Sedimentary Basins and Plate Tectonics: Overview

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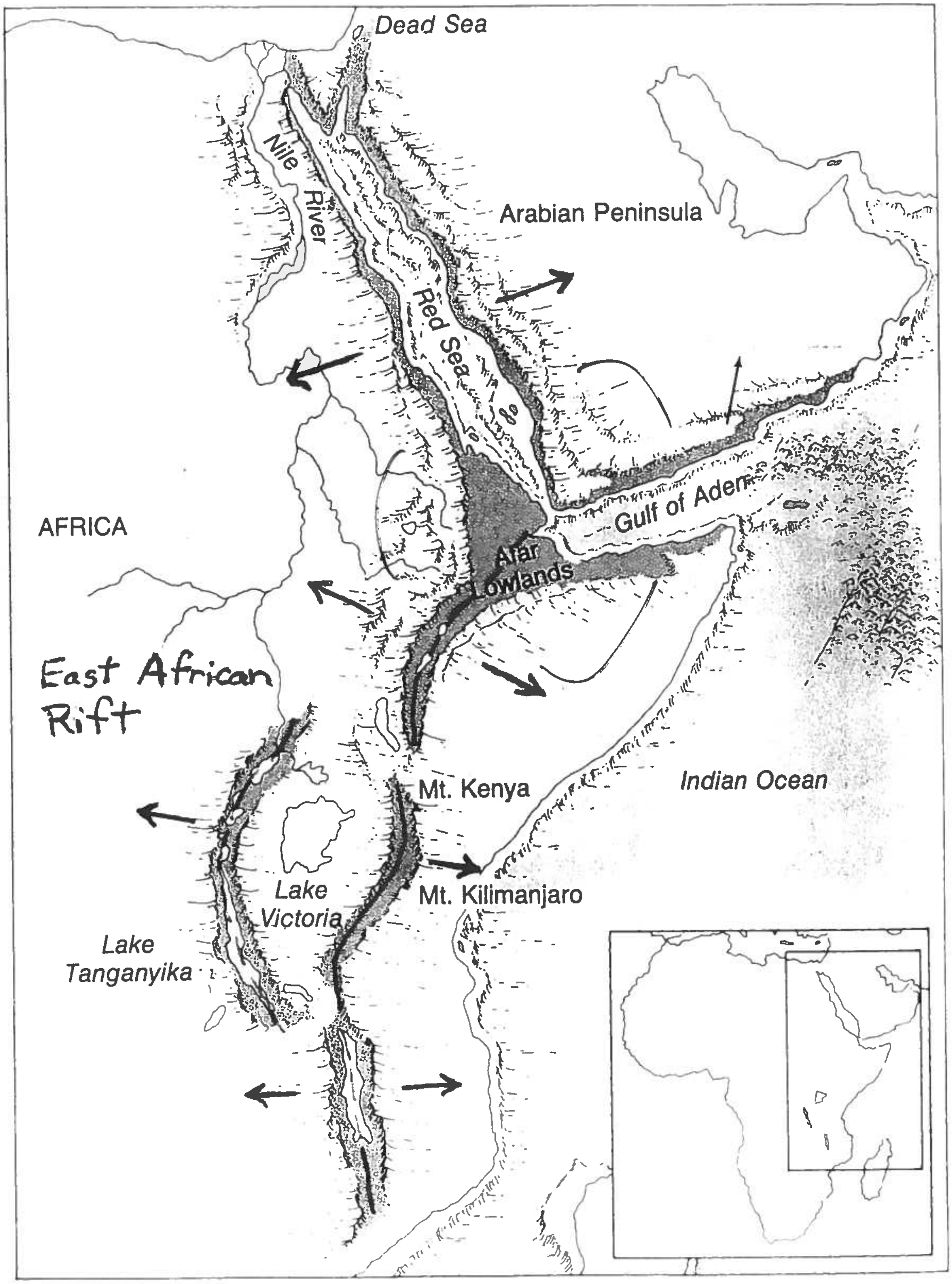
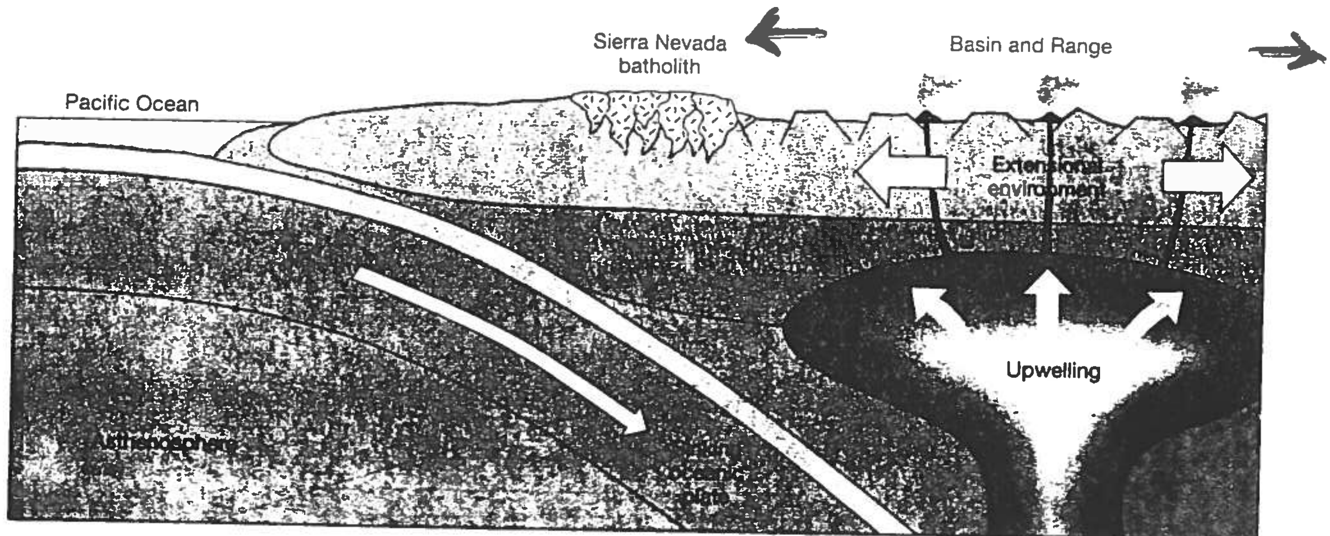
Sedimentary basins are areas of crustal subsidence where sediments accumulate by deposition in environments such as rivers, lakes, alluvial plains, coastal areas, deltas, continental shelves, and deep oceans. Whenever we see a thick (> ~100 meters) succession of sedimentary rocks in outcrop or in the subsurface, the basin analyst will ask: why did this pile of sediment accumulate here, how fast did the basin subside through time, where did the sediment come from, what types of environments and climate existed here during deposition, and what were the driving structural, tectonic and geophysical forces that created the basin? Through integrative analysis that includes stratigraphy, sedimentology, paleocurrents, structure, regional tectonics, and physical modeling, we often are able to answer these questions and thereby gain a good understanding of the geologic, climatic, and tectonic evolution of a region.

We can understand how basins form by considering different tectonic settings, the main geologic processes active in those regions, and the related physical mechanisms that cause subsidence. The following table provides a summary of the main processes that create sedimentary basins, provided in the context of common tectonic settings found on Earth today and in the past.

Plate-Tectonic Setting	Geologic Process	dominant Subsidence Mechanisms	Basin Name
• Continental Rift Zones	Extension, Crustal Thinning	Isostatic Subsidence	Rift Basin
• Passive Continental Margins	Lithospheric Cooling	Thermal Subsidence	Miogeocline
• Convergent Margins:			
- Orogenic Fold-Thrust Belts, Continental Collision Zones	Crustal Thickening, Loading	Flexural Subsidence	Foreland Basin
- Subduction Zones, Volc. Arcs	Lithosph. Cooling +/- Loading	Thermal +/- Flexural Subs.	Forearc Basin; Trench, Trench-Slope Basins
• Strike-Slip Fault Zones			
Transtensional	Oblique Extension	Isostatic Subsidence	Pull-Apart Basin
Transpressional	Oblique Contraction	Flexural Subsidence	Foreland-type
• Stable Plate Interiors	Slow Cooling	Slow Thermal Subsidence	Intracratonic Basin

Note: Smaller basins also exist: they tend to form by local deformation and deflection of the Earth's surface by growth of active structures such as faults and folds. Such basins are commonly found within the active settings described above, and are relatively small features produced by local deformation rather than the large-scale geodynamic processes listed above.


Dead Sea
Nile River
Arabian Peninsula
Red Sea
Gulf of Aden
AFRICA
Afar Lowlands
East African Rift
Mt. Kenya
Indian Ocean
Lake Victoria
Mt. Kilimanjaro
Lake Tanganyika



B.

Figure 17.16
A two-step proposal for the formation of the Basin and Range Province. ***A.*** *Nearly horizontal subduction of an oceanic plate produced compressional stresses which generally thickened the crust in the Basin and Range.* ***B.*** *Sinking of this oceanic slab allowed for the upwelling of magma from the astheno-sphere. The buoyancy of the magma caused upwarping and tensional fracturing in the crust above. This event was associated with volcanism and east-west extension of the crust by nearly 150 kilometers.*

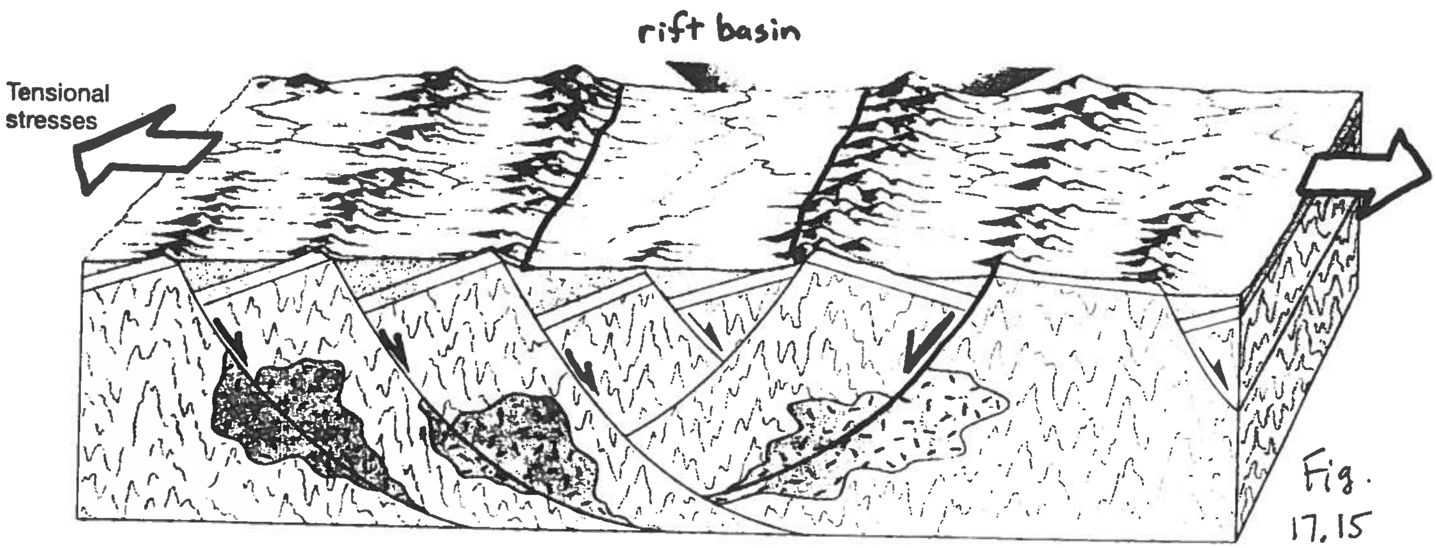
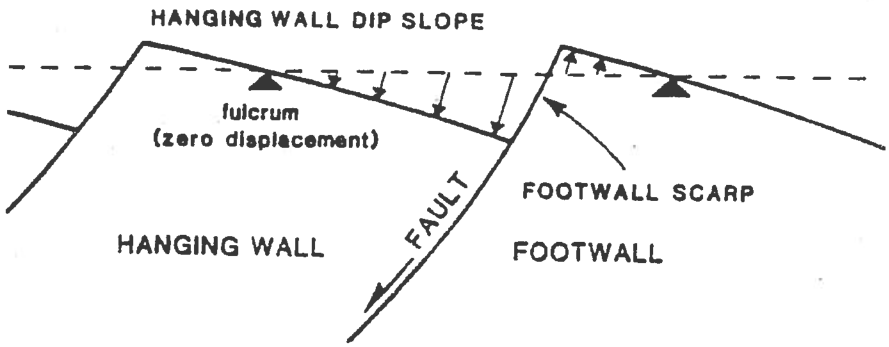


