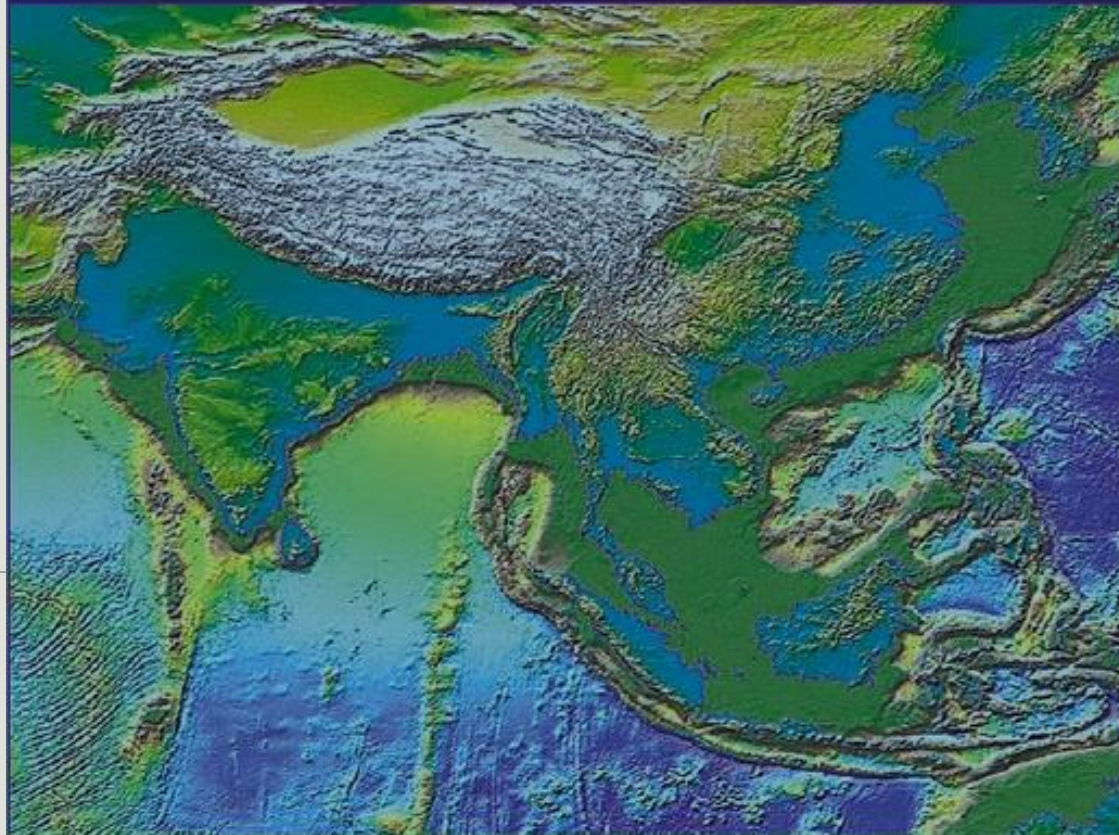


THIRD EDITION

Global Tectonics



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 WILEY-BLACKWELL

Global Tectonics G404 Lecture-6

Instructor
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Chapter 6 – Ocean Ridges

Ocean ridges are the longest mountain ranges on Earth, stretching over 55,000 km across the ocean floor. These ridges mark divergent plate boundaries where new oceanic lithosphere is created through seafloor spreading. We will examine their topography, structure, petrology, and the dynamic processes that shape them.

Ocean ridges are dynamic systems where new lithosphere forms, controlled by spreading rate, magma supply, and tectonic processes. Their study reveals Earth's thermal evolution and the interplay between melting, faulting, and hydrothermal activity.

Ocean Ridge Topography

Ocean ridges are linear, uplifted features with shallow-focus earthquakes along their crests and transform faults. Width: 1000–4000 km, with crests 2–3 km higher than surrounding ocean basins.

•Spreading Rate Controls Morphology:

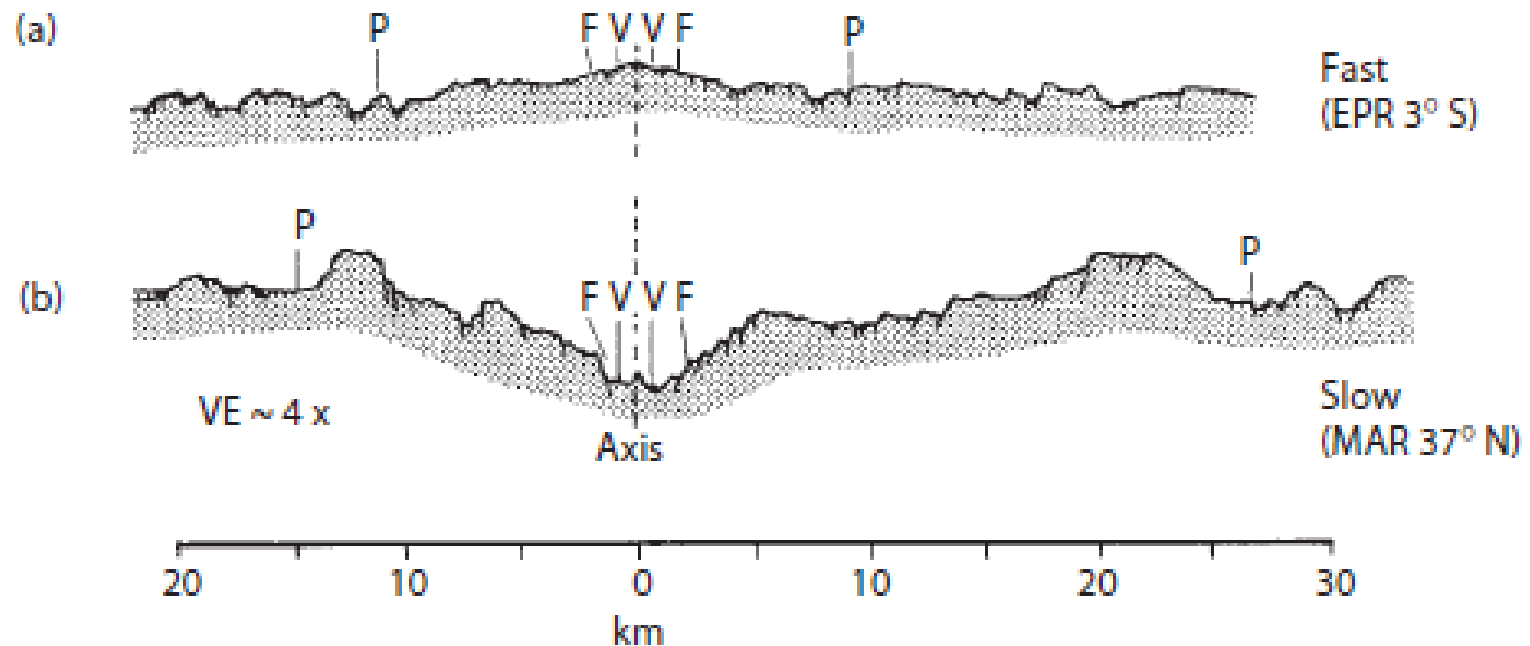
- **Fast-spreading ridges** (e.g., East Pacific Rise, ~150 mm/yr): Smooth topography, axial high.
- **Slow-spreading ridges** (e.g., Mid-Atlantic Ridge, ~20 mm/yr): Rugged, with a median rift valley.
- **Ultraslow-spreading ridges** (e.g., Gakkel Ridge, <20 mm/yr): Thin crust, exposed mantle peridotite.

Axial Structures:

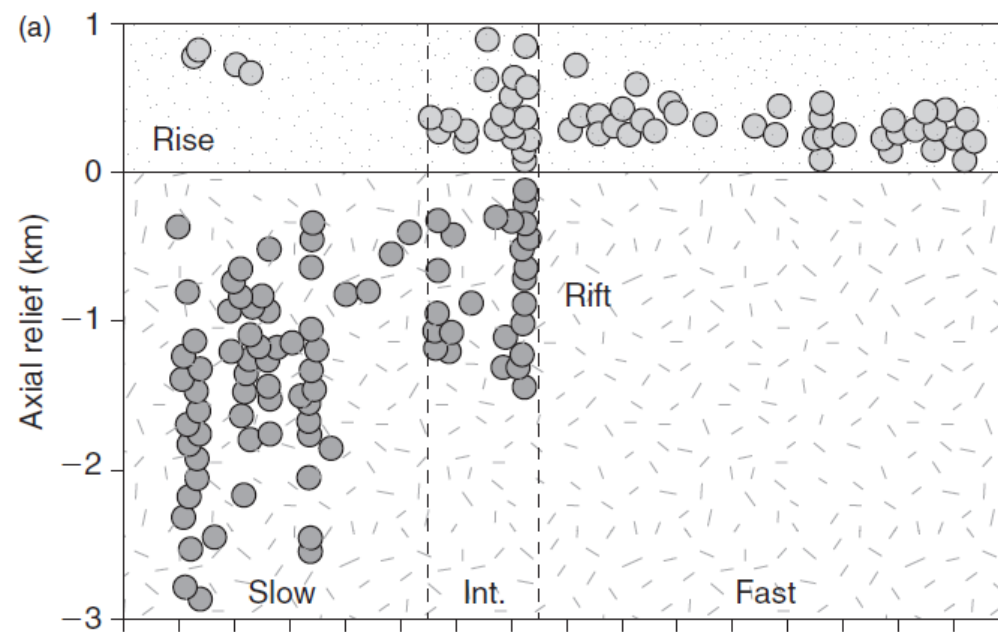
Fast-spreading ridges: Narrow volcanic zone (~1–2 km wide) with small grabens.

Slow-spreading ridges: Wider rift valleys (30–50 km) with fault scarps (~100 m high).

