

**Figure 9** Mid-Early Cretaceous (~120 Ma) to mid-Cenozoic (Eocene/Oligocene boundary) geotectonic features of the Cordilleran arc-trench system, including the Laramide province of intracontinental deformation. The main batholith belt is delineated as the magmatic arc, but subsidiary arc magmatism spread inland for varying distances (BOP, Omineca zone of backarc mid-Cretaceous plutonism). Active Paleogene strike-slip faults (red lines): De-CS, Denali-Chatham Strait; FR, Fraser River; QC, Queen Charlotte; RL, Ross Lake; SC, Straight

Dickinson 2004

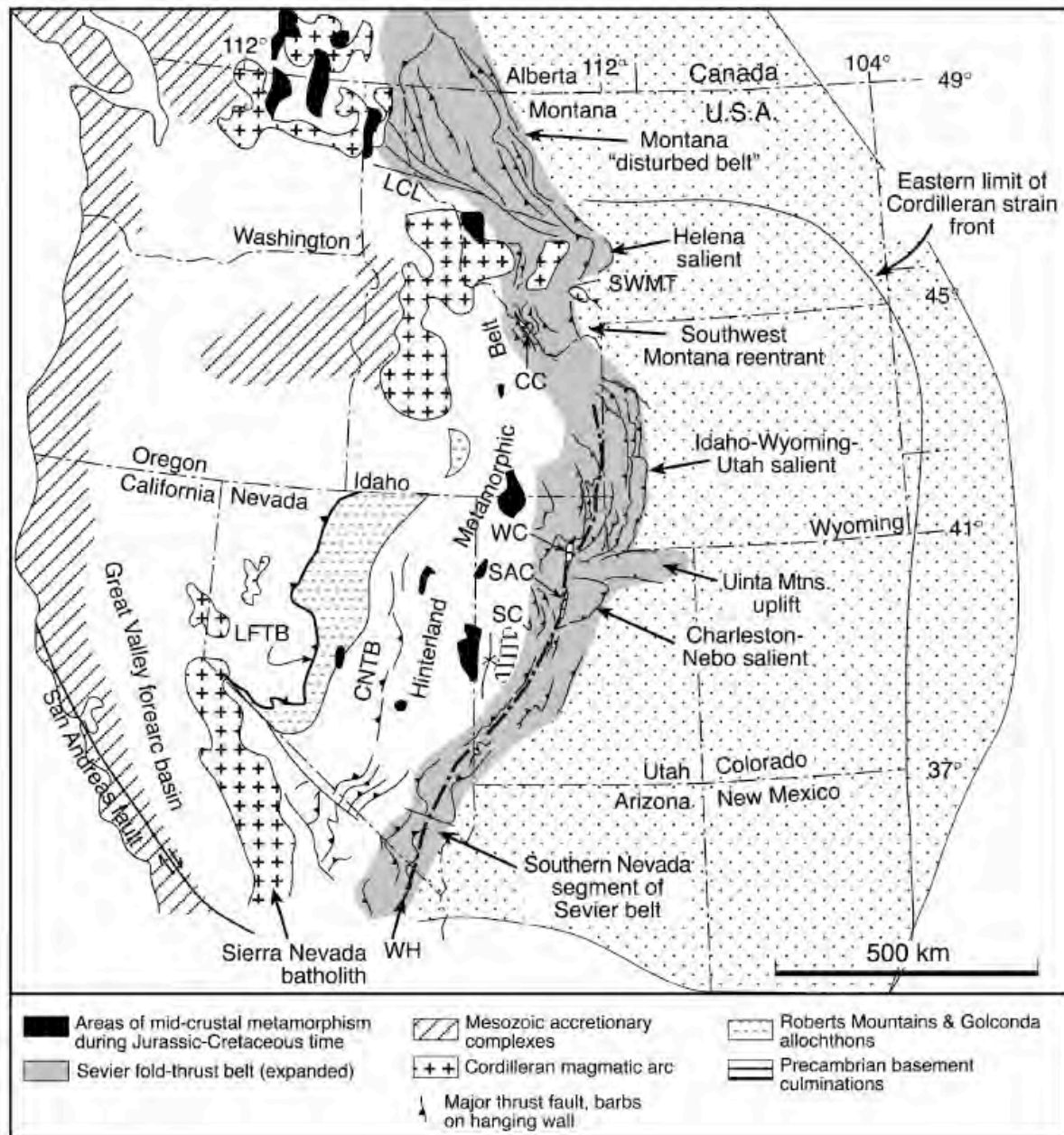


Fig. 5. Simplified version of figure 2, showing some of the major tectonic features in the Cordilleran thrust belt discussed in the text. Abbreviations as follows: LCL, Lewis and Clark line; SWMT, Southwest Montana transverse zone; CC, Cabin culmination; WC, Wasatch culmination; SAC, Santaquin culmination; SC, Sevier culmination; CNTB, Central Nevada thrust belt; LFTB, Luning-Fencemaker thrust belt; WH, Wasatch hinge line. Stippled region represents Cordilleran foreland basin system.

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Folded Cretaceous strata, 2 km east Turner Valley, AB



Mt Kidd, Banff National Park, Alberta



Mt Kidd, Banff National Park, Alberta



Banff National Park, Alberta



Thrust Fault cut-off, Kanaskia National Park, Alberta

Sevier Fold-Thrust Belt



Turner Valley, Alberta





Great Falls, Mt

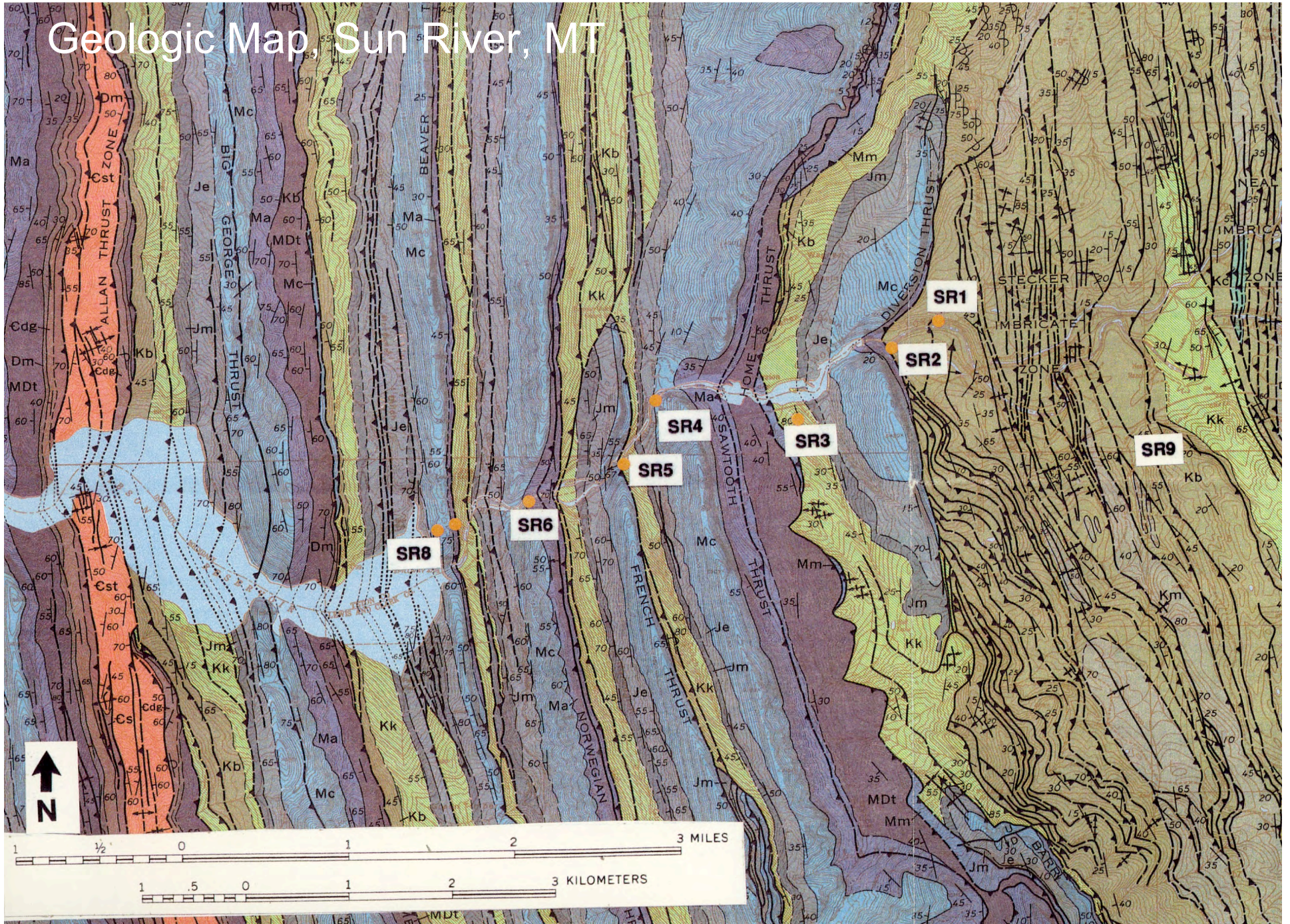


Thrust Fault, near Choteau, Montana



Thrust Fault, near Choteau, Montana

# Geologic Map, Sun River, MT



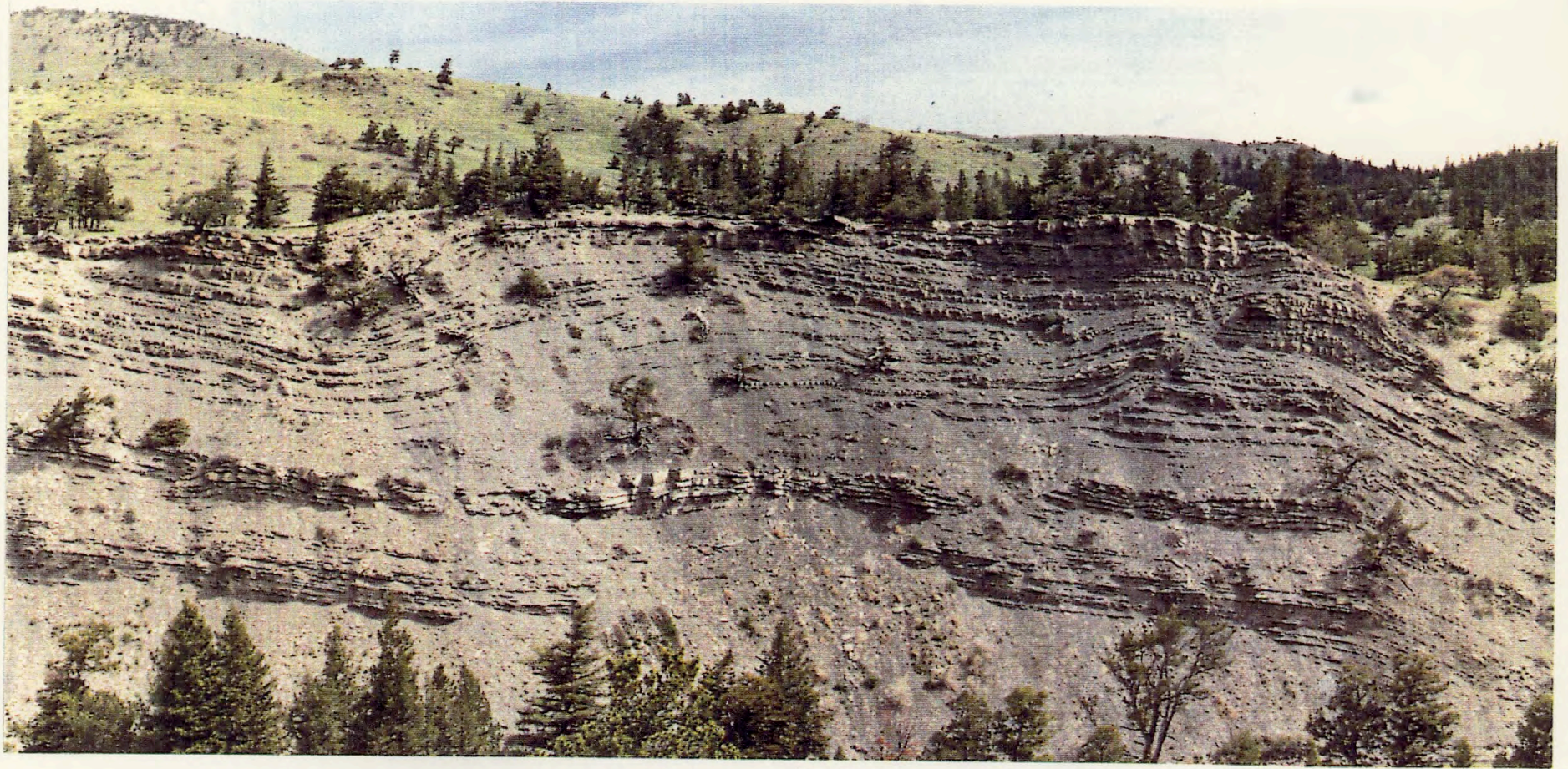


Figure 7. Stop SR 1. Fold-related thrusts in Cretaceous units in the Stecker imbricate zone in the Disturbed Belt .