Fig.
17.15



M.R. Leeder & R.L. Gawthorpe (1987)

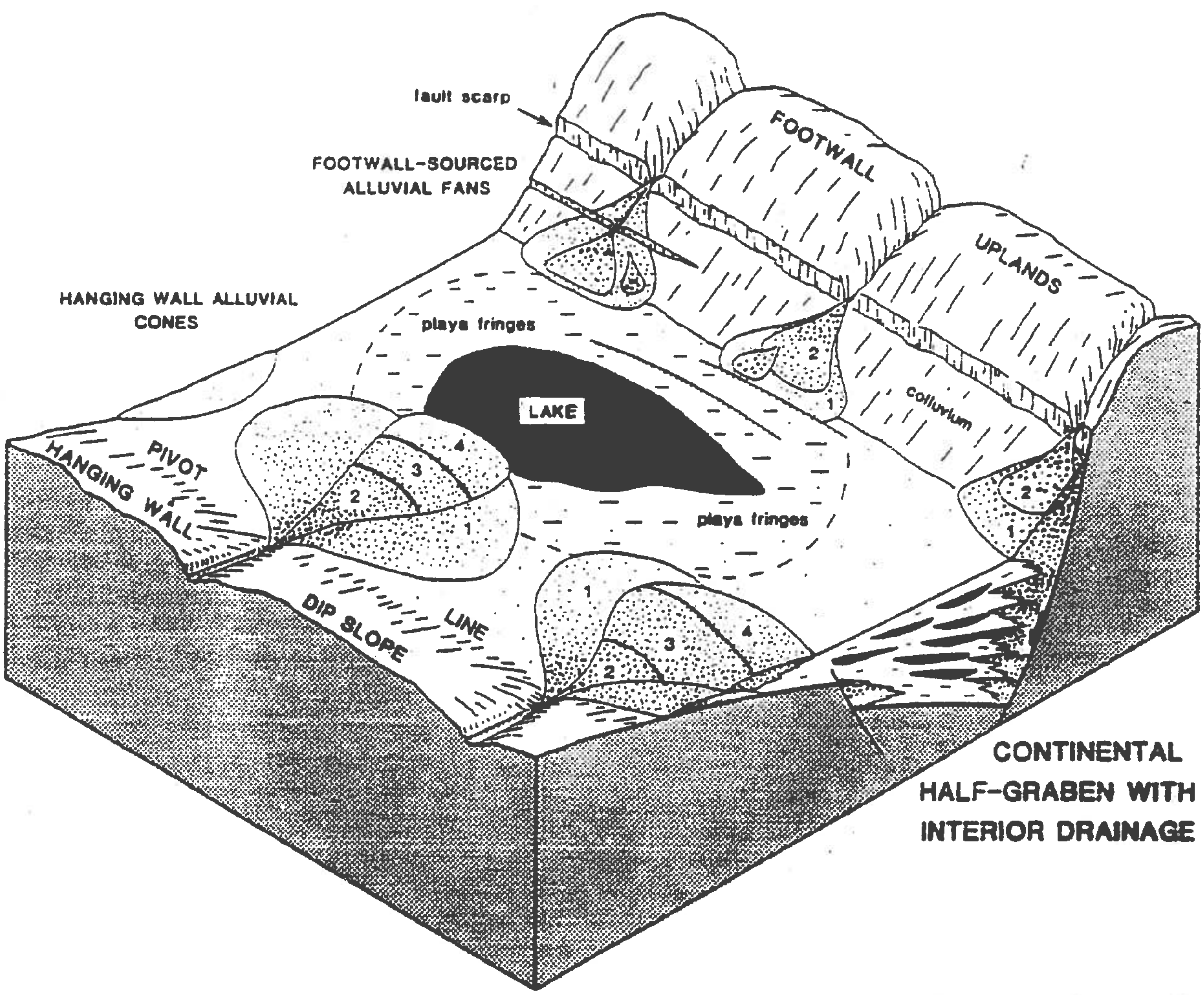
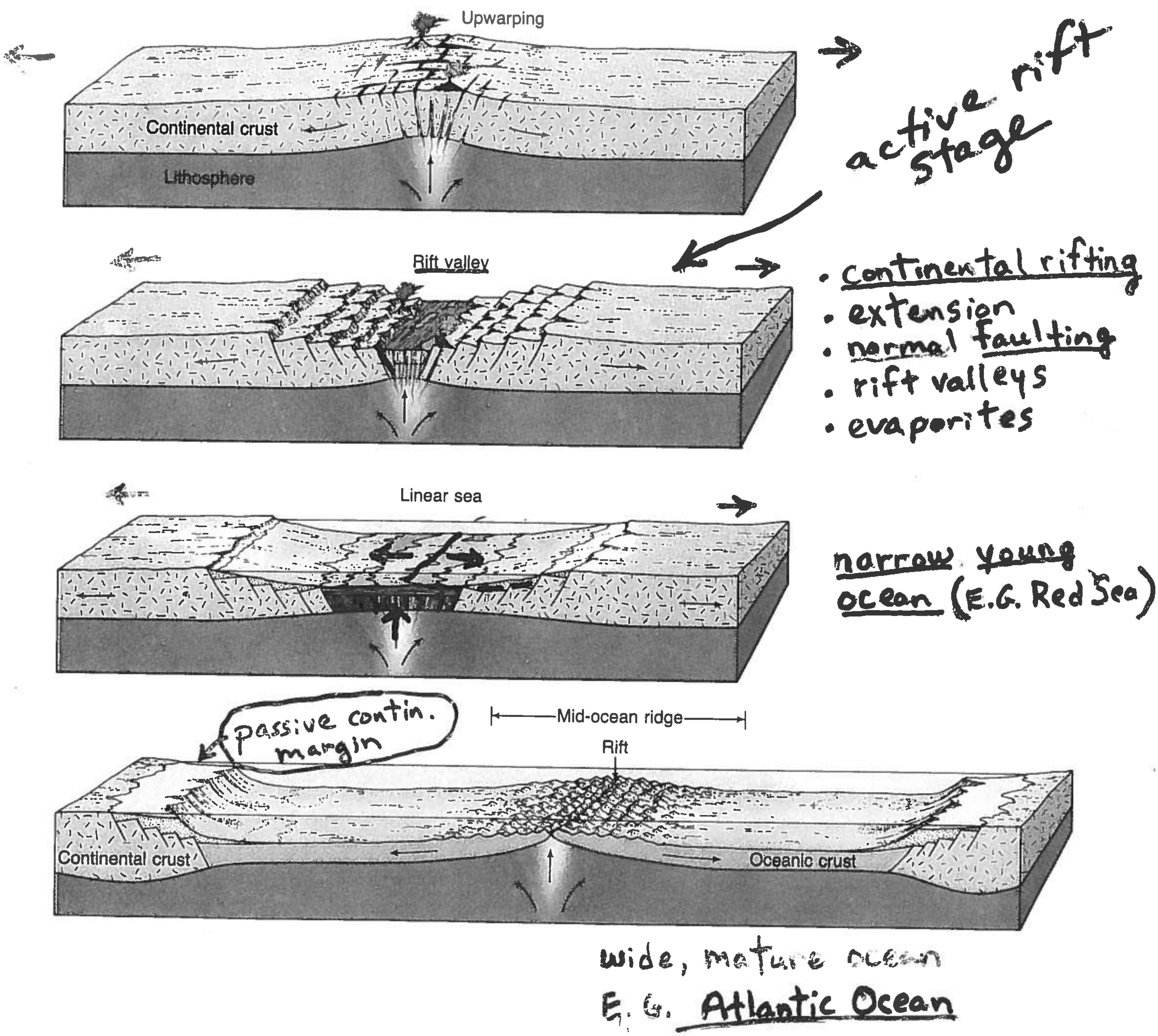


FIG. 3. Isometric diagram showing the main sedimentological features of facies model A: continental basin with interior drainage. Full discussion in text. Note: only the major basin-margin fault is shown; in natural examples the presence of antithetic, synthetic and transfer fault systems strongly modify certain depositional reactions to tilting. In addition, the sub-surface geometry is modified by differential compaction, thinning of the hanging wall associated with development of the roll-over and the presence of antithetic/synthetic fault systems within the sedimentary cover. 1, 2, 3 etc. indicate successive fan lobes.