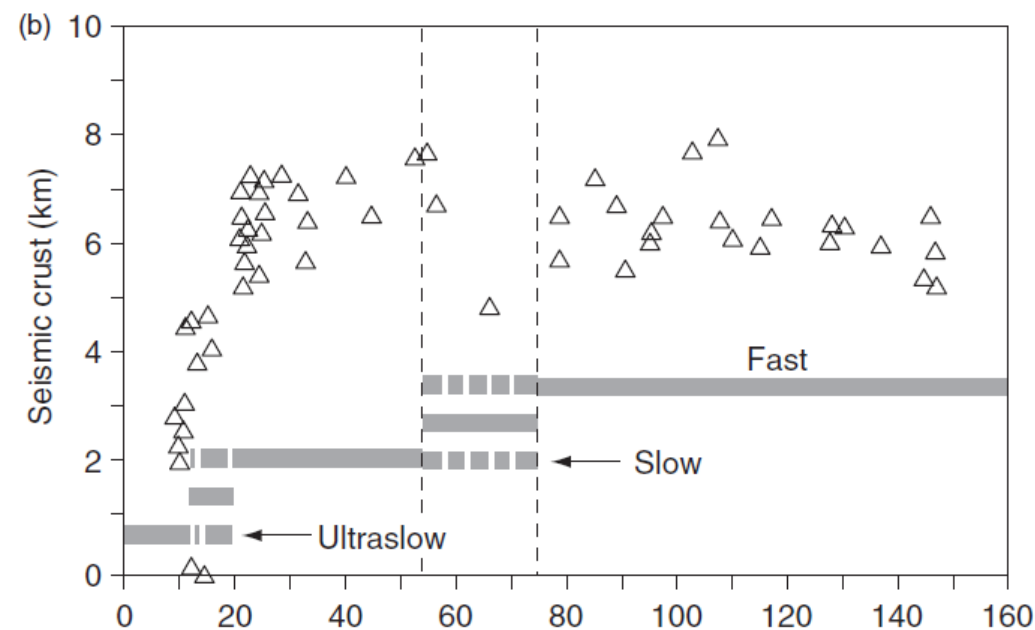
Axial volcanic ridges (AVRs): Formed by coalescing small volcanoes on slow-spreading ridges



Bathymetric profiles of ocean ridges at fast and slow spreading rates. East Pacific Rise (EPR); Mid-Atlantic Ridge (MAR). Neo-volcanic zone bracketed by Volcanic structures (Vs), zone of fissuring (Fs) by, extent of active faulting



(a) Axial relief and (b) seismic crustal thickness as a function of full spreading rate at mid-ocean ridge crests. A ridge classification scheme is shown by the heavy black straight lines which indicate the spreading rate ranges for ultraslow, slow, fast and two intermediate classes



Structure of the Upper Mantle Beneath Ridges

Isostatic Compensation:

Ridges are in isostatic equilibrium (free-air gravity anomalies ≈ 0). Compensation occurs via low-density mantle beneath ridges (Pratt mechanism).

Seismic and Gravity Evidence:

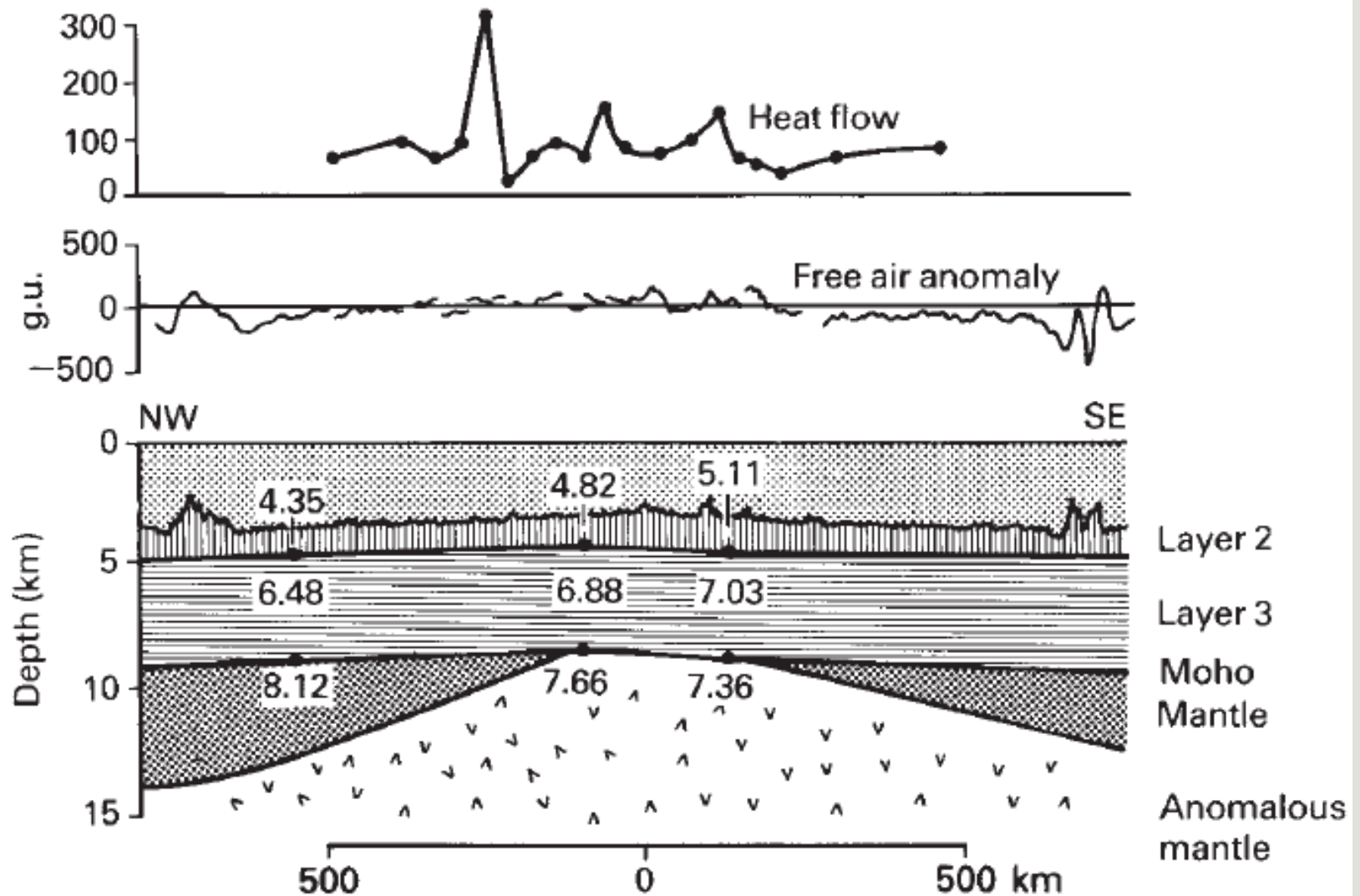
Low seismic velocities in the upper mantle indicate partial melting and thermal expansion. Two competing models:

- ❖ **Talwani et al. (1965):** Small, high-density contrast body (~ 30 km deep).
 - ❖ **Keen and Tramontini (1970):** Larger, low-density contrast body (~ 200 km deep).
-

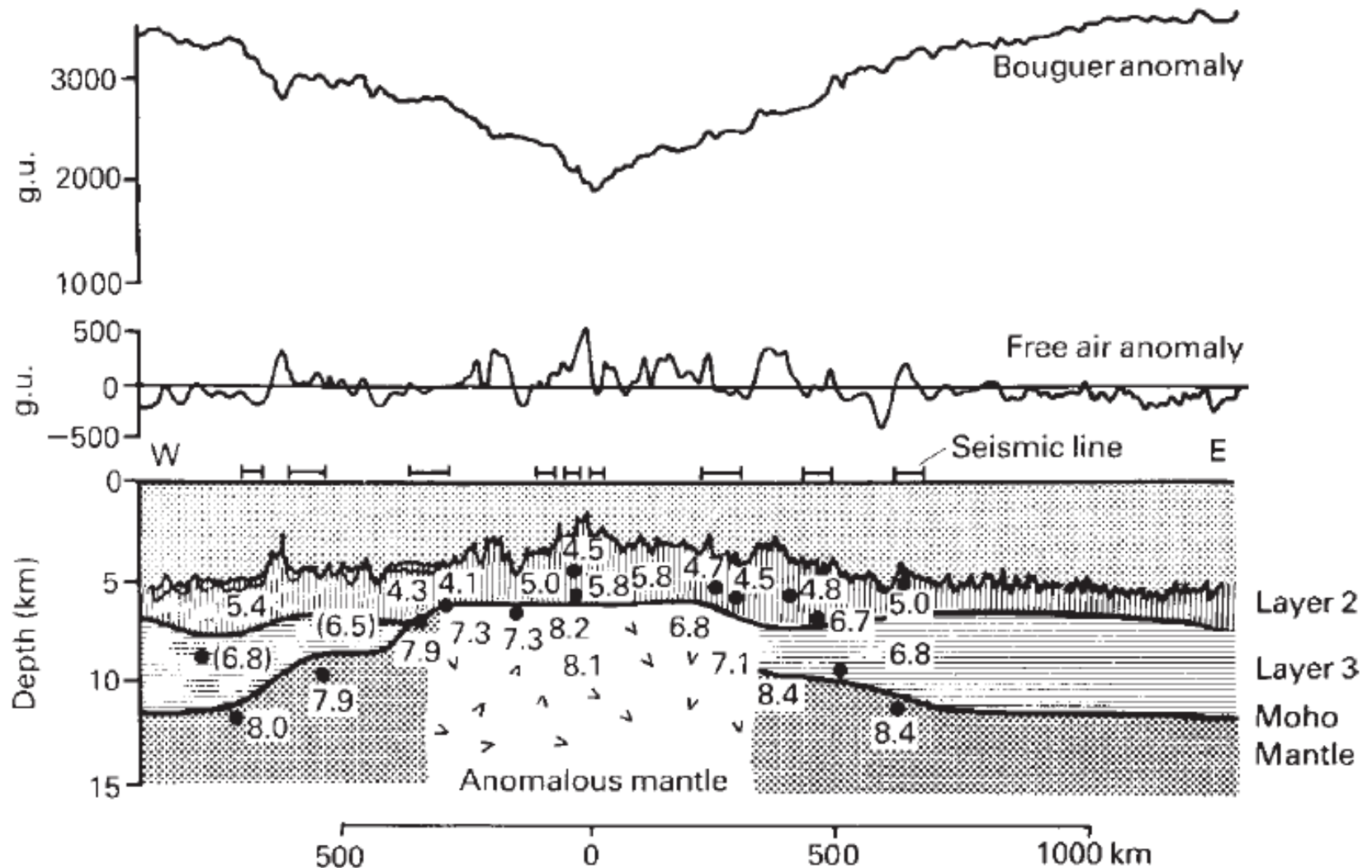
MELT Experiment (East Pacific Rise):

Revealed asymmetric partial melting (1–2% melt) extending to 100 km depth.

