Mantle downwelling and subduction zones

Reading:
Fowler p 320-335

Modes of mantle convection

**Ridges ⇐⇒ Upwelling**
- No, ridges are passive near-surface (upper 200 km) features

**Plumes ⇐⇒ Upwelling**
- Evidence that the Pacific and African super plumes extend to the CMB
- Little evidence for other plumes – the jury is still out

**Subduction ⇐⇒ Downwelling**

One layer or two? more today…
Subduction zones

**Tectonic features**
- Oceanic trench: typically 8 km deep
- Volcanoes 200-400 km behind trench
- Accretionary wedge

**Ocean-ocean:**
- Island arcs: Aleutians, Caribbean
- Back-arc basins: extension: West Philippine Basin, South Fiji Basin

**Ocean-continent:**
- Volcanoes produce mountains: Andes
- Shallower trenched due to high sedimentation

**Continental-continent:**
- Cannot subduct continent: collisional mountains: Himalaya
**Slab dip and trench curvature**

Radius of the indented circle

\[ r = \theta R \]

where \( R \) = radius of the Earth

Dip of the slab = \( 2\theta \)

\[ = \frac{2r}{R} \]

If \( r \approx 2500 \text{ km} \), \( R = 6371 \text{ km} \)

Then \( \theta \approx 45 \text{ deg} \)

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**Earthquakes and subduction**

80% of earthquake energy released around the ring of fire

15% across Alps, Turkey, Iran and Himalaya
Slab delineation using earthquake foci

Slab dip observations

- Slabs typically dip at 45 deg though there is variation
- The distance of the ocean islands behind the trench is related to the dip

Figure 8.36: Shallow geometry of subduction zones as defined by earthquake foci. Abbreviation of subduction zone names: NH, New Hebrides; CA, Central America; ALT, Aleutian; ALK, Alaska; M, Mariana; JB, Izu-Bonin; KER, Kermadec; NZ, New Zealand; T, Tonga; KK, Kamchatka; NC, North Chilie; CC, Central Chilie; SC, South Chilie; P, Peru. Solid triangle marks the volcanic line; vertical or horizontal lines mark the location or extent of the oceanic trench. Some sections have, for clarity, been offset from the others. (After Nakano and Kanamori 1977)
Stress orientations

Slab stresses

Down dip extension:
- At shallow depth the plate is being pulled down

Down dip compression:
- At depth the plate begins to compress
- Implication: the phase transition from olivine to spinel to postspinel provide a resistance to downward motion

[Isacks and Molnar, 1971]
Heat flow observations
Vancouver Island subduction zone

High heat flow over the volcanic arc due to near surface magma bodies.

Low heat flow over trench.

Temperature distribution in the slab

Cool lithosphere thrust into the mantle.

Distorted phase boundaries.

Clapeyron slope:
- 410 km
- 660 km

Water drives melting: convection of heat (not modeled).

Heating:
- Conduction
- Frictional

Increased slab density.

Downward pull:
- Plate contraction
- 410 phase change
- 660 phase change
Subduction profiles
Across the Chile Trench

Classic low-high pair
- Low over trench
- High on ocean-ward side of the volcanic arc

Density structure – how?

60km thick Andean crust
- Believed to have been thickened from below by intrusive volcanism from slab

Subduction profiles
Across the Japan Trench

Sea of Japan: back arc basin: thin crust

Mantle wedge:
- Low velocity
- High attenuation (low Q)

Japan: island arc

Low-high gravity anomaly

Lau Basin

Down dip extension
Subduction and mantle convection

Farallon slab
- Originates from a time when there was subduction all along the western US.
- We find evidence of this slab extending all the way to the core-mantle boundary.

Some evidence for slab penetration into the lower mantle.
Observations:
- High velocity slab, low velocity wedge
- Earthquakes in slab and rift
- Large number of compressional earthquakes above 660 km

Lower mantle subduction

Two slabs do extend into the lower mantle
- Farallon and Tethys
Modes of mantle convection

Subduction ↔ Downwelling → ...Yes

- Slabs clearly represent the downwelling mode in the upper mantle
- Some slabs pass through the transition zone into the lower mantle

One layer or two?
What is the evidence?

The “hybrid” model
1. Neither the 410 or 660 discontinuity seem to act as a barrier to flow
2. Still need a chemically distinct source
3. New boundary: around 1600 km depth with small density contrast
   Kellogg 1999

One layer or two?

One layer: the transition zone phase transitions do not prevent mass flux across the 410/660 discontinuity

Two layers: There still needs to be chemically distinct regions