T-53 Rising Magma Upwarps the Crust; a Rift Zone Forms; a Narrow Sea Forms; an Expansive Ocean Basin and Ridge System is Created



ESSENTIALS OF GEOLOGY, 5E
by Lutgens/Tarbuck

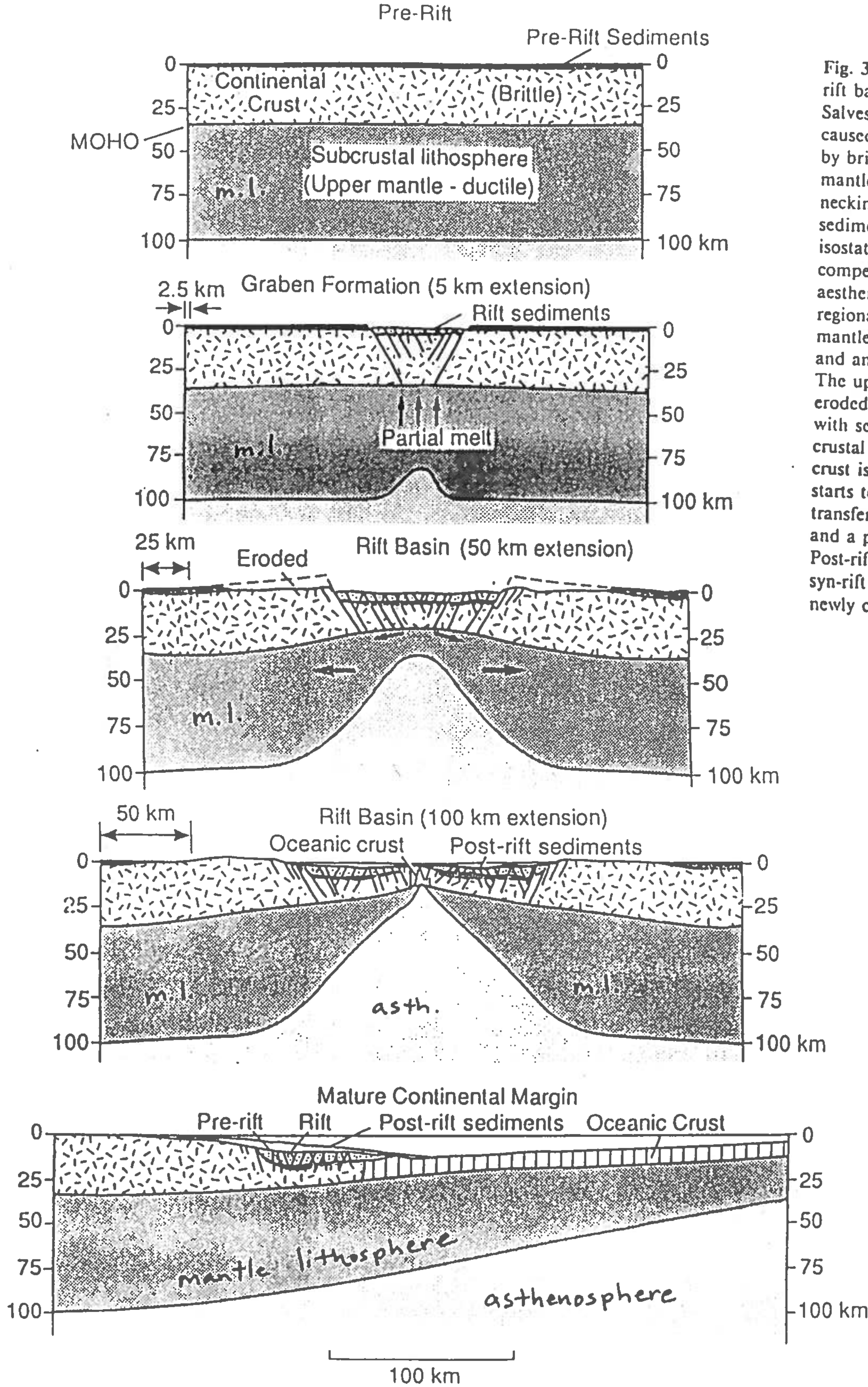


Fig. 3.8. Diagrammatic model of rift basin evolution following Salveson (1978). Tensional stresses caused the continental crust to fail by brittle fracture, whereas the mantle lithosphere fails by ductile necking. The formation of a sediment-filled graben causes isostatic disequilibrium and the compensating rise of the aesthenosphere; this leads to regional uplift. Partial melting of mantle promotes surface volcanism and an upward transfer of heat. The uplifted rift shoulders become eroded and the rift continues to fill with sediment. Eventually, as crustal extension continues, oceanic crust is created and the continent starts to cool as extension is transferred to the oceanic realm and a passive margin develops. Post-rift sediments drape the syn-rift fill and spread onto the newly created ocean floor.

Allen + Allen (1990)

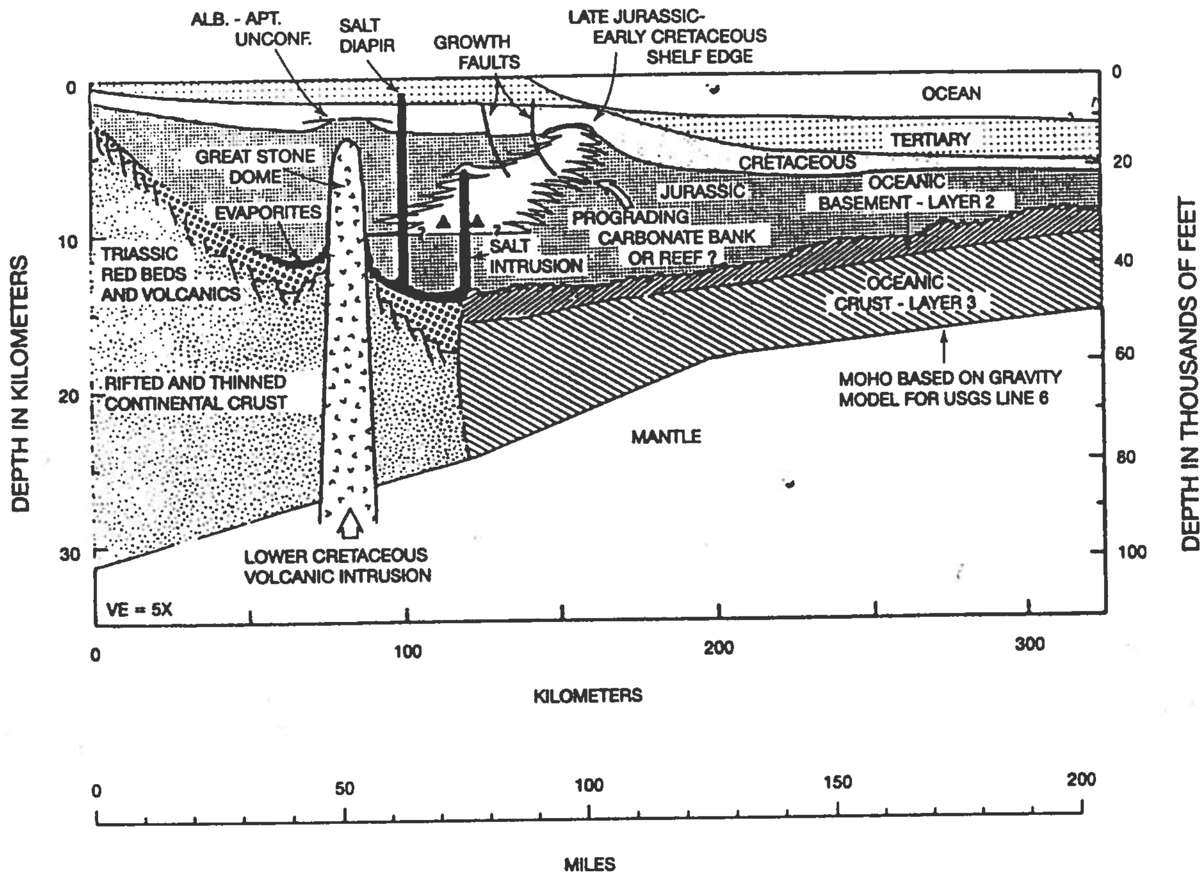


Figure 19.7

Interpretative stratigraphic section across the Atlantic continental margin of North America in the vicinity of Baltimore Canyon trough. Based on geophysical data and drill-hole information. [After Grow, J. A., 1981, Structure of the Atlantic margin of the United States, *in* Geology of passive continental margins: Am. Assoc. Petroleum Geologists Ed. Course Note Ser. No. 19, Fig. 13, p. 3–20, reprinted by permission of AAPG, Tulsa, OK.]

Boggs (2001)

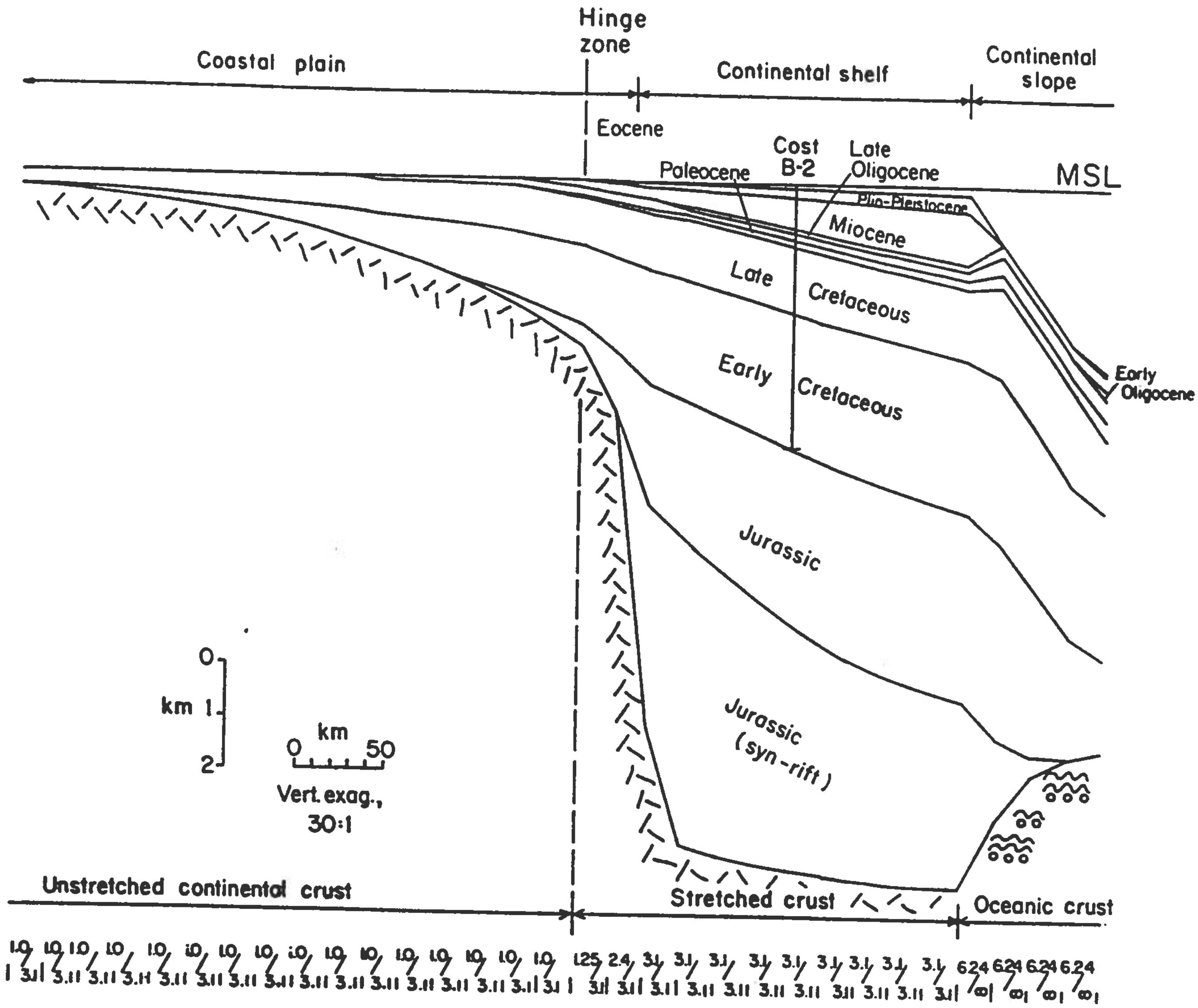
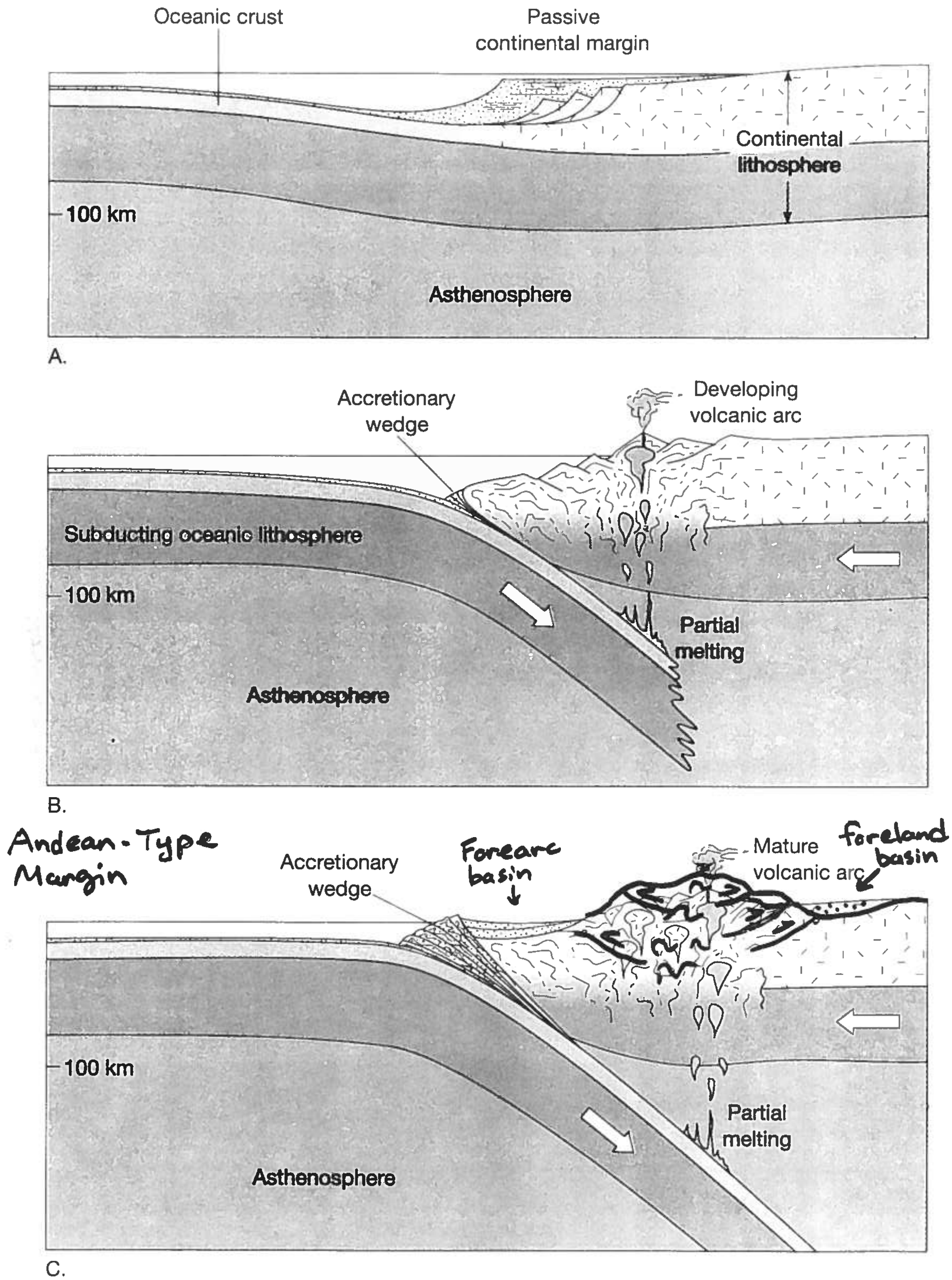