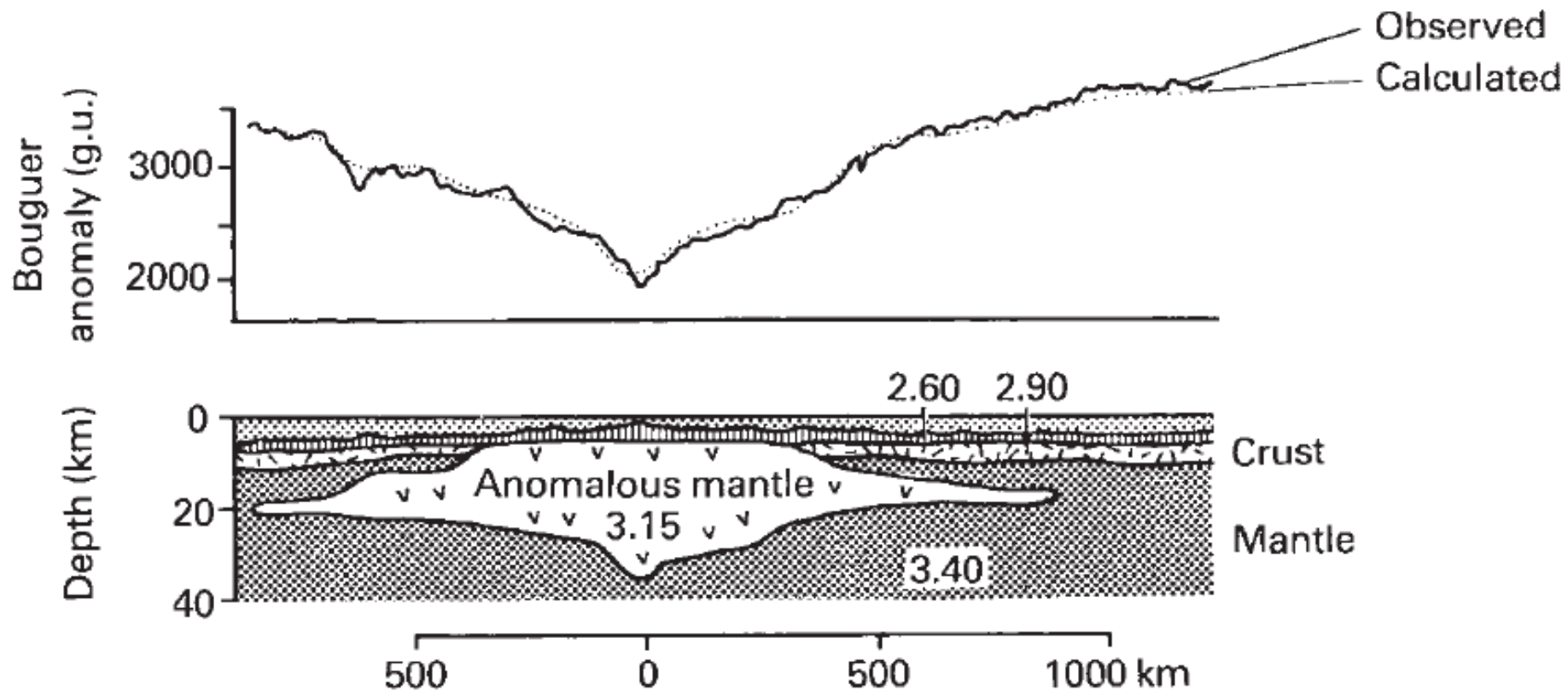
Due to faster plate motion on the Pacific side and influence of the South Pacific Supers well.



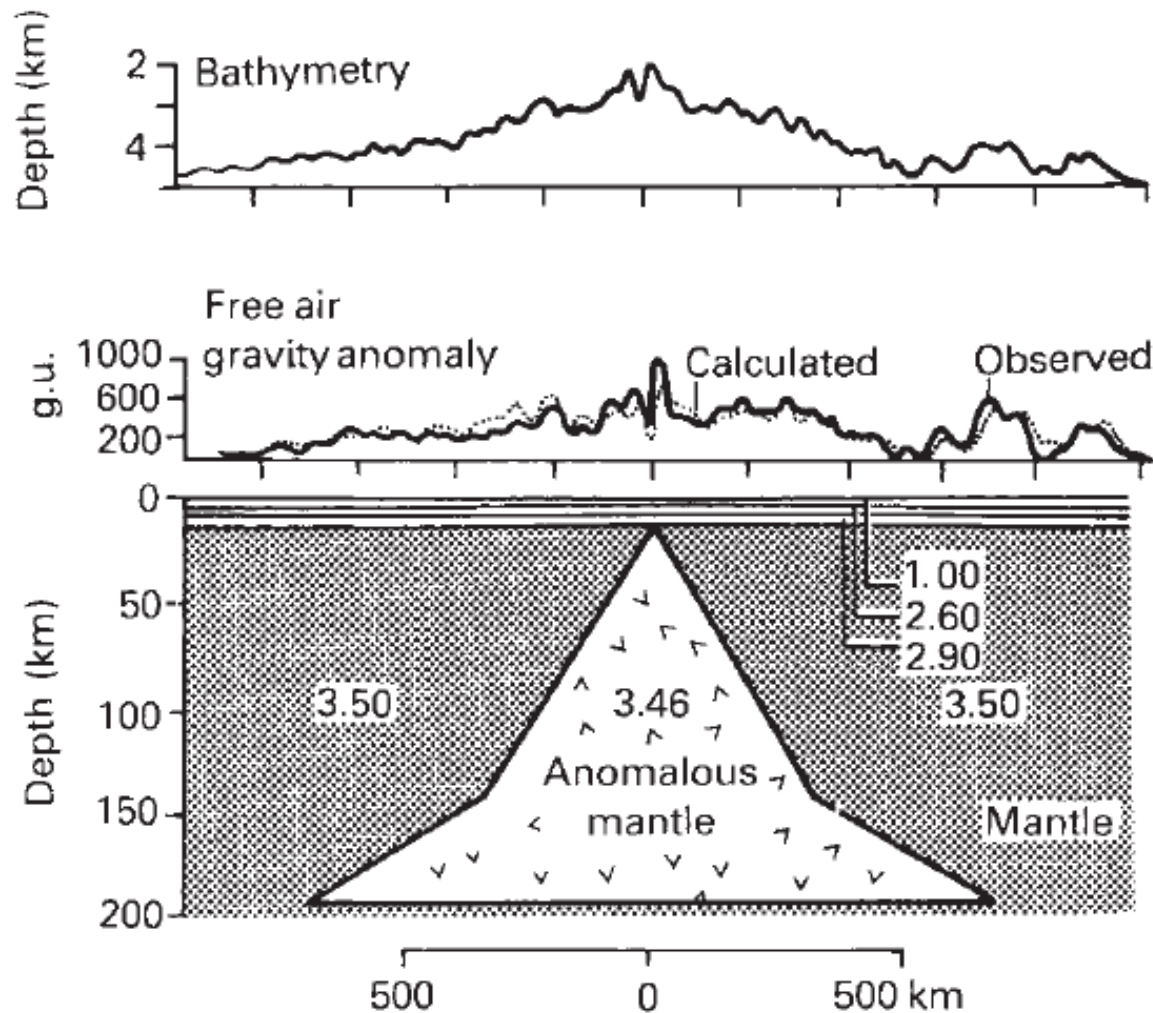
Heat flow, free air gravity anomaly and crustal structure defined by seismic refraction across the East Pacific Rise at 15–17°S. P wave velocities in km s^{-1}



Gravity anomalies and crustal structure defined by seismic refraction across the Mid-Atlantic Ridge at about 31°N. Bouguer anomaly reduction density 2.60 Mg m⁻³, P wave velocities in km s⁻¹



Possible model of the structure beneath the Mid-Atlantic Ridge from gravity modeling with seismic refraction control. Densities in Mg m^{-3}



