Global Tectonics
G404
Lecture-8

Instructor
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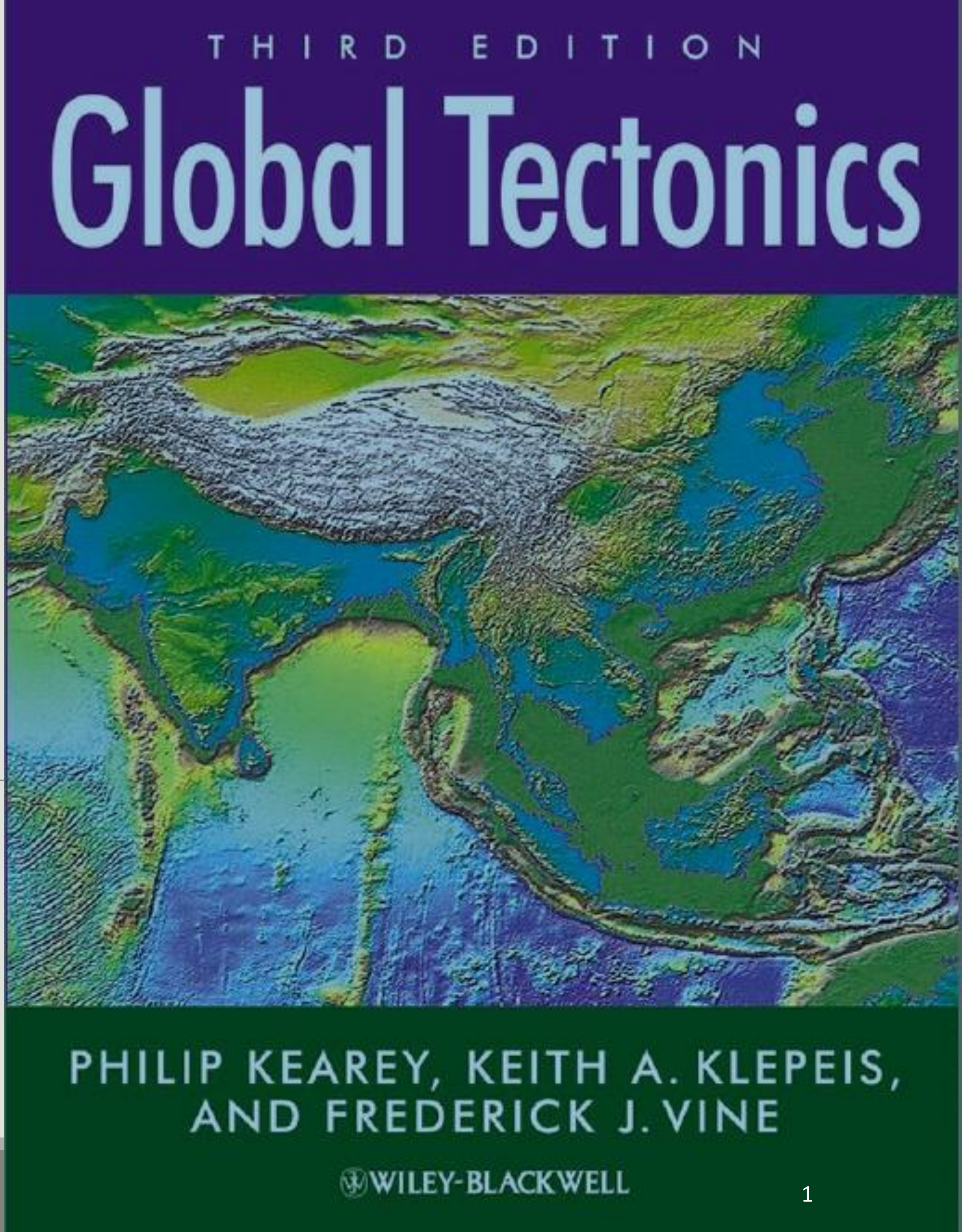
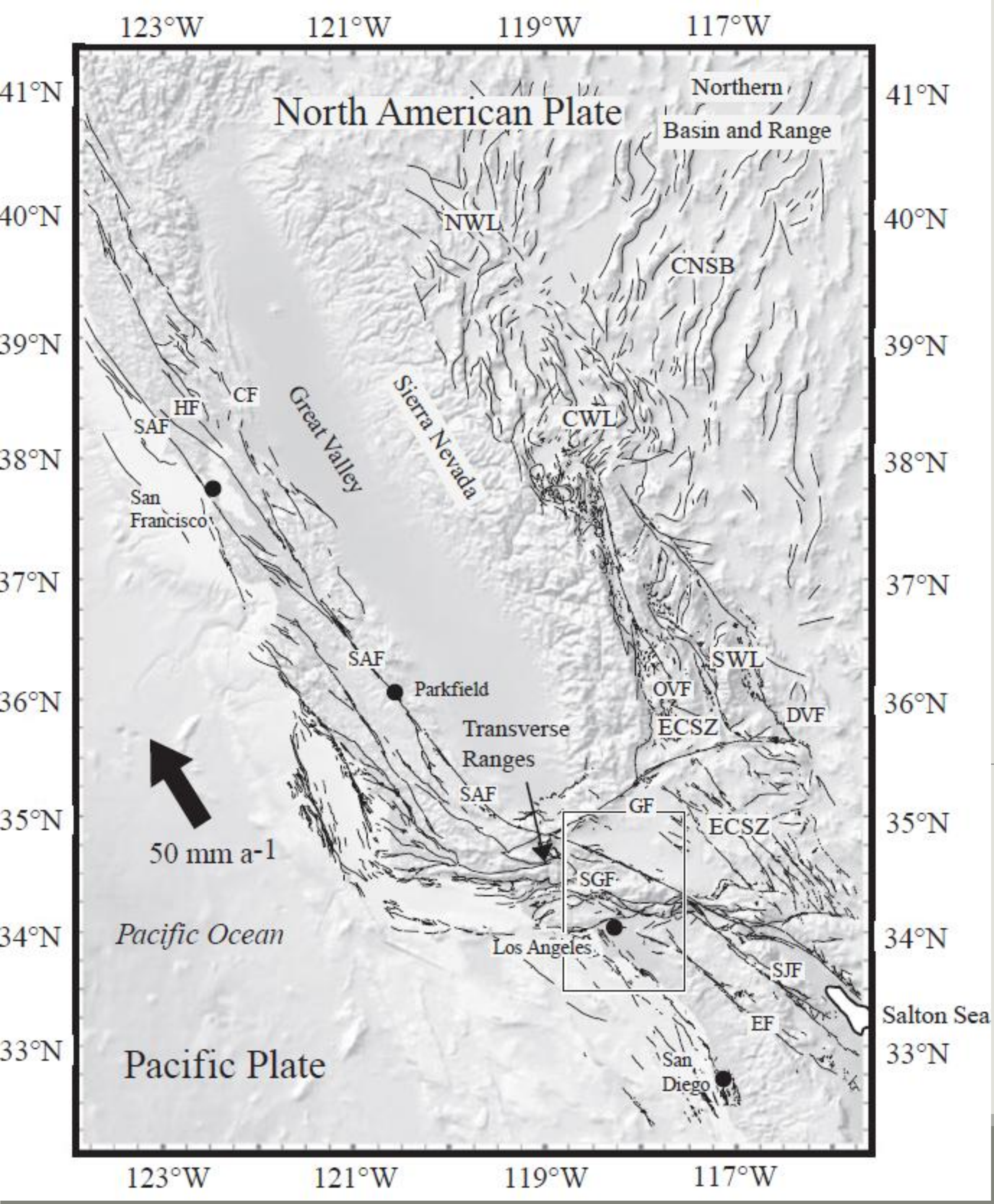


