Global Tectonics
G404
Lecture-7

Instructor
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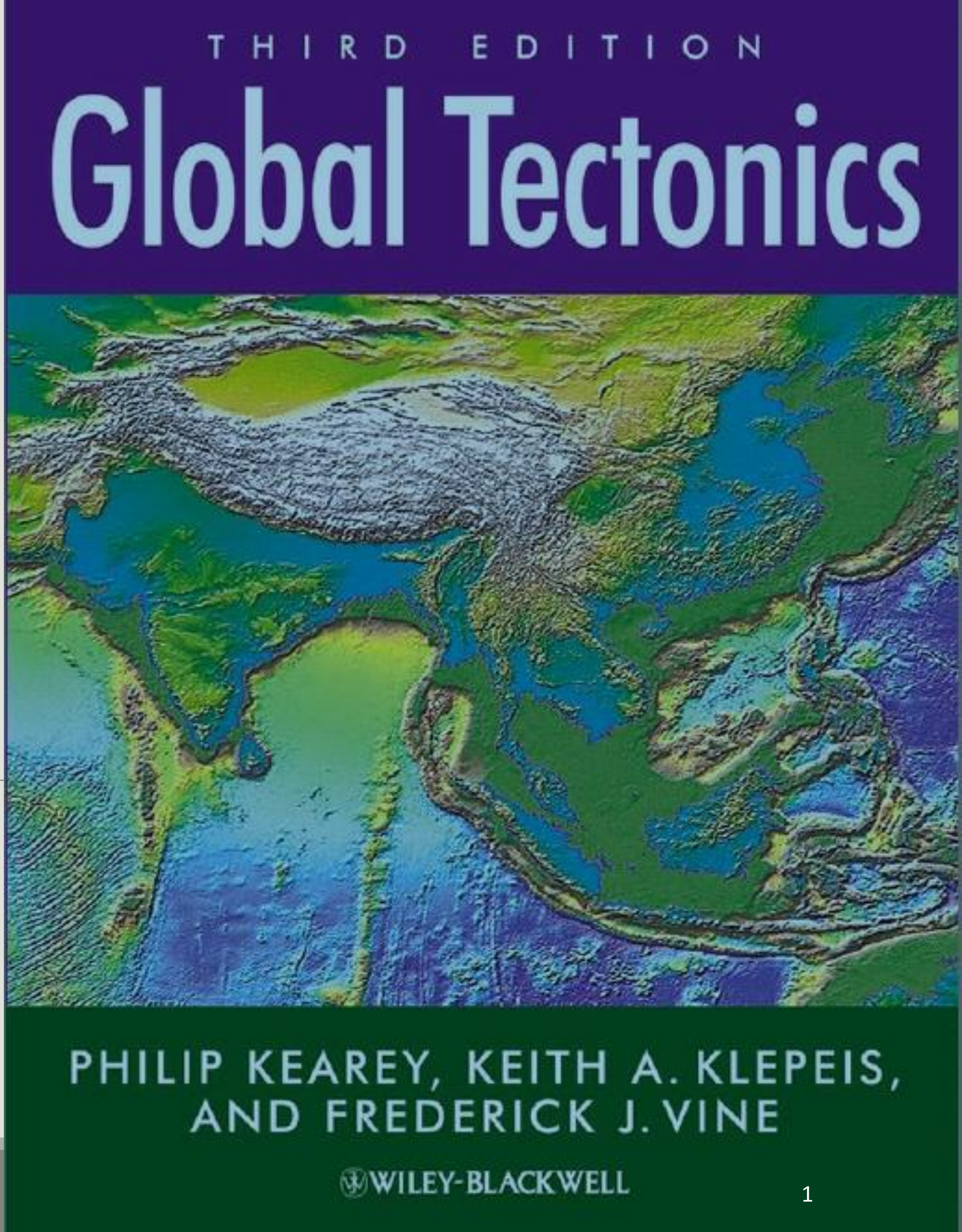


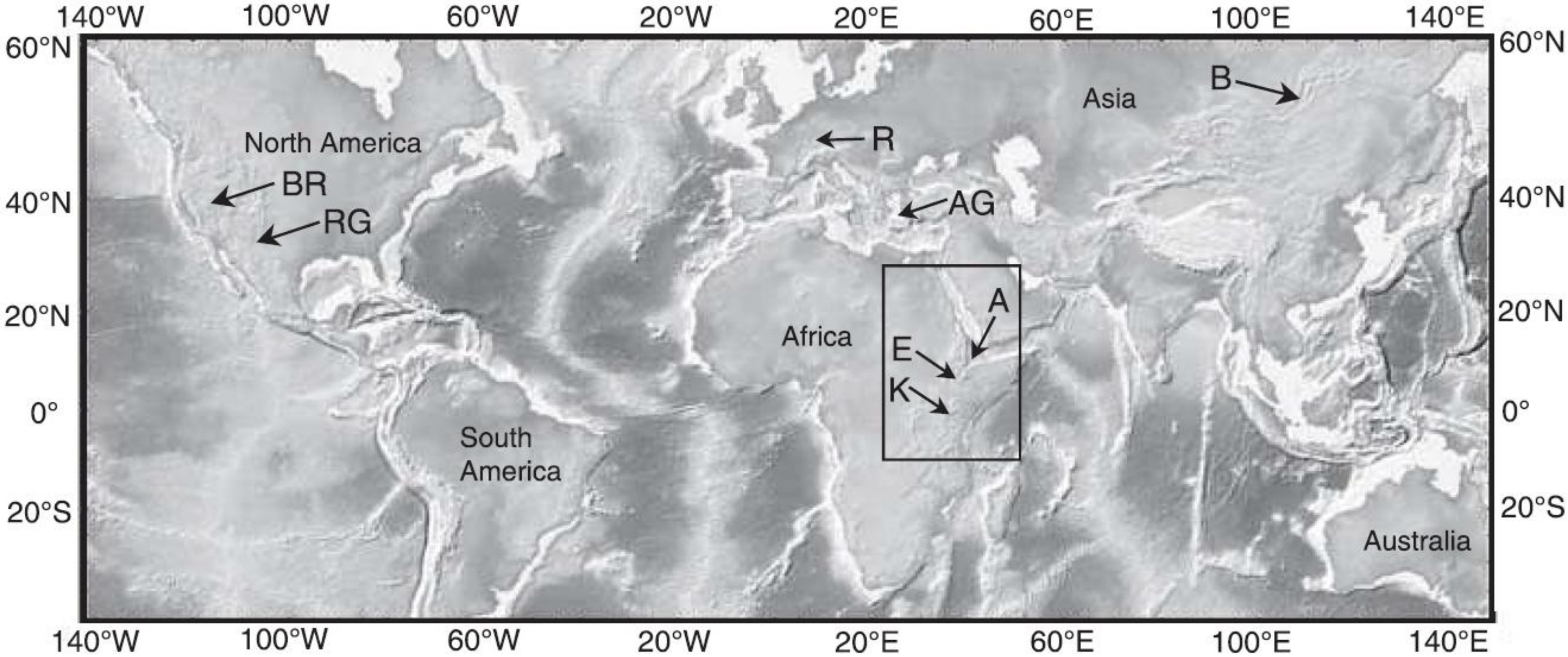
Chapter 7: Continental Rifts and Rifted Margins

Introduction:

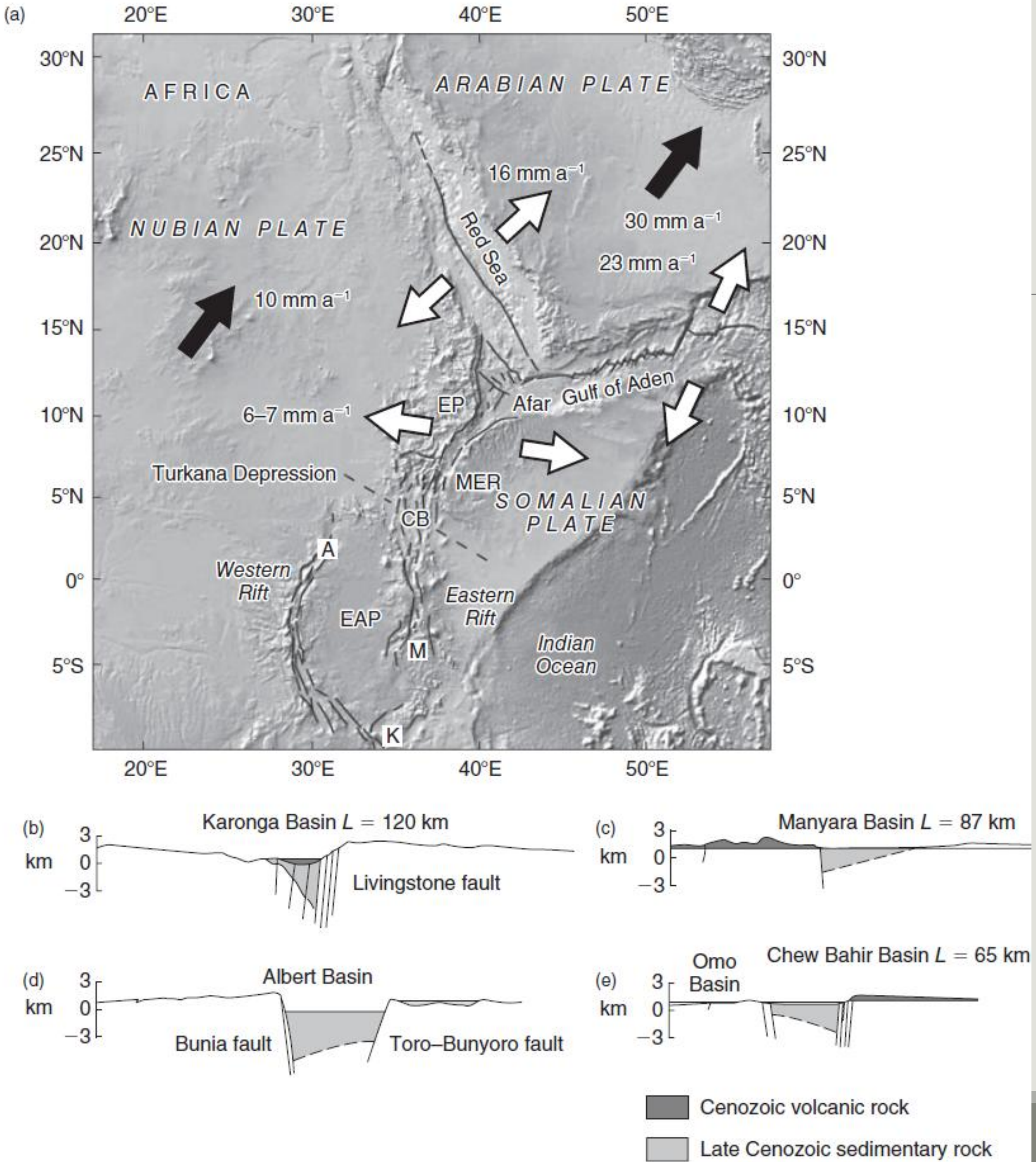
Continental rifts are zones where the lithosphere is stretched and thinned, often leading to the breakup of continents and the formation of new ocean basins. Rifts can evolve into rifted margins, which are the transition zones between continental and oceanic crust.

This chapter examines the geologic and geophysical characteristics of rifts, their volcanic activity, initiation mechanisms, and the processes of strain localization and delocalization.

The chapter differentiates between narrow rifts and wide rifts, noting that the former are characterized by localized deformation and often occur in strong lithosphere, while the latter involve broadly distributed deformation over a large area, typically in weak, hot lithosphere.



Shaded relief map showing selected tectonically active rifts.