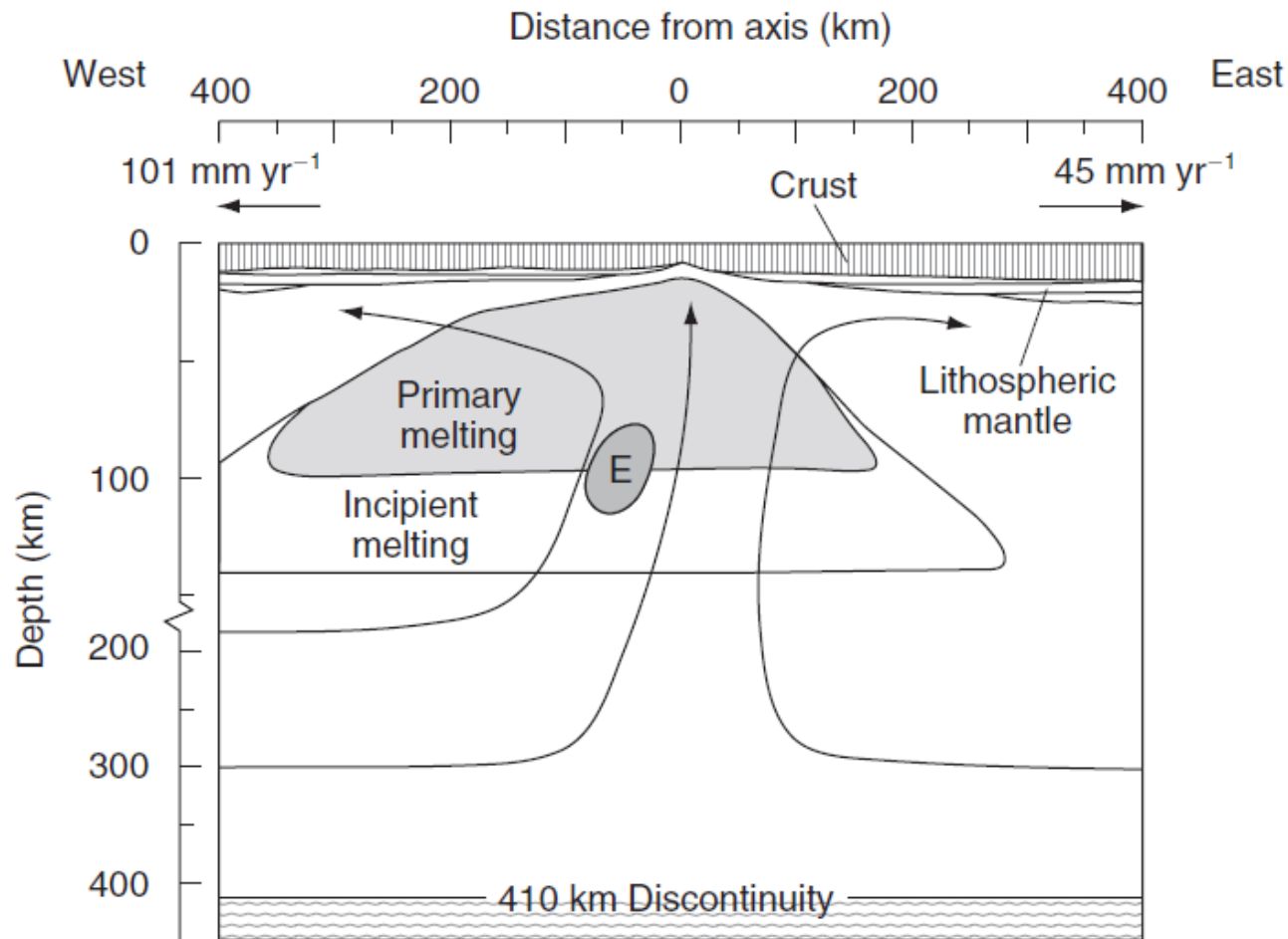
Alternative model of the structure beneath the Mid-Atlantic Ridge from gravity modeling. Profile at 46°N. Densities in Mg m^{-3}

Depth-Age Relationship of Oceanic Lithosphere

Cooling and Subsidence:

As lithosphere moves away from the ridge, it cools, contracts, and subsides. Depth (d) vs. Age (t) Models:

- Half-Space Model: $d=2500+350t$ (valid for <70 Ma).
 - Plate Model (Parsons & McKenzie, 1978): Accounts for convective cooling at depth.
 - GDH1 Model (Stein & Stein, 1992): Best fit for global data, plate thickness ~ 95 km.
-



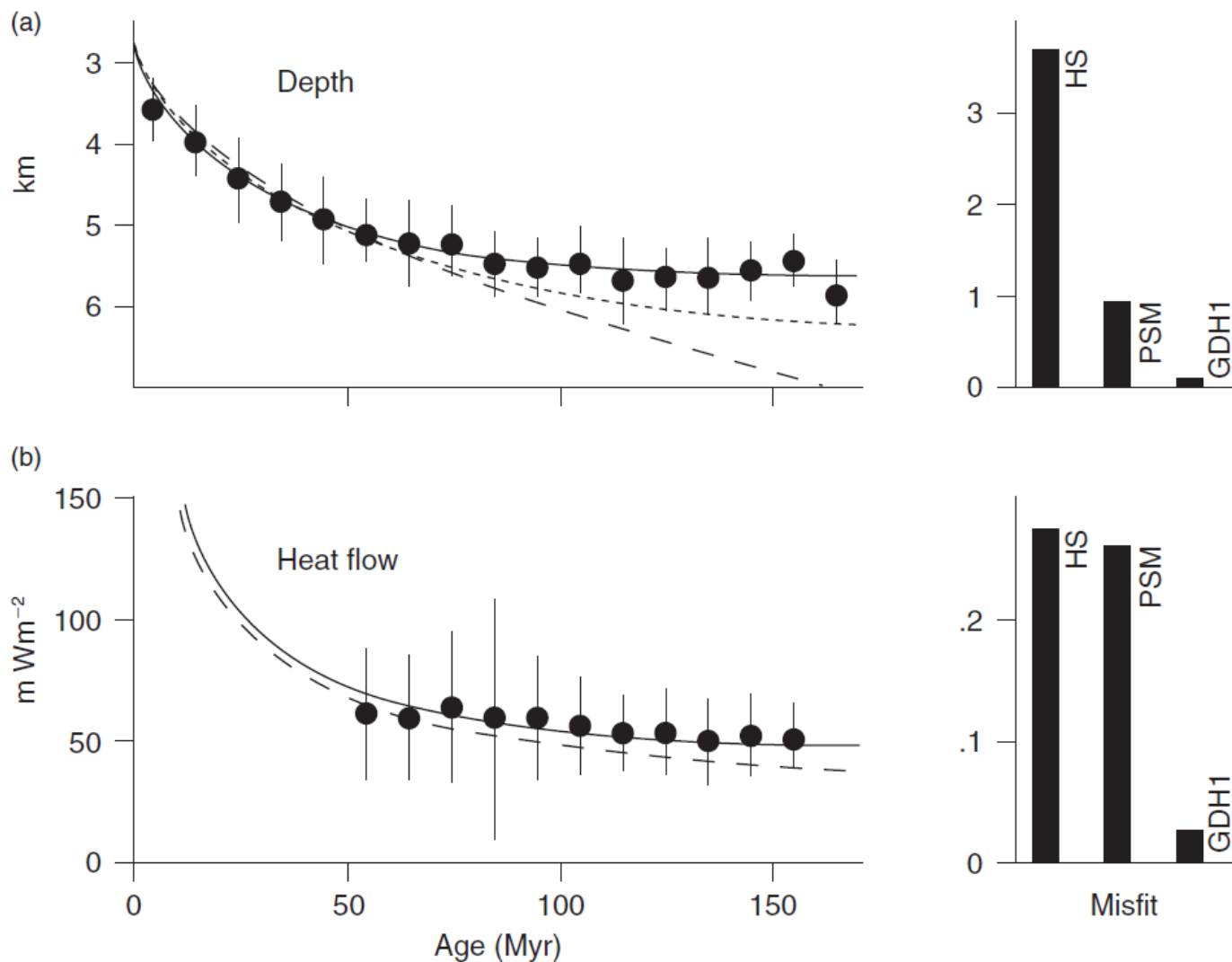
Schematic cross-section beneath the East Pacific Rise at 17°S illustrating the extent of partial melting in the mantle deduced from the results of the MELT experiment. Plate velocities are in the hot spot reference frame. The region labeled E (embedded heterogeneity) indicates enhanced melting due to anomalously enriched mantle or localized upwelling.

Heat Flow and Hydrothermal Circulation

Observed vs. Predicted Heat Flow: Young crust (<60 Ma) shows scattered heat flow due to hydrothermal circulation. Older crust (>60 Ma) matches conductive cooling models.

Hydrothermal Vents:

- Black smokers eject 400°C fluids, depositing metal sulfides.
 - Biological communities thrive on chemosynthesis.
 - Sealing age: ~60 Ma, when sediment blankets crust, stopping circulation.
-



Observed depth and heat flow data for oceanic ridges plotted as a function of lithospheric age, and compared to the predictions of three thermal models: HS, half space model; PSM, model of Parsons, Sclater and McKenzie; GDH1, global depth and heat flow model of Stein and Stein

Seismic Evidence for Axial Magma Chambers

Fast-Spreading Ridges (East Pacific Rise):

- Melt lens: 1–2 km below seafloor, ~1 km wide, tens of meters thick.
 - Low-velocity zone (LVZ): Hot, partially molten rock (~30% melt).
-