Chapter 8: Continental Transforms and Strike-Slip Faults

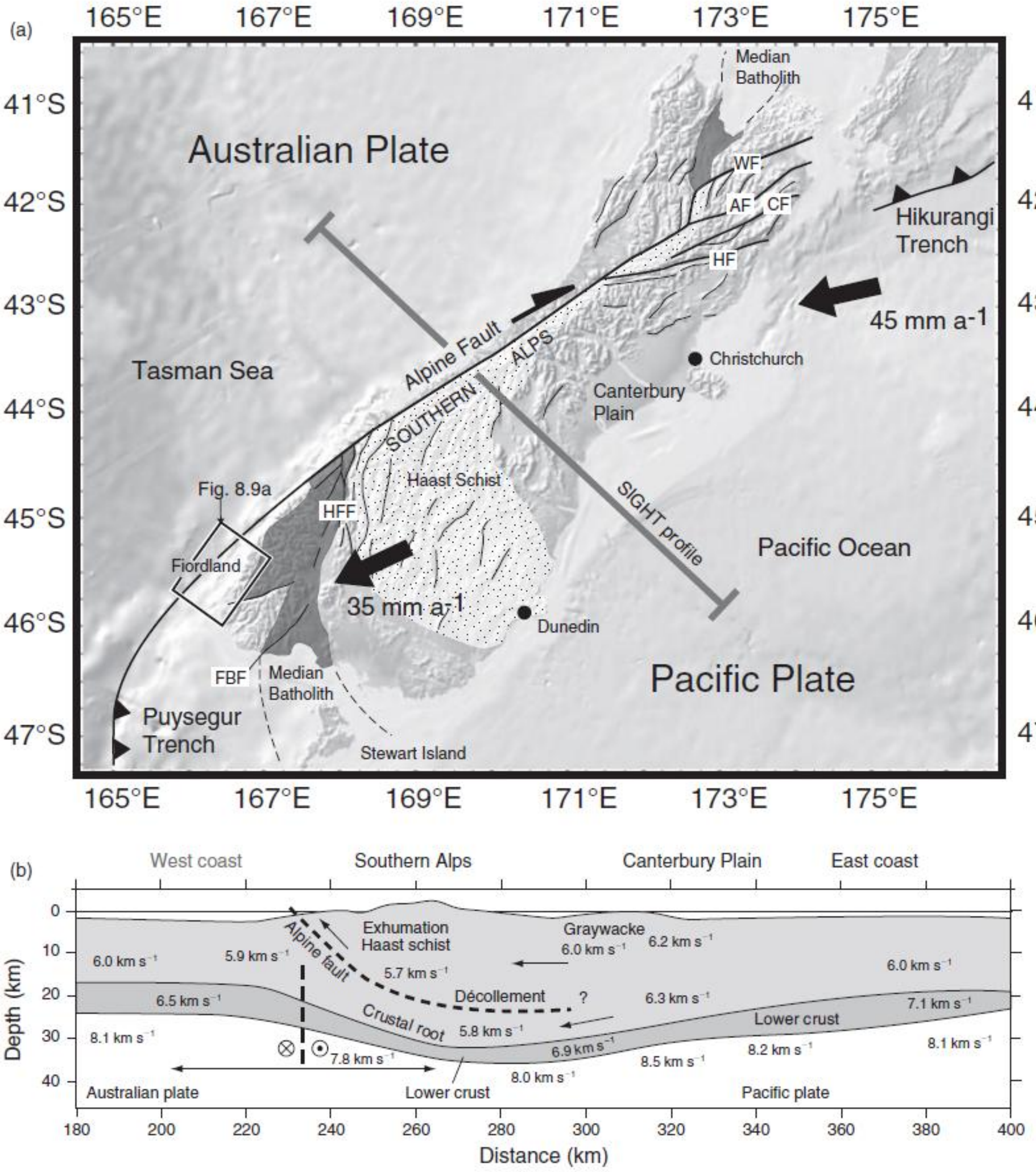
Definition and Characteristics:

Continental transforms are conservative plate boundaries where lithosphere is neither created nor destroyed, resulting in lateral displacements via strike-slip deformation. Unlike oceanic transforms, continental transforms exhibit complex structures due to variations in lithospheric thickness, composition, and thermal profiles. Examples: San Andreas Fault (USA): Motion distributed across a 1000-km-wide zone. Alpine Fault (New Zealand): Oblique convergence creates a >100-km-wide deformation zone. Dead Sea Transform (Middle East): Narrow (20–40 km) zone in cool, strong lithosphere.

Deformation Zones: The width of the deformation zone along continental transforms varies. In areas with weak continental lithosphere, such as the southwestern United States and New Zealand, the zone of deformation can be hundreds to thousands of kilometers wide. Conversely, in regions with strong, cool lithosphere, like the Dead Sea Transform, deformation is localized in a much narrower zone, approximately 20-40 km wide



Shaded relief map showing major faults and topographic features in California and western Nevada. SAF, San Andreas Fault; HF, Hayward Fault; CF, Calaveras Fault; GF, Garlock Fault; SGF, San Gabriel Fault; EF, Elsinore Fault; SJF, San Jacinto Fault; ECSZ, Eastern California Shear Zone; OVF, Owens Valley Fault; DVF, Death Valley Fault; CNSB, Central Nevada Seismic Belt. SWL, CWL, and NWL are the southern, central, and northern Walker Lane, respectively.



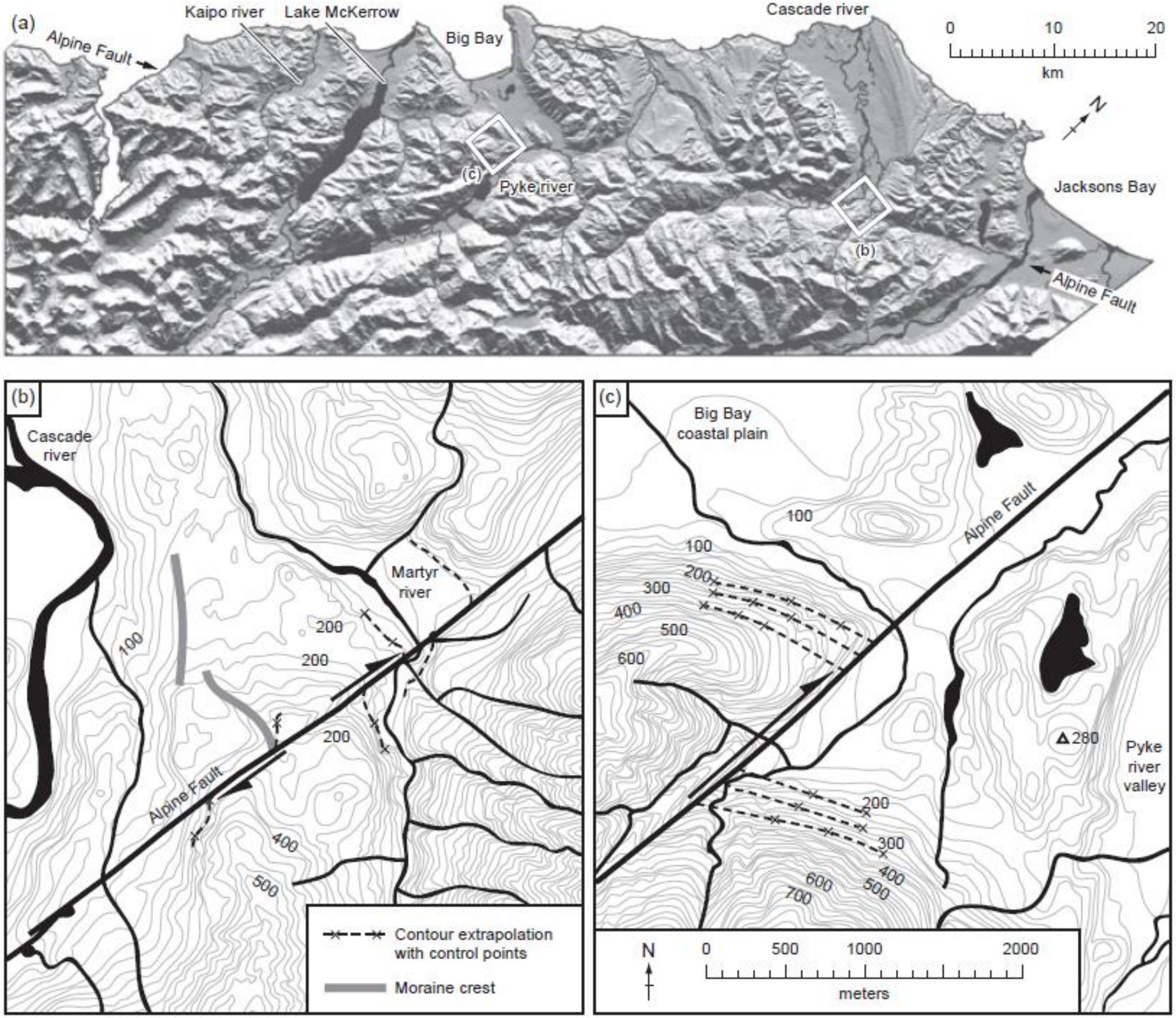
(a) Shaded relief map showing major faults and tectonic features of the Australian-Pacific plate boundary on the South Island of New Zealand. WF, Wairau Fault; AF, Awatere Fault; CF, Clarence Fault; HF, Hope Fault; HFF, Hollyford Fault; FBF, Fiordland Boundary Fault.