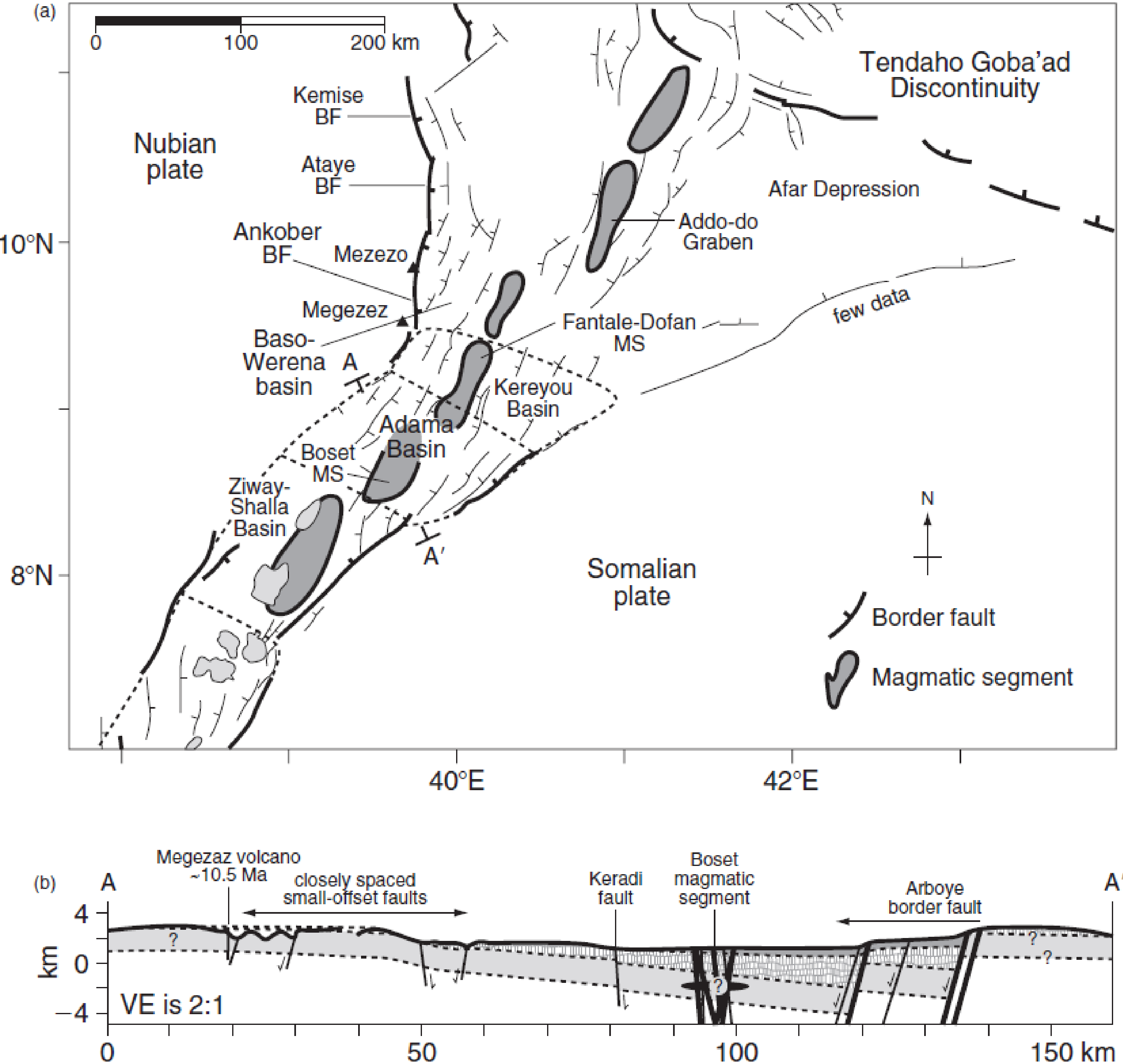
(a) Shaded relief map and geodynamic setting of the East African Rift system White arrows indicate relative plate velocities. Black arrows indicate absolute plate motion in a geodetic, no-net-rotation (NNR) framework

(b–e) Cross-sections showing fault and half-graben morphology

General Characteristics of Narrow Rifts

These rifts, such as the East African Rift system, are defined by a narrow zone of deformation (tens of kilometers wide). They are characterized by fault-bounded basins and high-relief topography, with deformation primarily concentrated along the rift axis. Seismic tomography studies of the East African Rift suggest a connection between the rift and a deep, broad zone of upwelling known as the African superswell.

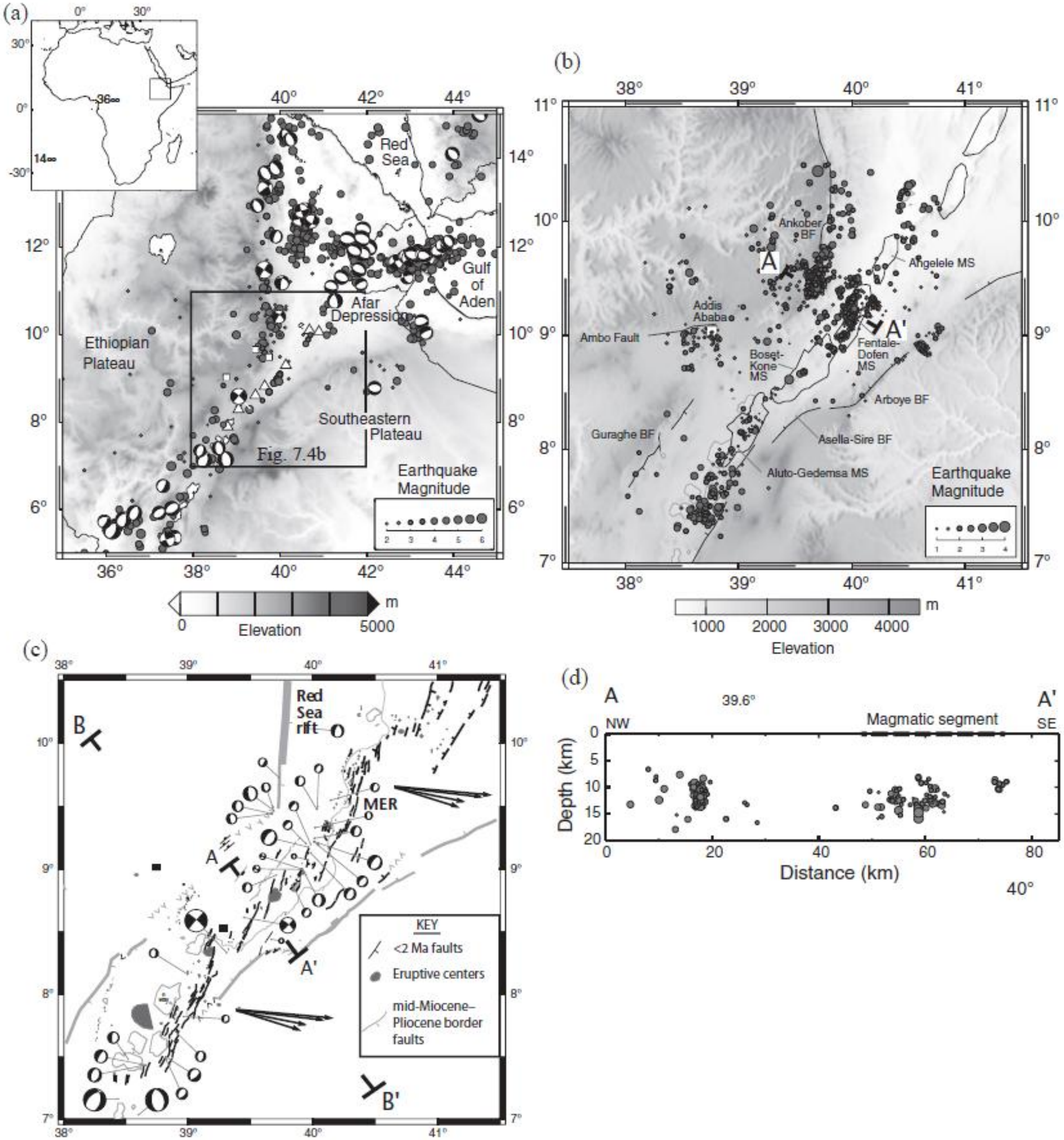
Examples:
East African Rift: Active rift with volcanism and seismicity.
Baikal Rift: Asymmetric extension with a major bounding fault.



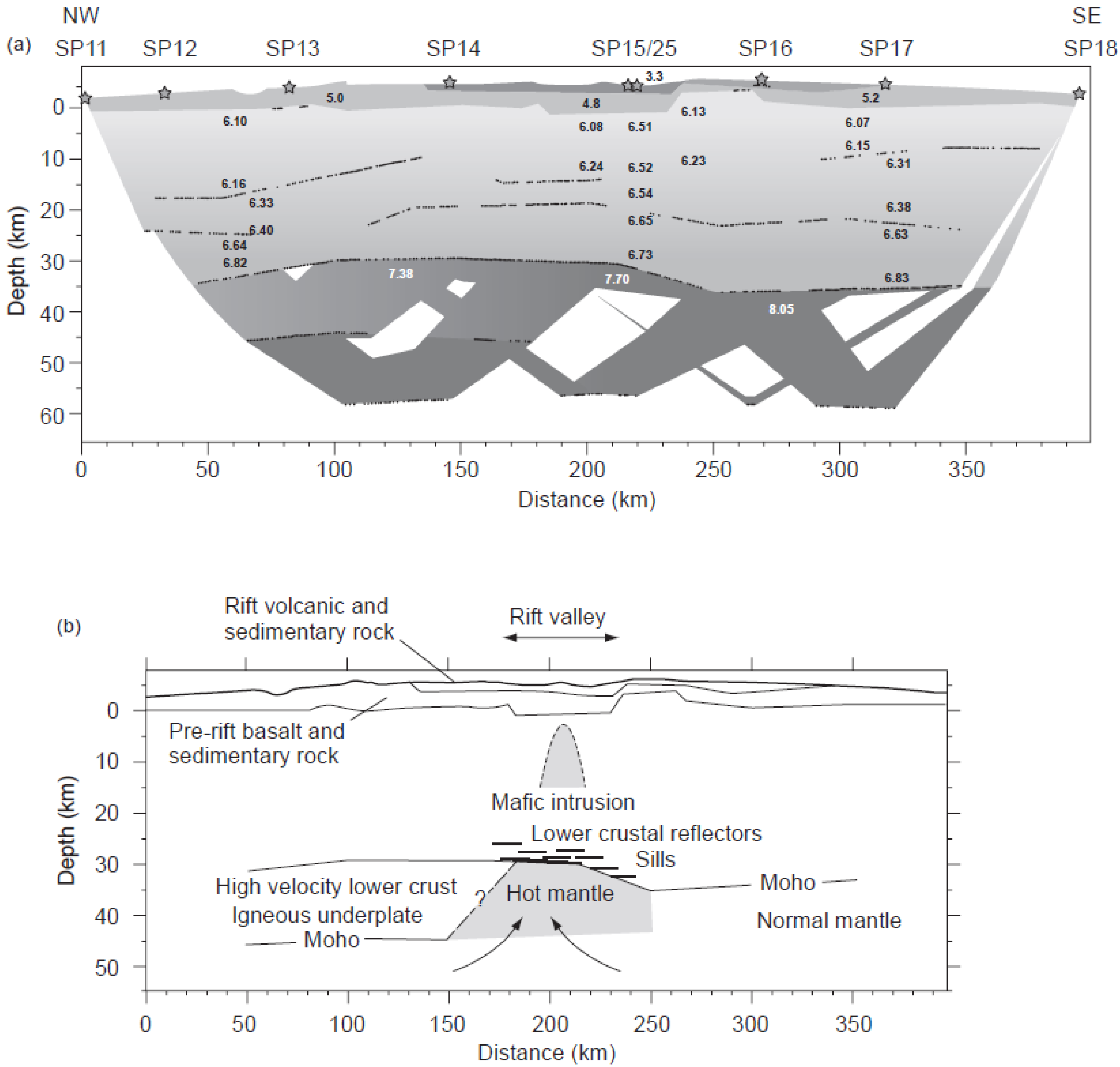
a)Major faults and segmentation pattern of the northern Main Ethiopian rift.

(b) cross-section of Adama Rift Basin showing half graben morphology.