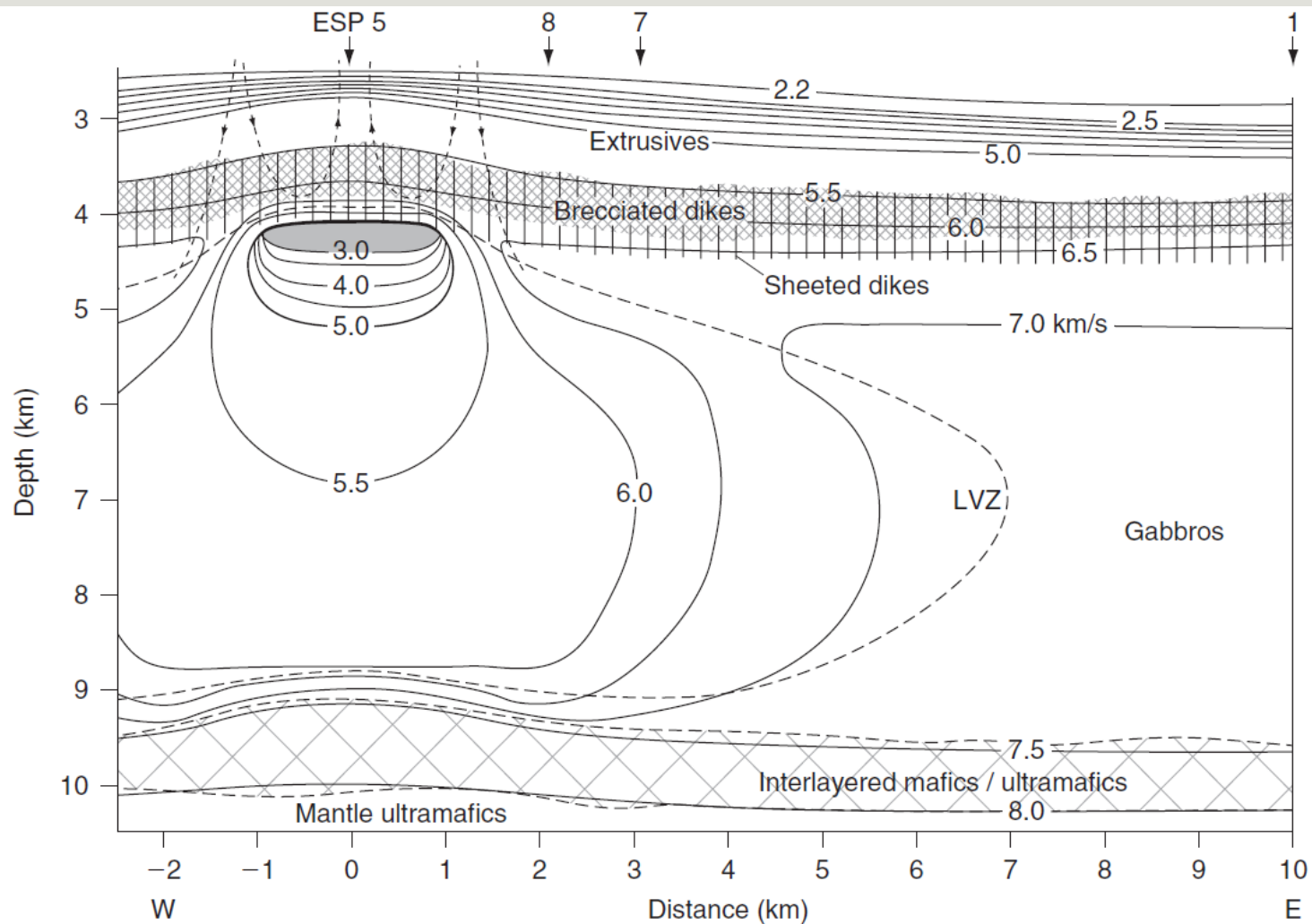
Slow-Spreading Ridges (Mid-Atlantic Ridge):

- No steady-state magma chamber; transient melt lenses during magmatic pulses.

Ultraslow-Spreading Ridges (Gakkel Ridge):

- Magmatic segments with thin crust, amagmatic segments with exposed mantle.

Note: The Gakkel Ridge is located in the Arctic Ocean, between Greenland and Siberia. It is a mid-oceanic ridge, which is a divergent tectonic plate boundary where new oceanic crust is being formed



The variation of P wave velocity in the oceanic crust, at the crest of the East Pacific Rise at 9°30'N, deduced from expanded spread (ESP) and common depth point seismic profiling. Shaded area indicates a region with a high percentage of melt. An interpretation of the velocities in terms of rock units, and an indication of the extent of the zone of anomalously low seismic velocities (LVZ), are also shown

Along-Axis Segmentation of Ridges

Orders of Segmentation:

1. First-order: Transform faults (300–500 km spacing).

2. Second-order: Overlapping spreading centers (OSCs, 50–300 km).
3. Third-order: Small OSCs (30–100 km).
4. Fourth-order: Deviations in axial linearity (<10–50 km).

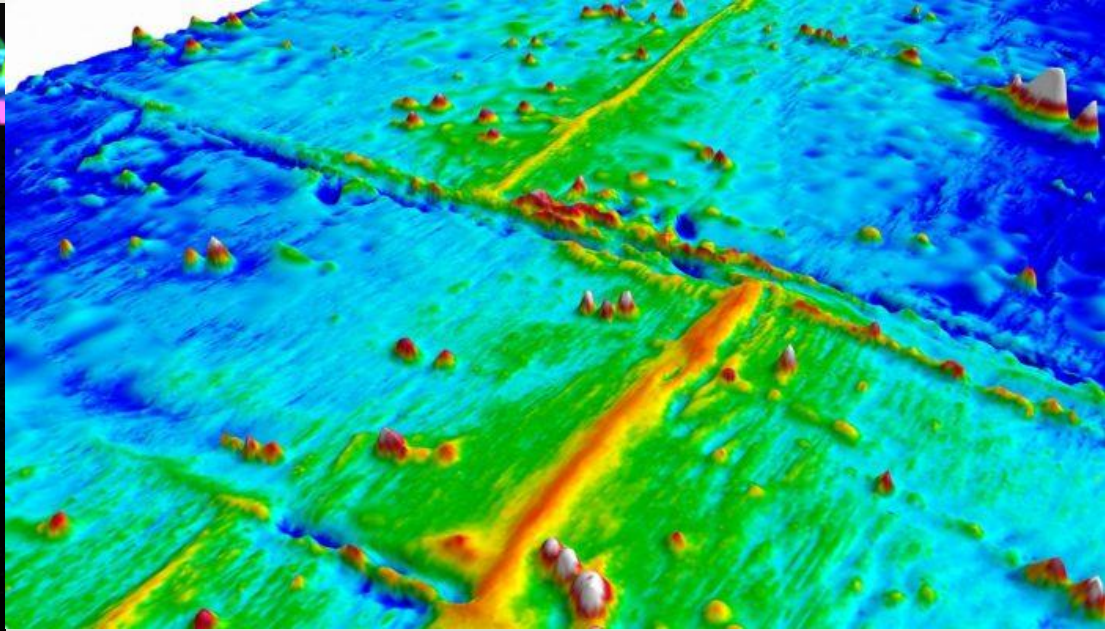
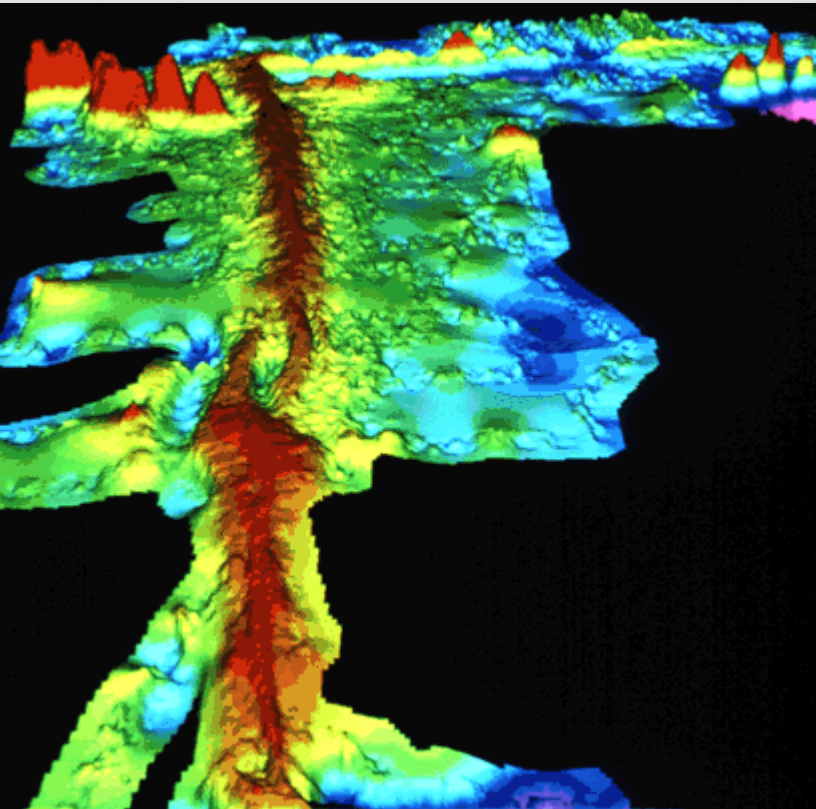
Slow vs. Fast-Spreading Segmentation:

Fast-spreading: Smooth axial high, OSCs.

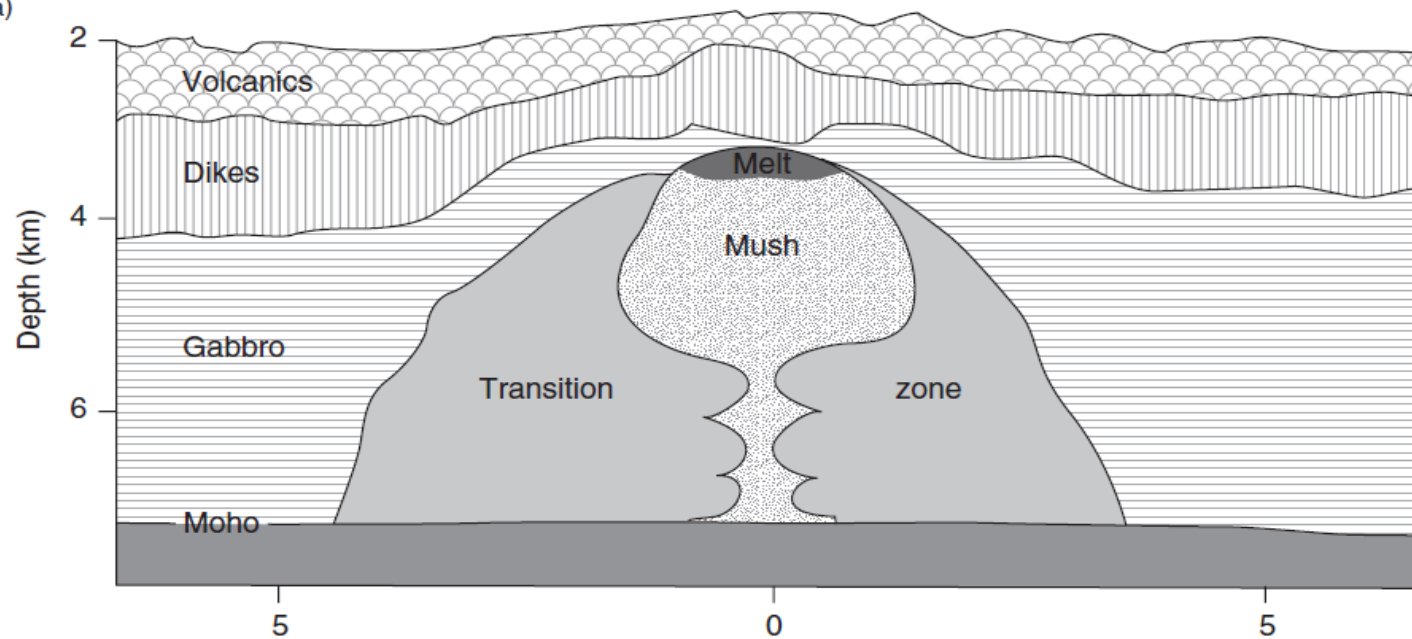
Slow-spreading: Volcanic ridges, fault-bounded valleys.