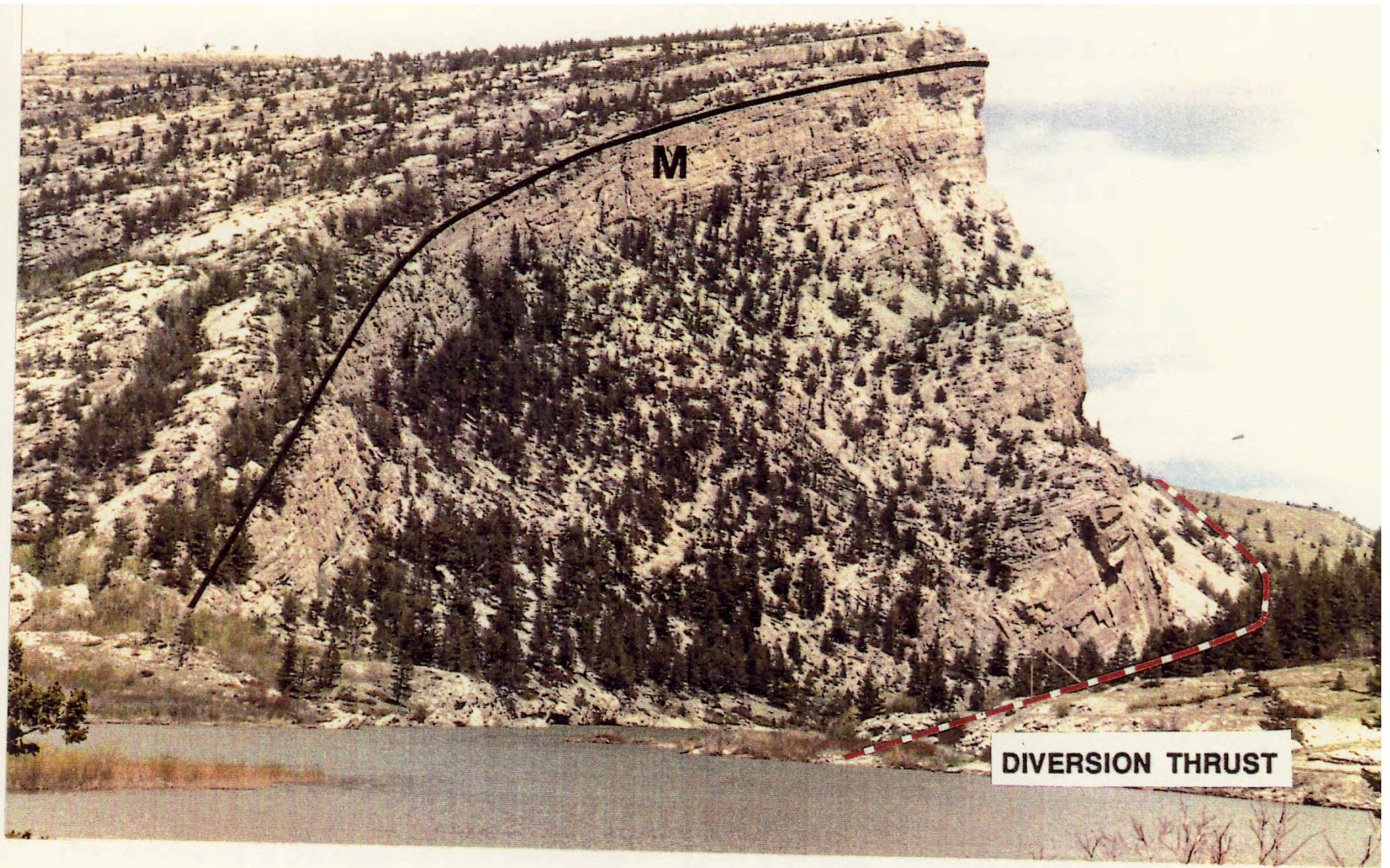


Figure 13. Stop SR 2. Hanging wall cutoff of Mississippian carbonates in the Diversion thrust. View looking east.

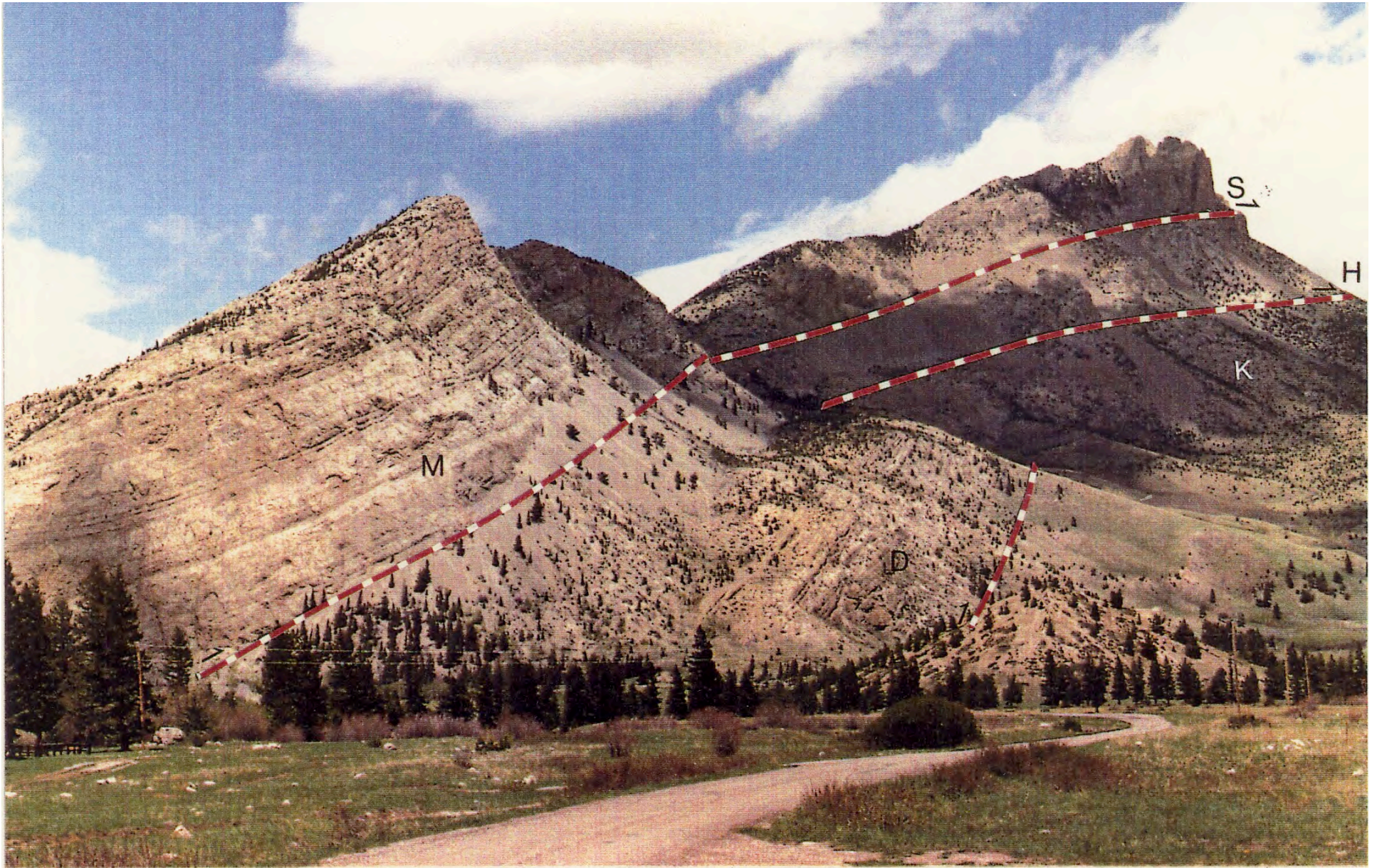


Figure 14. Stop SR 3. View looking north of the Home and Sawtooth thrust at Castle Reef.

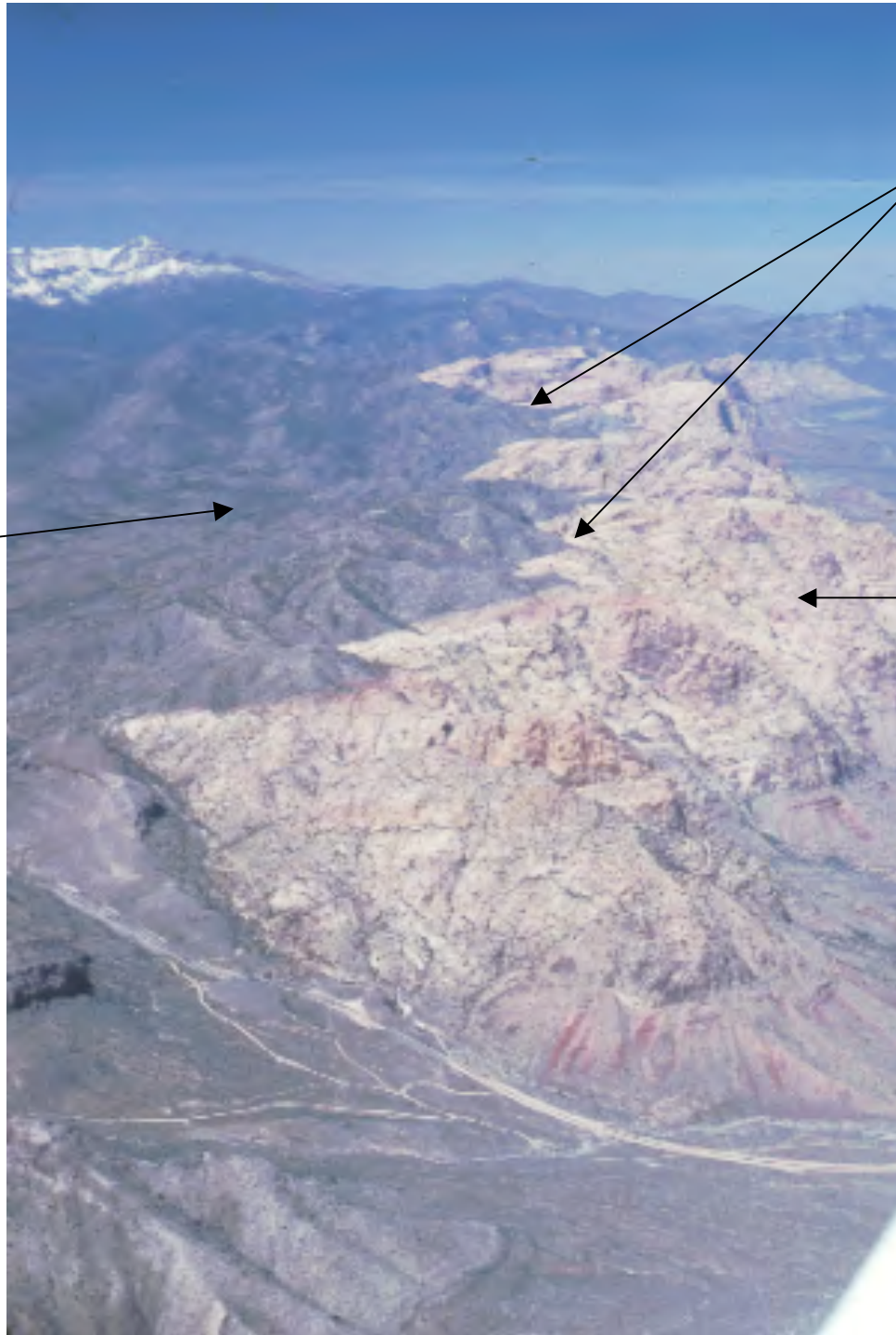


Figure 22. Stop SR 8. View looking east from Gibson Reservoir overlook. The hanging wall rocks of the Diversion, Home and Norwegian thrusts form a sawtooth pattern. Note that the dips increase progressively westward.