Fig. 7 The complete model for the stratigraphy of the US Atlantic continental margin based on the input parameters listed in Tables 1 and 2. The model incorporates 2-layer stretching (Fig. 3b), flexure, variable compaction (Fig. 6), sea level changes (Fig. 4, curve labelled '+'), and slow erosion. The assumed age of rifting is 186 Ma. (Lower Jurassic/Middle Jurassic). The 144 Ma. (Jurassic/Cretaceous), 98 Ma. (Early Cretaceous/Late Cretaceous), 65 Ma. (Palaeocene/Late Cretaceous), 55 Ma. (Eocene/Palaeocene, 38 Ma. (Oligocene/Eocene), 25 Ma. (Oligocene/Miocene and 5 Ma. (Pliocene/Miocene) stratigraphic horizons are shown by solid lines. Two prominent unconformities characterize the stratigraphy: one at the Palaeocene/Late Cretaceous boundary where > 10 m.y. is missing and another at the Miocene/Eocene boundary where > 13 m.y. is missing. The numbers below the complete model indicate the crustal (upper value) and lithospheric (lower value) stretching factors that were assumed in the model

Watts + Thorne (1984)



Orogenesis along an Andean-type subduction zone.

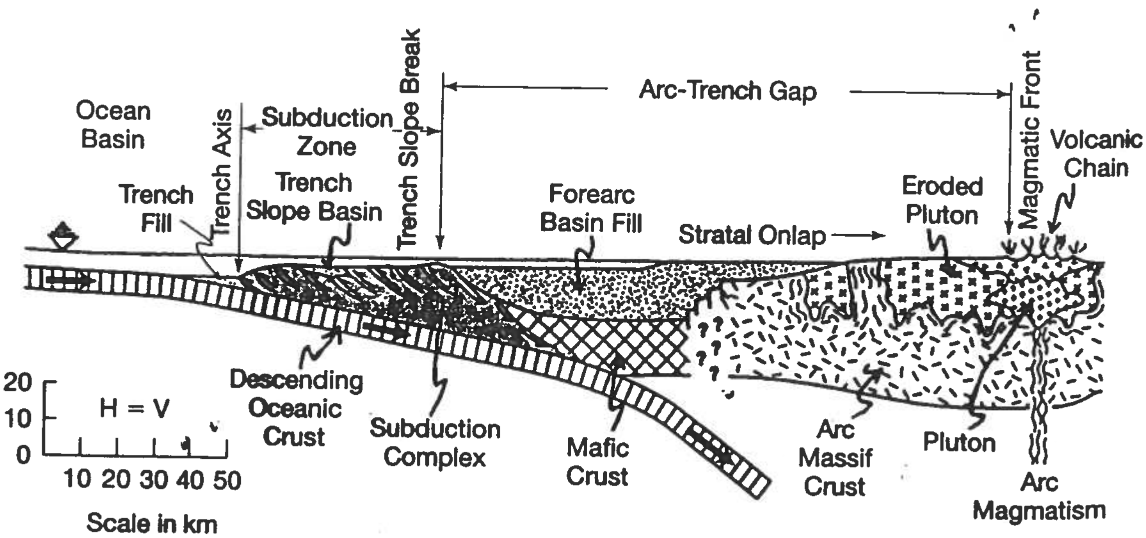
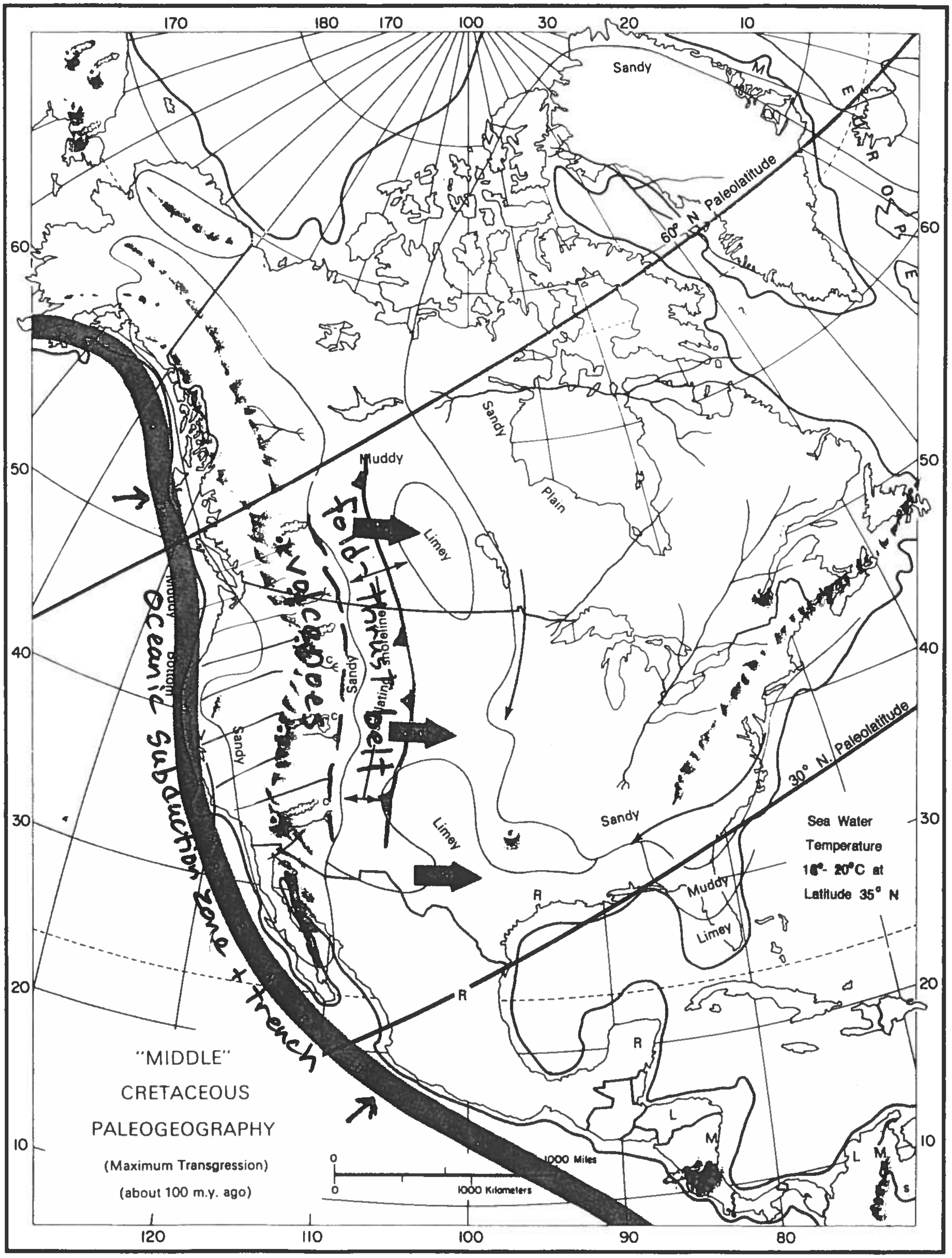


Figure 19.8

Schematic representation of basin structure in the trench-fore arc zone of a subduction setting. [After Dickinson, W. R., 1995, Forearc basins, *in* Busby, C. J. and R. V. Ingersoll (eds.), Tectonics of sedimentary basins: Blackwell Science, Cambridge, MA, Fig. 6.1, p. 221. Reproduced by permission.]

