheet melting (~20,000 years ago).
  - Reveals mantle viscosity (~10^{21} Pa s).



(a) Airy mechanism of isostatic compensation. h, height of mountain above sea level; z,depth of water of density r*w ; TA , normal thickness of crust of density* r*c ; r, thickness of root; a, thickness of antiroot; DA , depth of compensation below root;* r*m , density of mantle. (b) The Pratt mechanism of isostatic compensation. Legend as for (a) except Tp , normal thickness of crust;* r*h , density of crust beneath mountain;* rz *, density of crust beneath ocean; Dp , depth of compensation below Tp .*

Lithosphere & Asthenosphere

- **Lithosphere**:
  - Rigid outer shell (crust + uppermost mantle).
  - Thickness:
    - Oceanic: 60–100 km (thickens with age).
    - Continental: 100–250 km (thickest under cratons).
- **Asthenosphere**:
  - Weak, ductile (LVZ, 100–300 km depth).
  - Facilitates plate motion via convection.

Heat Flow

- **Sources**:
  - Radioactive decay (K, U, Th in crust).
  - Primordial heat (leftover from Earth's formation).
- **Global Patterns**:
  - **High heat flow**: Mid-ocean ridges, rifts.
  - **Low heat flow**: Old cratons, deep ocean basins.