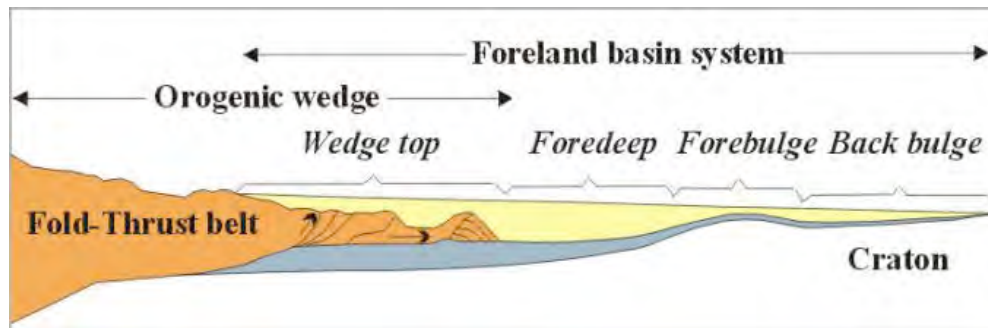
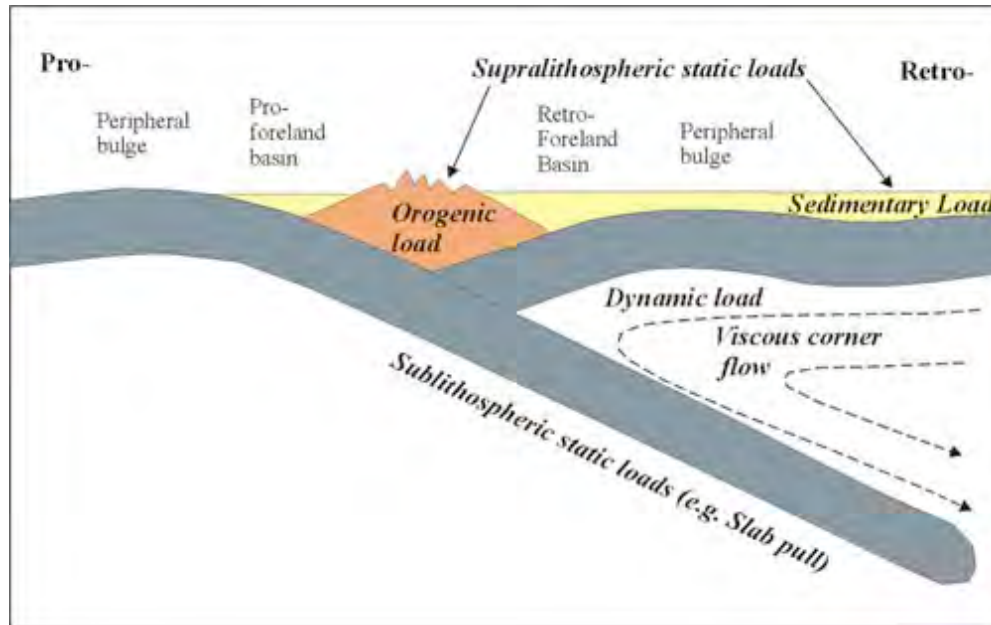
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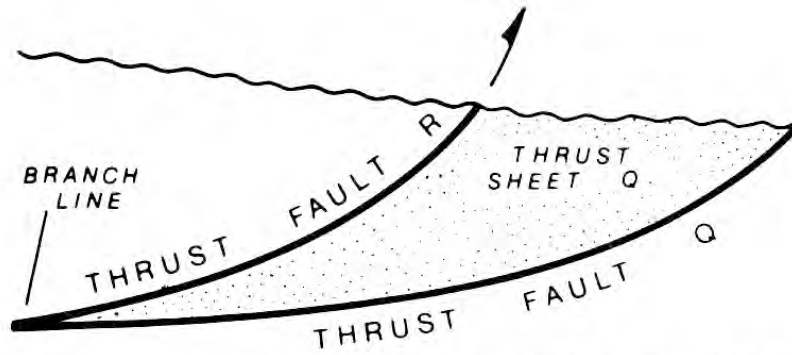


Cambrian  
Limestone

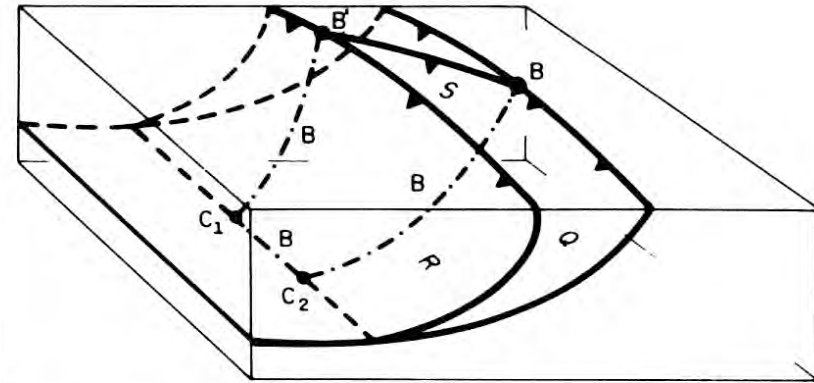
Wilson Cliffs  
Thrust,  
Nevada

Jurassic  
Aztec  
Sandstone





**FIG. 1**—Cross section through thrust sheet (Q), which is  
 une of rock above leading fault (Q) and below trailing  
 (R).



**FIG. 7**—Two major faults (Q, R) with connecting splay (S).  
 Two branch lines (B) have surface terminations (B, B') and one  
 branch line at depth has two corners (C<sub>1</sub>, C<sub>2</sub>).

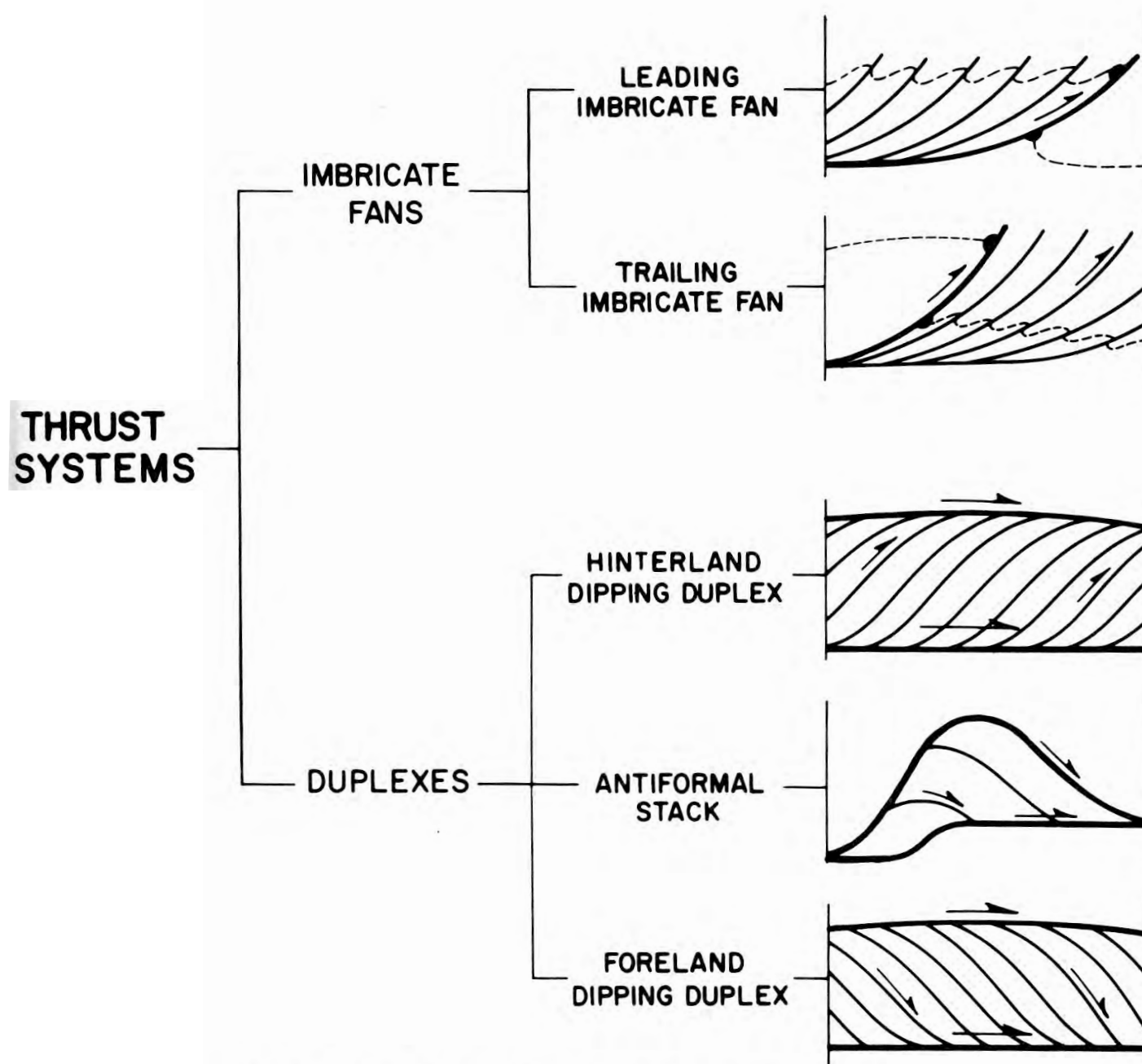


FIG. 12—Classification of different systems of thrusts; most are imbricate.

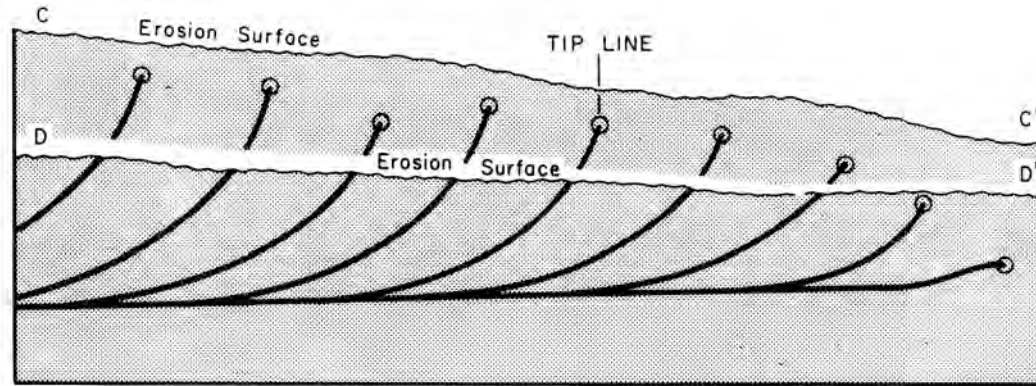


FIG. 11—Cross section of imbricate fan at two different levels of erosion. Each thrust sheet is an upward-opening crescentic slice and all curve asymptotically downward to a common basal sole thrust. If most faults cut synorogenic erosion surface DD' we have an emergent imbricate fan. Alternatively, it is possible that tip lines do not reach synorogenic erosion surface CC', producing blur imbricate fan. Note that subsequent erosion (CC' down to DD') may obliterate any means of distinguishing two kinds of imbricate fans.

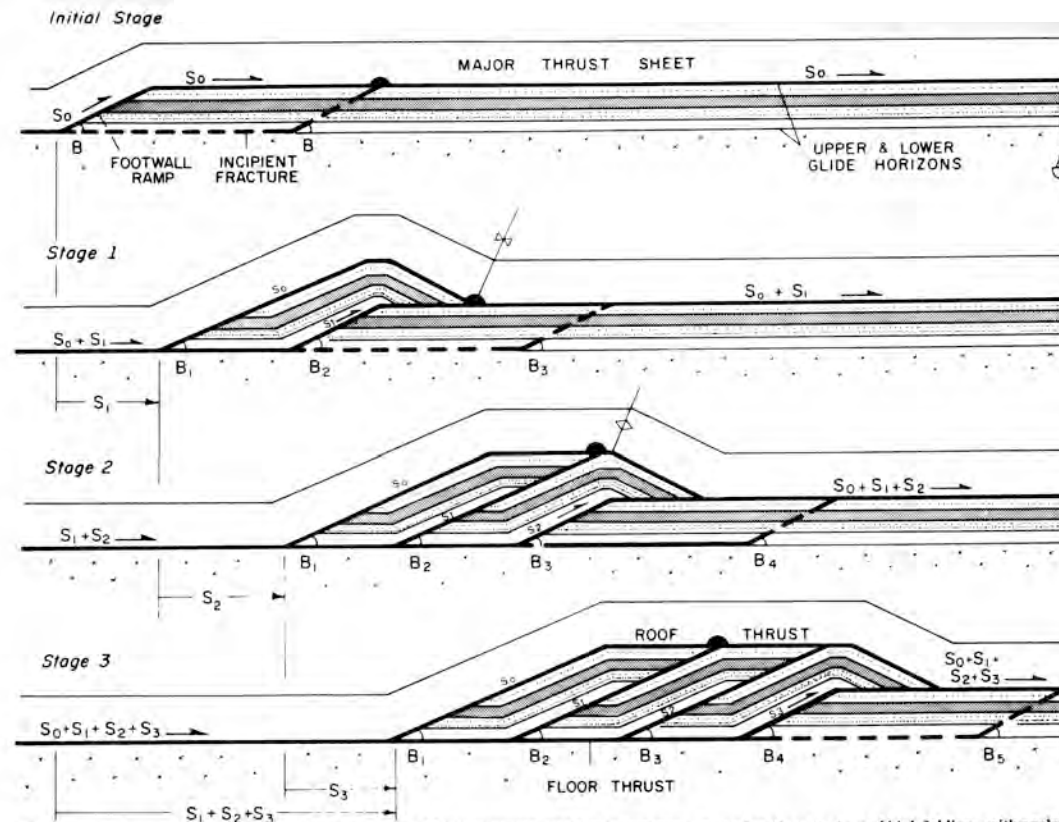


FIG. 19—Progressive collapse of footwall ramp builds up duplex. This is measured graphical experiment, assuming plane strain and kink folding, with angles and ratios of dimensions typical of natural examples (Table 1). Roof thrust sheet undergoes complex sequence of folding and unfolding, seen by following black half dot. Modified from Boyer (1978).