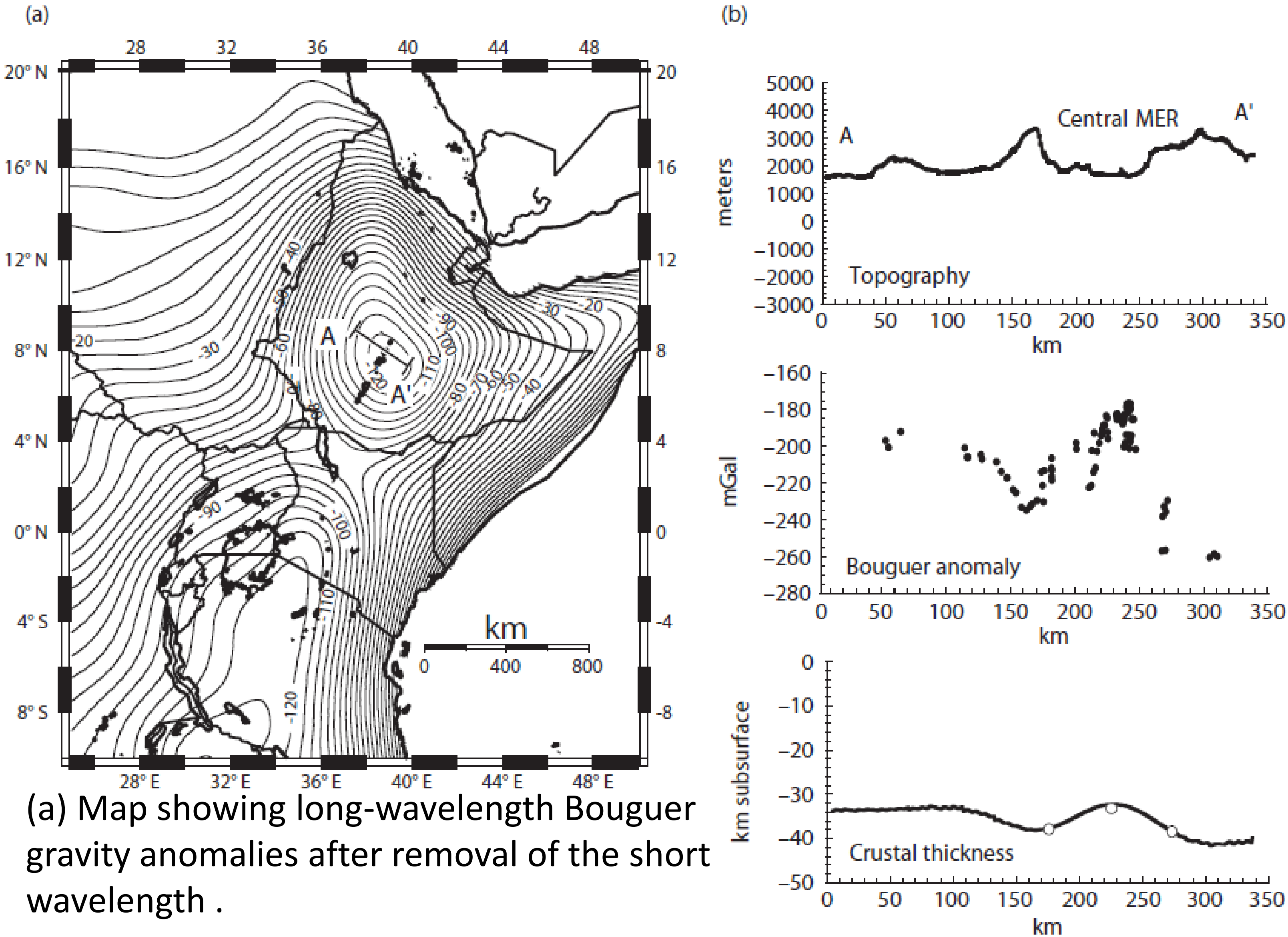
MS, magmatic segment; BF, border fault. In (b) note the wedge-shaped geometry of the syn-rift Miocene and younger ignimbrite and volcanic units (vertical lined pattern and upper shaded layer). Pre-rift Oligocene flood basalts (lowest shaded layer) show uniform thickness.



(a) Seismicity and focal mechanisms of East Africa between 1960 and 2005. Late Cenozoic volcanoes shown by triangles. (b) Seismicity of rift segments in the northern Main Ethiopian Rift (MER) between October 2001 and January 2003. (c) Faults that cut <1.9 Ma lavas and late Cenozoic eruptive centers comprising magmatic segments (MS). Miocene border faults in rift basins also shown. Size of focal mechanism solutions indicates relative magnitude of earthquakes. Black arrows show approximate range of plate velocity vectors derived from geodetic data. (d) Earthquake depth distribution across profile A–A′ shown in (c). Cross-section B–B′ shown



(a)P-wave velocity model and (b) interpretation of the Main Ethiopian Rift (after Mackenzie et al., 2005, mission from Blackwell Publishing). Location of profile (B–B′) shown



(a) Map showing long-wavelength Bouguer gravity anomalies after removal of the short wavelength .

(b) Profiles (A–A’) of topography, short-wavelength Bouguer gravity anomaly, and crustal thickness estimates of the central Main Ethiopian Rift (MER). Profile location shown in (a). Circles in crustal thickness profile indicate depths estimated from receiver function studies.

General Characteristics of Wide Rifts

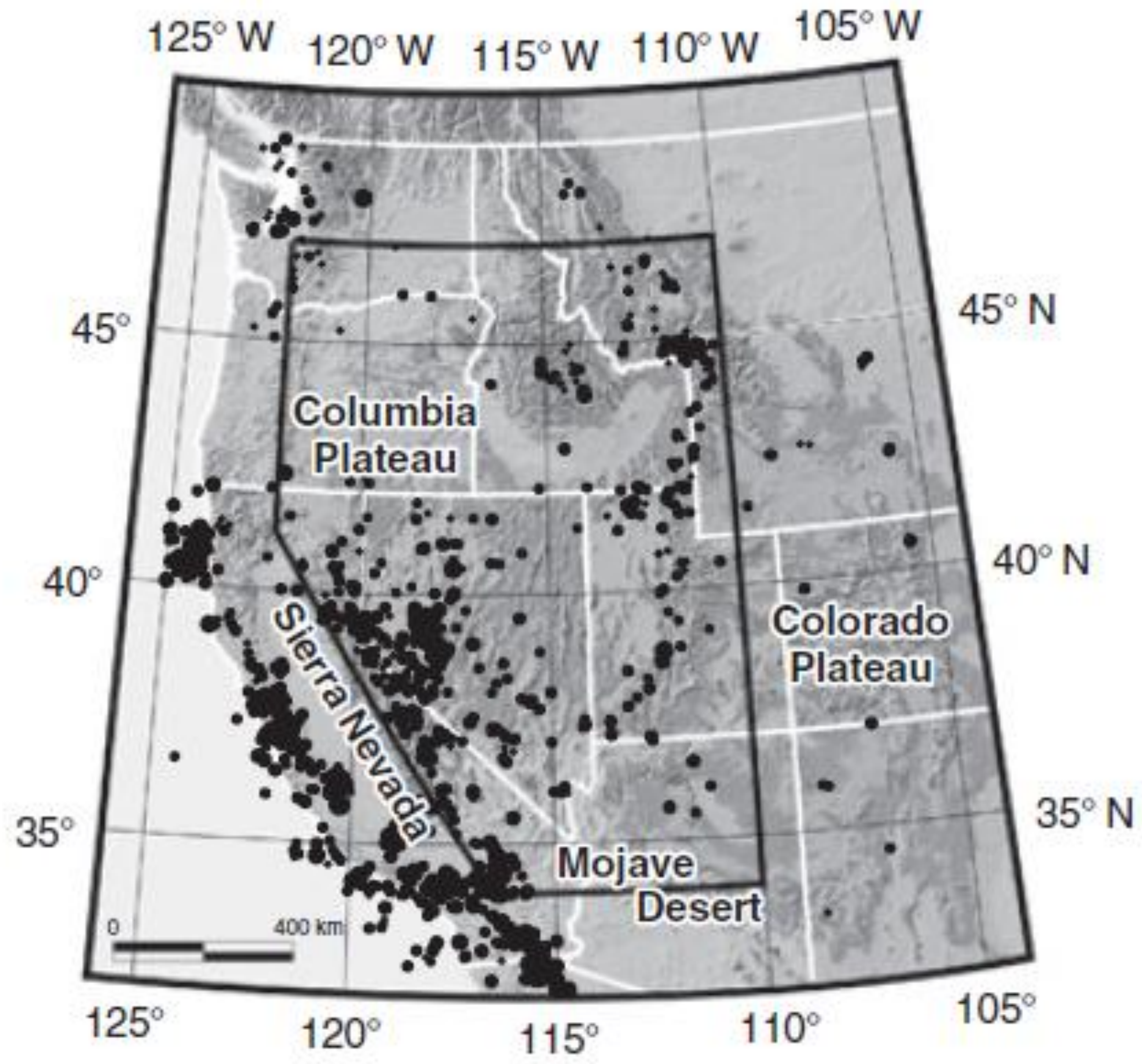
The Basin and Range Province of western North America is a classic example of a wide rift, where deformation is spread across a zone 500 to 800 km wide. This extensive deformation has resulted in numerous linear mountain ranges and basins, demonstrating that continental lithosphere can undergo significant extension without rupturing to form a new ocean.

Structural Features: Distributed Faulting: Numerous normal faults over a wide area.
Lower Crustal Flow: Ductile flow in the lower crust accommodates extension.

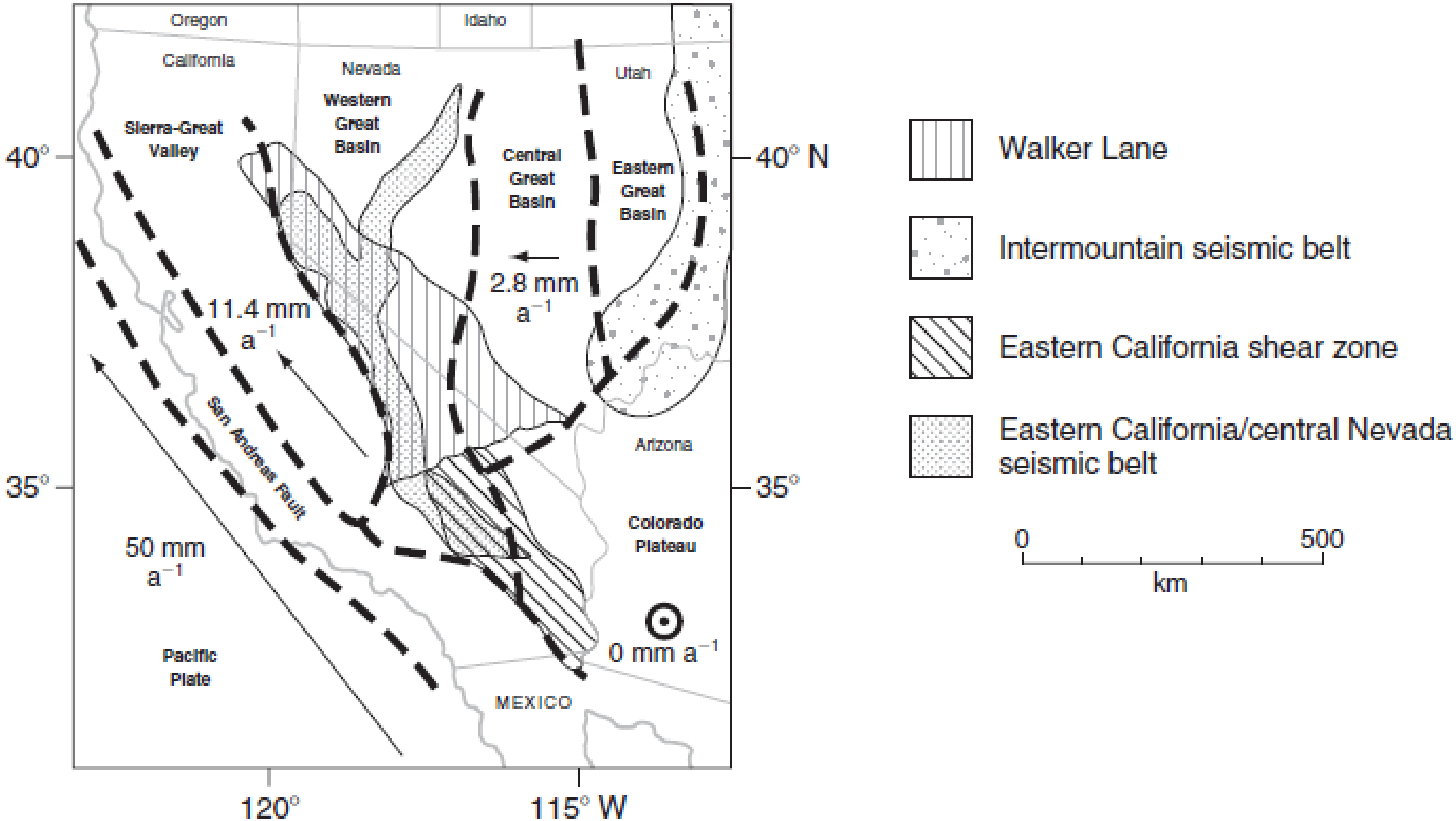
•**Geophysical investigations**: Moderate heat flow. Crustal thinning is less localized than in narrow rifts.