(b) Seismic velocity profile constructed without vertical exaggeration

Fault Styles and Physiography
Continental transforms display distinct surface and upper-crustal features:

1. **Linear Fault Scarps and Offsets**: Active strike-slip faults often create linear scarps and troughs due to erosion. The lateral movement along the fault can offset surface features like rivers, glacial moraines, and valleys, which can be used to determine slip rates. For instance, the Alpine Fault in New Zealand has offset topographic features and has an estimated slip rate of 21-24 mm per year. Vertical motion creates pressure ridges (uplift) and sag ponds (subsidence).

2. **Step-Overs, Push-Ups, and Pull-Apart Basins**: Most large strike-slip faults are segmented. Where a fault segment terminates near another, motion is transferred across the gap, leading to localized extension or contraction. Pull-apart basins are extensional troughs formed in releasing step-overs, which are characterized by tension. An example is the Río Lempa pull-apart basin in El Salvador, which has formed between the San Vicente and Berlin fault segments. Push-ups are topographic uplifts that form in restraining step-overs, where the intervening region is compressed. Mt. Diablo in northern California is a prominent example, having formed between the Greenville and Concord faults. The uplift rate there is comparable to the slip rates on the adjacent faults.



(a) Shaded relief map and (b, c) 1 : 50,000 topographic maps showing linear scarp and offset surface features along a segment of the Alpine Fault on the South Island of New Zealand. Curved bold black lines in (b) and (c) are rivers or creeks. Contour interval is 20 m.

3. Strike-Slip Duplexes and Flower Structures:

- ✓ **Duplexes**: Imbricate fault-bounded blocks (lens-shaped basins or uplifts).
- ✓ **Flower Structures**: Fault splays converge downward; **positive** (reverse faults) or **negative** (normal faults).

4. Strike-Slip Partitioning:

- ✓ Oblique motion splits into strike-slip and dip-slip components.

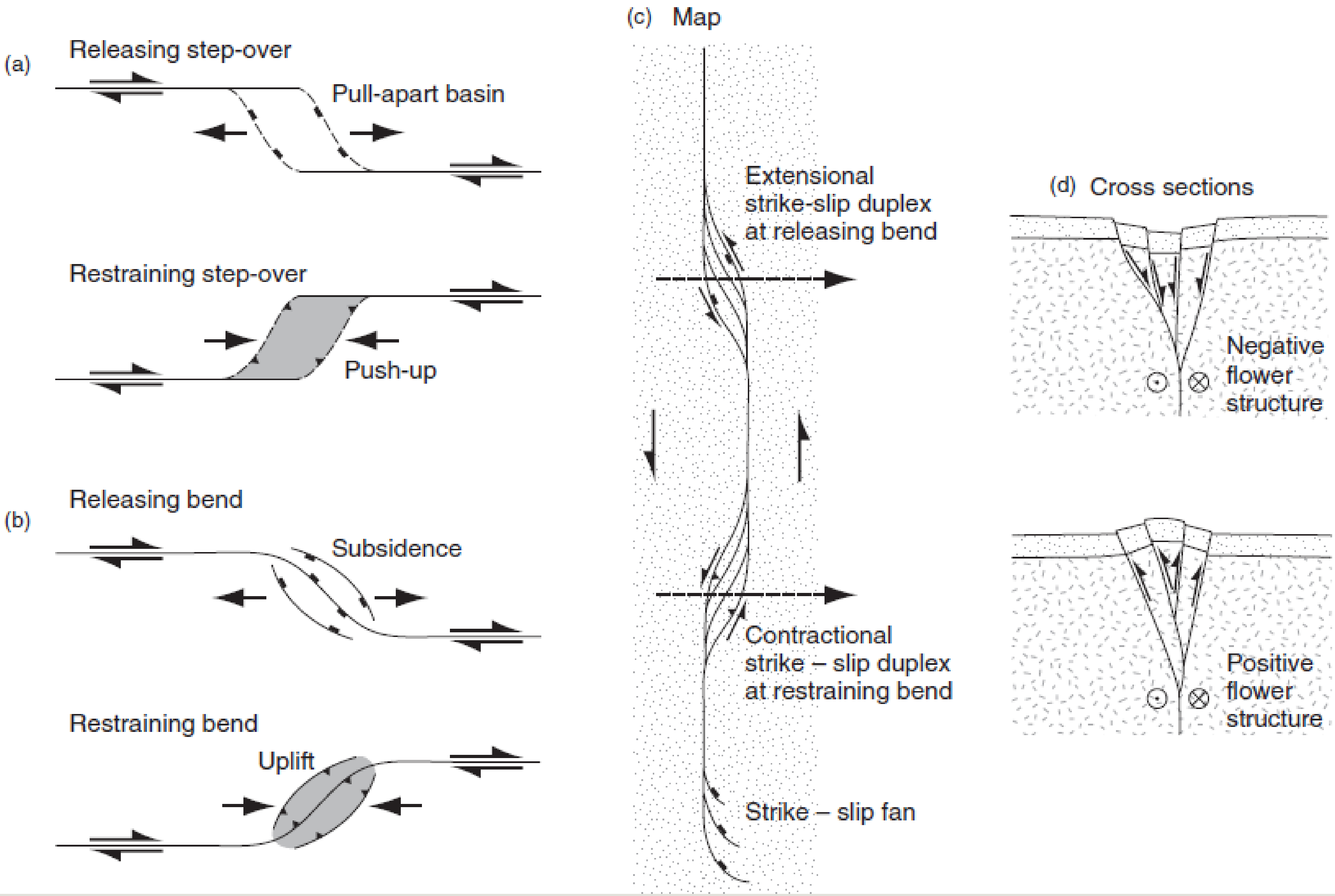
  Example: Alpine Fault (New Zealand) separates pure strike-slip (Fiordland) from oblique thrusting (central segment).