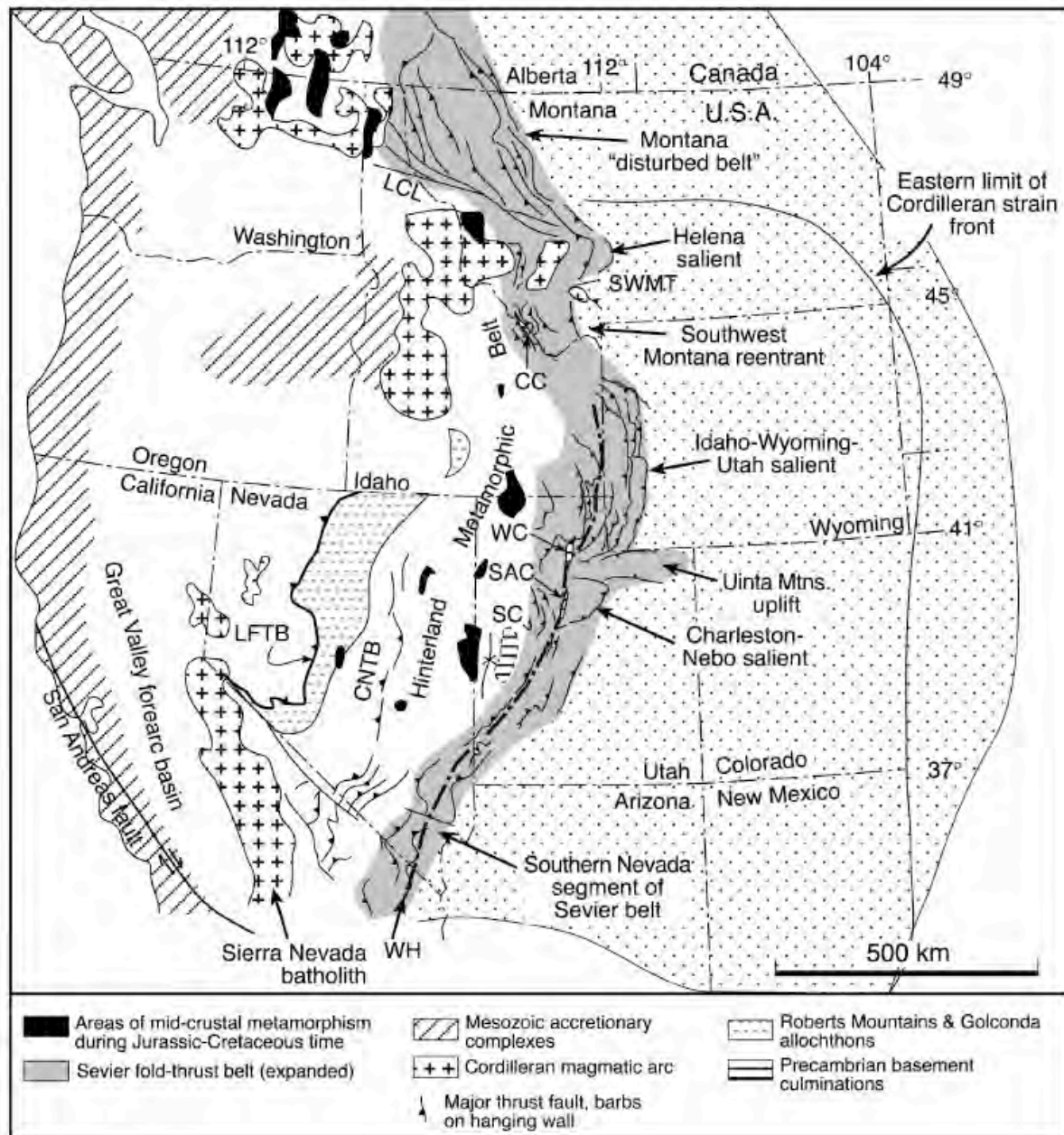
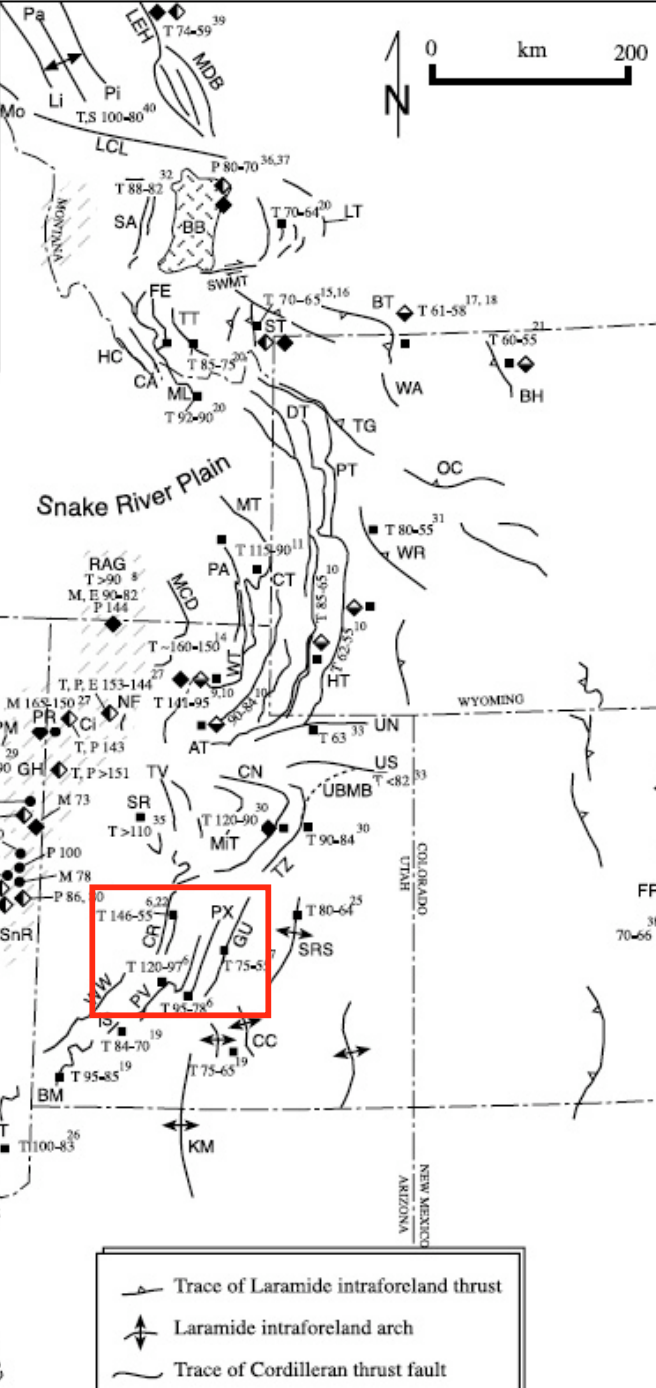


Fig. 5. Simplified version of figure 2, showing some of the major tectonic features in the Cordilleran thrust belt discussed in the text. Abbreviations as follows: LCL, Lewis and Clark line; SWMT, Southwest Montana transverse zone; CC, Cabin culmination; WC, Wasatch culmination; SAC, Santaquin culmination; SC, Sevier culmination; CNTB, Central Nevada thrust belt; LFTB, Luning-Fencemaker thrust belt; WH, Wasatch hinge line. Stippled region represents Cordilleran foreland basin system.

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**Tectonic, Plutonic & Metamorphic Activity:**  
 T = Thrust faulting  
 S = Strike-slip faulting  
 P = Plutonic activity  
 E = Extension  
 M = Barrovia metamorphism

**Geochronological Systems:**  
 ◆ APATITE/ZIRCON FT  
 ■ STRATIGRAPHIC  
 ◆ <sup>40</sup>Ar-<sup>39</sup>Ar  
 ● U-Pb  
 ◆ K-Ar



**KEY TO LOCATIONS:**  
 AT- Absaroka thrust  
 BB- Boulder batholith  
 BH- Bighorn Range  
 BM- Blue Mountain thrust  
 BT- Beartooth Range  
 CA- Cabin thrust  
 CC- Circle Cliffs uplift  
 CL- Clery thrust  
 CN- Charleston & Nebo thrusts  
 CNTB- Central Nevada thrust belt  
 CR- Canyon Range thrust  
 CT- Crawford thrust  
 DT- Darby thrust  
 EH- East Humboldt Range  
 ESTB- Eastern Sierra thrust belt  
 FE- Four Eyes Canyon thrust  
 FR- Front Range  
 GH- Grant Hills  
 GL- Glendale thrust  
 GP- Gas Peak thrust  
 GU- Gunnison thrust  
 HC- Hawley Creek thrust  
 HT- Hogsback thrust  
 IS- Iron Springs thrust  
 KM- Kaibab monocline  
 LC- Last Chance thrust  
 LCL- Lewis & Clark lineament  
 LEH- Lewis/Eldorado/Hoadley thrust  
 LFTB- Luning-Fencemaker thrust belt  
 Li- Libby thrust  
 LT- Lombard thrust  
 MCD- Manning Canyon detachment  
 MDB- Montana Disturbed Belt  
 ML- Medicine Lodge thrust  
 Mo- Moyle thrust  
 KMM- Keaney/Mojusk Mine thrust  
 KT- Keystone (Muddy Mtn.) thrust  
 MC- Marble Canyon thrust  
 MP- Mesquite Pass thrust  
 MT- Meade thrust  
 MIT- Midas thrust  
 NF- Newfoundland Mountains  
 OC- Owl Creek Range  
 PA- Paris thrust  
 Pa- Purcell anticlinorium  
 Pi- Pinkham thrust  
 PM- Pequo Mountains  
 PR- Pilot range  
 PT- Prospect thrust  
 PV- Pavant thrust  
 PX- Paxton thrust  
 RAG- Raft River-Albion-Grouse Creek Ranges  
 RU- Ruby Mountains  
 SA- Sapphire thrust  
 SnR- Snake Range  
 SR- Sheeprock thrust  
 SRS- San Rafael Swell  
 ST- Scarface thrust  
 SWMT- SW Montana transverse zone  
 TG- Teton-Gros Ventre Range  
 TT- Tendoy thrust  
 TV- Tintic Valley thrust  
 TZ- Frontal triangle zone of Charleston-Nebo salient  
 UBMB- Uinta Basin/Mt. Boundary thrust  
 UN- Uinta North Flank thrust  
 US- Uinta south flank thrust  
 WA- Washakie Range  
 WH- Wood Hills  
 WP- Wheeler Pass thrust  
 WpP- Winters Pass-Pachalka thrust  
 WR- Wind River Range  
 WT- Willard thrust  
 WW- Wah Wah thrust

— Trace of Laramide intraforeland thrust  
 ↗ Laramide intraforeland arch  
 ~ Trace of Cordilleran thrust fault