Examples:

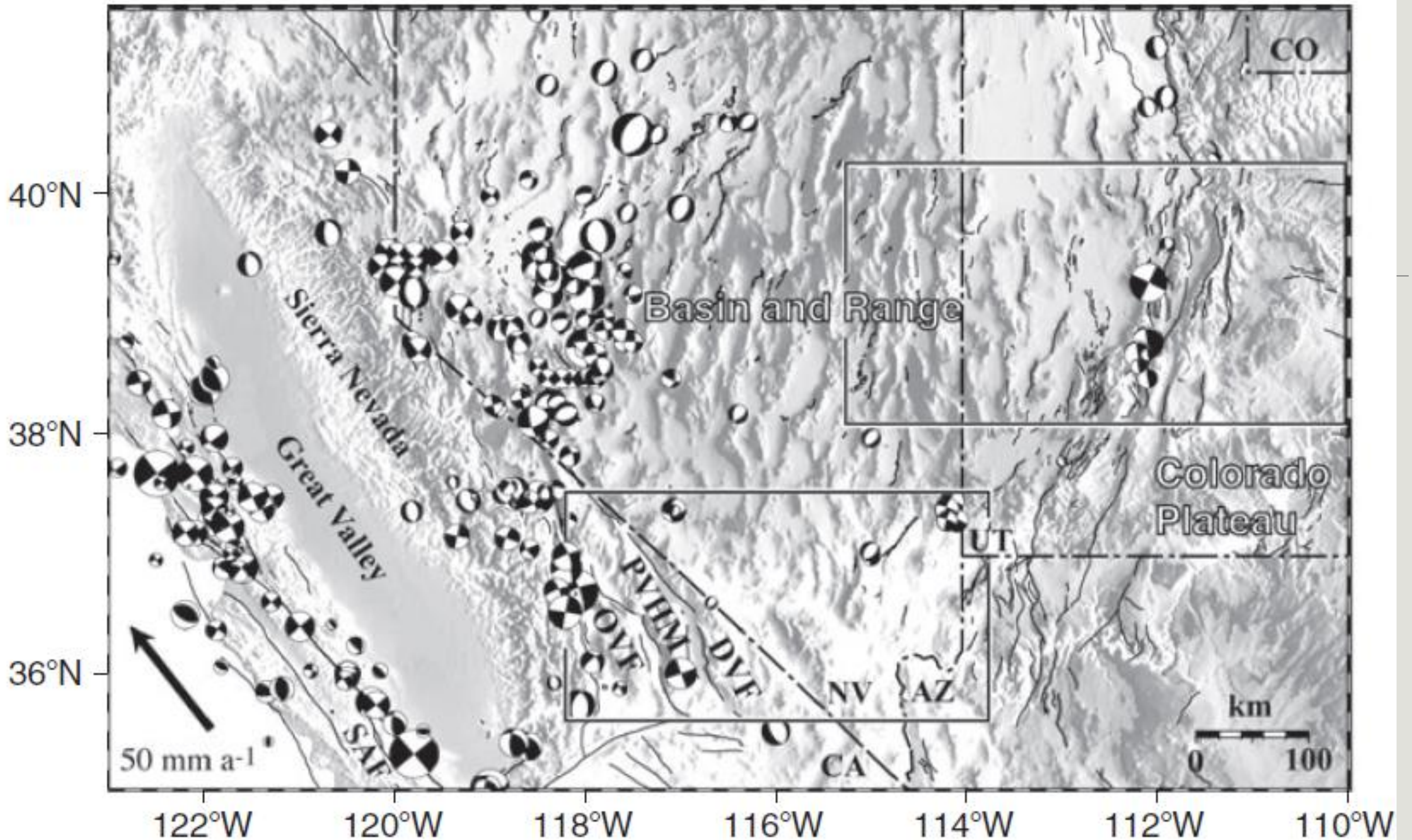
- **Basin and Range Province**: Extensive crustal stretching with metamorphic core complexes.



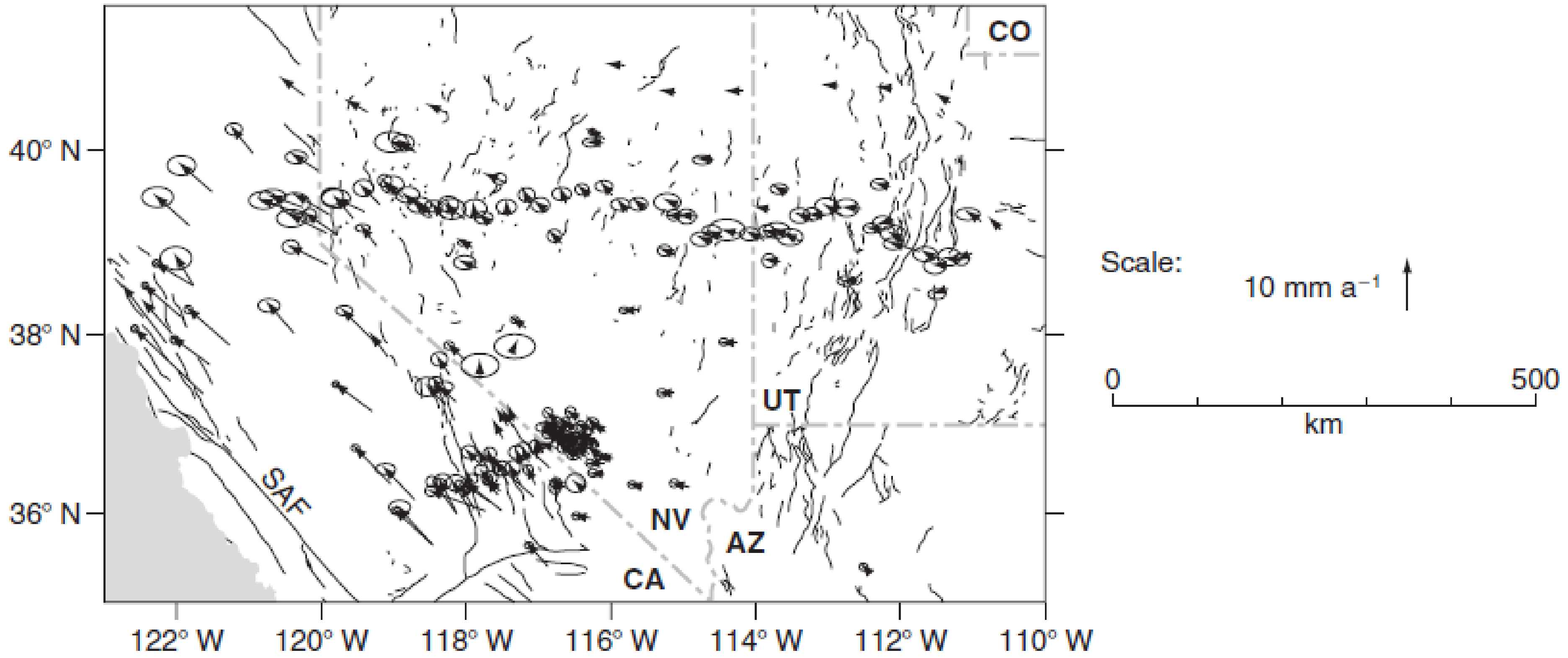
Shaded relief map of the western United States showing topography and earthquakes with M ≥ 4.8 in the northern and central sectors of the Basin and Range. Circle radius is proportional to magnitude. The area outlined with a bold polygon encloses all major earthquakes that are associated with deformation of the Basin and Range.



Map showing the various tectonic provinces of the Basin and Range determined from geodetic and geologic data. Rates given are relative to the North American plate.



Shaded relief map of the northern Basin and Range showing major faults and earthquake focal SAF, San Andreas Fault. Northward translation of the Sierra Nevada–Great Valley microplate is accommodated by strike-slip motion on the Owens Valley (OVF), Panamint Valley–Hunter Mountain (PVHM), and Death Valley (DVF) fault zones.



GPS velocities of sites in the Sierra Nevada–Great Valley microplate, northern Basin and Range, and Colorado Plateau with respect to North. Error ellipses represent the 95% confidence level. Velocity estimates were derived from continuous GPS data from GPS networks in and around the northern Basin and Range. SAF, San Andreas Fault.

Volcanic Activity and Mantle Dynamics

Volcanic activity is a common feature of continental rifting.

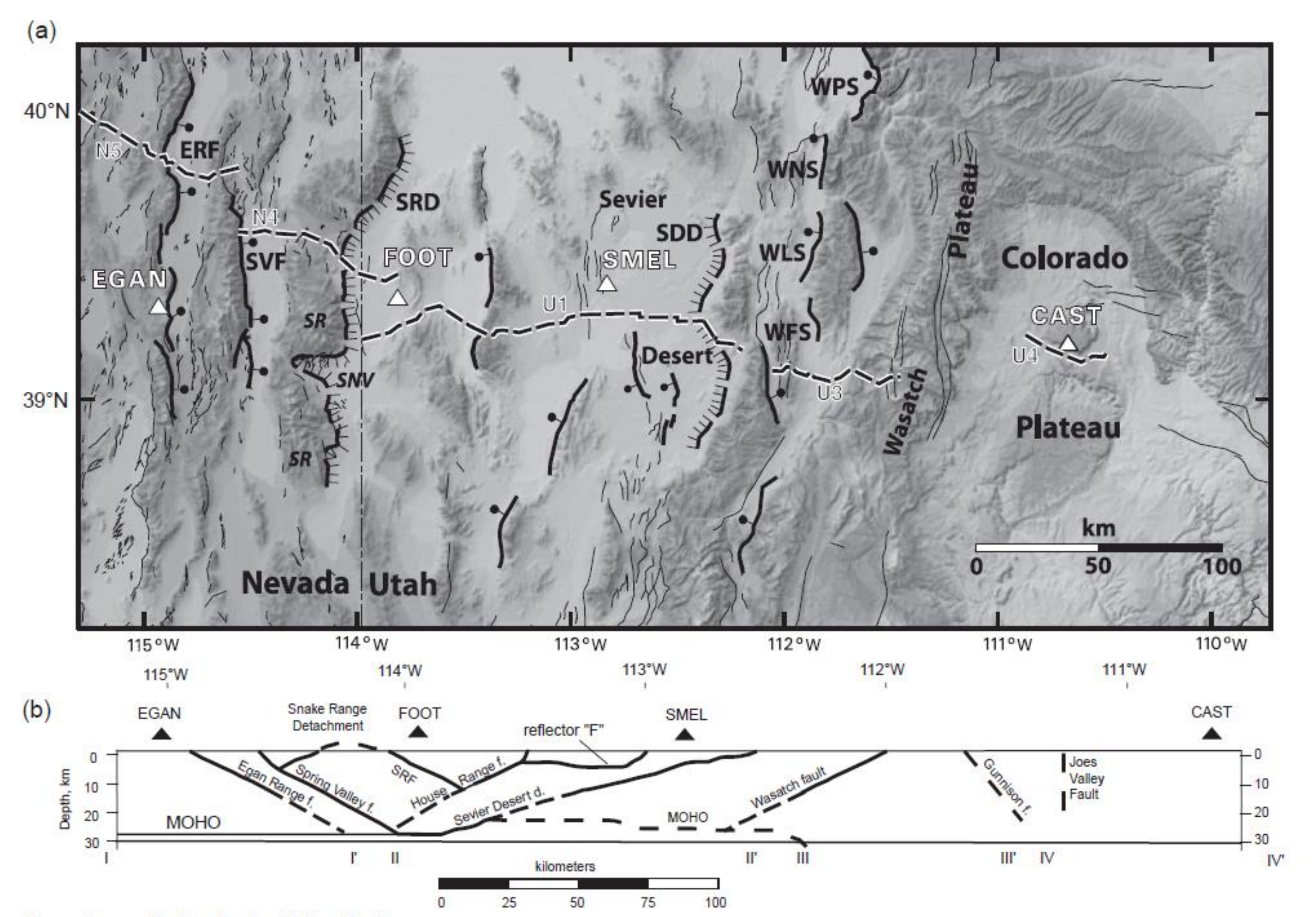
- **Large Igneous Provinces (LIPs)**:which are massive accumulations of flood basalts and silicic volcanic rocks found on volcanic rifted margins.(e.g., Deccan Traps, Columbia River Basalts). Associated with mantle plumes or hotspots.

- **Petrogenesis of Rift Rocks**: petrogenesis of rift-related rocks and the role of mantle upwelling beneath rifts. Magmas range from tholeititic to alkaline basalts. Partial melting of the mantle due to decompression.