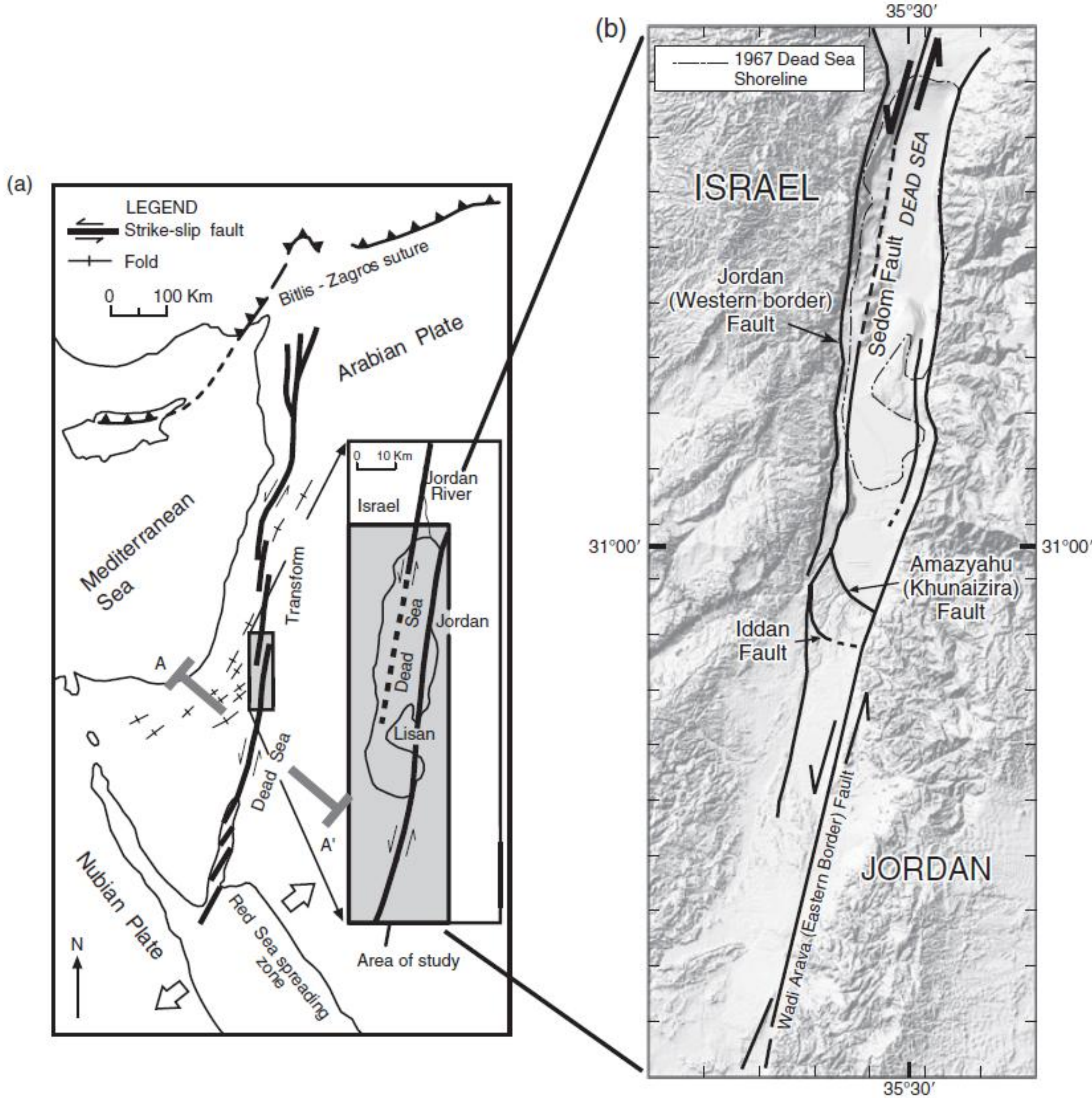
Bends: Similar to step-overs, continuous strike-slip faults can have local curves or bends that create zones of shortening and extension.

•**Releasing bends** are characterized by subsidence, pull-apart basins, and normal faults.

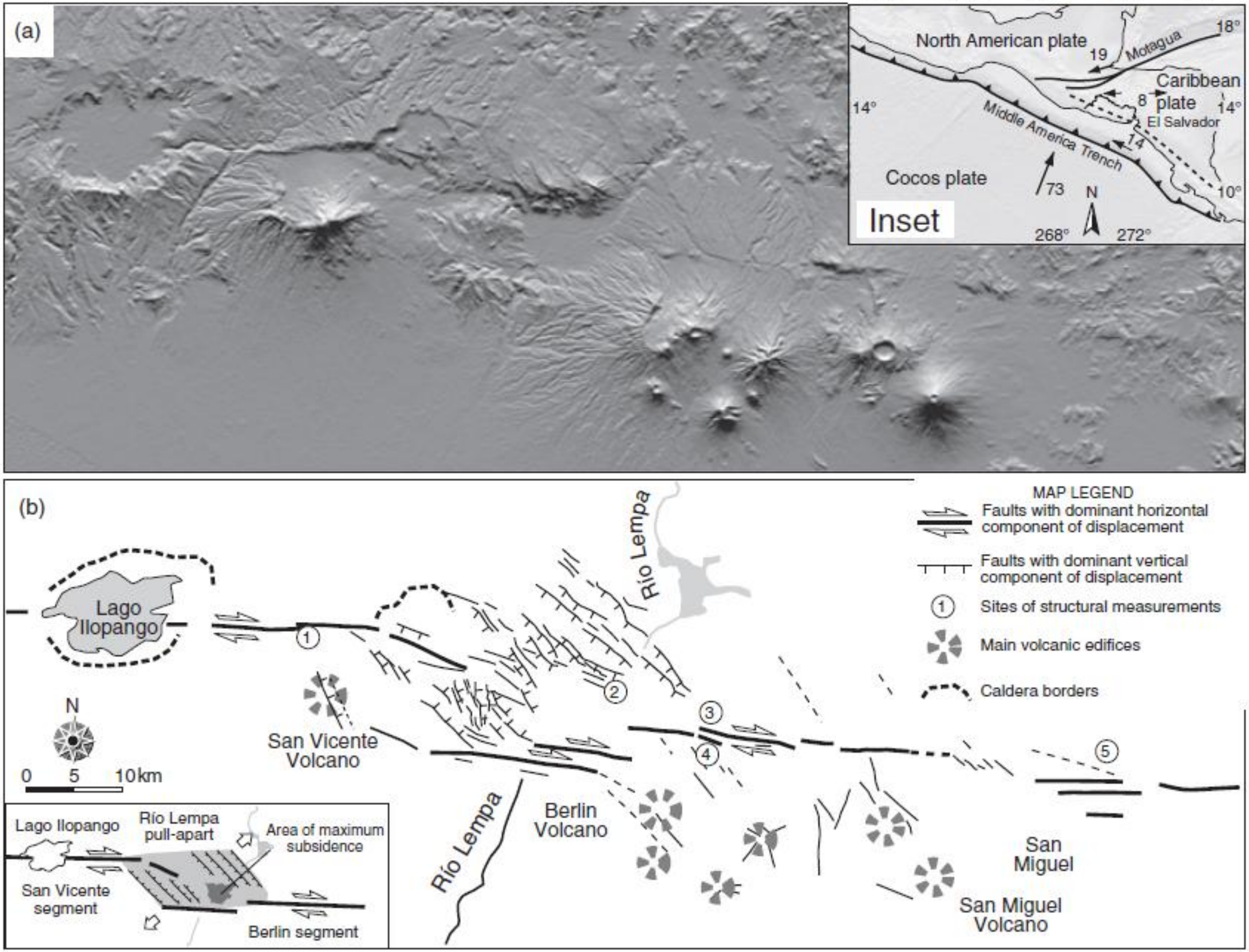
•**Restraining bends** display uplift, folds, thrust faults, and push-ups. These structures are often referred to as

flower structures, with a negative flower structure associated with releasing bends and a positive flower structure associated with restraining bends.