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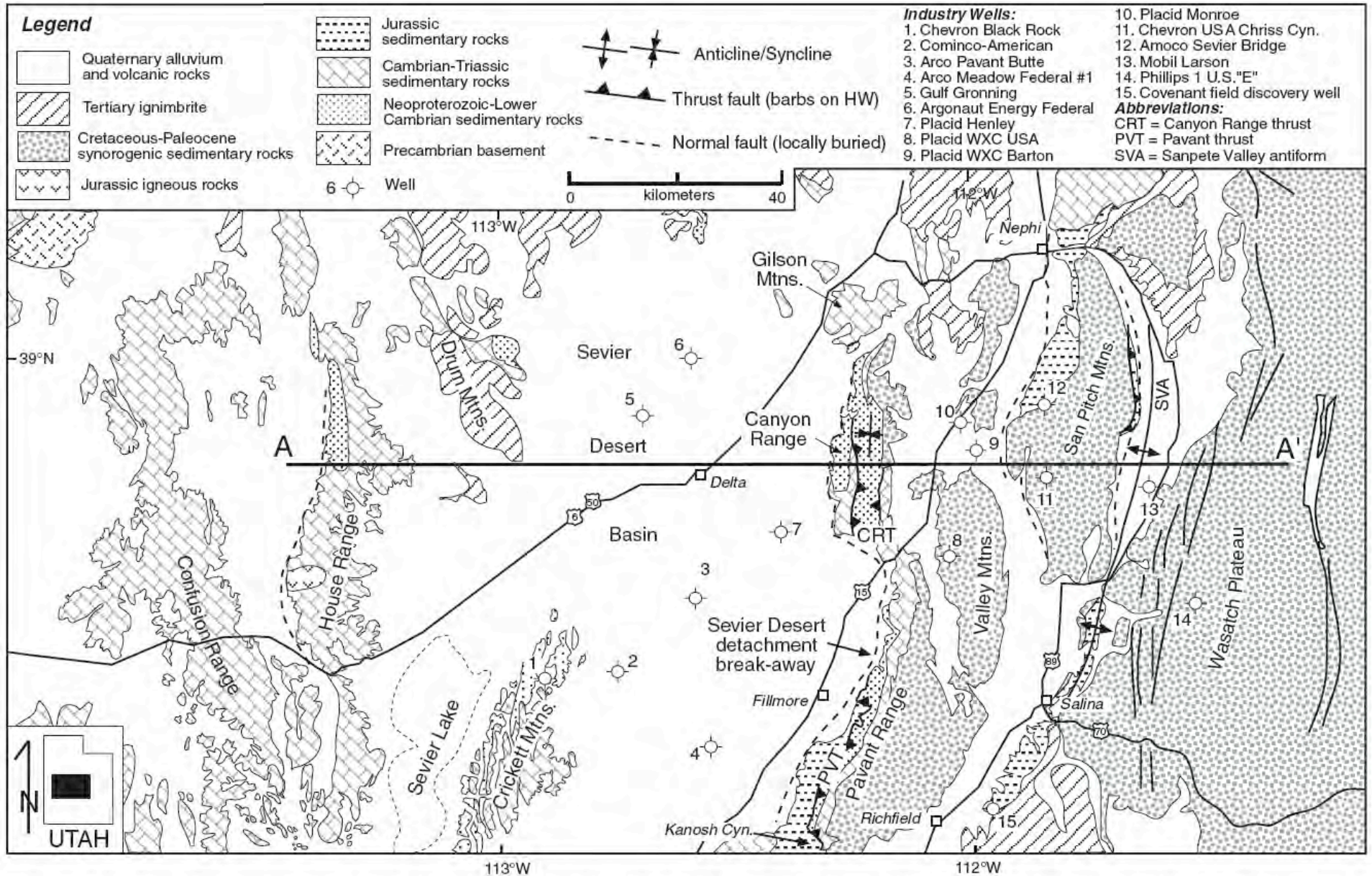
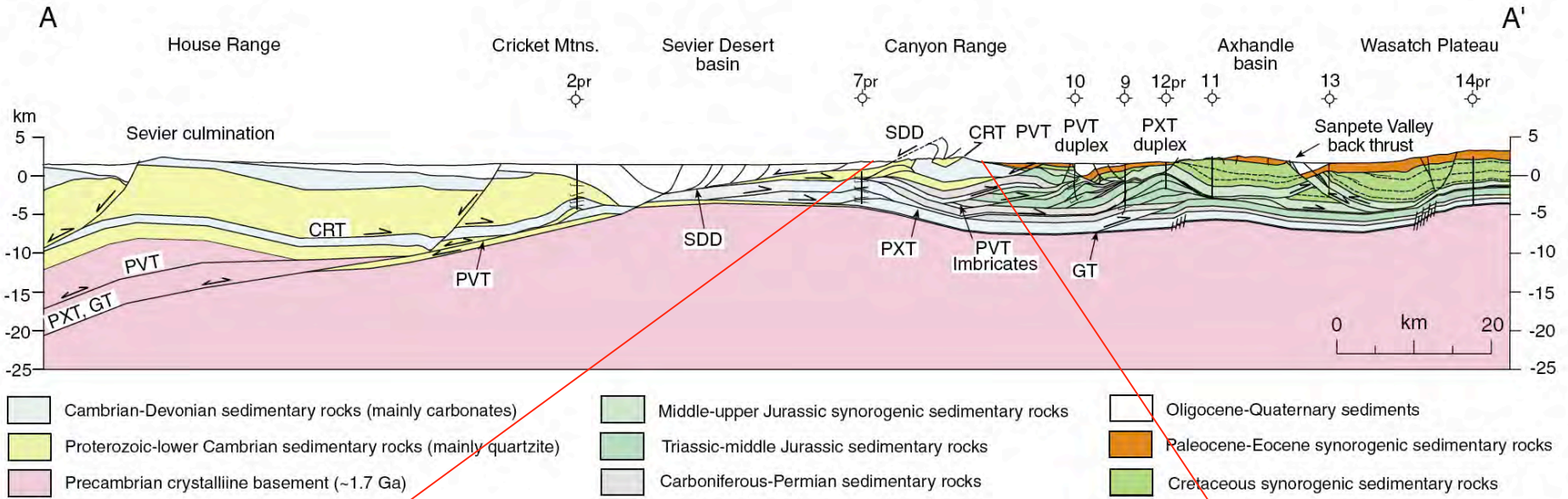
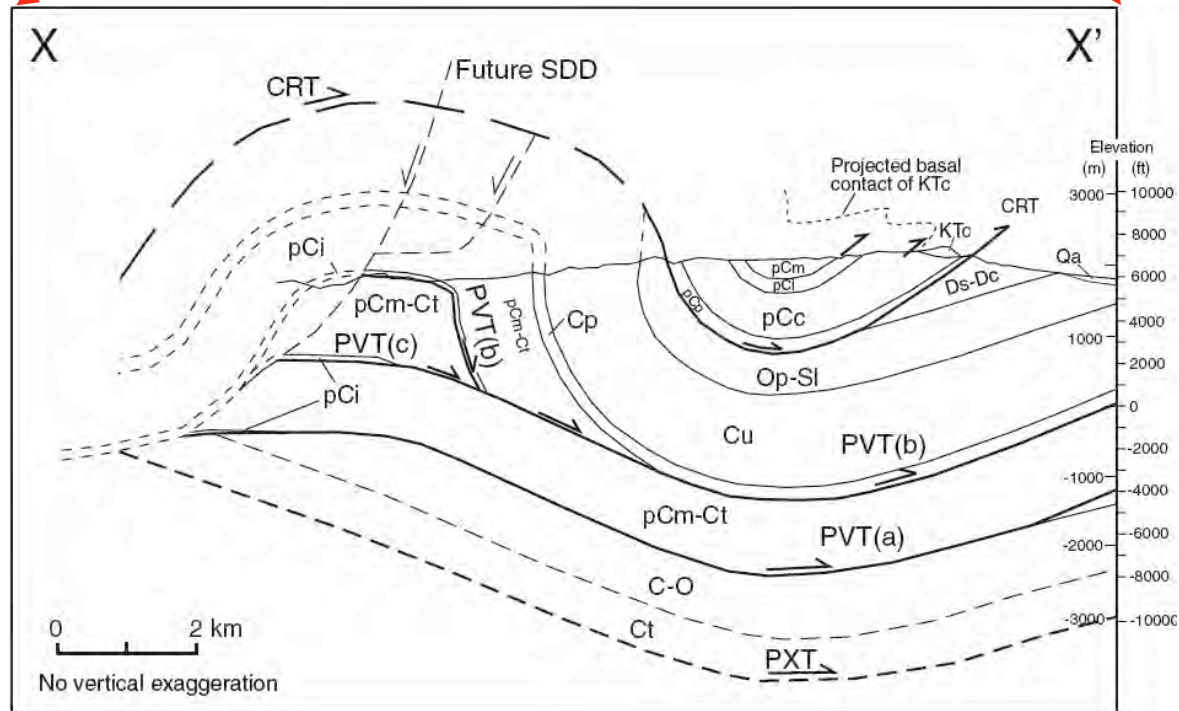


Figure 2. Geological map of central Utah after Hintze (1980), showing relevant hydrocarbon industry wells. A-A' marks the line of cross section shown in Figure 3. HW—