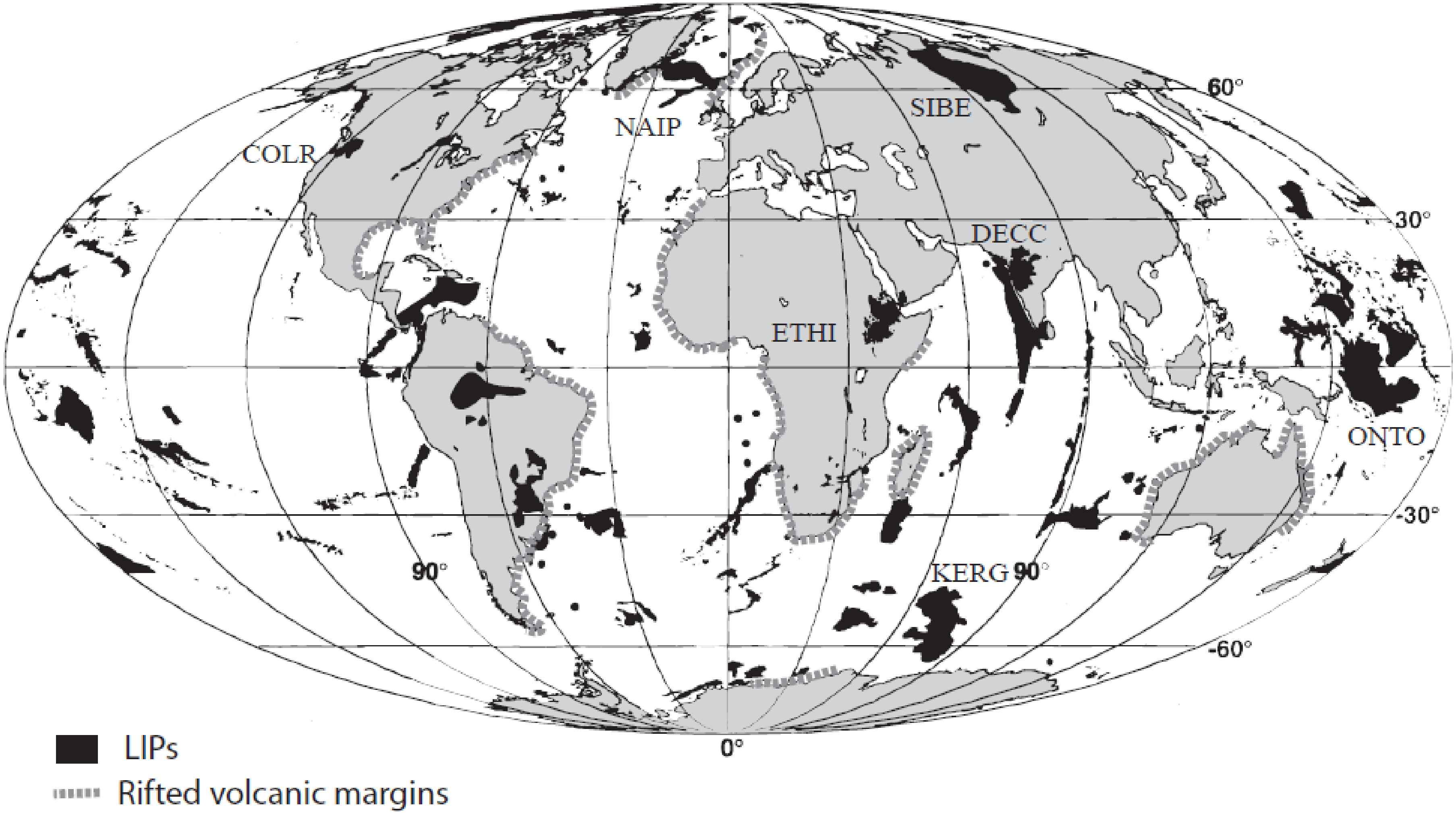
- **Mantle Upwelling**: Rifting is often accompanied by mantle upwelling, leading to volcanic activity. The upwelling is a key mechanism for heat transfer that contributes to the thinning and weakening of the lithosphere.

Rift Initiation : Rifting can be triggered by:

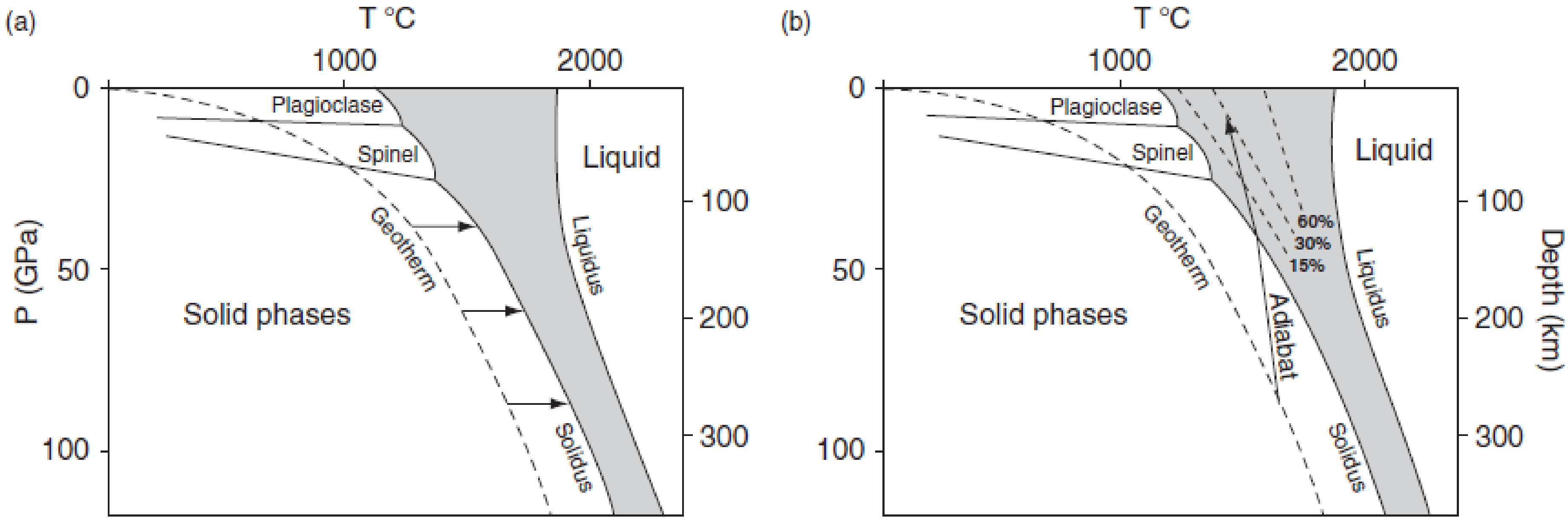
- **Mantle Plumes**: Thermal weakening of the lithosphere.
- **Far-Field Stresses**: Tectonic forces from plate boundaries.
- **Pre-Existing Weaknesses**: Ancient suture zones or faults.



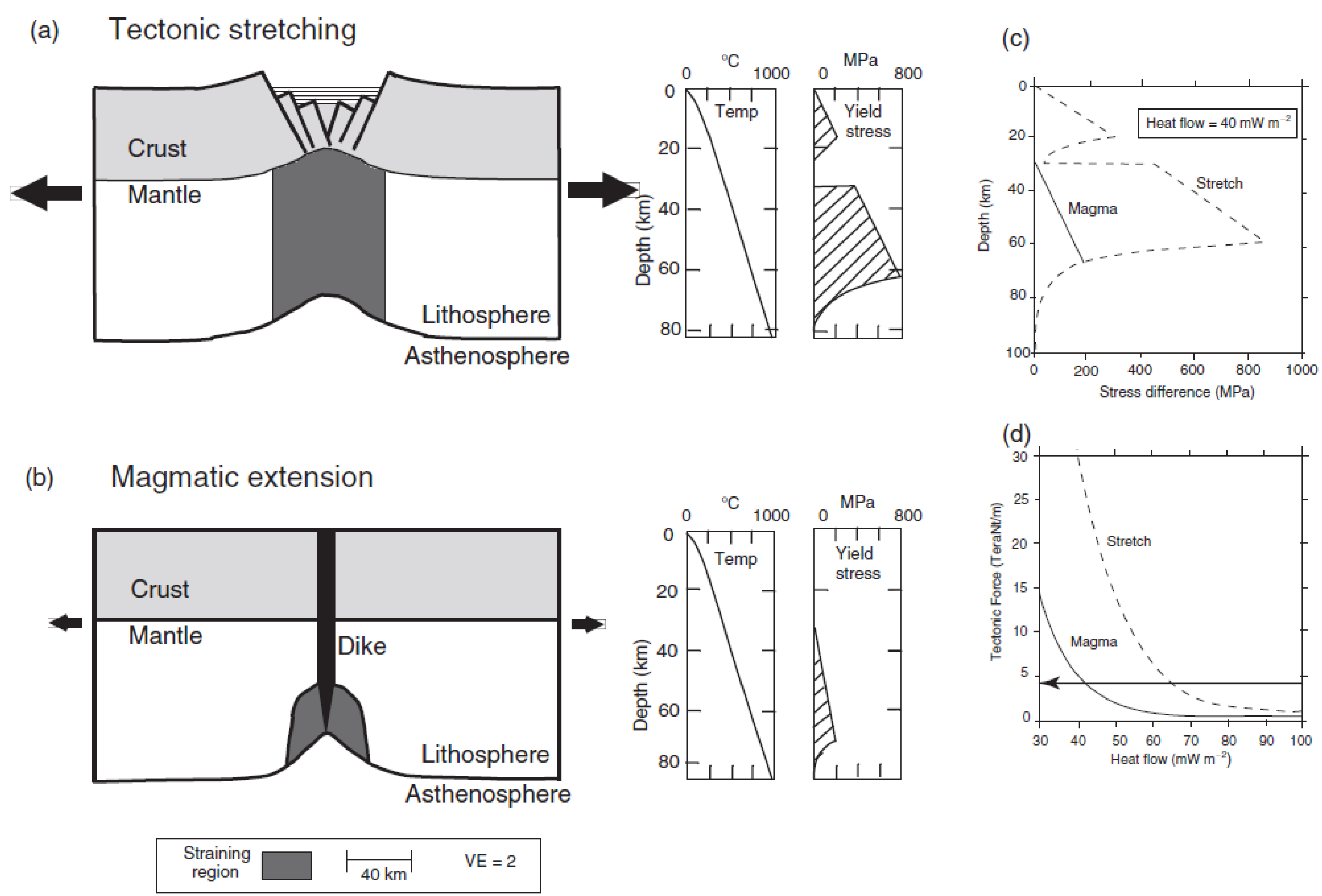
a) Shaded relief map of a part of the eastern Basin and Range showing range-bounding faults and locations of seismic reflection profiles (black dashed lines) and GPS sites (white triangles). High-angle faults show ball and bar symbol in the hanging wall, low-angle faults show hachured pattern. Faults mentioned in the text include the Egan Range Fault (ERF), the Spring Valley Fault (SVF), the Sevier Desert Detachment (SDD), the Wasatch Fault Zone (WFS, WLS, WNS, WPS), and the Snake Range Detachment (SRD).
b)Cross-section (b) constructed using seismic reflection data



Map showing global distribution of Large Igneous Provinces. Rifted volcanic margins . Labeled LIPs: Ethiopian flood basalts (ETHI); Deccan traps (DECC); Siberian basalts (SIBE); Kerguelen plateau (KERG); Columbia River basalts (COLR); Ontong Java (ONTO); North Atlantic igneous province (NAIP).



(a) Melting by raising temperature. (b) Melting by decreasing pressure. melting occurs when the adiabat enters the shaded melting zone. Percentages of melting are shown.



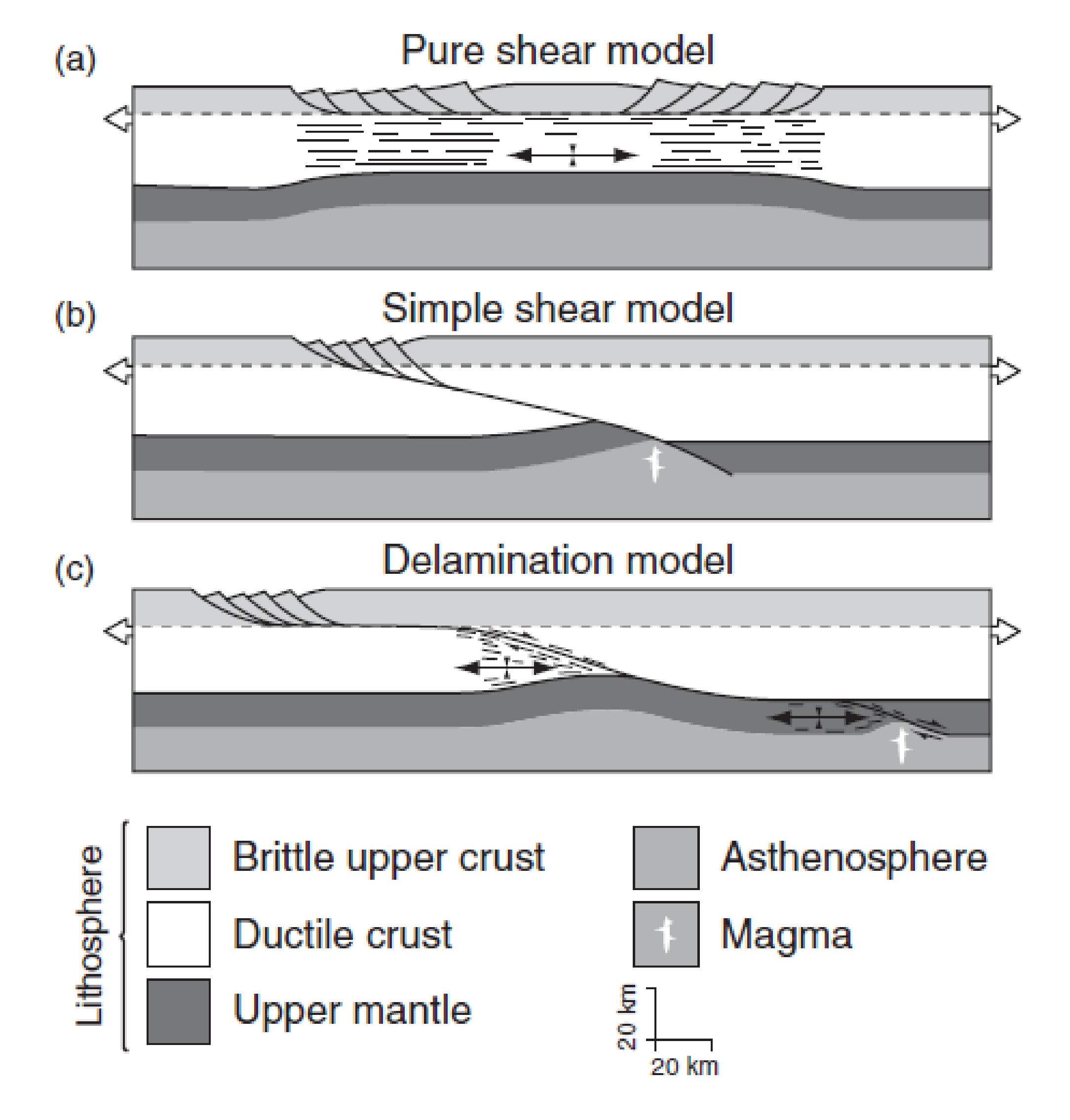
Sketches showing the difference between extension of thick lithosphere without (a) and with (b) magmatic intrusion by diking. Temperature and yield stress curves for each case are show to the right of the sketches. VE, vertical exaggeration. (c) Example of yield stresses for strain rate 10−14 s−1 for 30-km-thick crust. Solid line, stress difference for magmatic rifting; dashed line, stress difference for lithospheric stretching. (d) Tectonic force for rifting with and without magma as a function of heat flow. The bold black line in (d) shows the estimated value of driving forces