Boggs (2001)

≈ Fig. 17-24



~100 M.Y. ago: Andean-type convergent margin ...
subduction, magmatism, thrust faulting + folding,
orogeny (mt. building)

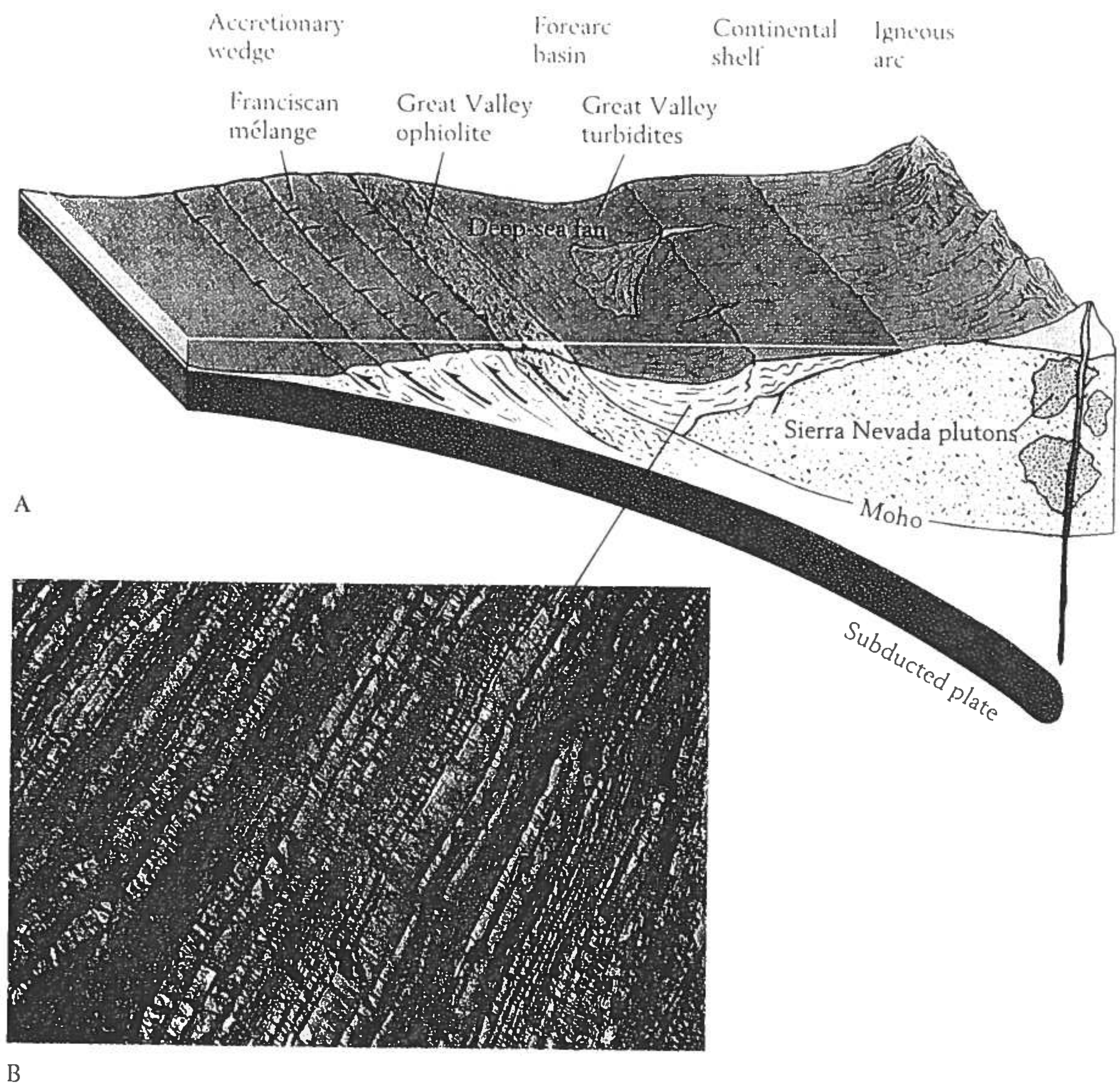


Figure 16-31 **The Pacific margin of northern California in Jurassic time.** The Franciscan mélange formed an accretionary wedge along the marginal subduction zone (see Figure 8-23). The Great Valley ophiolite was a zone of seafloor that was squeezed up along the eastern margin of the accretionary wedge, and the Great Valley sequence formed in Late Jurassic time as turbidites on deep-sea fans and in adjacent environments. The photograph shows turbidites that now lie along the western margin of the Sacramento Valley in California, where they have been tilted to a high angle b tectonic activity. The accretion of the Franciscan and Grea Valley terranes to the continental margin during Late Juras sic and Cretaceous time extended North America westwa (Figure 16-28). Today the Great Valley sequence still occu pies a low region, the Central Valley of California. West of the Central Valley, portions of the Franciscan mélange hav been elevated as part of the Coast Ranges. *(A. Adapted fro R. K. Suchecki, Jour. Sedim. Petrol. 54:170–191, 1984.)*

foreland basin

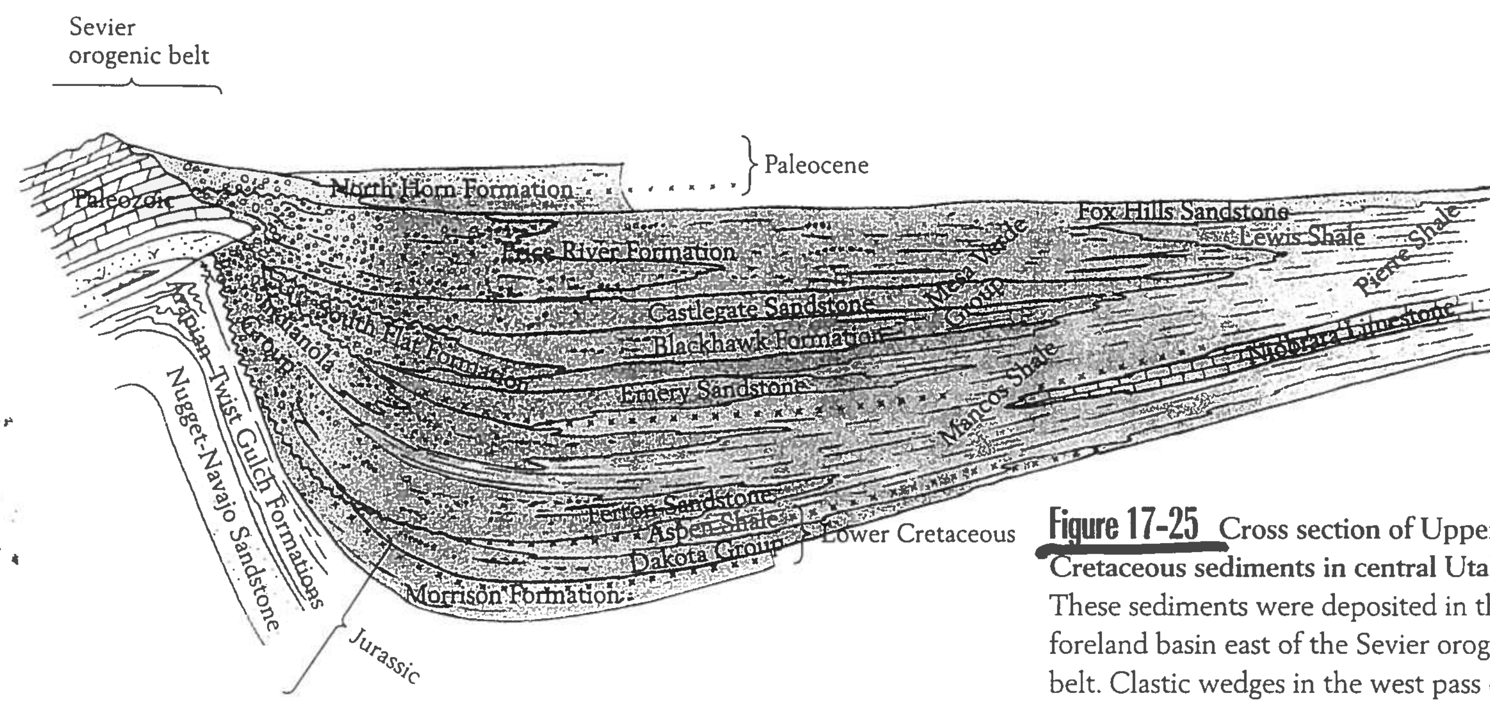
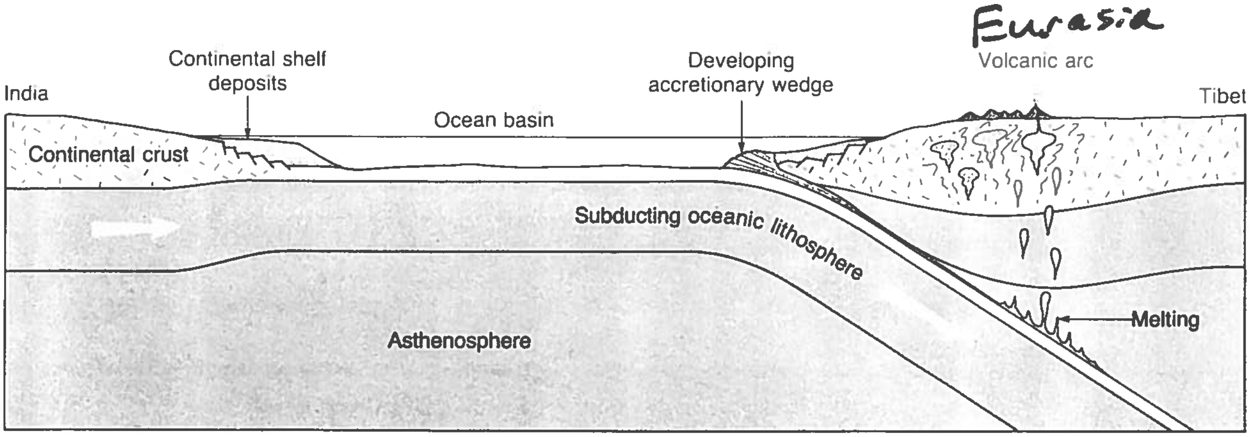


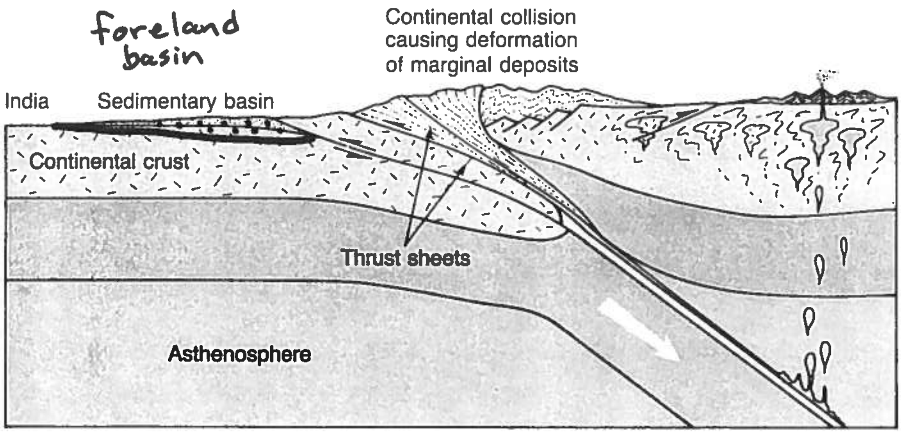
Figure 17-25 **Cross section of Upper Cretaceous sediments in central Utah.** These sediments were deposited in the foreland basin east of the Sevier orogenic belt. Clastic wedges in the west pass eastward into finer-grained marine sediments. *(After R. L. Armstrong, Geol. Soc. Amer. Bull. 79:429–458, 1968.)*