Sevier fold-and-thrust belt



DeCelles and Coogan 2006

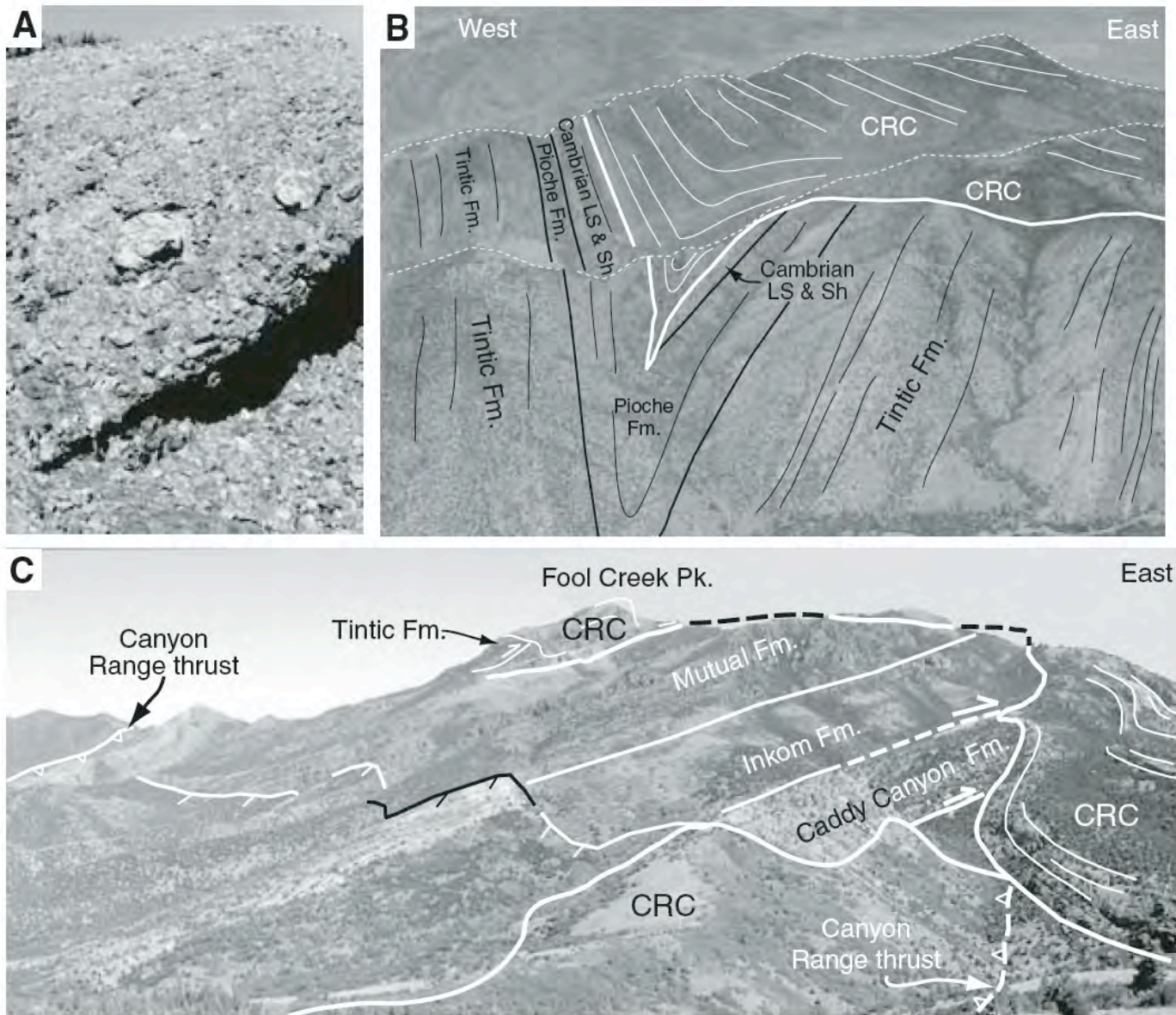
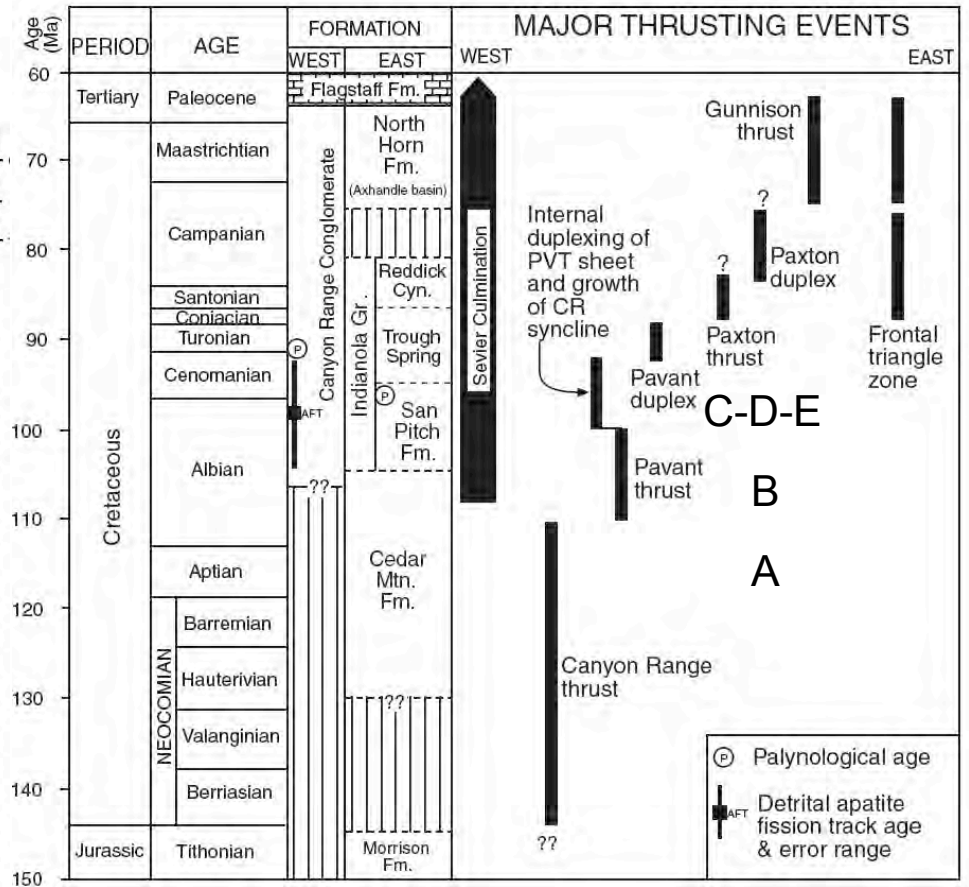
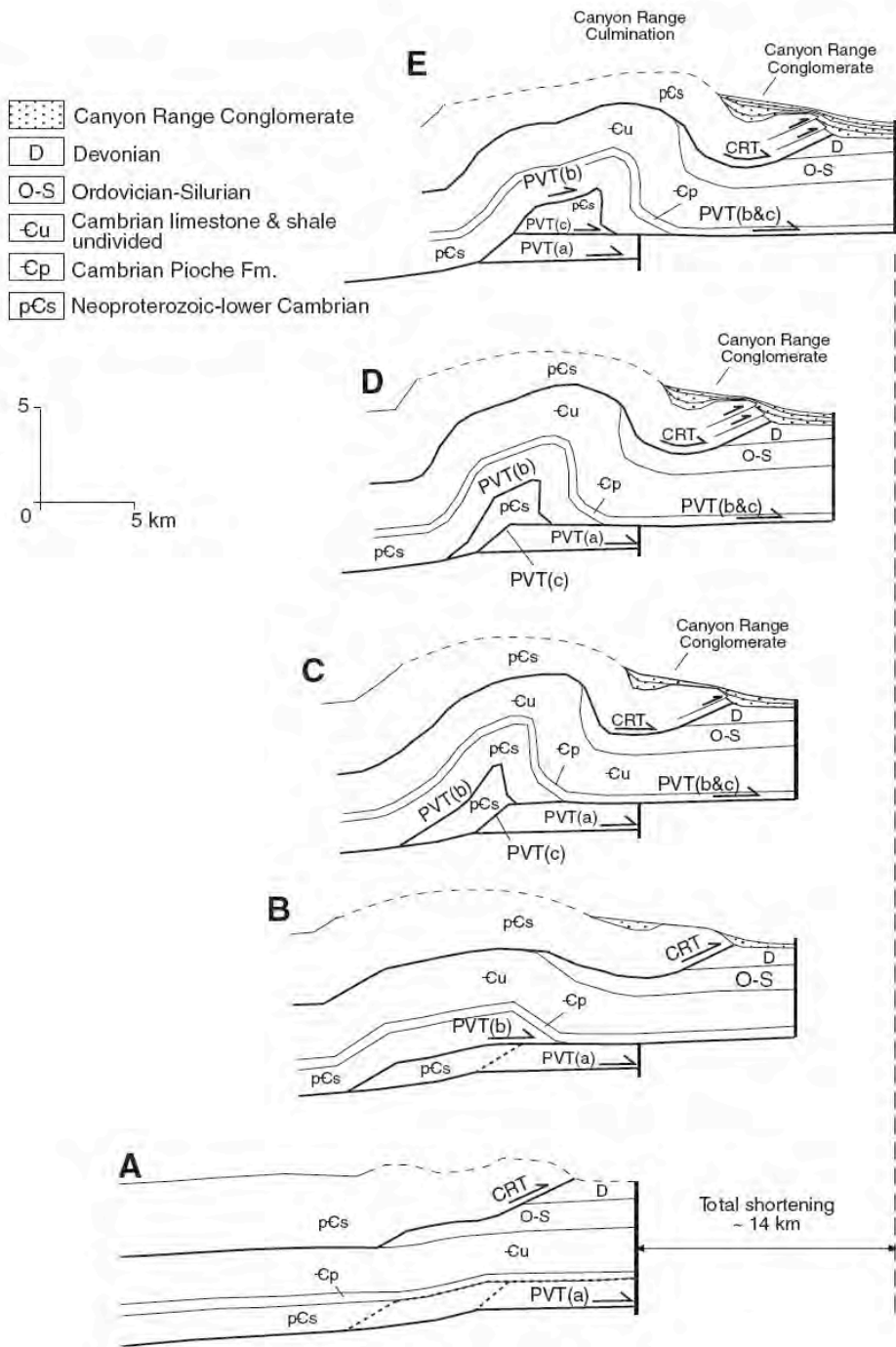
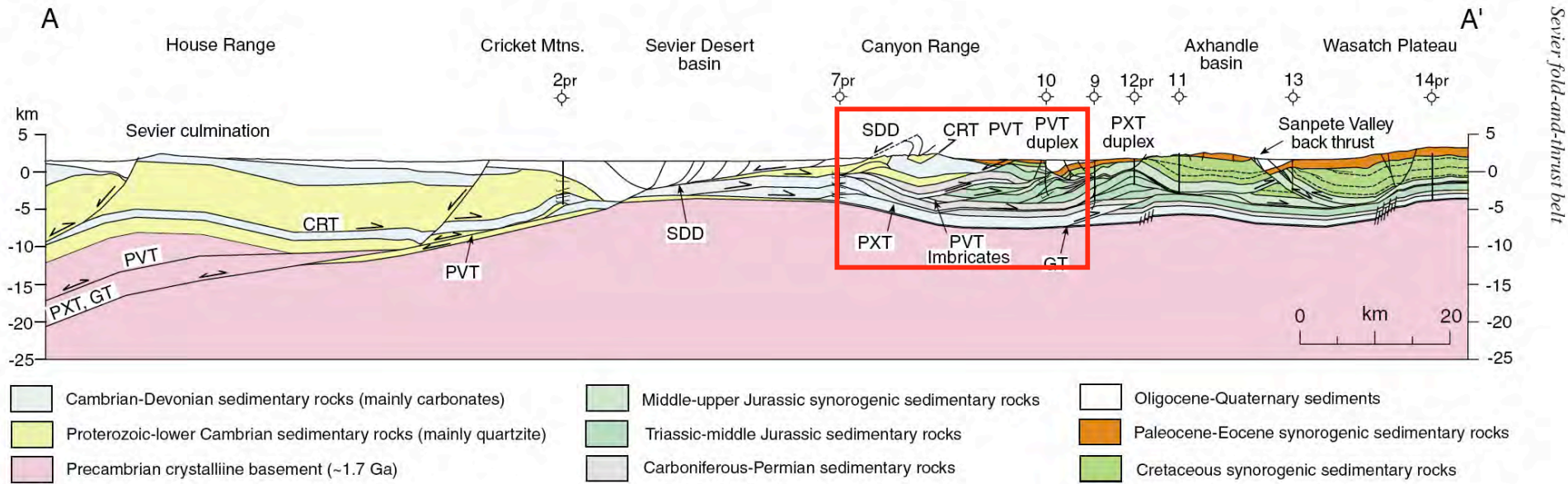
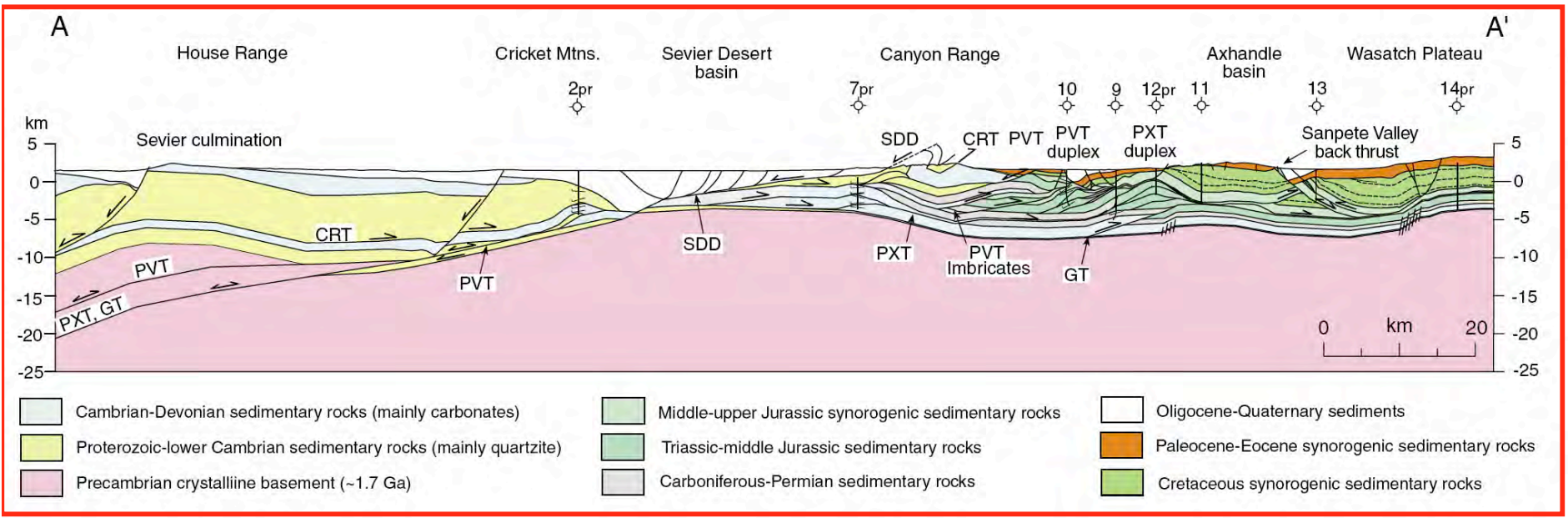


Figure 7. (A) Boulder-conglomerate lithofacies, dipping westward, in Canyon Range Conglomerate just below Fool Creek Peak. (B) Oblique aerial photograph of the core of the Canyon Range synform between Dry Fork and Wildhorse Peak (see Fig. 4 for location). Note the tight synclinal fold in the Paleozoic section, the overlapping angular unconformity at the base of the Canyon Range Conglomerate (CRC), and the growth syncline in the CRC. LS—limestone; Sh—shale. Width of image is ~3 km. (C) Panoramic photograph of the north side of Oak Creek Canyon, showing the western trace of the Canyon Range thrust (far left), the approximate location of the eastern, buried trace of the thrust (lower right), the eastern limb of the Canyon Range synform, and overlapping, growth-folded Canyon Range Conglomerate (CRC). Width of image is ~5 km.





Sevier fold-and-thrust belt



Sevier fold-and-thrust belt

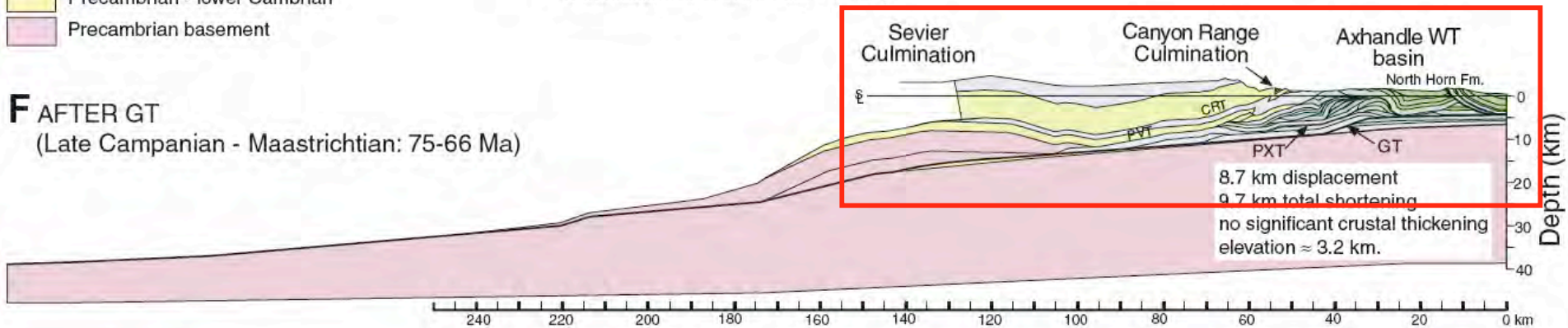
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- Cretaceous Paleocene foreland basin deposits
- Middle-upper Jurassic
- Triassic - middle Jurassic
- Upper Paleozoic
- Lower Paleozoic
- Precambrian - lower Cambrian
- Precambrian basement

Total crustal thickening  $\approx$  16 km.  
 Maximum Surface elevation  $\approx$  3.2 km  
 (assuming that surface was at sea level in early  
 Cretaceous and initial Tcrust = 35 km)