Strain Localization and Delocalization Processes

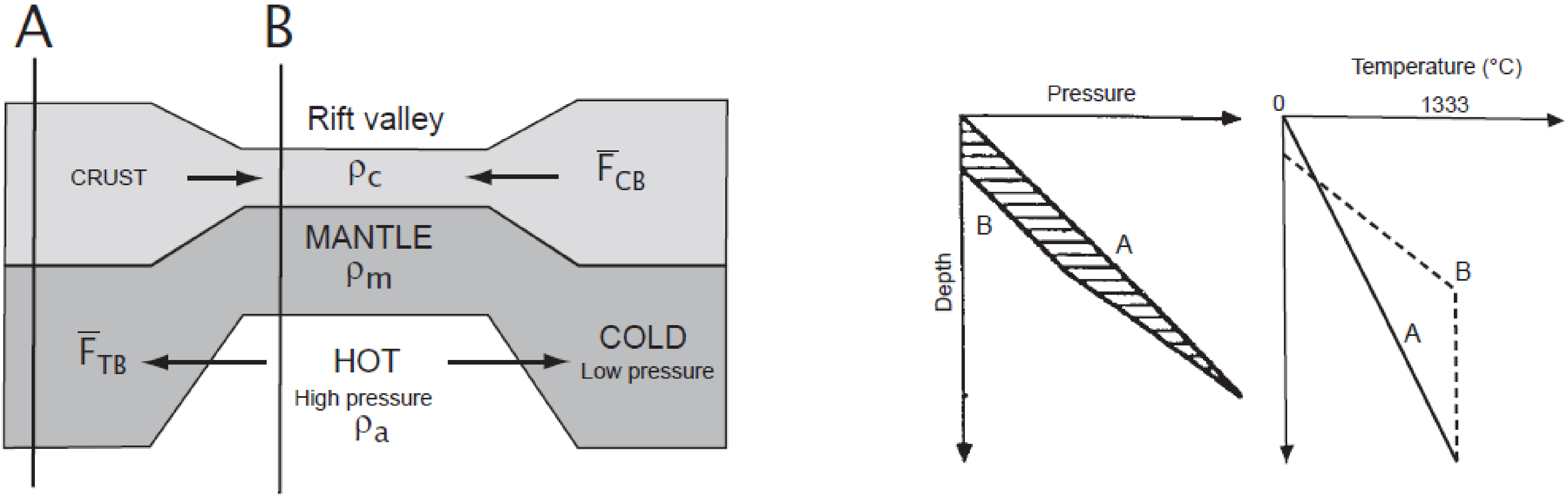
The rheological stratification of the lithosphere is crucial, with a strong upper crust and upper mantle sandwiching a weaker lower crust. The concentration of strain along the rift is influenced by factors such as:

Lithospheric Stretching: Initially distributed strain becomes localized into narrow rift zones.
Buoyancy Forces and Lower Crustal Flow: Ductile lower crust flows to compensate for thinning.
Lithospheric Flexure: Bending of the lithosphere due to loading or unloading.
Strain-Induced Weakening: Fault zones weaken due to repeated deformation.
Rheological Stratification: The lithosphere's strength varies with depth, influencing rift style.
Magma-Assisted Rifting: Magma intrusion reduces crustal strength, facilitating extension.

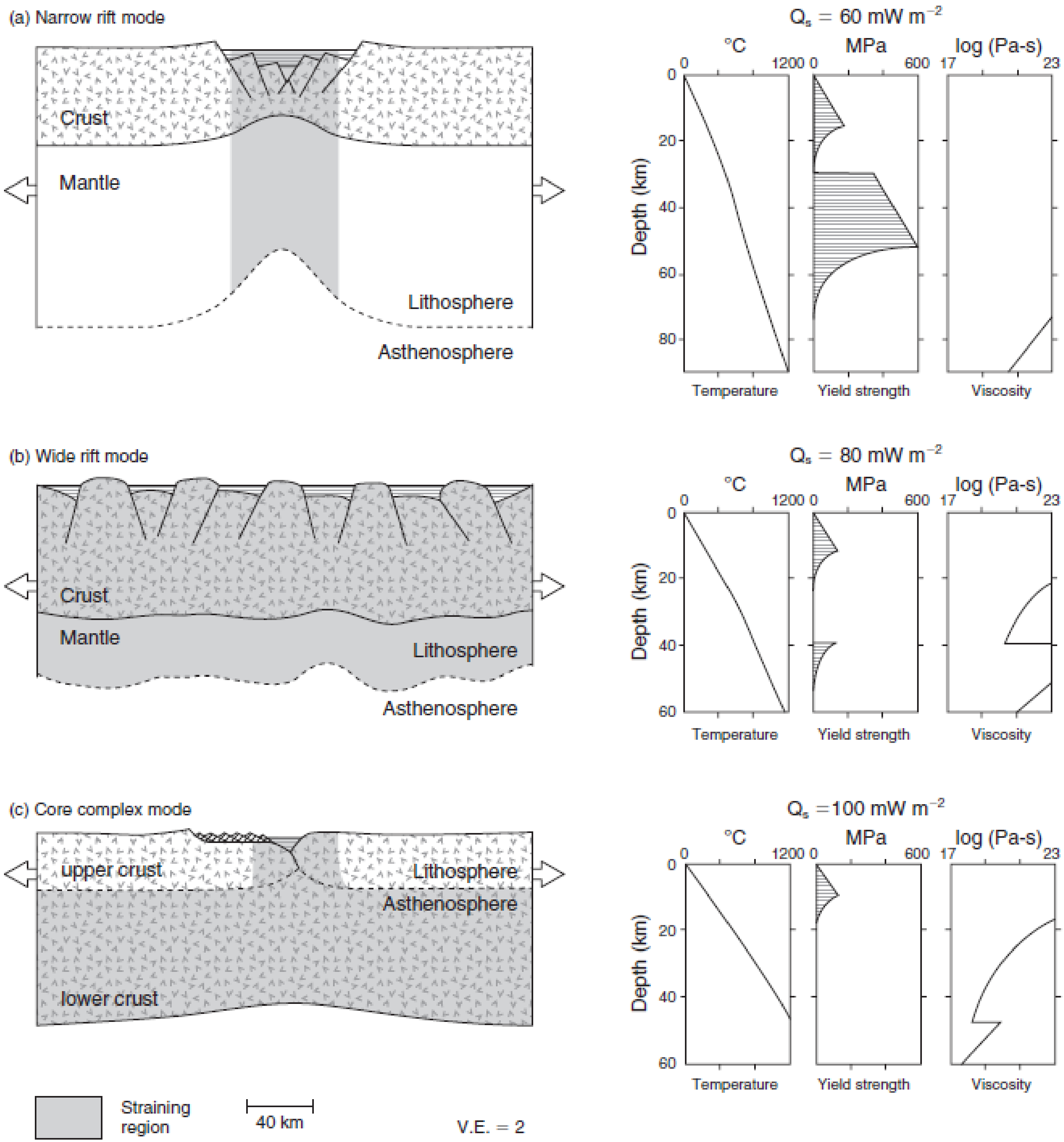
Note: **rheology is** *branch of physics that deals with the deformation and flow of matter, especially the non-Newtonian flow of liquids and the plastic flow of solids.*



Kinematic models of continental extension

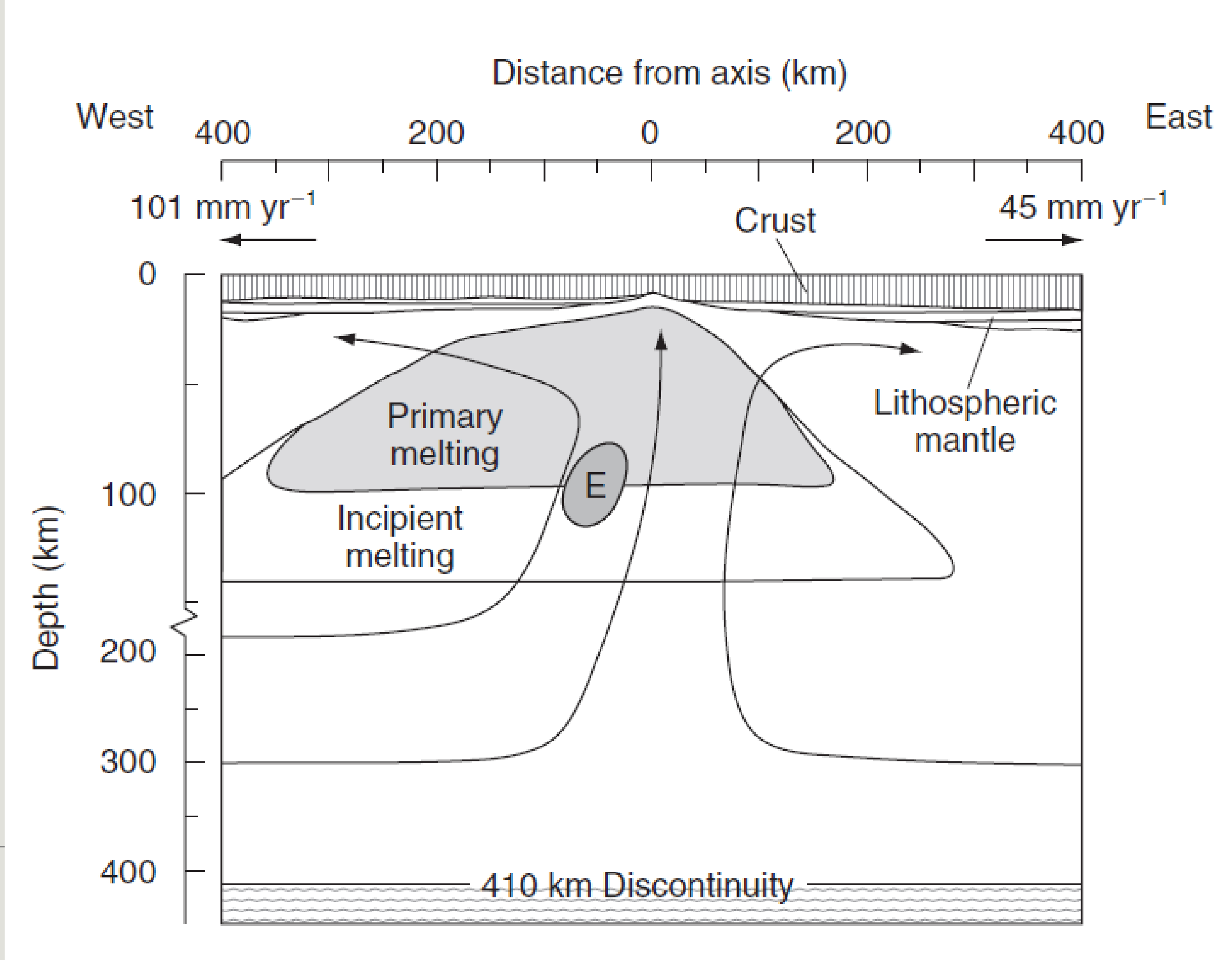


Schematic diagram illustrating thermal and crustal buoyancy forces generated during rifting. A and B represent vertical profiles outside and inside the rift valley, respectively. Pressure and temperature as a function of depth for each profile are shown to the right of sketch.