HIMALAYAN OROGENY: Continental Collision

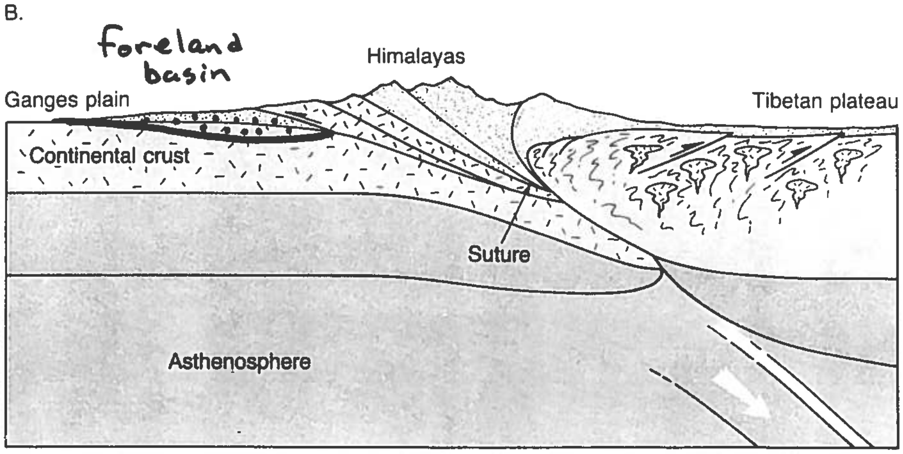


A.

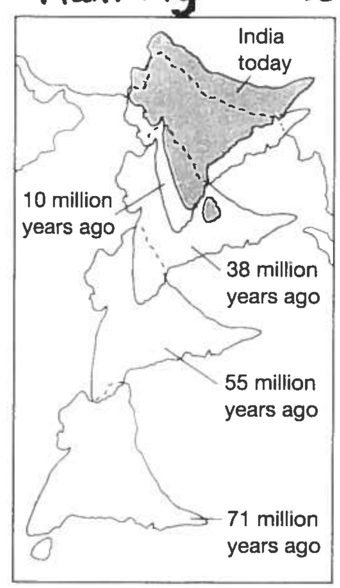
Orogenesis = mt. building
- thrust faulting + folding
- crustal thickening
- metamorphism
- magmatism
- uplift + erosion
- flanking basins *



B.



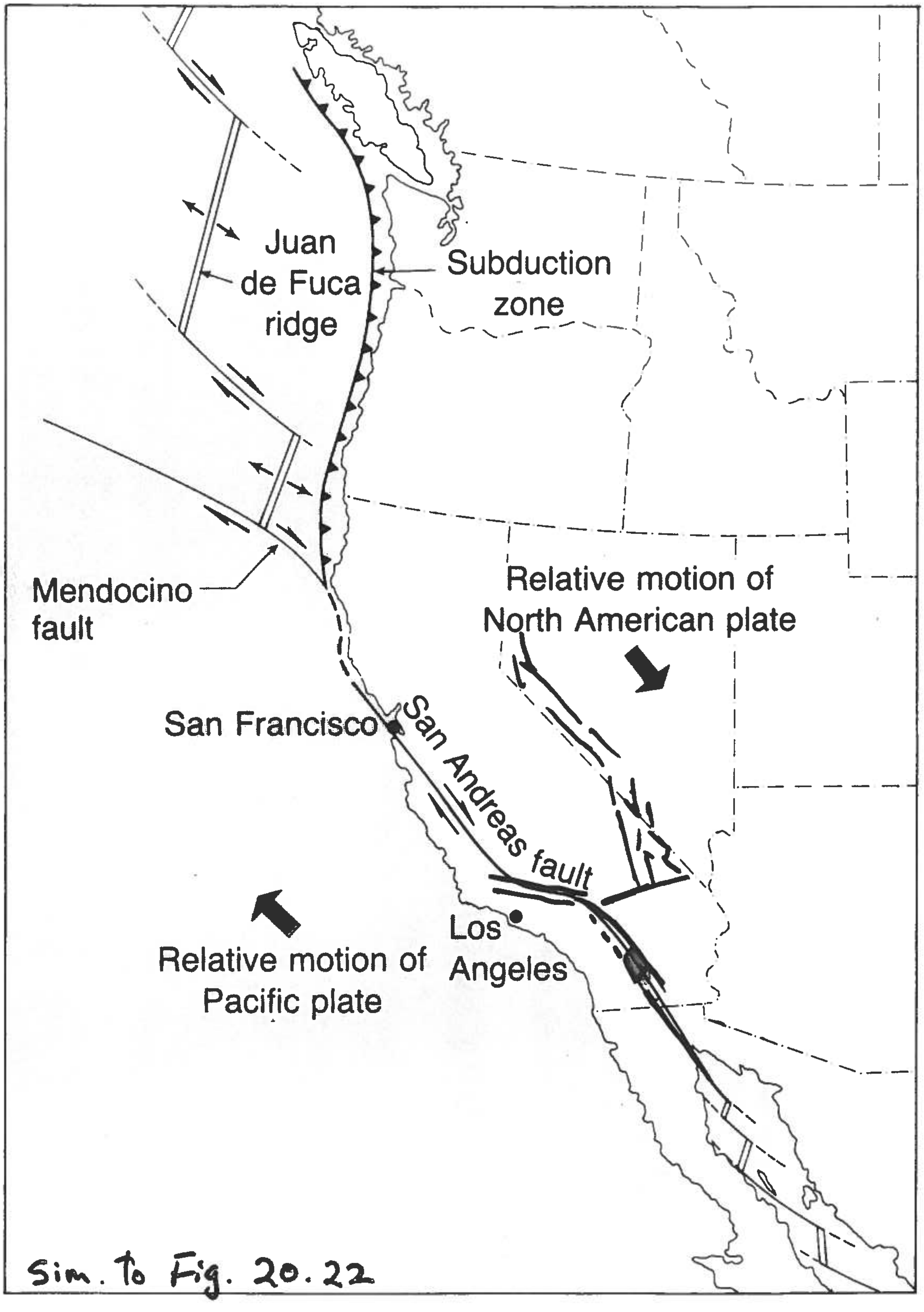
C.



D.

Migration and collision of India with the Eurasian plate.

T-57 Role of Transform Faults



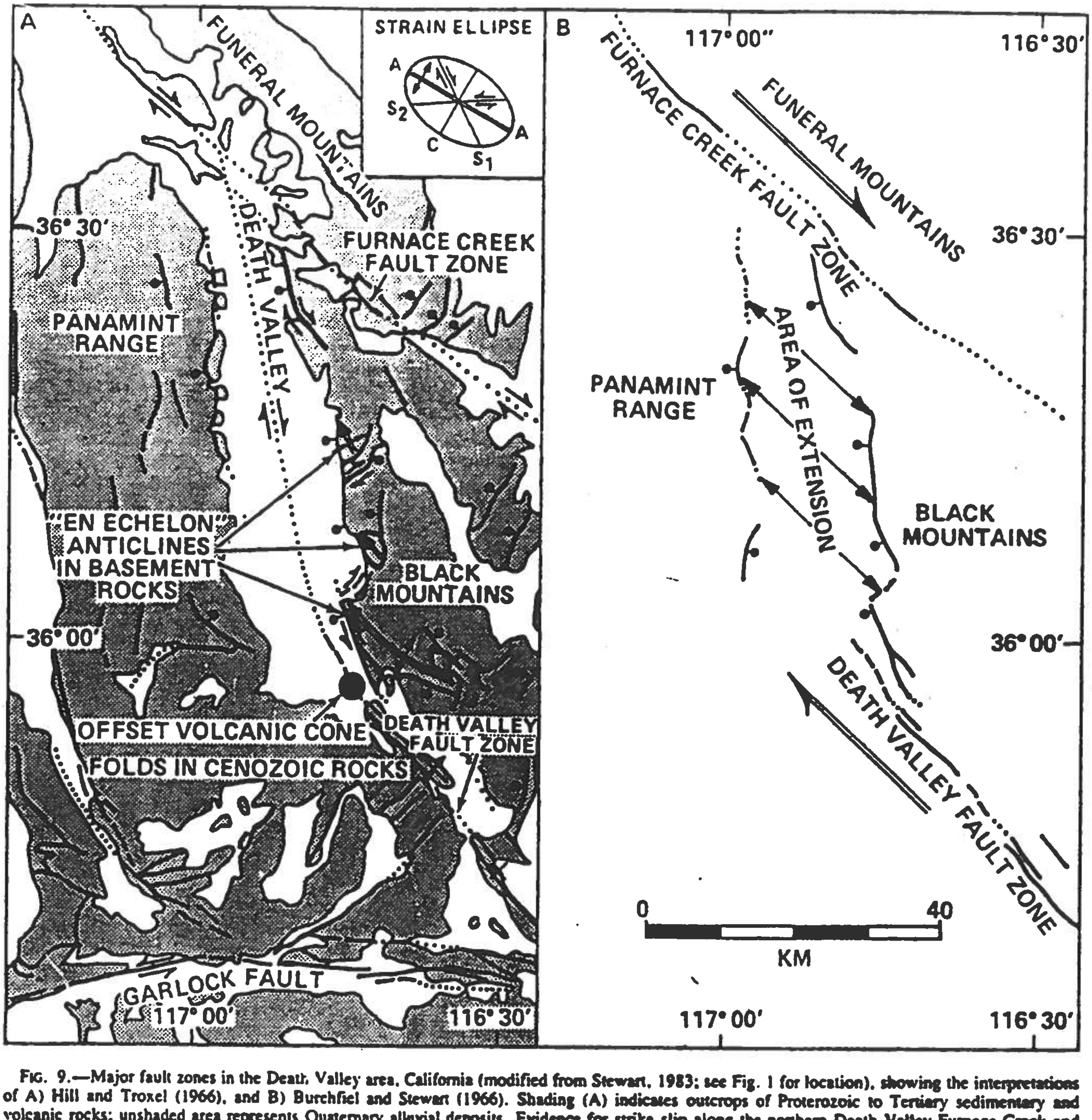


FIG. 9.—Major fault zones in the Death Valley area, California (modified from Stewart, 1983; see Fig. 1 for location), showing the interpretations of A) Hill and Troxel (1966), and B) Burchfiel and Stewart (1966). Shading (A) indicates outcrops of Proterozoic to Tertiary sedimentary and volcanic rocks; unshaded area represents Quaternary alluvial deposits. Evidence for strike slip along the northern Death Valley-Furnace Creek and southern Death Valley fault zones includes en echelon folds in Cenozoic rocks and an offset volcanic cone, together with regional stratigraphic arguments.

A) A buried strike-slip fault is inferred in the central north-trending segment of Death Valley on the basis of oblique striae on fault surfaces in the Black Mountains, and of "en echelon" anticlines in basement rocks (Hill and Troxel, 1966). The insert compares the orientations of observed structures with an idealized strain ellipse for the overall deformation; right slip inferred parallel to direction C is incompatible with orientations summarized in Figure 5.