Oceanic Core Complexes:

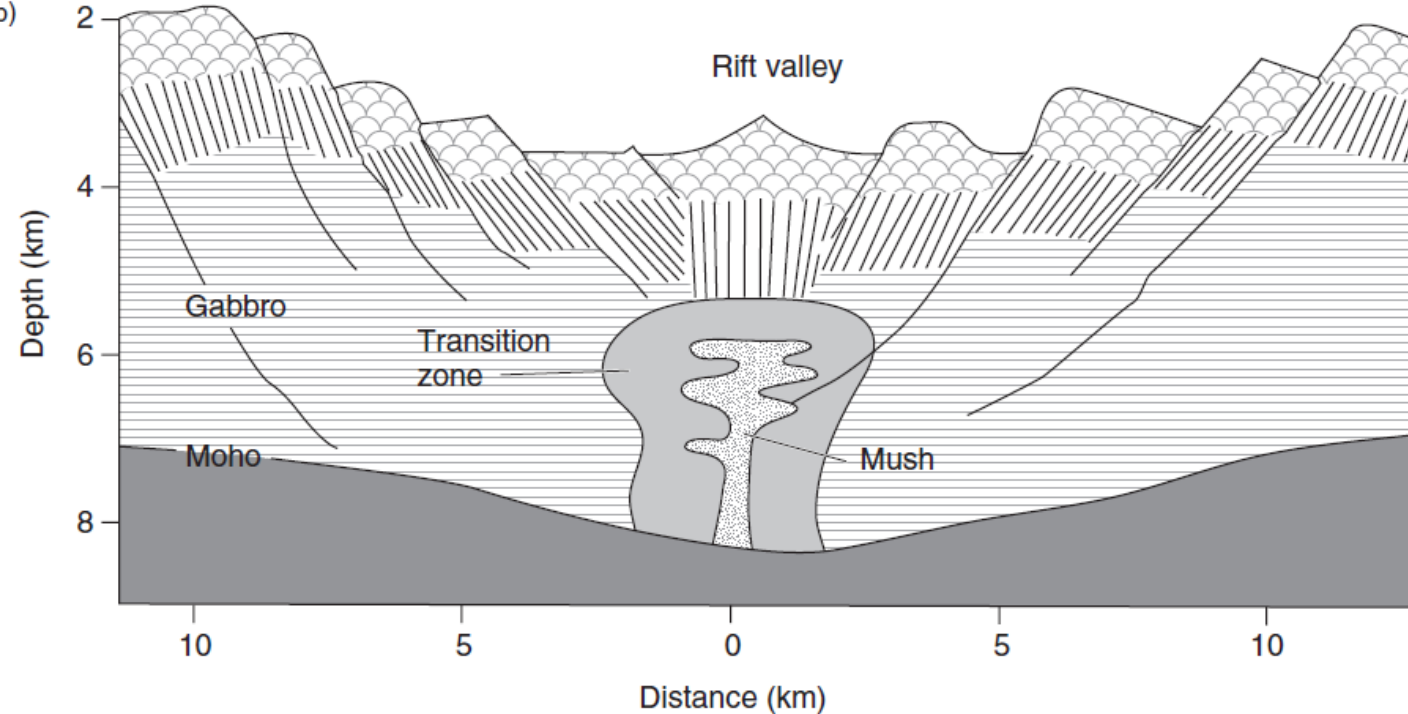
- Detachment faults expose serpentinitized peridotite (e.g., Atlantis Massif).



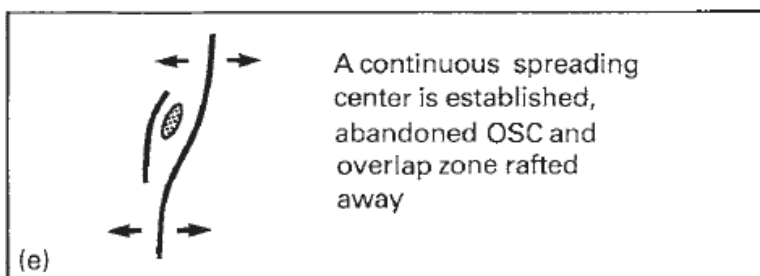
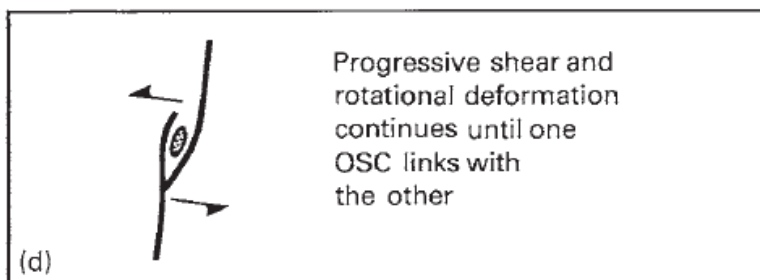
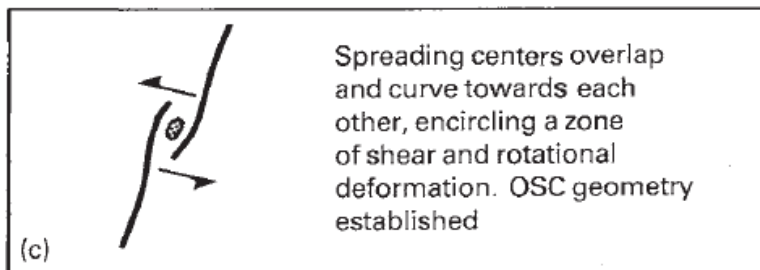
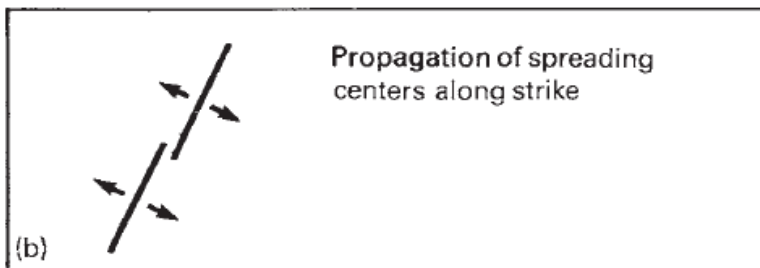
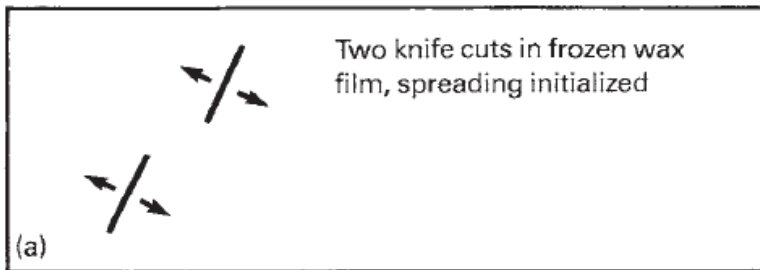
(a)



(b)

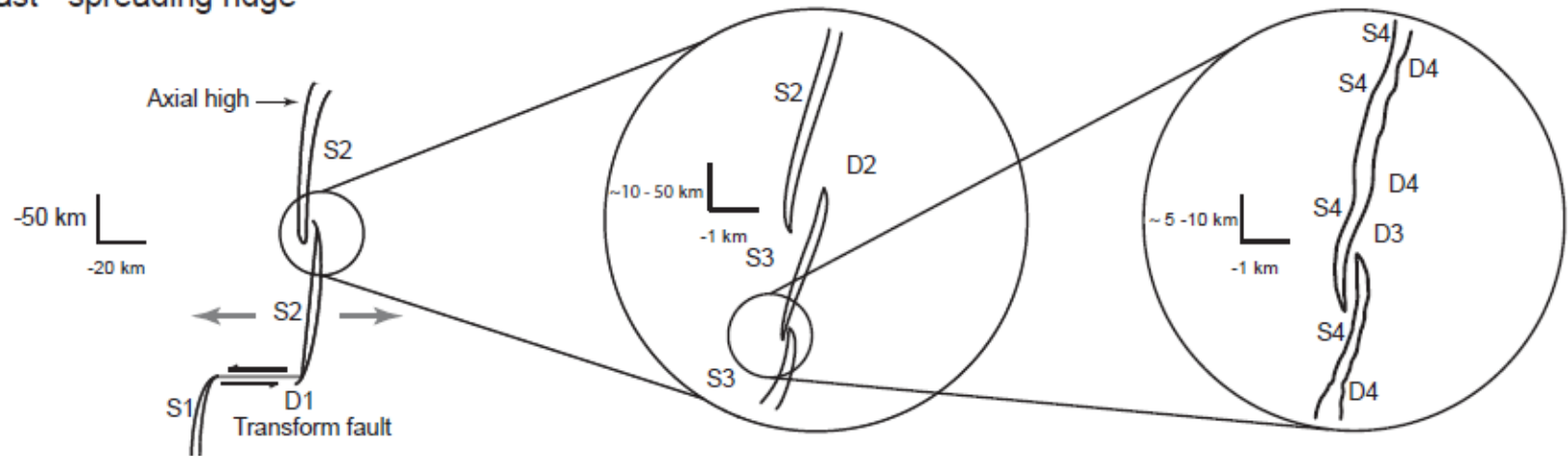


Interpretive models
of magma
chambers beneath
a fast (a)
and slow (b)
spreading ridge