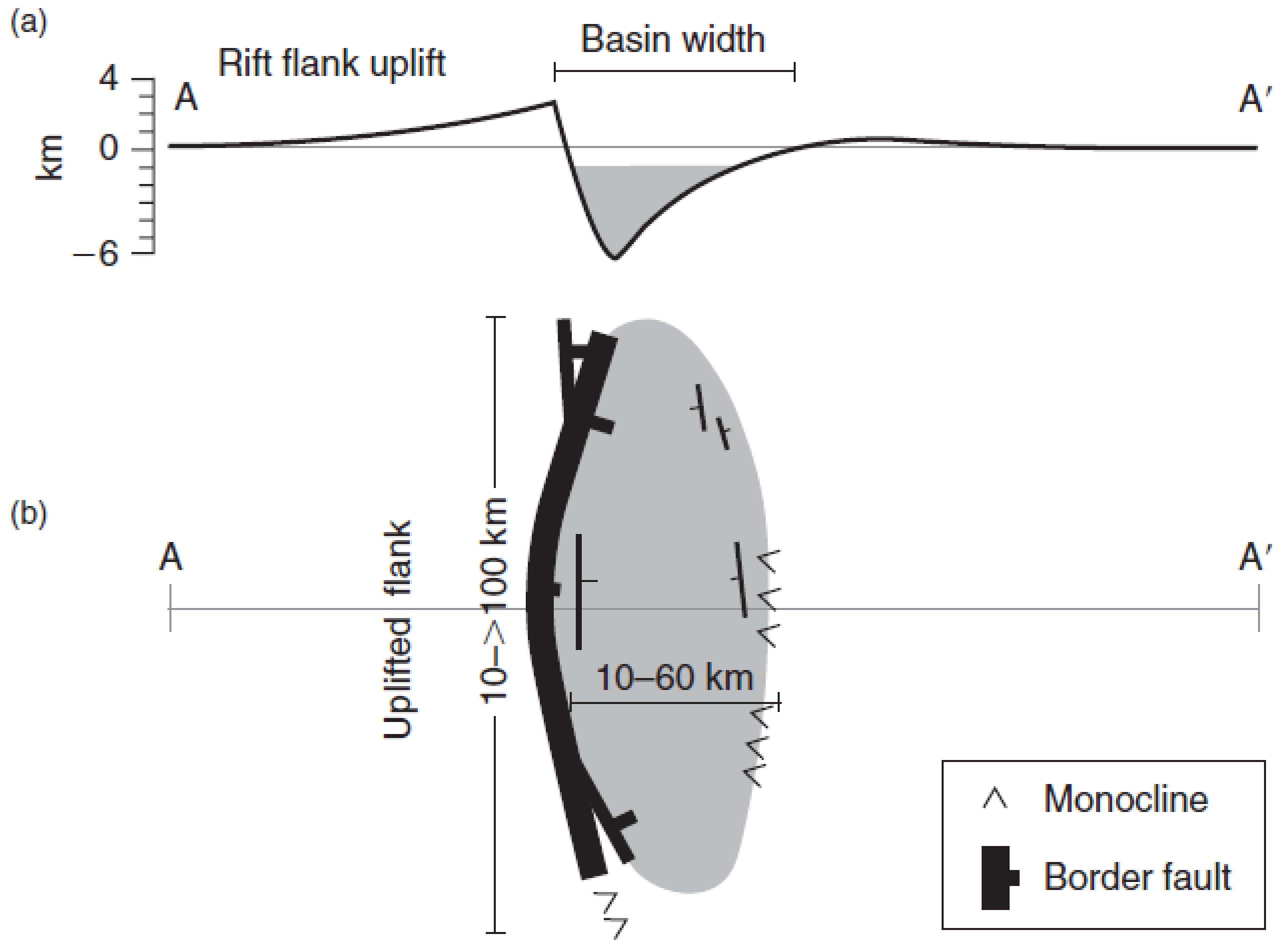


Sketches of the lithosphere illustrating three modes of extension emphasizing the regions undergoing the greatest amount of extensional strain.

(a) Narrow mode, (b) wide mode, (c) core complex mode. Lithosphere is defined as areas with effective viscosities of >1021 Pas^{-1}.



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.

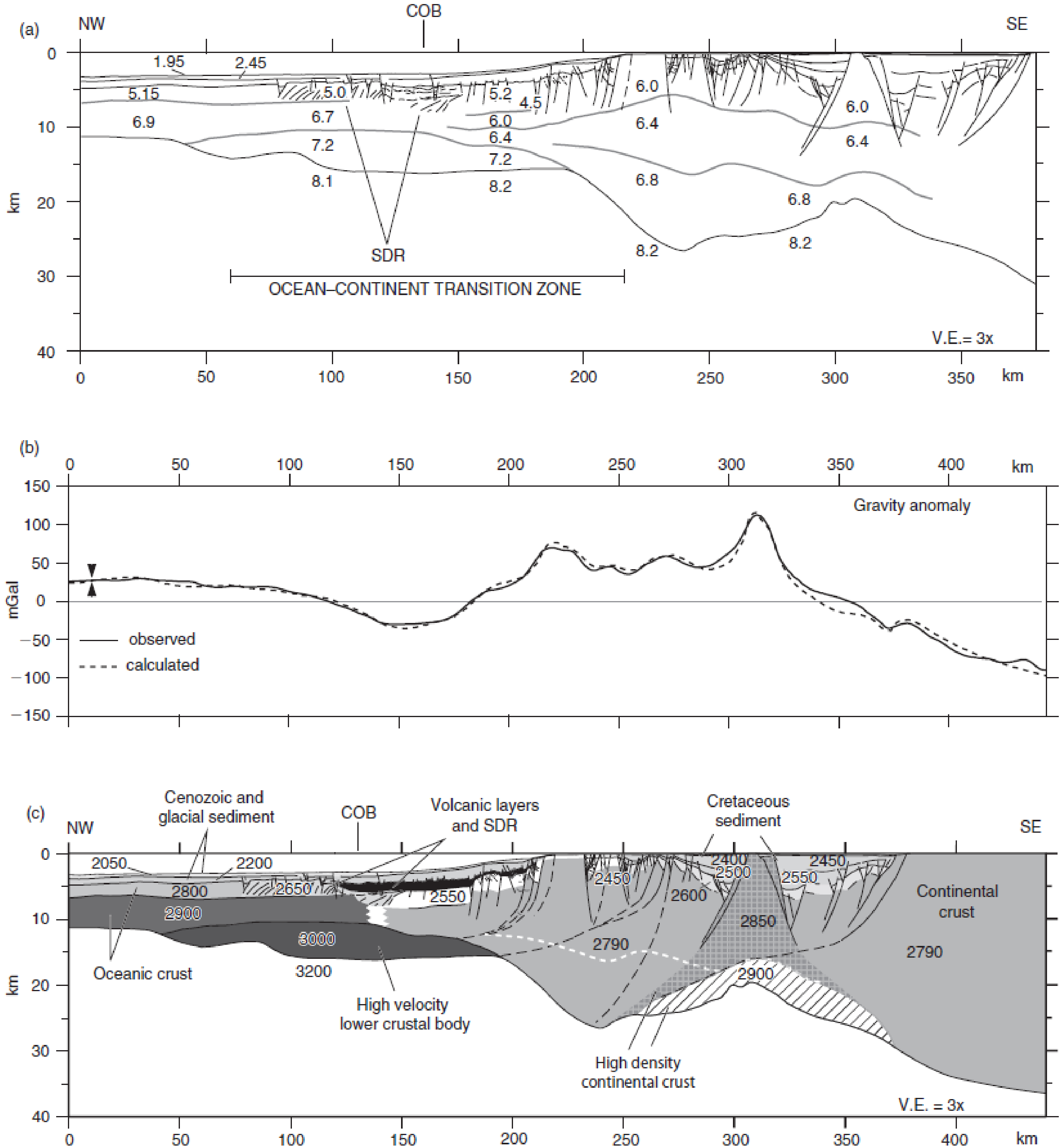


Generalized form of an asymmetric rift basin showing border fault in (a) cross-section and (b) plan view. Line of section (A–A′) shown in (b). Shading in (b) shows areas of depression.

Rifted Continental Margins

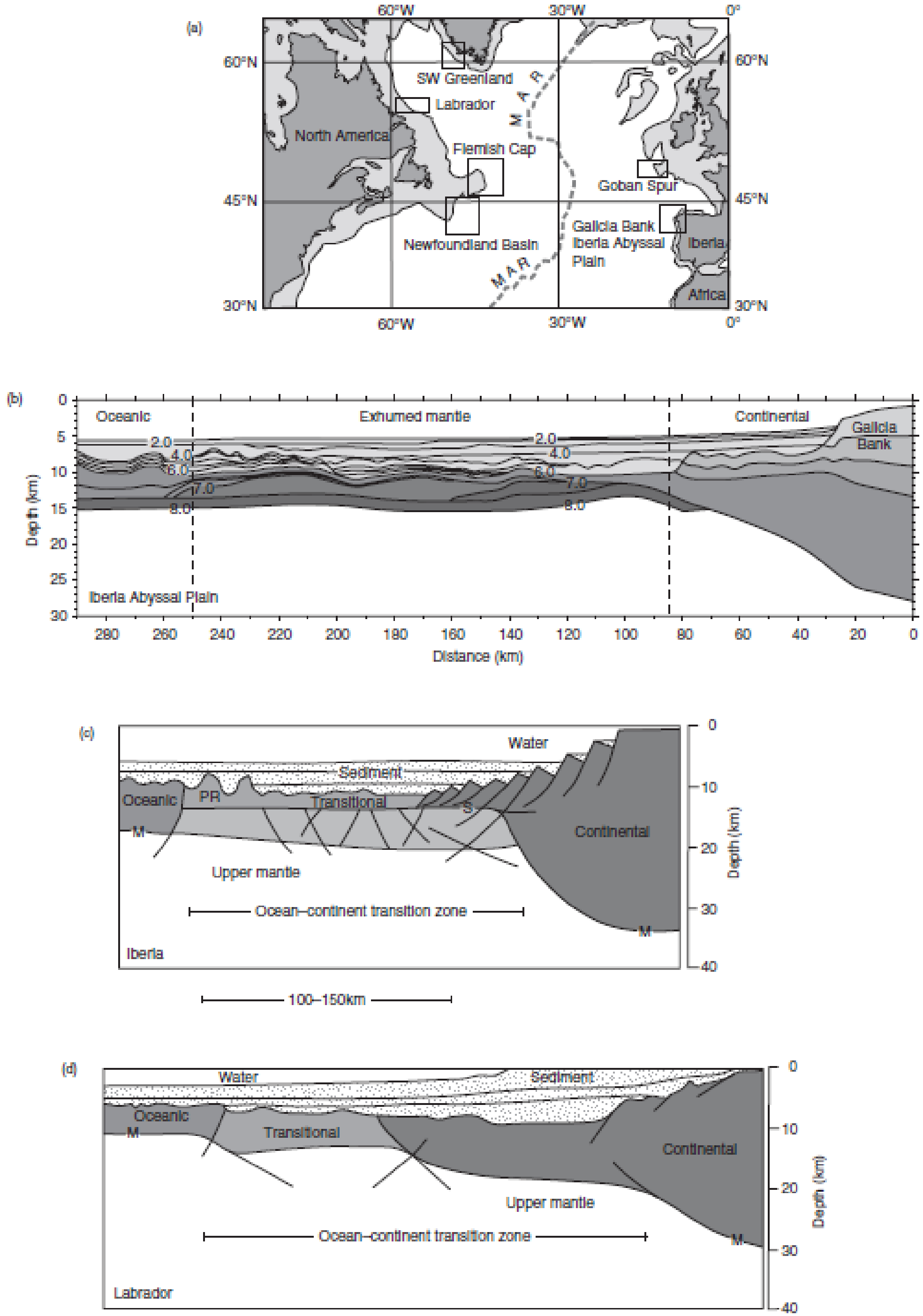
- ❑ **Volcanic Margins**:
  - ✓ Characterized by thick volcanic sequences (e.g., thick flood basalts, high-velocity lower crust, and seaward-dipping reflectors.). The high-velocity lower crust is interpreted as an accumulation of gabbroic intrusions. The Lofoten–Vesterålen margin off Norway is provided as a case study
  - ✓ Example: North Atlantic margins.
- ❑ **Nonvolcanic Margins**:
  - ✓ Lack significant volcanism such as large igneous provinces and seaward-dipping reflectors extension is accommodated by faulting. They are characterized by a narrow continental shelf and a steep ocean-continent transition zone. An example of a nonvolcanic margin is the Ivory Coast–Ghana margin.
  - ✓ Example: Iberia-Newfoundland margin.