B) Death Valley interpreted as a pull-apart along an oblique segment of a strike-slip fault system (Burchfiel and Stewart, 1966). Indicators of crustal stress and regional seismicity indicate continued extension in an approximately northwest-southeast direction parallel with the Furnace Creek and southern Death Valley fault zones (Sbar, 1982). See text for further explanation.

Christie-Blick and Biddle (1985)

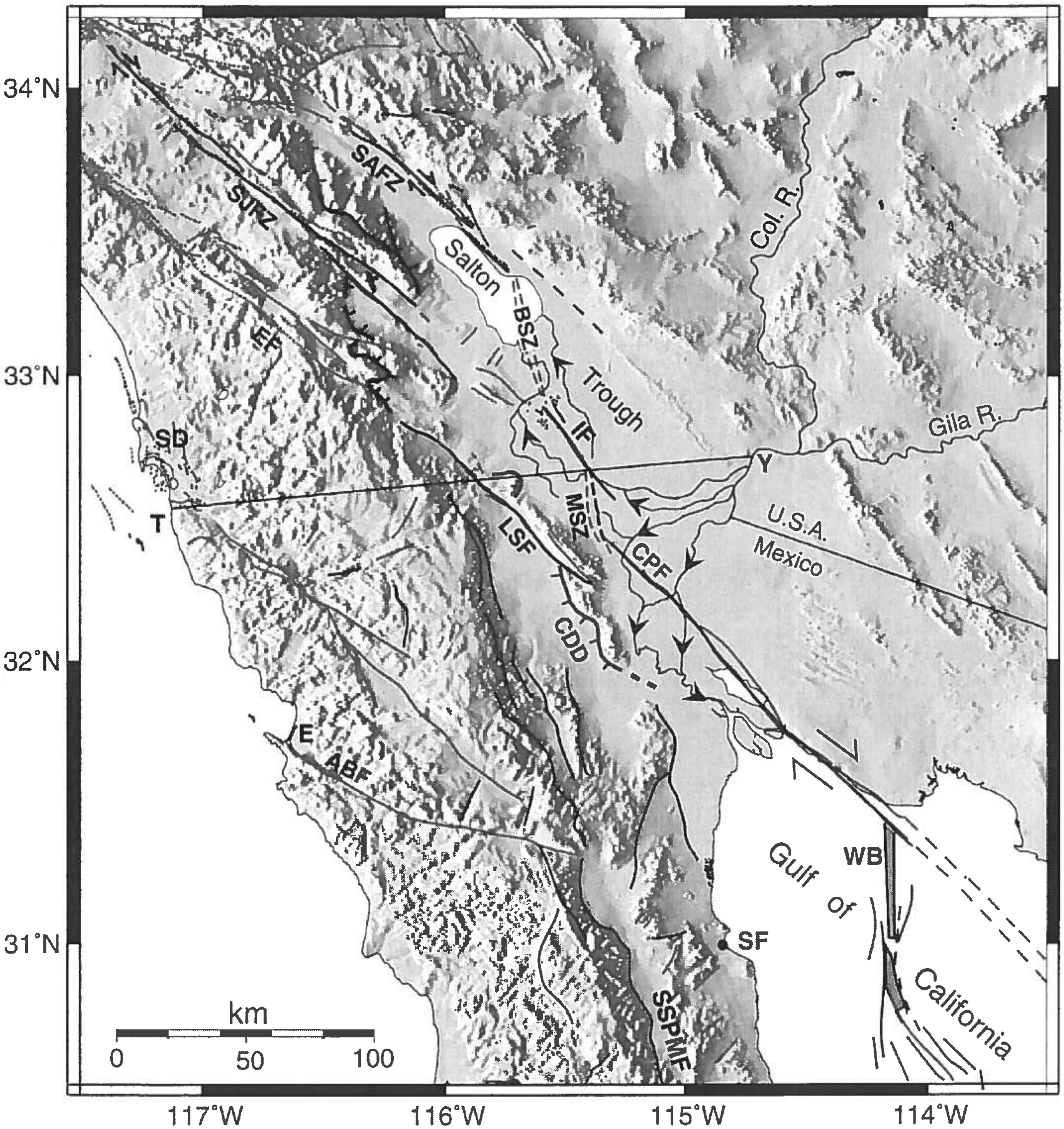


Figure 7. Faults and topography of the northern Gulf of California and Salton Trough region. Decorated thicker blue lines are detachment faults, tick marks on upper plate; red lines are high-angle normal and strike-slip faults. ABF, Agua Blanca fault; BSZ, Brawley Spreading zone; CDD, Canada David detachment; CPF, Cerro Prieto fault; E, Ensenada; IF, Imperial fault; SAFZ, San Andreas fault zone; SD, San Diego; SGP, San Gorgonio Pass; SF, San Felipe; SJFZ, SanJacinto fault zone; SSPMF, Sierra San Pedro Martir fault; T, Tijuana; WB, Wagner basin. Shaded-relief map base courtesy of H. Magistrale.

Mann et al. (1983)

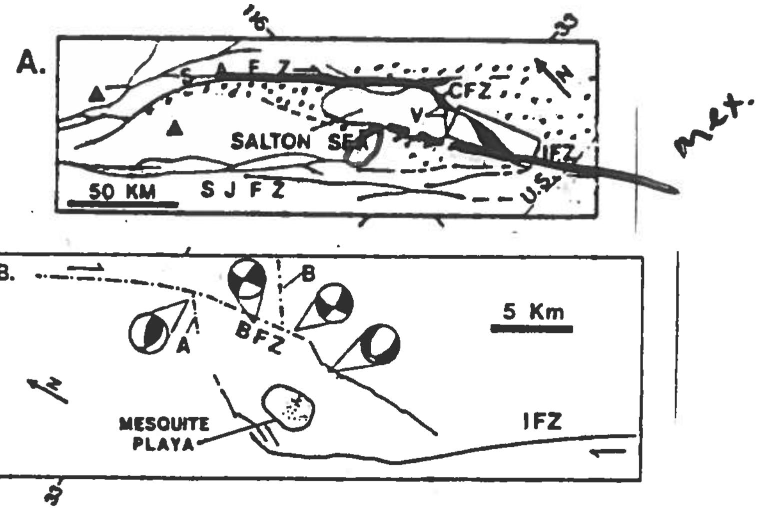


FIG. 6.—Examples of nucleating pull-apart basins along active strike-slip faults. *A*, Regional setting of pull-aparts in Salton Trough, California, from Crowell (1981); abbreviations are: SAFZ San Andreas Fault Zone; SJFZ San Jacinto Fault Zone; CFZ Calipatria Fault Zone; V recent volcanic dome; dots indicate areas of Quaternary basin fill; black triangles are peaks about 3 km in elevation in the western part of the Transverse Ranges restraining fault bend; box indicates Salton Trough map area shown in figure 6*B*. *B*. Fault map and earthquake focal mechanism solutions of Mesquite Basin between Brawley (BFZ) and Imperial (IFZ) Fault Zones from Johnson and Hadley (1976). Scarps are shown by solid lines; buried faults inferred from seismicity are dashed. *C*. Fault and sediment map of Clonard Basin, Haiti, based on photoin-

Christie-Blick and Biddle (1985)

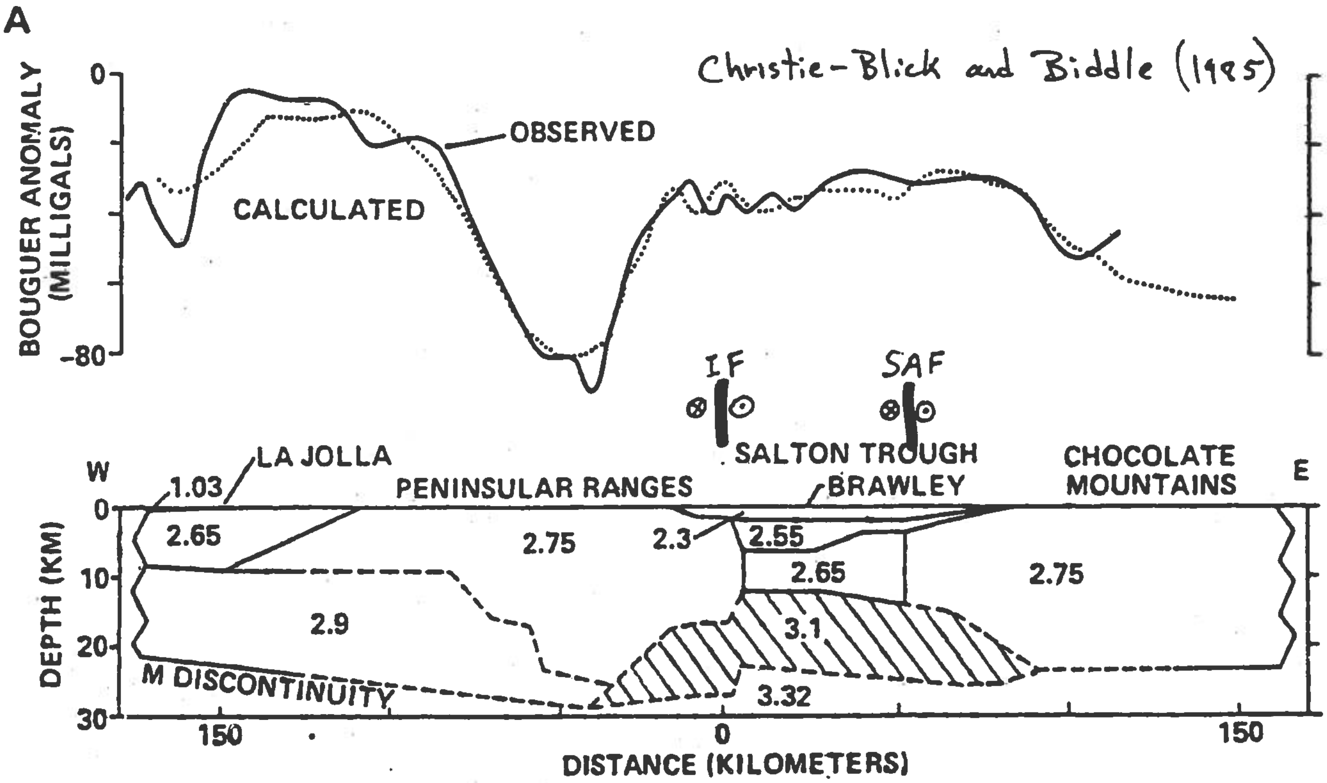


Fig. 10

A) Cross section of southern California from La Jolla to the Chocolate Mountains (from Fuis et al., 1984, see Fig. 1 for location). The observed gravity anomaly is compared with the anomaly calculated from the model (densities in gm/cm³). Solid boundaries are those controlled by seismic refraction data; dashed lines indicate boundaries adjusted to fit the gravity data. Sub-basement (lined area, density 3.1 gm/cm³) beneath the Salton Trough provides most of the gravitational compensation for sedimentary rocks (densities 2.3 and 2.55 gm/cm³) and inferred metasedimentary rocks (density 2.65 gm/cm³). The San Andreas and Imperial faults are located near the east and west edges of the block with density of 2.65 gm/cm³.