(a)
Releasing step-over
Pull-apart basin
Restraining step-over
Push-up
(b)
Releasing bend
Subsidence
Restraining bend
Uplift
(c) Map
Extensional strike-slip duplex at releasing bend
Contractional strike – slip duplex at restraining bend
Strike – slip fan
(d) Cross sections
Negative flower structure
Positive flower structure



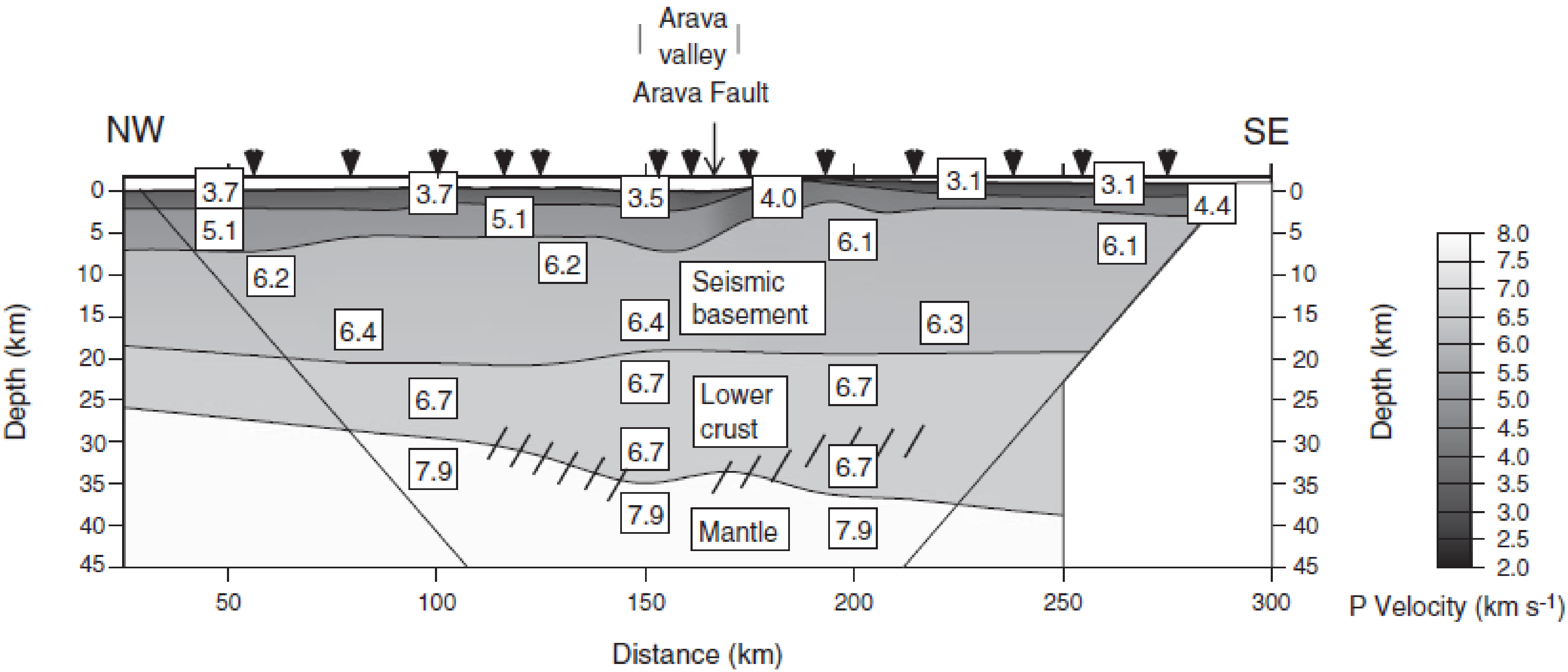
(a) Tectonic map and (b) shaded relief map showing major fault segments of the Dead Sea Transform and pull-part basin. coastline of the Dead Sea, showing subsidence of the basin, Profile A–A′. Folds reflect Mesozoic–Early Cenozoic shortening.



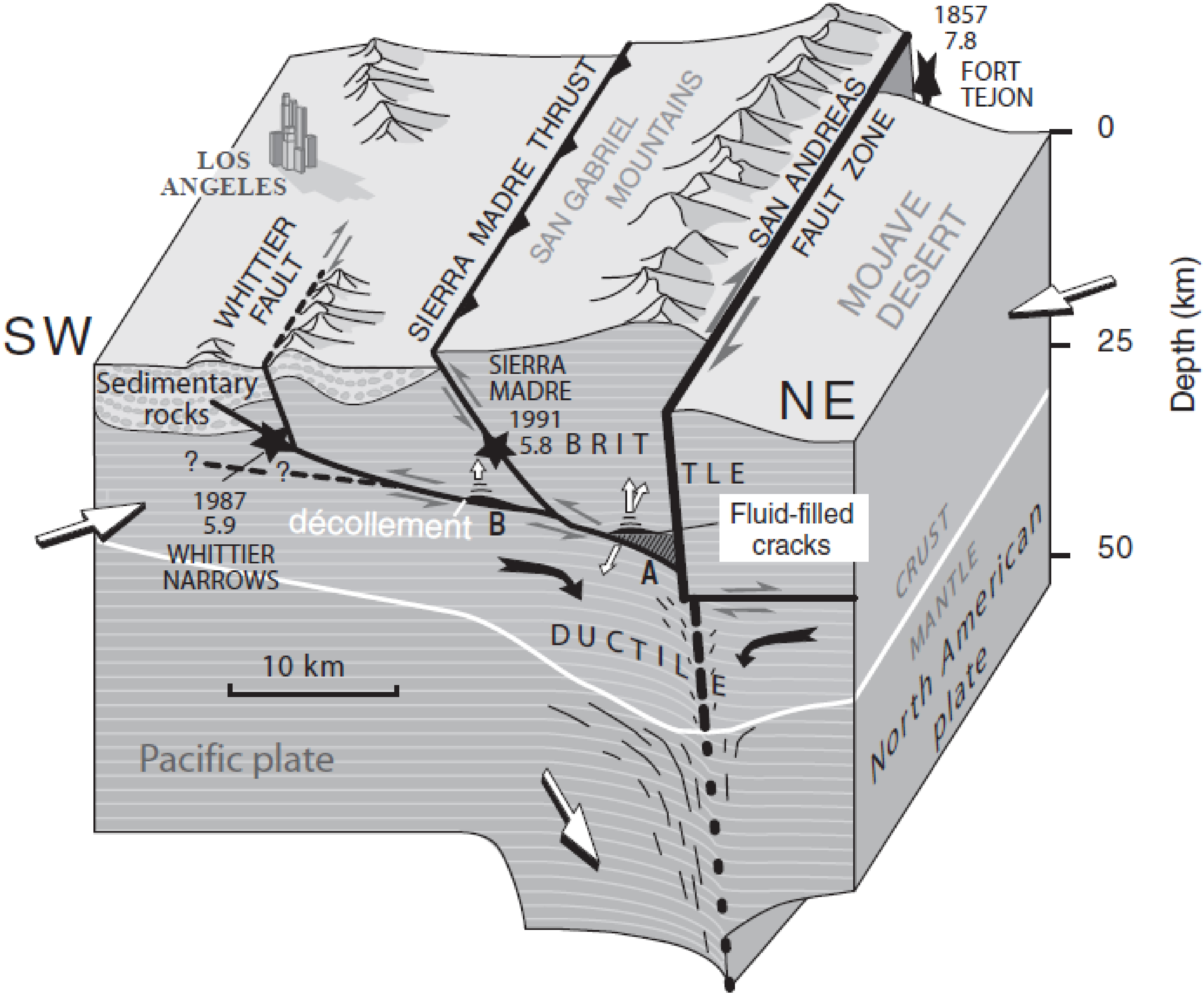
(a) Shaded relief map and (b) interpretation of the Río Lempa pull-apart basin between the San Vicente and Berlin fault segments of the El Salvador Fault Zone Inset shows the plate tectonic setting of Central America and plate velocities (mm a^{-1})

Deep Structure of Continental Transforms

1. **Dead Sea Transform**:
   - ✓ Transtensional, left-lateral fault with pull-apart basins (e.g., Dead Sea Basin: 8.5 km sediment fill).
   - ✓ Seismic data show a vertical fault zone broadening into ductile lower crust.
2. **San Andreas Fault**:
   - ✓ Formed via Pacific-Farallon ridge collision (Oligocene).
   - ✓ **Central Segment**: Aseismic creep; **Locked Segments** (e.g., near Los Angeles) accumulate elastic strain.
   - ✓ Deep structure includes a crustal root beneath Transverse Ranges and mantle shear zone (SKS anisotropy).
3. **Alpine Fault (New Zealand)**:
   - ✓ Oblique thrust (40–50° dip) with a crustal root (Moho at 37 km depth).
   - ✓ Mantle deformation extends 200–335 km wide, supporting transpression models.