- ❑ **Evolution of Rifted Margins**:
  - ✓ Progresses from rift initiation to continental breakup and seafloor spreading.



a) Seismic velocity structure along the southern Lofoten–Vesterålen margin. COB, continent–ocean boundary.

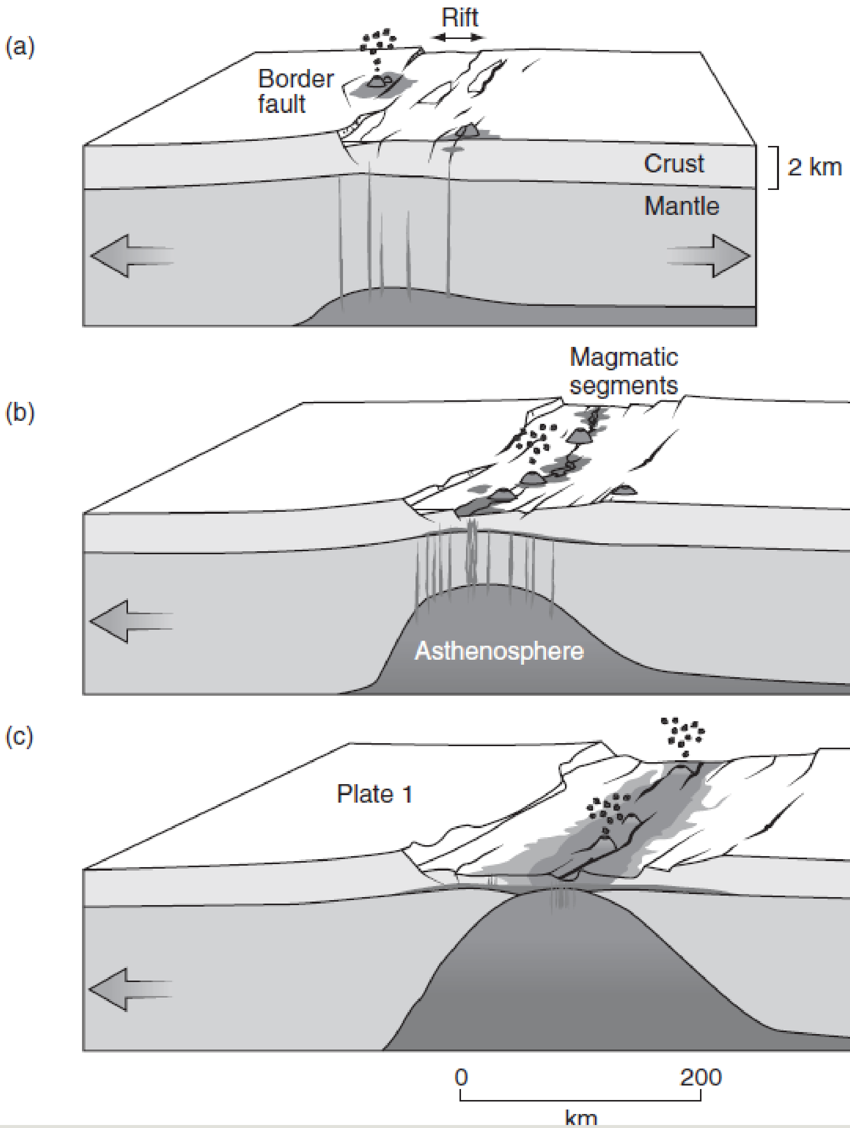
(b,c) Gravity modeled transect and interpretation of the geology. Densities in (c) are shown in kilograms per cubic meter. SDR, seaward dipping reflectors



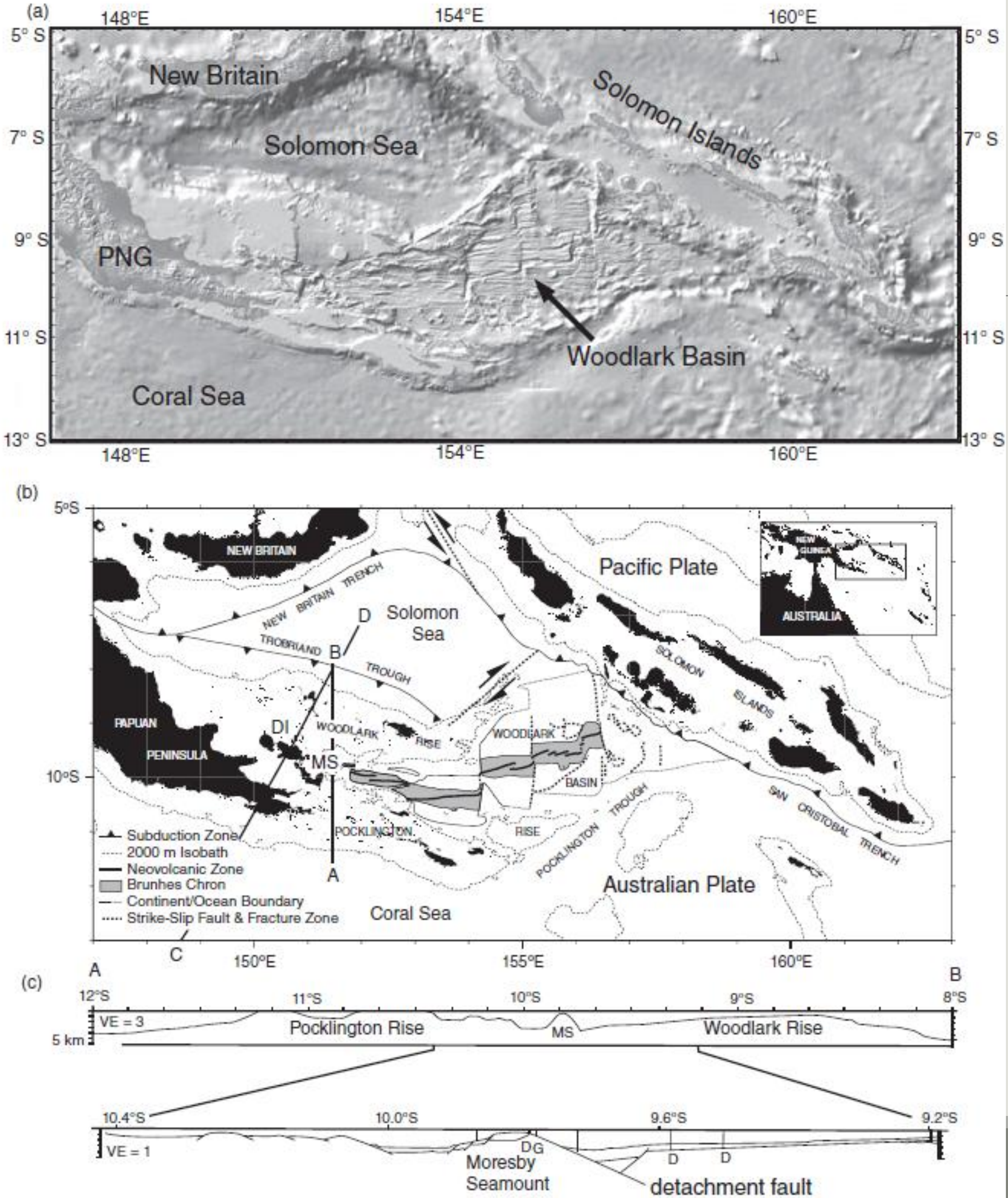
(a) Map of the North Atlantic showing location of selected nonvolcanic margins. MAR, Mid-Atlantic Ridge.
(b) Velocity model of the West Iberia margin and the Iberia Abyssal. The dashed lines mark the approximate edges of the ocean–continent transition zone. Velocities in km s^{-1}.
(c,d) Two end-member types of nonvolcanic margin. PR, peridotite ridge; S, reflections interpreted to represent a detachment fault or shear zone; M, Moho reflections.

Case Studies

- **East African Rift System**:
  - ✓ An active rift transitioning from continental rifting to incipient ocean formation.
- **Woodlark Rift (Papua New Guinea)**:
  - ✓ An example of continental breakup transitioning to seafloor spreading.



Three-stage model for continental break-up leading to the formation of a volcanic passive margin

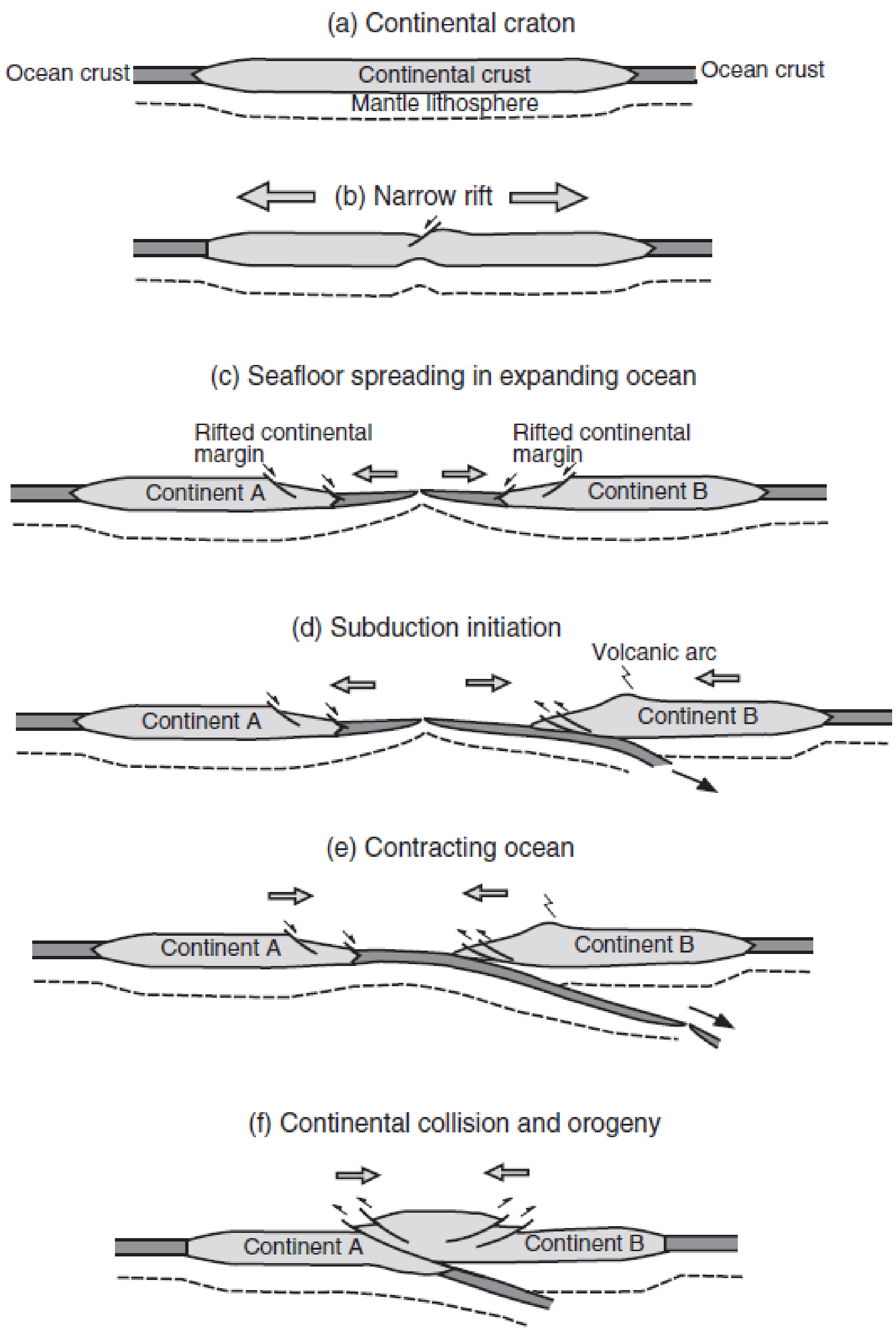


(a) Shaded relief map constructed. (b) Tectonic map of eastern Papua New Guinea (PNG) and the Solomon Islands showing present-day tectonic setting and (c) cross-section (A–B) of western Woodlark Rift showing topography and detachment fault DI, D' Entrecasteaux Islands; MS, Moresby Seamount; D, dolerite; G, gabbro

The Wilson Cycle

It is a model that describes the cyclical opening and closing of ocean basins.

Continental rifting and the formation of rifted margins are the initial stages of this cycle, which progresses through the creation of an ocean, its eventual closure through subduction, and culminates in continental collision. The East African Rift system and the Woodlark Rift are presented as case studies for the transition from rift to rifted margin, illustrating these initial steps.



The Wilson cycle showing:

(a) continental craton;

(b) formation of a narrow rift;

(c) initiation of seafloor spreading and formation of rifted continental margins in an expanding ocean basin;

(d) initiation of subduction;

(e) a closing ocean basin;

(f) continental collision and orogeny.