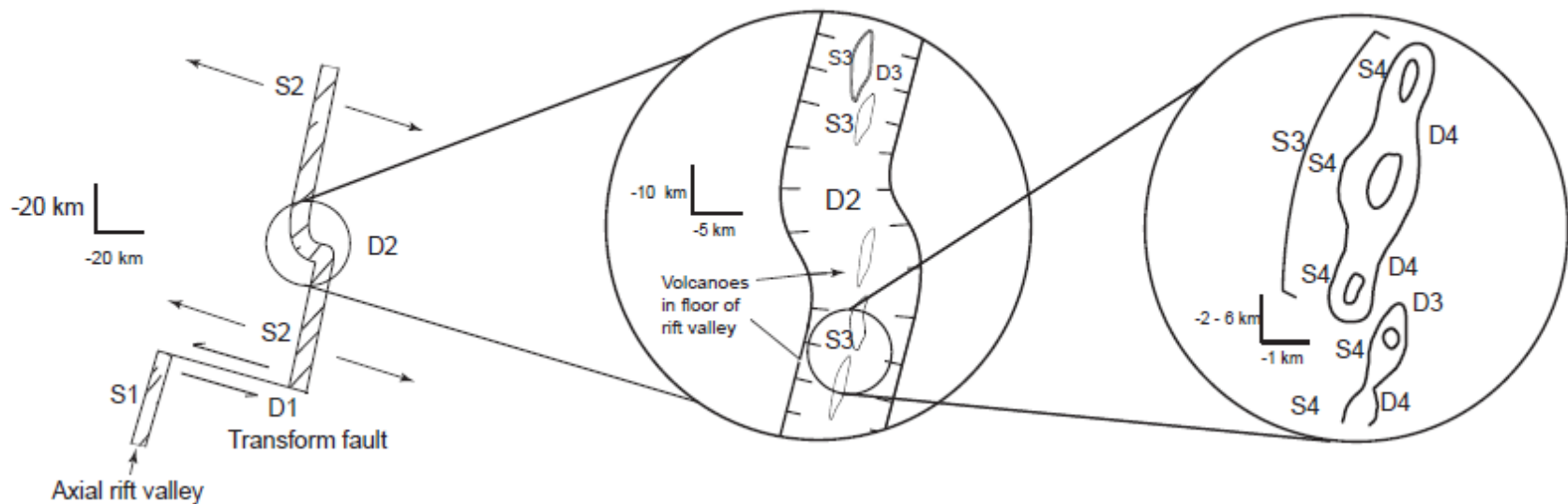
Possible evolutionary sequence in the development of an overlapping spreading center

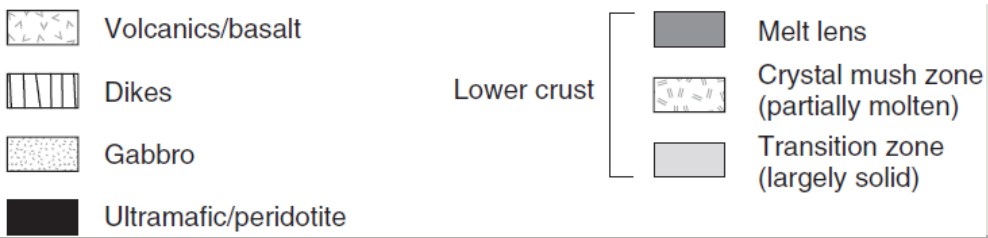
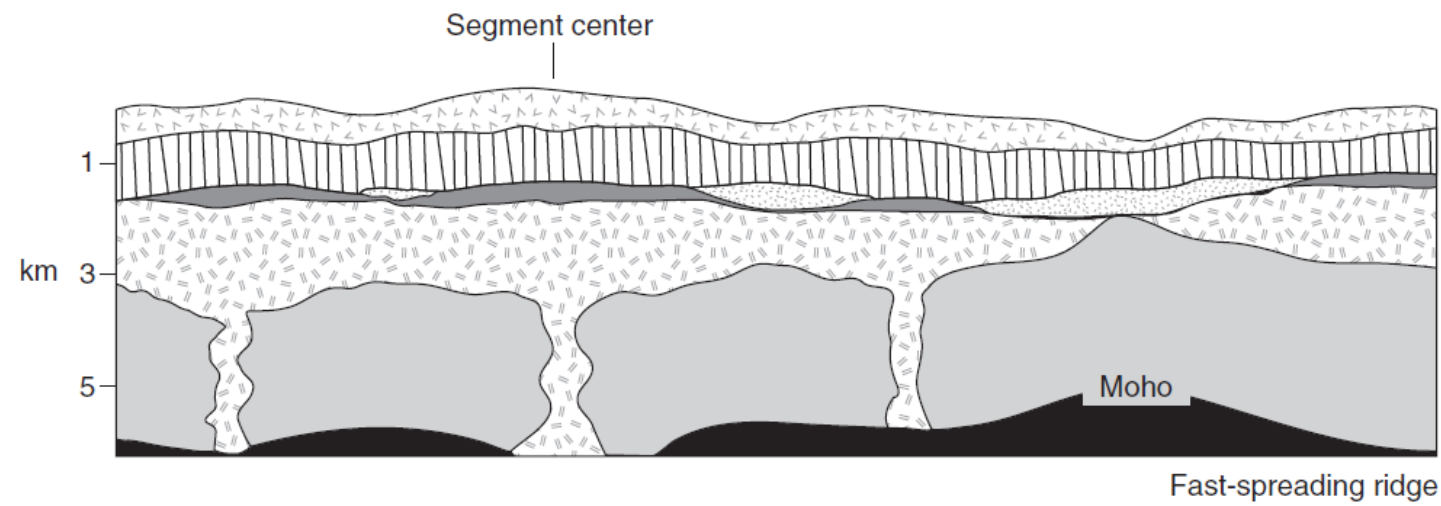
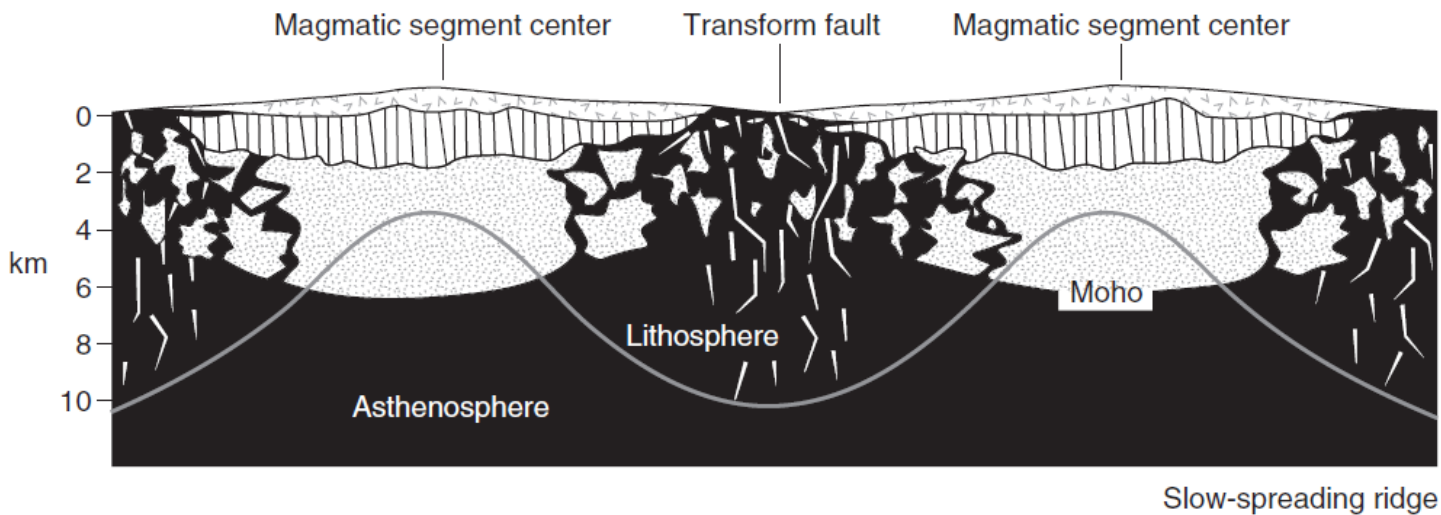
Fast - spreading ridge



Summary of the hierarchy of segmentation on fast- and slow-spreading ridges. S1 , S2 , S3 , and S4 – first to fourth order ridge segments. D1 , D2 , D3 , and D4 , – first to fourth order discontinuities.

Slow - spreading ridge





Along axis sections illustrating the variation in crustal structure between segment centers and segment ends on slow- and fast-spreading ridges, as envisioned by Cannat et al. (1995) and Sinton and Detrick (1992) respectively

Petrology of Ocean Ridges

Mid-Ocean Ridge Basalts (MORB):

- ✓ **Olivine tholeiite**, formed by ~**10–20% partial melting** of mantle peridotite.
- ✓ **Fast-spreading ridges**: Low-pressure fractionation (Fe-rich).
- ✓ **Slow-spreading ridges**: Complex, high-pressure fractionation.

Ultraslow-Spreading Ridges:

- ✓ Lower Na, higher Fe, indicating **deeper, less melting**.

Origin of Oceanic Crust

Fast-Spreading Crustal Formation:

1. **Layer 2:** Pillow lavas & sheeted dikes.
 2. **Layer 3:** Gabbro from steady-state magma chamber.
-

Slow-Spreading Crustal Formation:

Transient magma chambers, more faulting, serpentinized mantle.