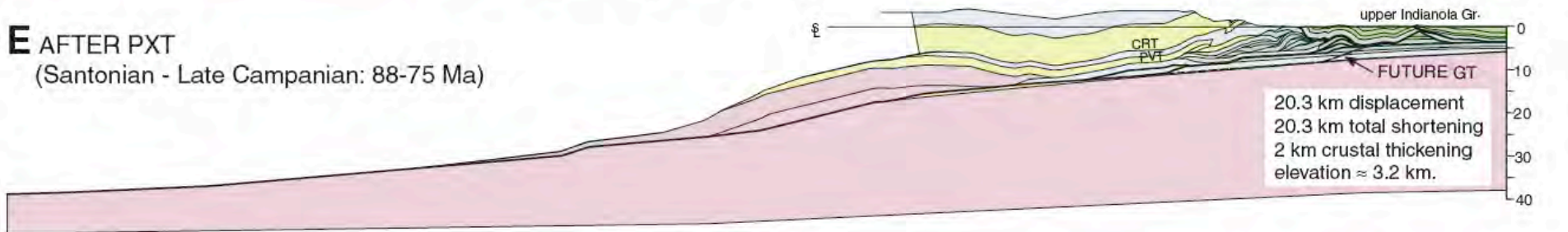
**F** AFTER GT

(Late Campanian - Maastrichtian: 75-66 Ma)



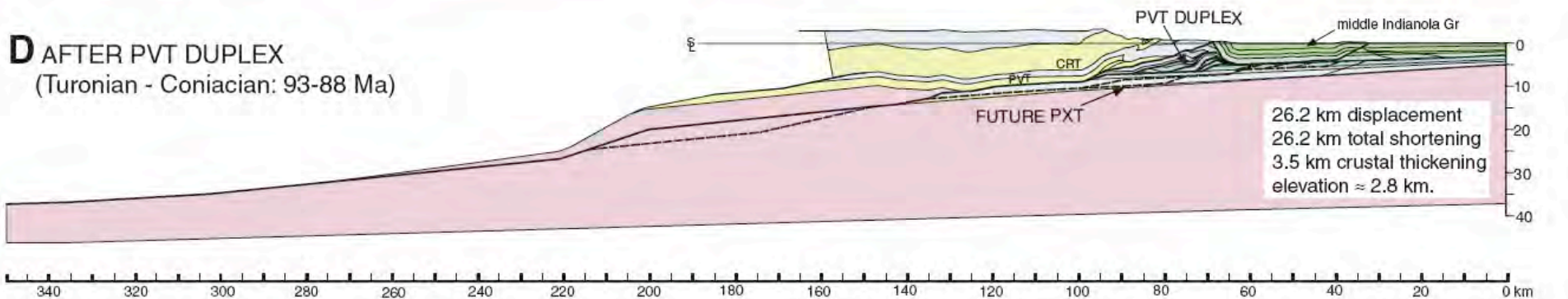
**E** AFTER PXT

(Santonian - Late Campanian: 88-75 Ma)



**D** AFTER PVT DUPLEX

(Turonian - Coniacian: 93-88 Ma)



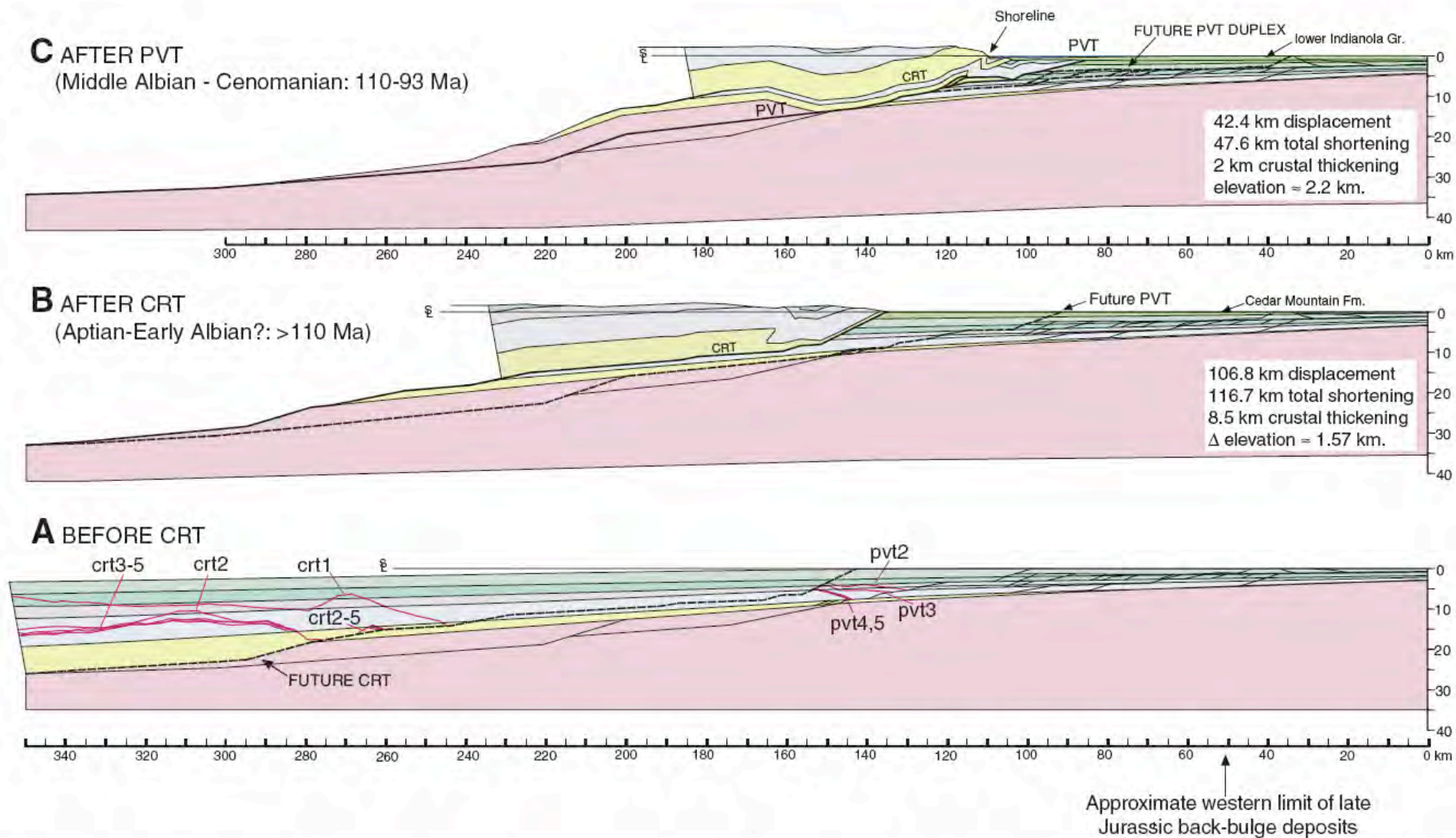
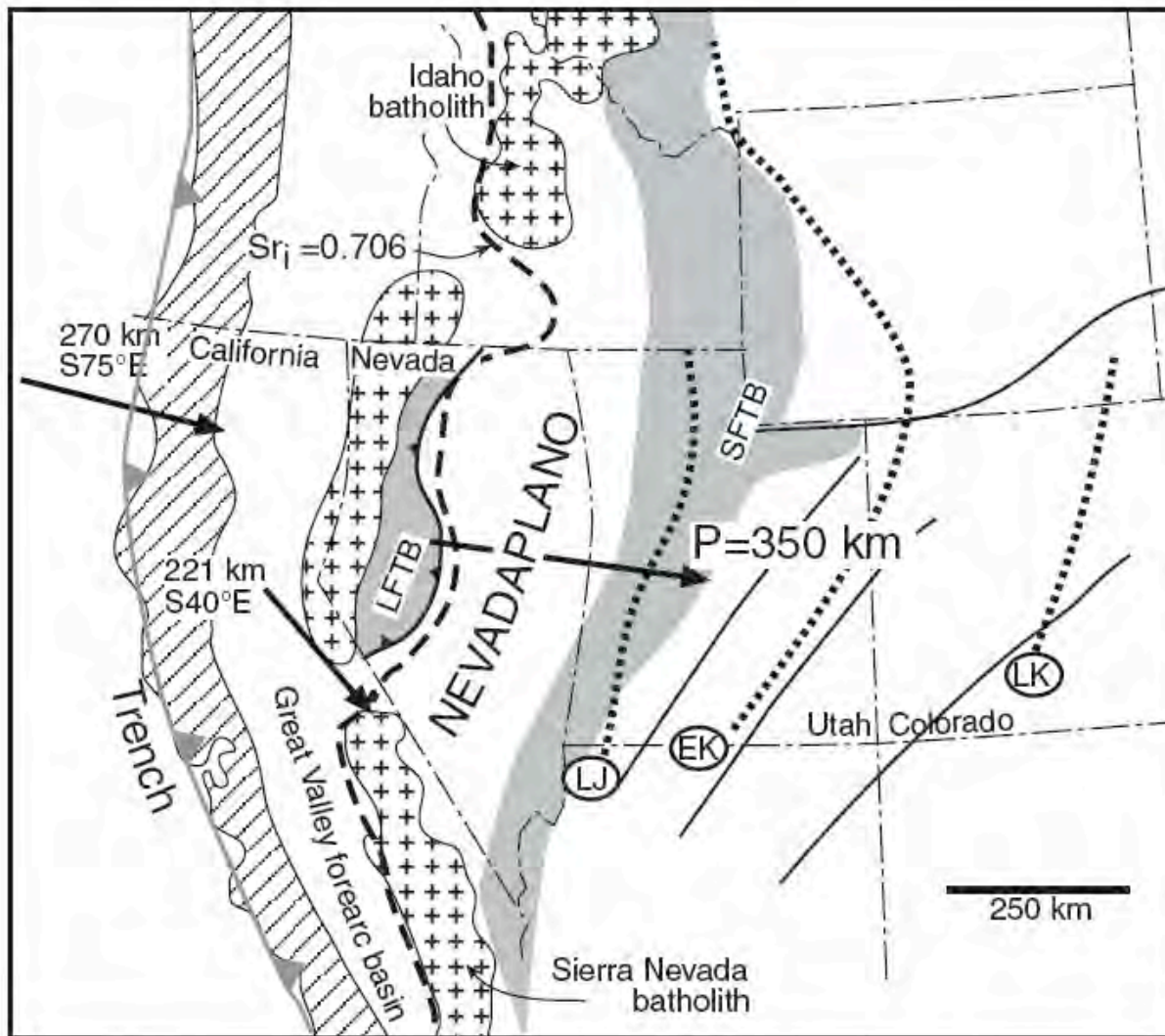




Figure 8 (on this and previous page). Balanced, incremental retrodeformation of the central Utah segment of the Sevier thrust belt, based on initial deformed state (with Cenozoic extension restored) of cross section shown in Figure 3. In panel A, the dotted lines represent erosion surfaces in the Canyon Range (CRT) and Pavant (PVT) thrust sheets through time. PXT—Paxton thrust; GT—Gunnison thrust; SDD—Sevier Desert detachment.



-  Accretionary complexes
-  Cordilleran magmatic arc


-  Highlands of Luning-Fencemaker and Sevier fold-thrust belts

Figure 11. Palinspastically reconstructed tectonic-paleogeographic map of the North American Cordilleran orogenic belt in the western United States. Arrows indicate distances and directions of restored Neogene extension, from Wernicke et al. (1988), Snow and Wernicke (1994), and Dickinson and Wernicke (1997). Bold arrow labeled P indicates approximate distance of forward propagation of the thrust belt from Late Jurassic through Cretaceous time. Solid lines in eastern Utah and southern Wyoming represent Precambrian shear zones after Karlstrom and Williams (1998). Dashed lines indicate approximate restored positions of the crest of the forebulge in the foreland basin system at times corresponding to the labels as follows: L, J—Late Jurassic (Currie, 1997); E, K—Early Cretaceous (Currie, 2002; DeCelles and Burden, 1992); LK—Late Cretaceous (White et al., 2002). LFTB—Luning-Fencemaker thrust belt; SFTB—Sevier fold-and-thrust belt.