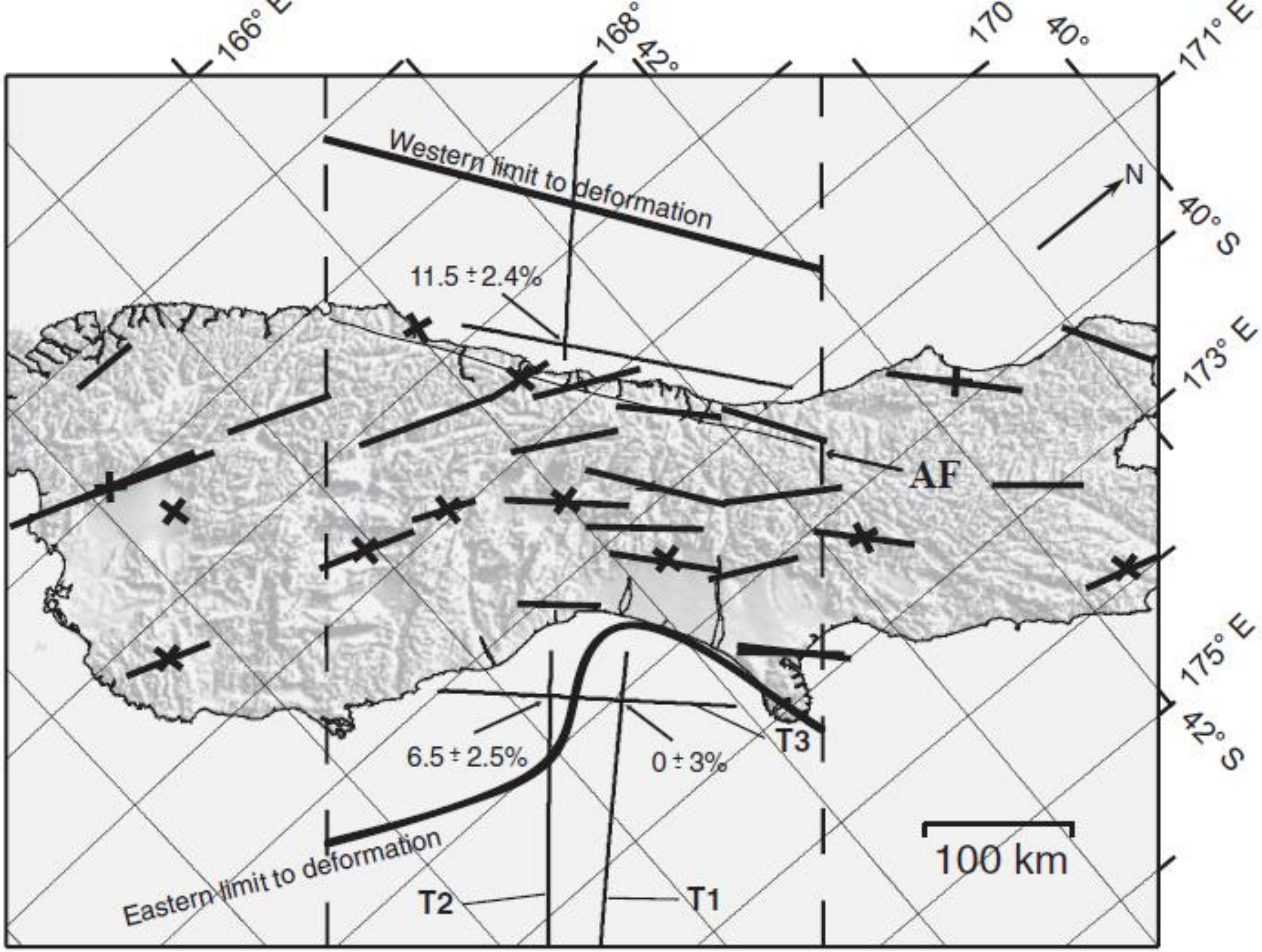


P-wave velocity model of the crust and mantle below the Arava Fault within the southern segment of the Dead Sea Transform. Triangles indicate shot points
along a wide angle seismic reflection and refraction survey used to obtain the velocities (km s^{-1}). Hatched area near crust–mantle boundary represents zone of strong lower crustal reflections. The boundaries and P-wave velocities located northwest of the fault