Thermal Models (Chen & Morgan, 1990):

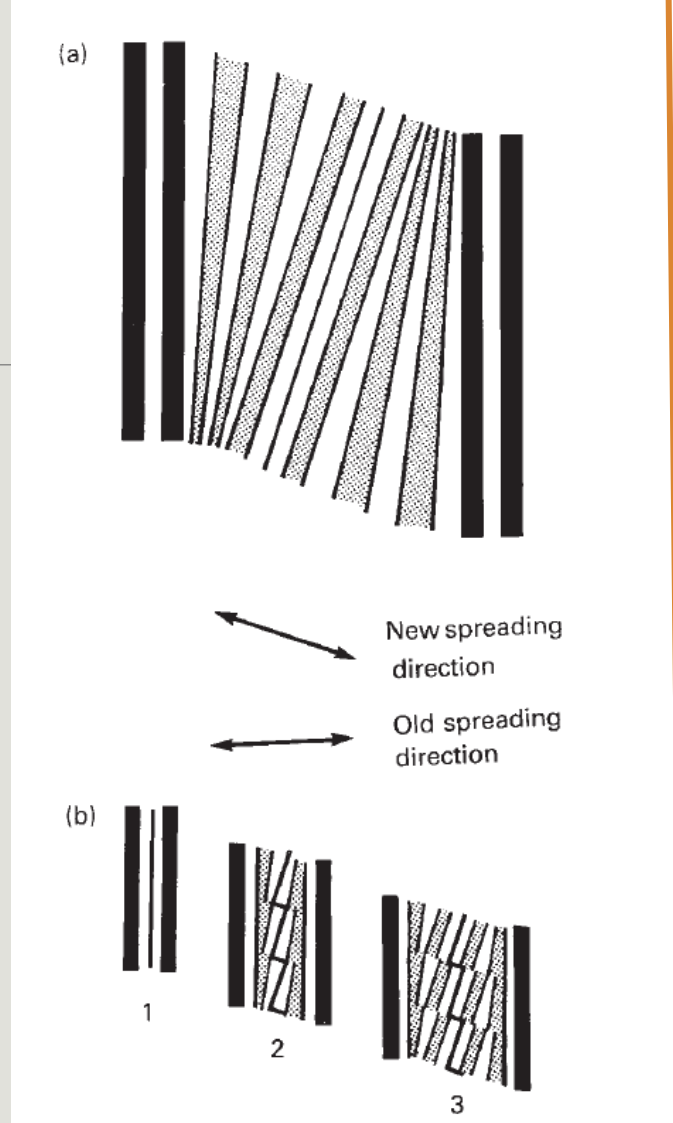
- **Fast-spreading:** Thin brittle layer, narrow accretion zone.
- **Slow-spreading:** Thick brittle layer, median valley.

Propagating Rifts and Microplates

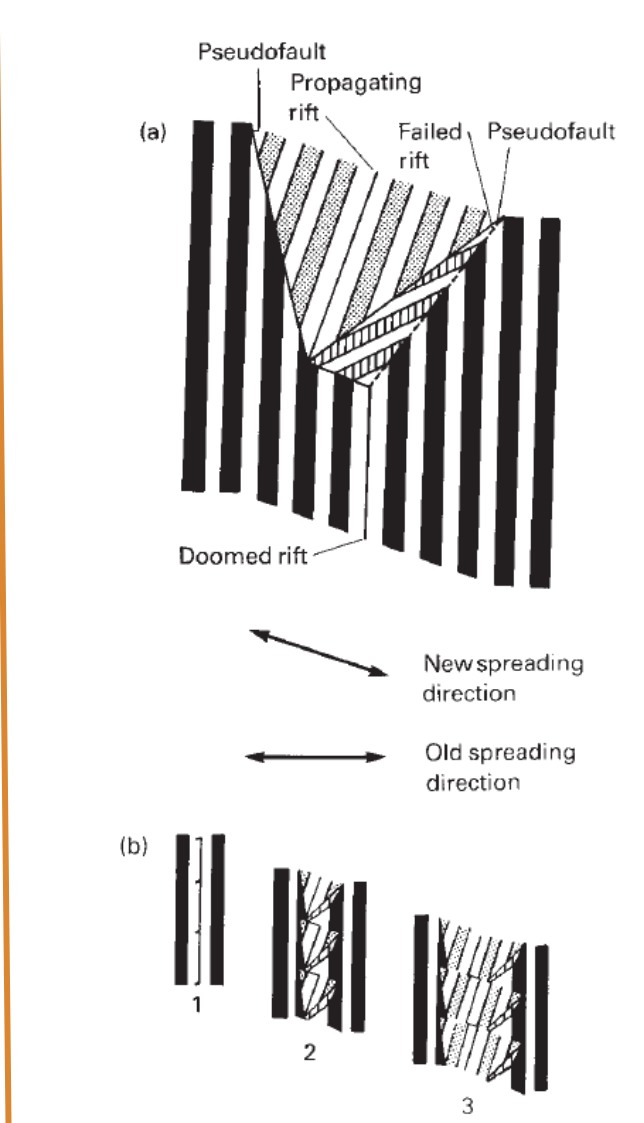
Ridge Propagation:

New rift replaces old one, forming **V-shaped pseudofaults**. Example: **Galapagos Rift propagation**.

Microplates (Easter, Juan Fernandez): Rotating crustal blocks between overlapping rifts. Lifetime: **5–10 Myr** before merging with a major plate.



(a) Ridge rotation model of spreading center adjustment; (b) evolution of a stepped ridge following rotation



(a) Ridge adjustment by rift propagation; (b) evolution of a stepped ridge following propagation

Oceanic Fracture Zones

Characteristics:

- ☐ Active transform faults + fossilized traces.
 - ☐ Thin, altered crust near transforms (serpentinized mantle).
-

Transverse Ridges:

- ☐ Uplifted blocks due to changes in spreading direction.
- ☐ Example: St. Peter and St. Paul Rocks.

Leaky Transforms:

- ☐ Develop when spreading is not orthogonal to the ridge.

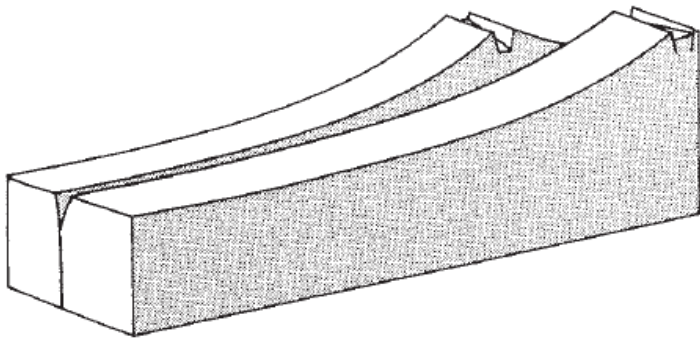
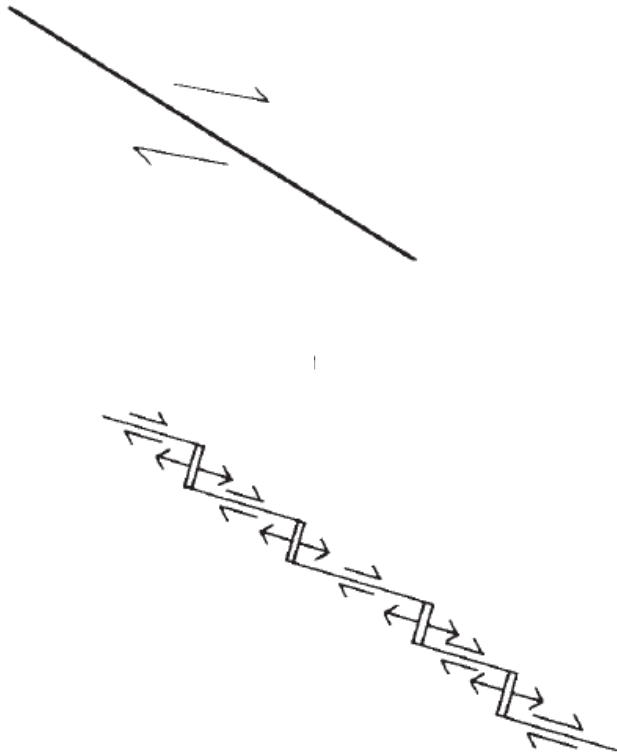
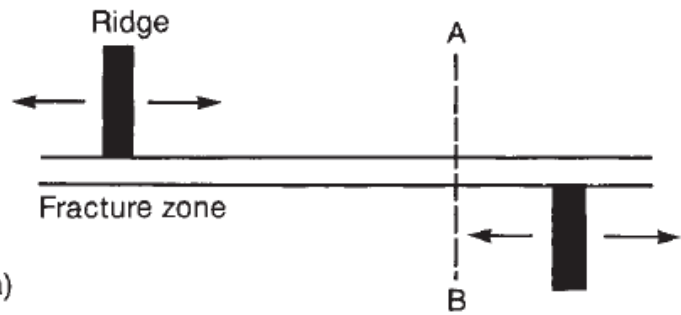


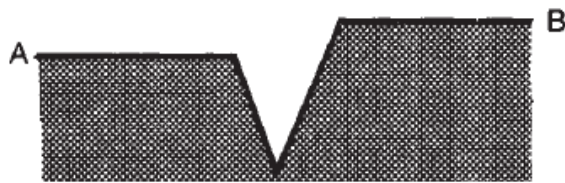
Fig. 6.24 *Differential topography resulting from transform faulting of a ridge axis.*



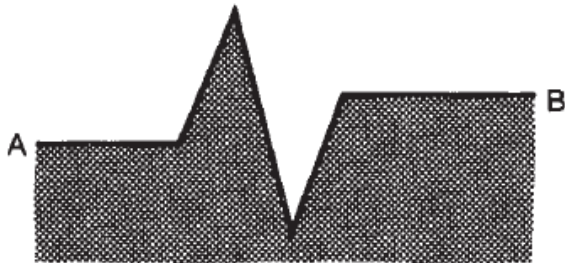
Development of a leaky transform fault
because of a change in the pole of rotation.



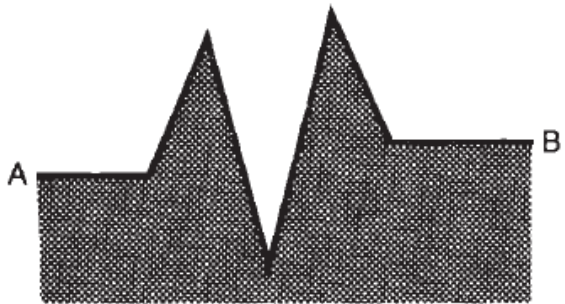
(a)



(b)



(c)



(d)

Different types of basement morphology
across fracture zones