The physical structure of
Oceanic lithosphere

Reading: Fowler p278 – 308

The ocean basins
Physics and chemistry of the Earth's interior – Oceanic lithosphere

**Depth distribution**

**Mid-ocean ridges**

The longest, highest mountain chain on Earth

- 60,000 km in length
- Typically rise 3 km above ocean basin floor
- 100’s km across
- Slope related to spreading rate
  - Atlantic: slow spreading (~2 cm/yr), narrow ridge
  - East Pacific Rise: fastest at ~10 cm/yr, broad ridge

**Depth distribution**

**The ocean basins**

Depth distribution is related to age
  - Age squares: North Atlantic
  - Circles: North Pacific

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Plate model:

There is a limit to the lithospheric thickness available for cooling

squares: North Atlantic
circles: North Pacific
Depth distribution

Passive continental margins

**Continental shelf:** Broad shallow waters immediately offshore, continental crust

**Continental slope:** Rapid increase in water depth, continental-oceanic crustal transition

**Continental rise:** Thicker sediments deposited from the shelf edge

**Ocean basin:** Deepest waters above oldest oceanic lithosphere

Ocean basins

Sediment thickness

**Thickest** sediments found at the base of the continental slope – landslides

**Thinnest** at the ridge – no time for deposition
Oceanic crust

Velocity structure

Many refraction studies in the ocean basins revealed a remarkably uniform velocity structure.

Layer 1 Sediments. $V_p$ 1.5 to 2 km/s
Layer 2 Oceanic basement, rapid increase in velocity with depth. $V_p$ 4 to 6 km/s
Layer 3 The "Oceanic layer" is thicker with a small velocity gradient. $V_p$ 6.5 to 7 km/s
Layer 4 Mantle. Average $V_p$ 8.1 km/s

Oceanic crust

Velocity structure - interpretation

Based on additional observations of the petrology:
- Samples collected from the ocean floor
- Ocean drilling project

Extrusive to intrusive transition is the cause of the rapid velocity increase.
Oceanic crust

Refraction data

North Atlantic

Refractions: $P_3$, $S_3$, $P_n$, $S_n$
Reflections: $P_mP$, $S_mS$

Oceanic lithosphere

The Moho

The crust-mantle boundary

Defined seismically: the step in velocity from ~7.5 to 8.1 km/s and believed to be the transition downward into ultramafic rock

...the seismic Moho

The petrological Moho: the divide between residual mantle ultramafics and material derived from melt (including cumulate ultramafics like dunite)

Velocities, density and porosity from laboratory experiments on Ophiolites
Mid-ocean ridges

Gravity

Variations in the Earth’s gravitational field across mid-ocean ridges can be used to constrain density structure.

Ambiguity in gravity models:

Gravity data can be interpreted as deep structure with small density anomaly.

Or, shallow structure with large density anomaly.

Mid-ocean ridges

Global tomography

Low velocities in upper ~150 km

(Fowler says 250 km – from early models)

What do low velocities mean?

• High temperatures
• Partial melt
• Compositional variations
**Mid-ocean ridges**

**East Pacific Rise**

**Large (mantle) scale structure**

- Mantle temperature means that passive upwelling as the plates separate will cause mantle material to melt.
- Region of partial melt: 100's km across and ~150 km depth though most melting occurs in the spinel stability field i.e. <60km.
- Melt is then focused into a region a few km across where the new crust is formed.

From the MELT experiment:
Forsyth et al, Science 280 1215 1998

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**Mid-ocean ridges**

**Topography**

At some spreading ridges a **median valley** runs along the axis. Normal-faulted block sit to either side of the ridge.

**Fast spreading**
- No median valley, axial high
- Topography controlled by melt buoyancy

**Slow spreading**
- Median valley forms, axial low
- Valley depth controlled by strength of lithosphere
- Cycle of crustal formation (10-50 Ka), topography determined by how recently magma was emplaced.
**Mid-ocean ridges**

**Magma chamber models**

**The infinite onion**

- Developed based on ophiolite observations
- Magma chamber extends through entire crust generating basaltic melt for eruption (layer 2) and mafic cumulates (layer 3)

This large magma chamber would be easily detectable with geophysical methods.

Not seen, so East Pacific Rise model

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**Mid-ocean ridges**

**Axial velocity models**

**Normal uppermost mantle velocity: 8.1 km/s**

Beneath the ridge axis, the uppermost mantle velocity is reduced: 7.1-7.6 km/s

Normal uppermost mantle velocity are found 10s of km away from the ridge axis

Does this imply melt? For this we need to compare P- and S-velocities

Evidence for a magma chamber?

Slow-spreading: no large continuous magma chamber observed
Fast-spreading: evidence for magma chambers, ~10 km wide and thin
Axial magma chambers

East Pacific Rise: fast-spreading ridges

Comparison of P- and S-waves traveling along and adjacent (10 km offset) to the ridge axis show significant shear attenuation along ridge.

→ Suggest melt along ridge axis

- Narrow zone of magmatic activity (< 10 km) at surface and within crust
- Vertical extent of magma chamber ~1 km thick

Reflections from axial magma chamber (AMC)

- AMC continuous beneath ridge for 10s km
- Negative polarity: significant low velocity anomaly
- 3 km wide
- Depth 1.2-2.4 km below sea bed
- Gap in Moho beneath magma chamber
Mid-ocean ridges

Wide angle data

East Pacific Rise: fast-spreading ridges

**Summary of crustal structure**

East Pacific Rise: fast-spreading ridges

**Crust**
- Thin, narrow magma chamber in the upper crust
- Melt forms extrusive layer 2, cumulates form layer 3
- Magma piped from mantle through narrow vertical conduits

**Mantle**
- Broad region (100s km) of low velocities due to partial melting
- Passive upwelling in the upper few 100 km as lithosphere is pulled apart

**Supports reflection data conclusions**
- Along ridge: shadow zone for arrivals beyond 11 km suggest crustal low velocity zone
- 3.6 km from ridge: no evidence for low velocity zone, normal oceanic velocity structure
- Total width of magma chamber ~5 km
Mid-ocean ridges
Tomography
East Pacific Rise: fast-spreading ridges

Magda 2000, EPSL