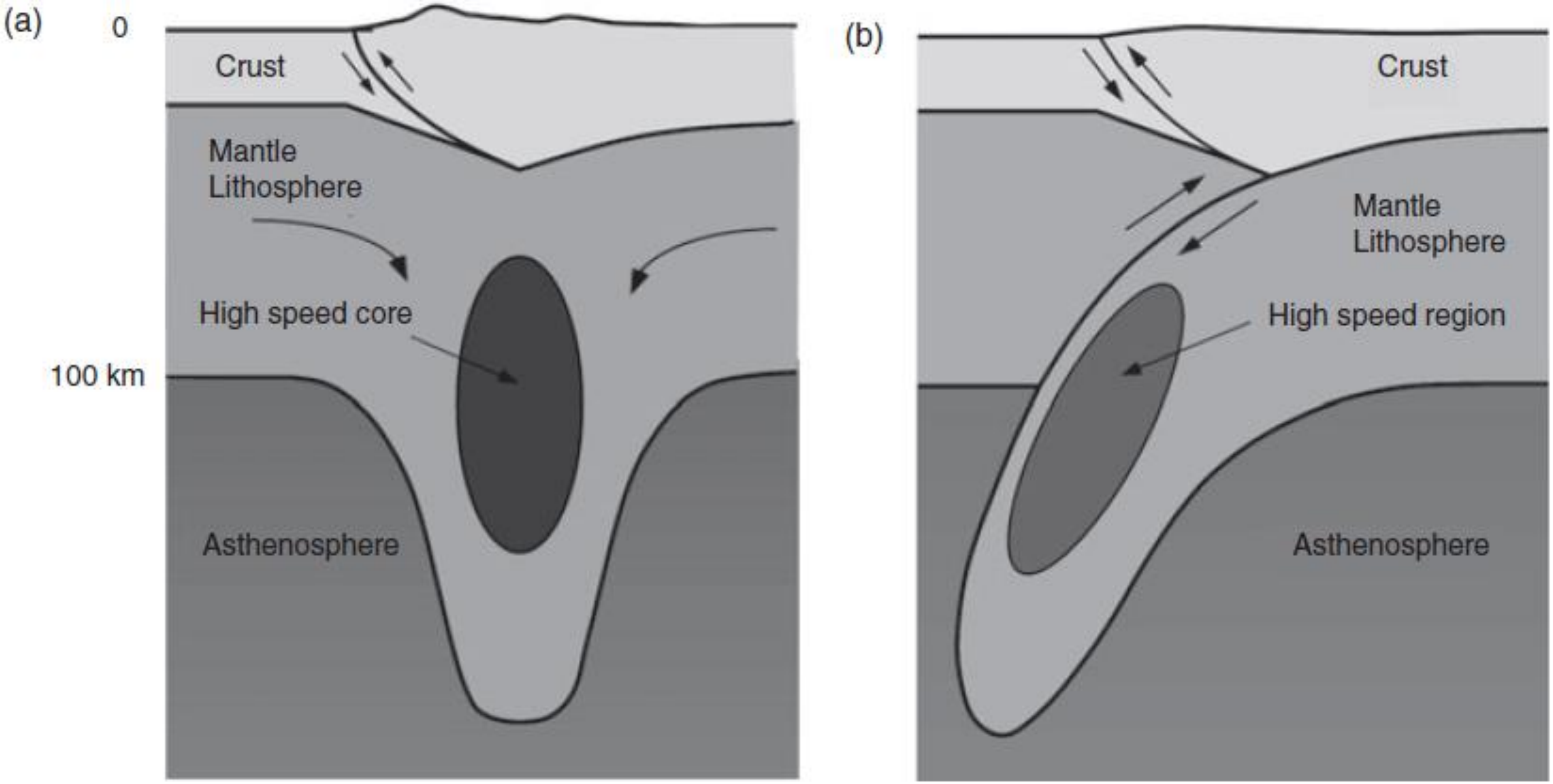


1857
7.8
FORT
TEJON
0
25
50
Depth (km)
LOS
ANGELES
SW
NE
WHITTIER
FAULT
SIERRA MADRE THRUST
SAN GABRIEL
MOUNTAINS
SAN ANDREAS
FAULT ZONE
MOJAVE
DESERT
Sedimentary
rocks
SIERRA
MADRE
1991
5.8
BRIT TLE
1987
5.9
WHITTIER
NARROWS
décollement
B
A
Fluid-filled
cracks
CRUST
MANTLE
North American
plate
DUCTILE
10 km
Pacific plate

Schematic block diagram showing the three-dimensional geometry of active faults of the Los Angeles region. Moderate and large earthquakes are shown with black stars, dates, and magnitudes. Small white arrows show block motions in vicinities of bright reflective regions A and B. Large white arrows show relative convergence direction of Pacific and North American plates. Regions A and B are zones of cracks that transport fluids migrating up from depth. A décollement surface ascends from cracked region A at San Andreas Fault, above which brittle upper crust is imbricated along thrust and reverse faults and below which lower crust is flowing toward San Andreas Fault (black arrows), depressing the Moho. Mantle of Pacific plate sinks beneath the San Gabriel Mountains.



Map showing the geometry of the SIGHT experiment and SKS measurements with an interpretation of mantle deformation below the Alpine Fault (AF) . Three seismic transects (T1, T2, T3) are shown. Black bars indicate direction of maximum seismic velocity. Bar length is proportional to the amplitude of shear wave splitting determined from the SKS results. Pn anisotropy measurement of 11.5 ± 2.4%



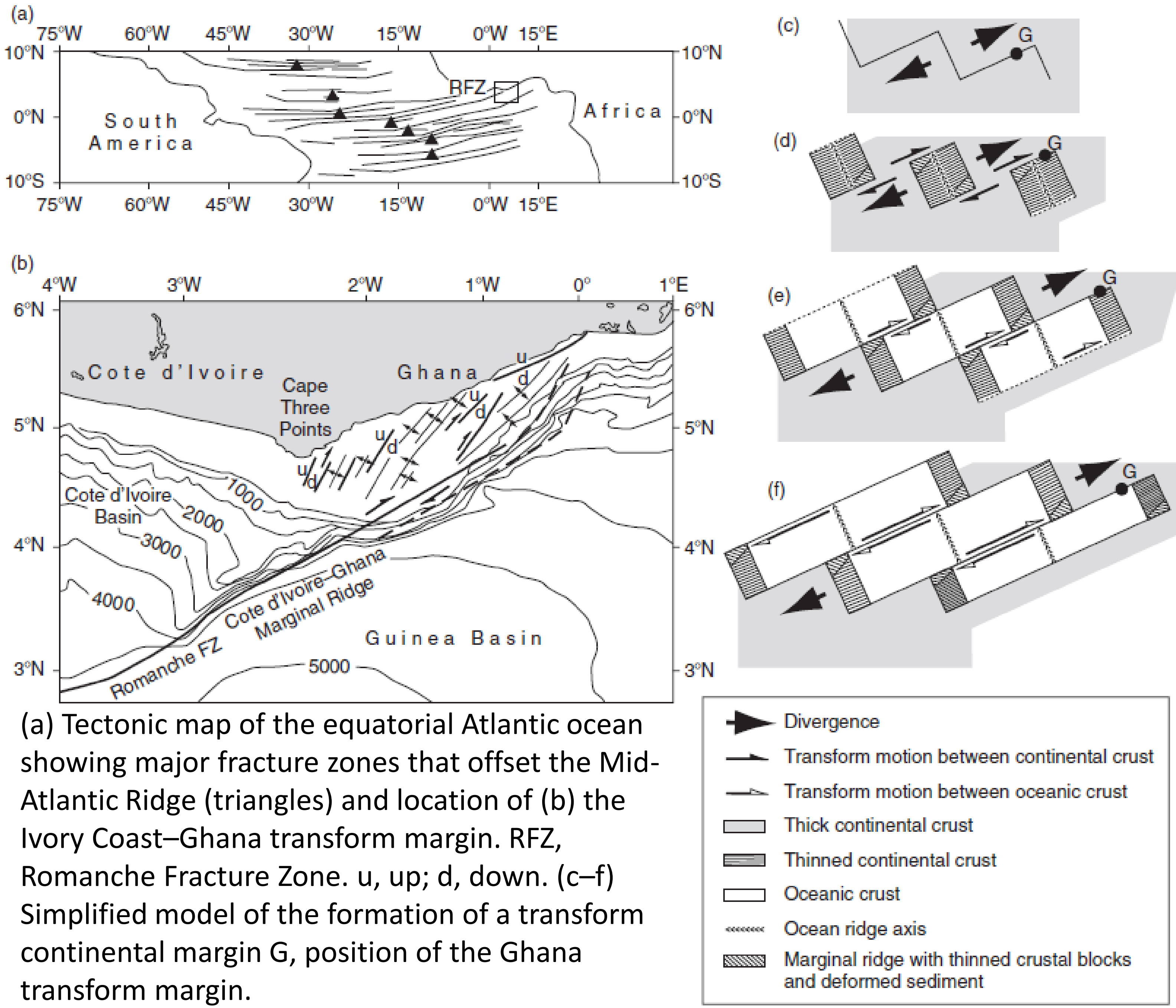
Cartoons showing two possible modes of convergence in the mantle below the Alpine Fault. (a) Symmetric root formed by homogeneous shortening and thickening.
(b) Westward under-thrusting of Pacific mantle lithosphere beneath the Australian plate forming a zone of intracontinental subduction.

Transform Continental Margins

Form during rifting when transforms separate continents.

Ivory Coast-Ghana Margin: Four-phase evolution:

- Continental contact with strike-slip deformation.
- Rifting and marginal ridge formation.
- Ocean-continent transform (heating near spreading center).
- Fossil fracture zone (cooling subsidence).



(a) Tectonic map of the equatorial Atlantic ocean showing major fracture zones that offset the Mid-Atlantic Ridge (triangles) and location of (b) the Ivory Coast–Ghana transform margin. RFZ, Romanche Fracture Zone. u, up; d, down. (c–f) Simplified model of the formation of a transform continental margin G, position of the Ghana transform margin.

Continuous vs. Discontinuous Deformation

Geodetic Data: GPS reveals smooth velocity fields but conflicts with geologic slip rates.

- **Models**:
  - ✓ **Continuous**: Distributed strain (e.g., Eastern California Shear Zone).
  - ✓ **Discontinuous (Block Models)**: Rigid microplates rotating about vertical axes (e.g., Sierra Nevada block).
- **Locking Depth**: Transition from elastic (shallow) to ductile (deep) deformation; affects slip rate estimates.