ASYMMETRIC SPREADING IN THE SALTON TROUGH:
Near-surface detachment slip accommodated by accretion at depth?

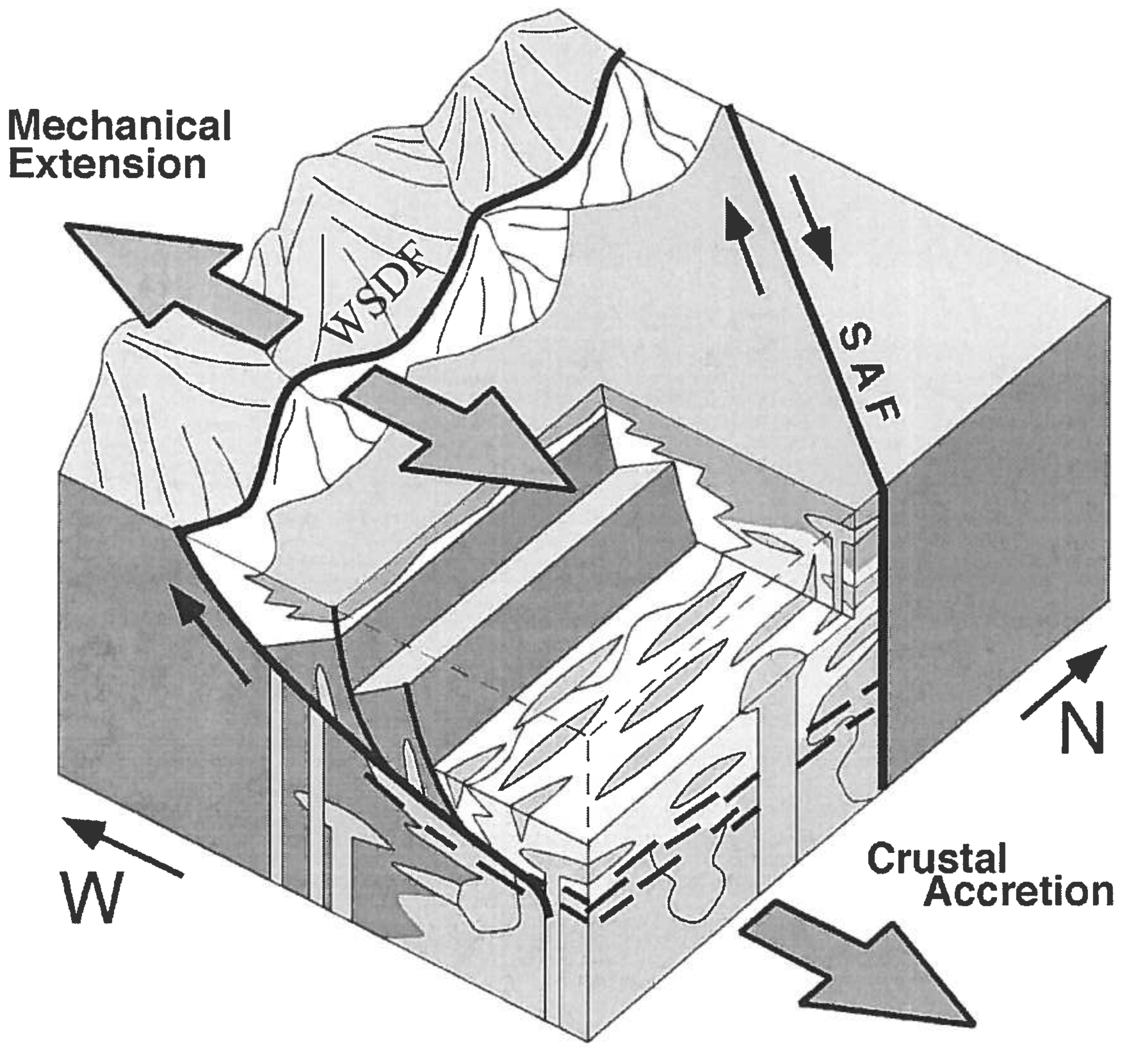
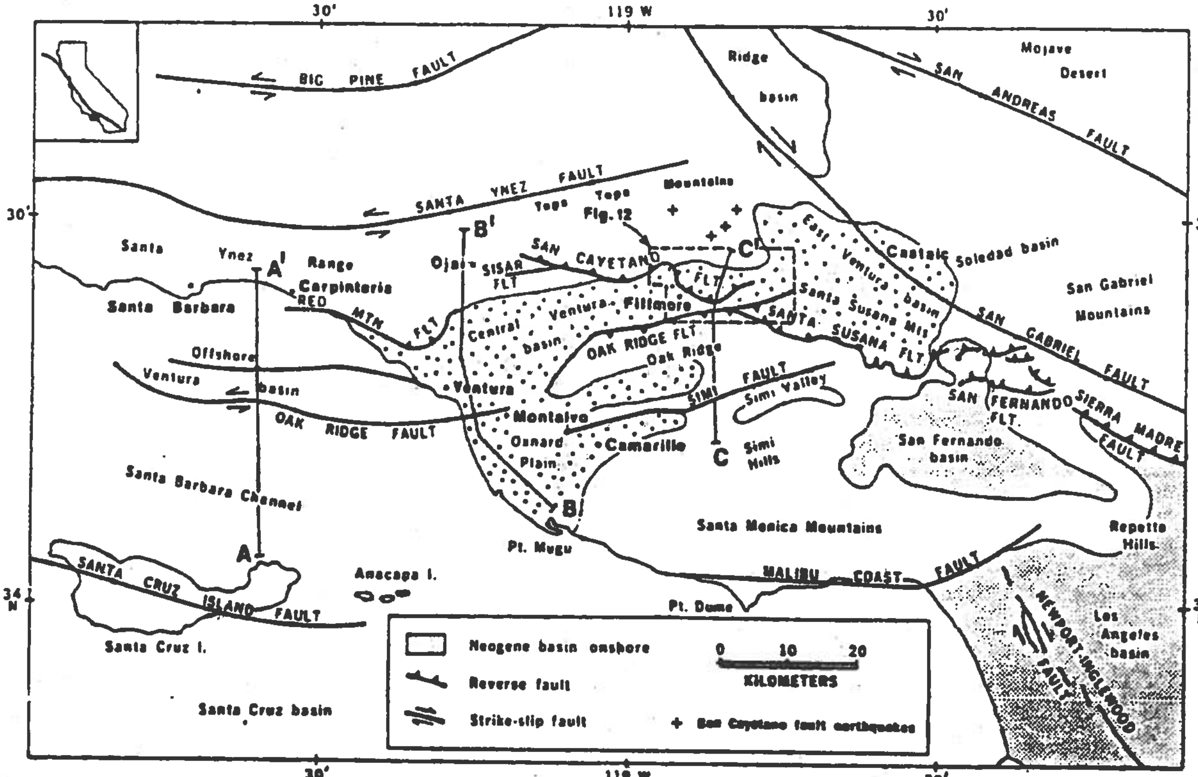


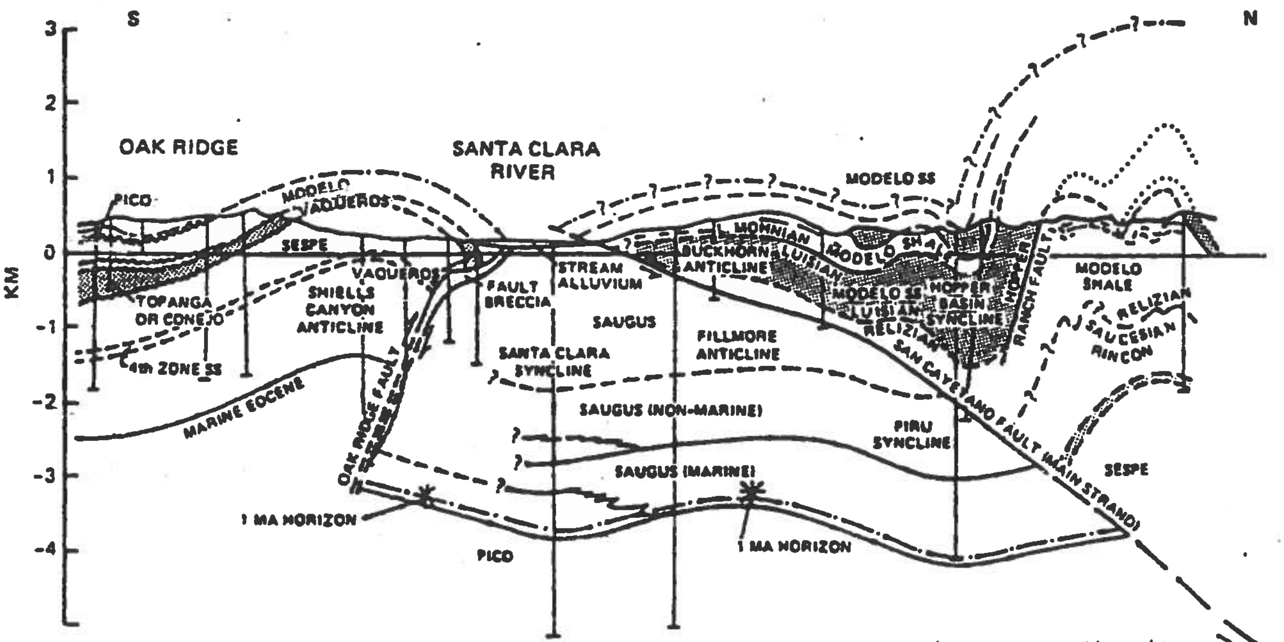
Figure 8. Conceptual model for Plio-Pleistocene regional strain partitioning of the southern San Andreas fault (SAF) and west Salton detachment fault system (WSDF; Axen and Fletcher, 1998; Axen, 2000). Crustal accretion takes place in the Brawley seismic zone where continental crust has been completely attenuated by oblique rifting (Fuis et al., 1984). The space created by lithospheric rupture is filled with upper-mantle basaltic intrusions from below and voluminous sediment accumulation from above. This diagram depicts "ideal" partitioning of regional strain into strike-slip on the San Andreas fault and dip-slip extension on the west Salton detachment fault. Ongoing work for this project (Axen, Janecke, Dorsey, and Housen) suggests a more complicated strain field in which a significant share of strike-slip occurred on the detachment fault system, possibly in the later stages of fault slip and related basin evolution.



Yeats (1983)

Fig. 1. Index map of central Transverse Ranges. Shaded areas indicate onshore areas underlain by thick sequence of post-Miocene sedimentary rocks. A-A', B-B', C-C' locates sections along which convergence rates were calculated by Yeats [1981b]. Dashed line locates Figure 12. Pluses north of San Cayetano fault traces are epicenters of earthquakes located by Yerkes and Lee [1979] and discussed in text.

B



Christie-Blick + Biddle (1985)

FIG. 15.—A comparison of strike-slip basins in profile.
A) The Dead Sea Rift, bounded by faults with normal separation (from Zak and Freund, 1981; see Fig. 11B for location).
B) The Ventura Basin, California, bounded by faults with reverse separation (from Yeats, 1983; see Fig. 1 for location).