Strain Localization and Delocalization

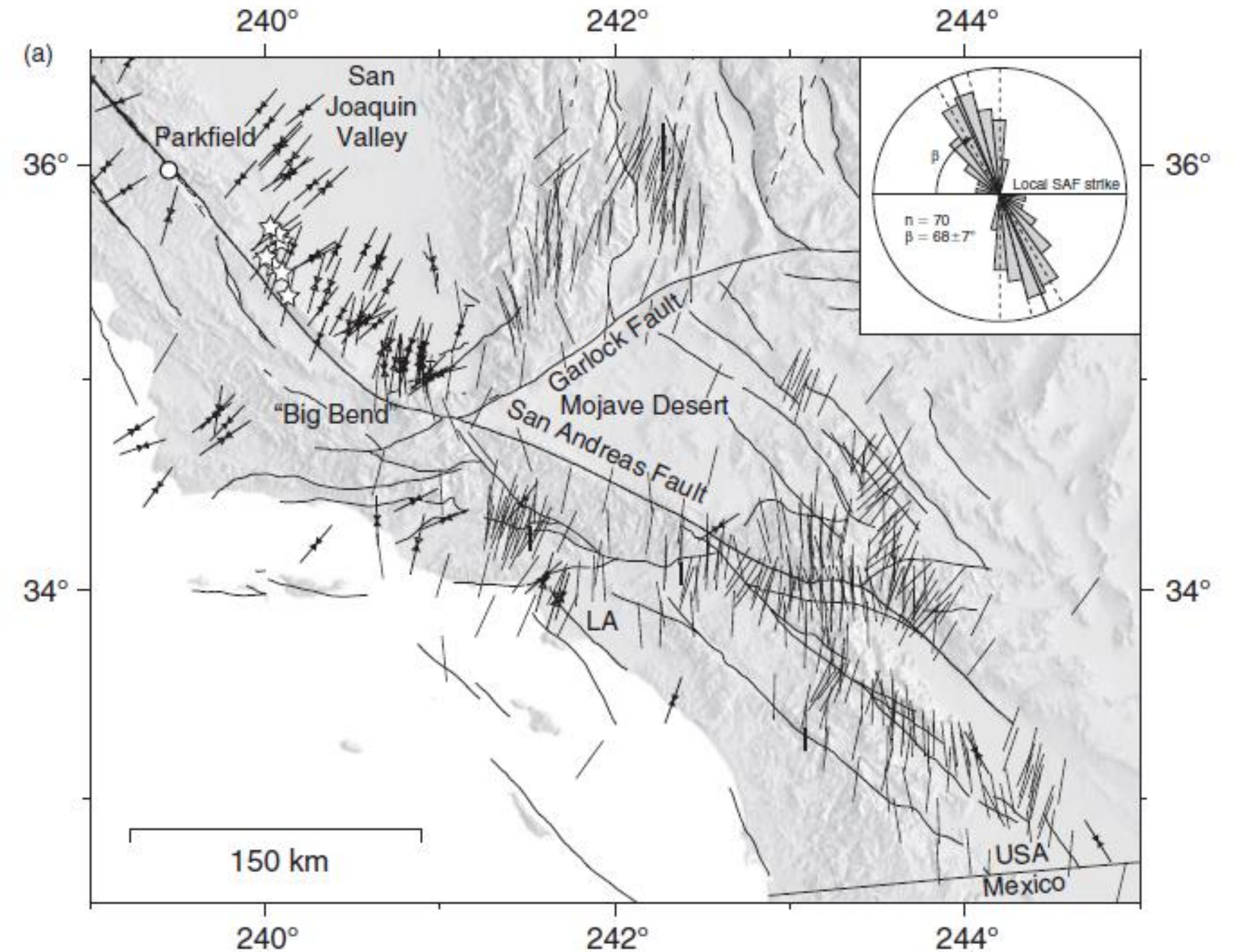
- **Lithospheric Heterogeneity**:
  - Strain localizes where crust is weak (thinner/hotter).
  - Numerical models: show decoupling in weak lower crust.
- **Strain-Softening Feedbacks**:
  - **Fluid Pressure**: Alpine Fault's low-velocity zone: reduces strength via high pore pressure.
  - **Erosion/Exhumation**: Rapid uplift advects heat, weakening crust (e.g., Southern Alps.

Strength of Transforms

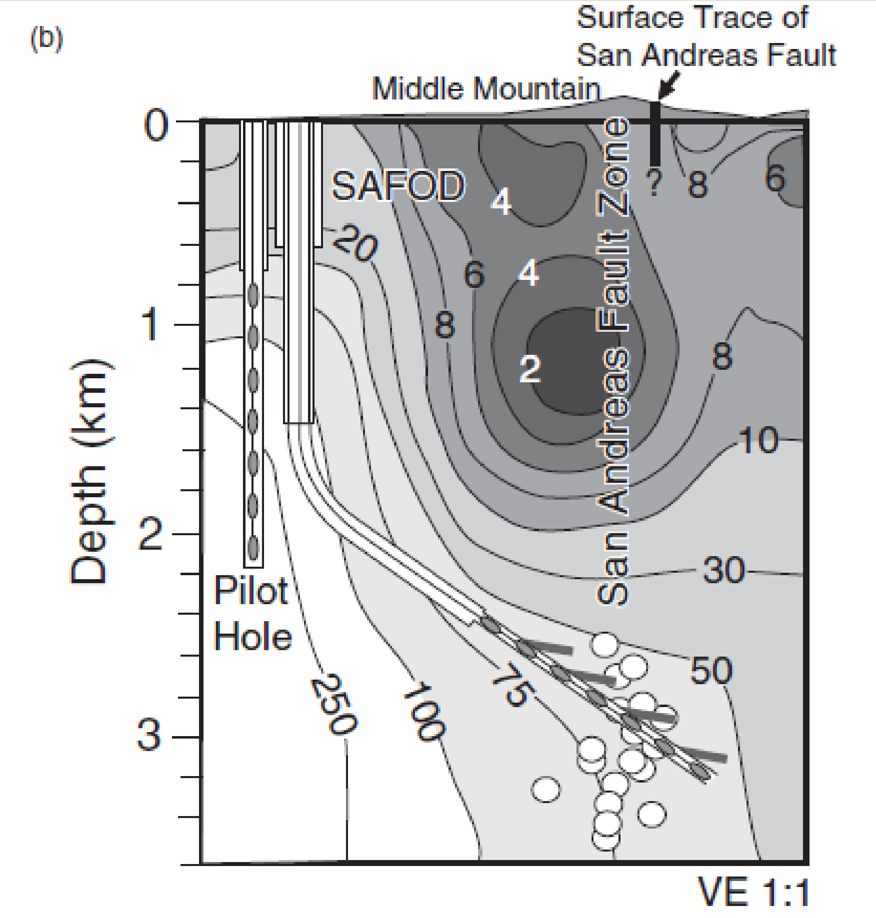
--San Andreas Fault Paradox:

- High-angle σ_1 (68–85°) suggests weak fault (low shear stress).
- Heat flow data support low friction.

--SAFOD Drilling Project: Preliminary data indicate a locally weak fault in strong crust



(a) Maximum horizontal compression from southern California . Stress determinations are as follows: inward-point arrows, borehole breakouts; stars, hydraulic fracturing experiments; plain straight lines, earthquake focal mechanisms. Inset summarizes the angle.



(b) between the maximum principal compressive stress and the local fault strike within 10 km of the San Andreas Fault (SAF). The angle of 68 ± 7° suggests a relatively low frictional strength for a 400-km-long fault segment. (b) Vertical profile showing location of SAFOD drill hole experiment near Parkfield. Magnetotelluric resistivity readings .White circles are earthquake hypocenters. Ovals in drill holes represent down-hole sensors. Contours show resistivity in ohm-meters.