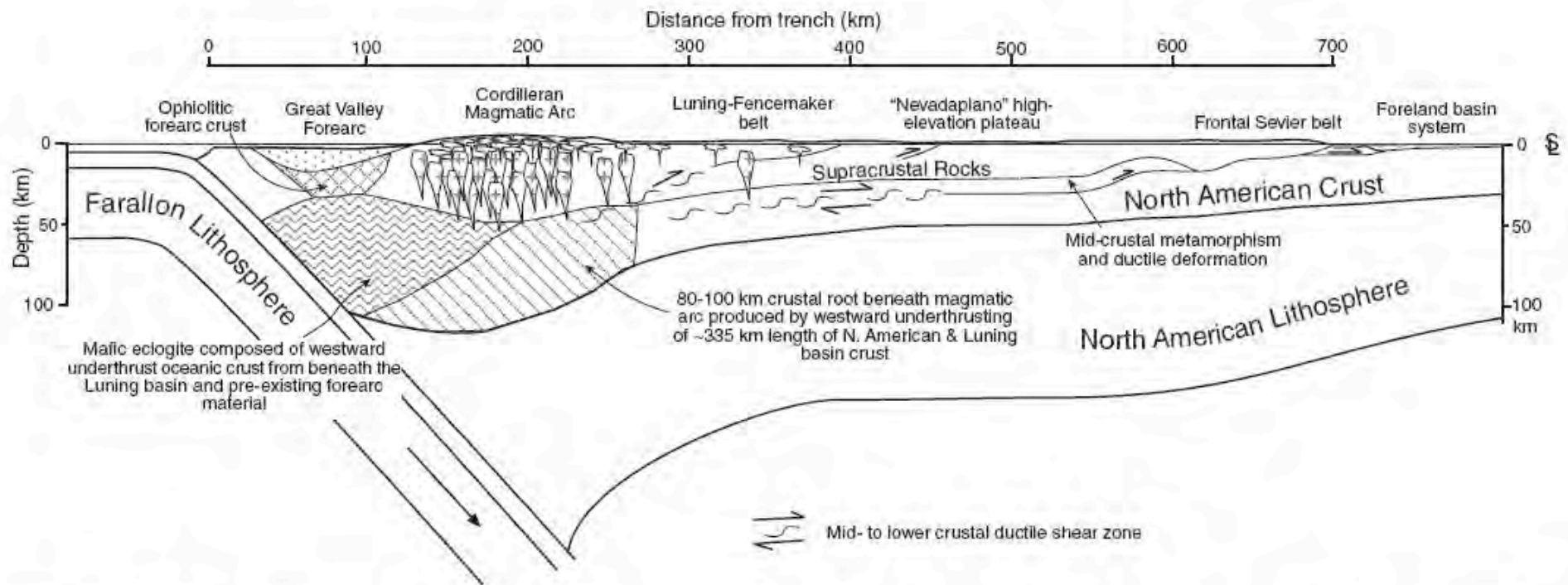
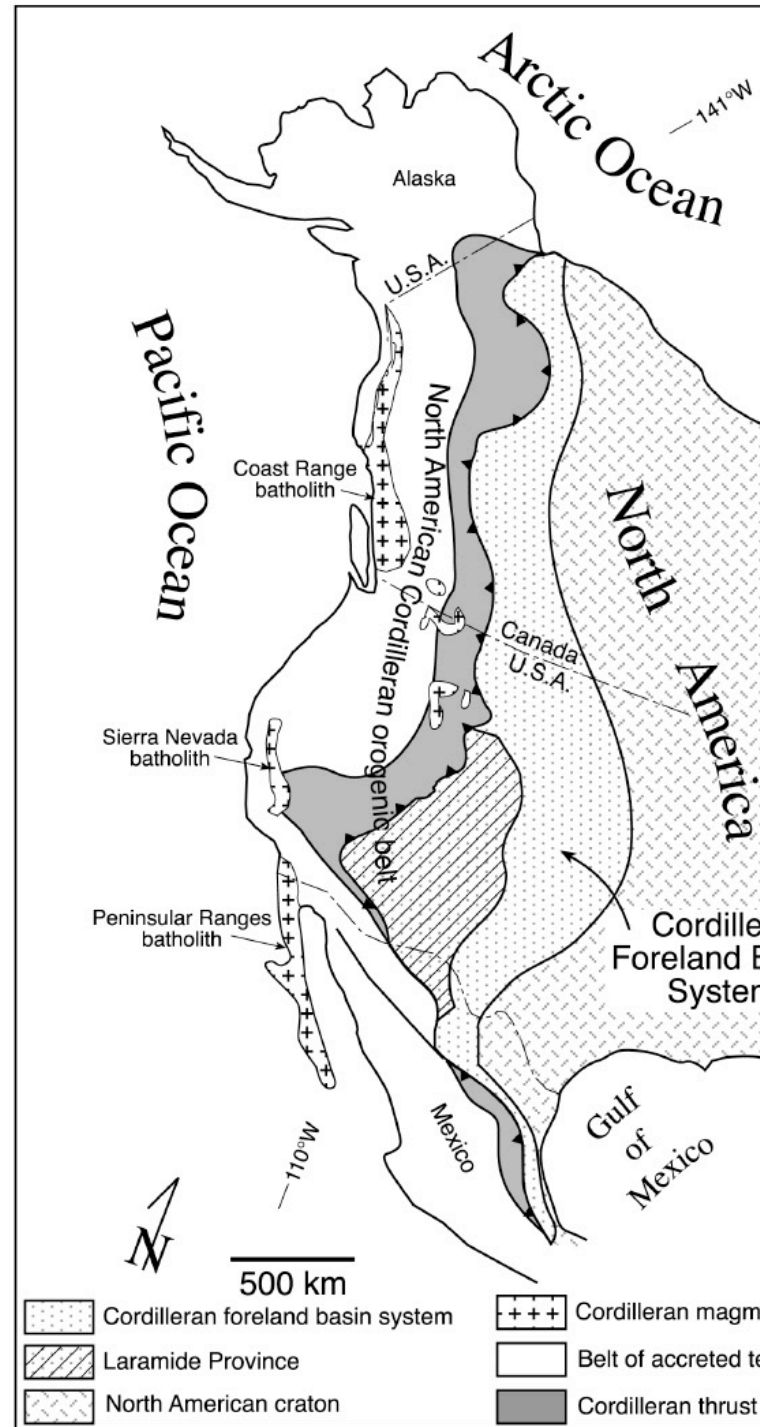
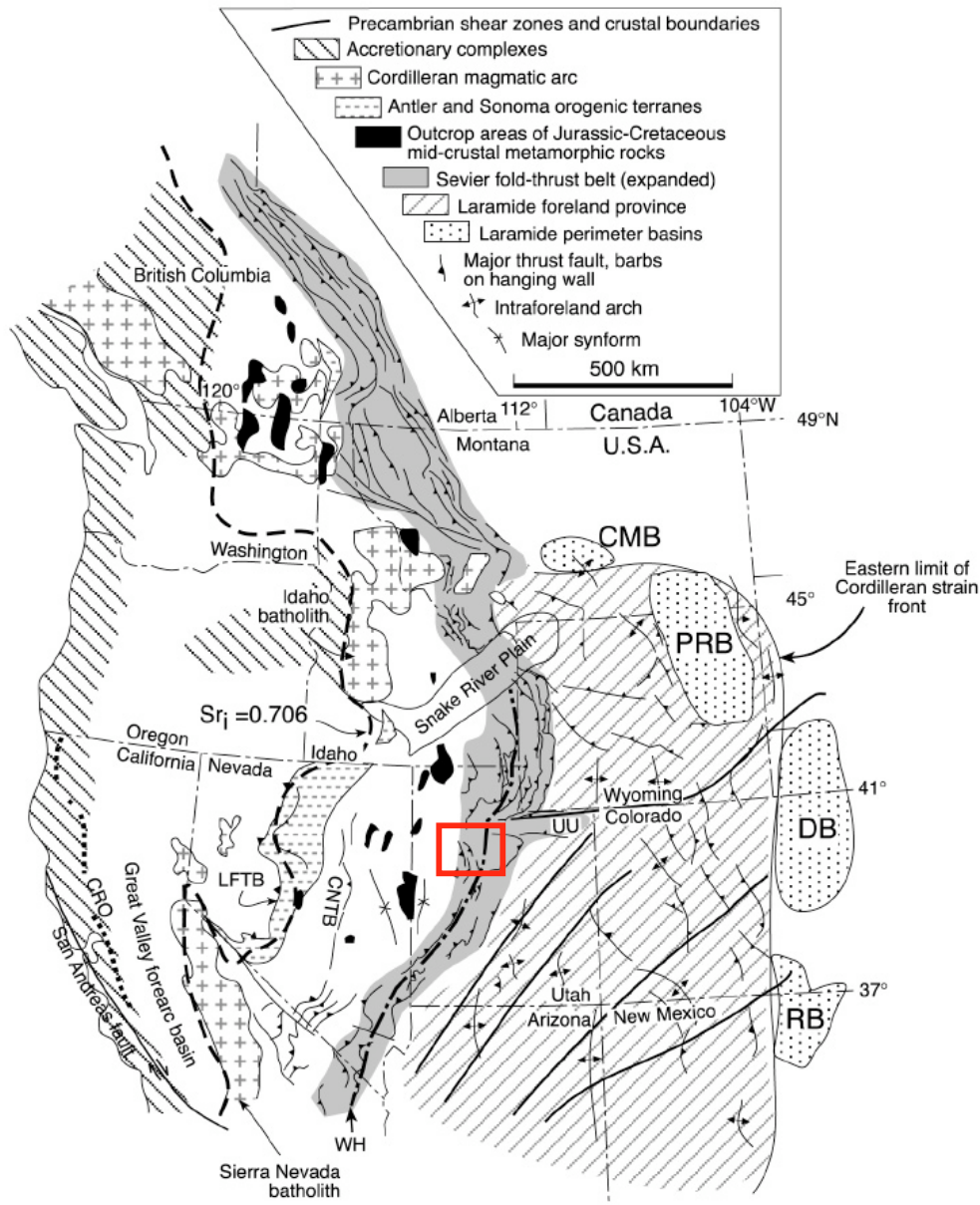
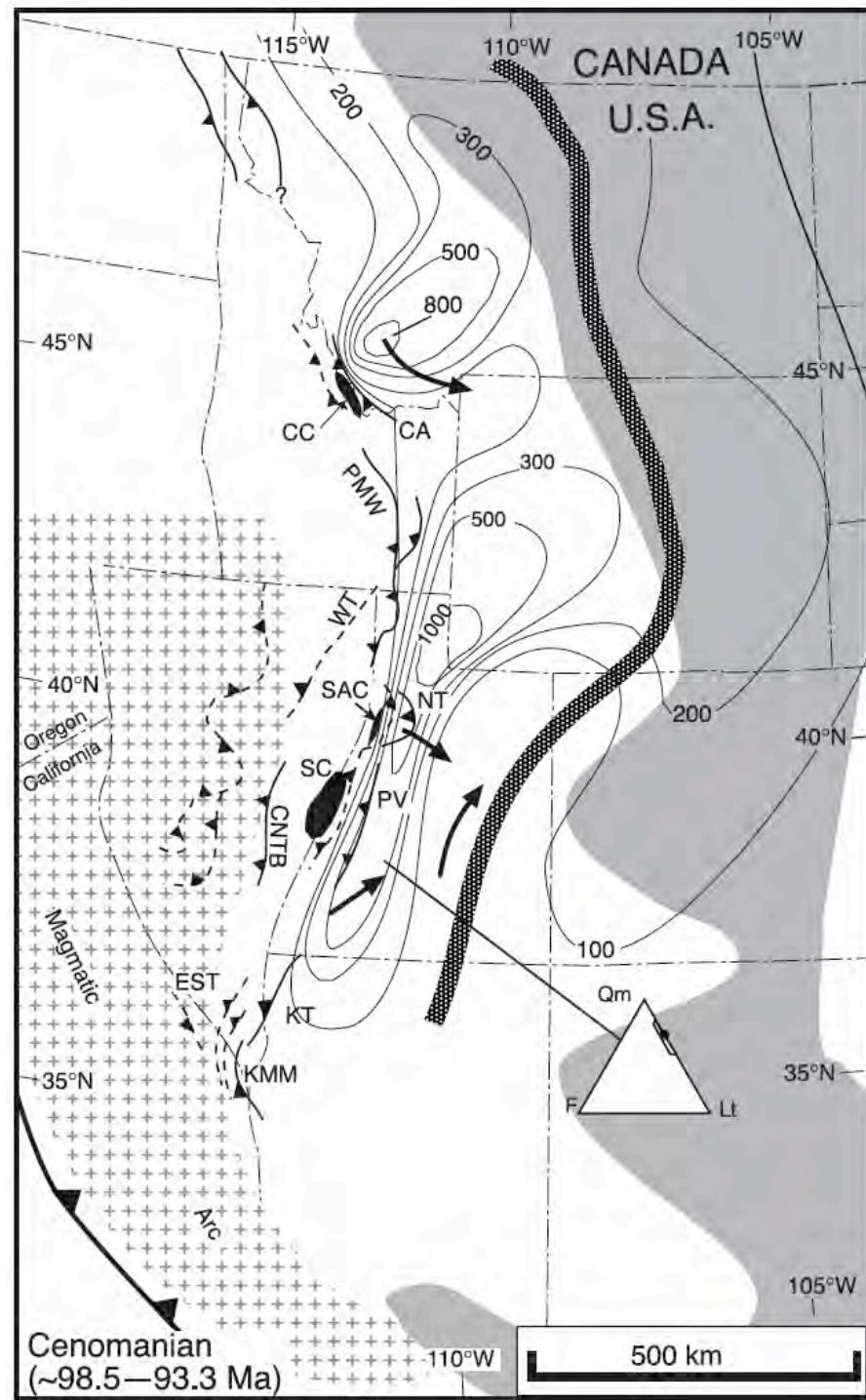
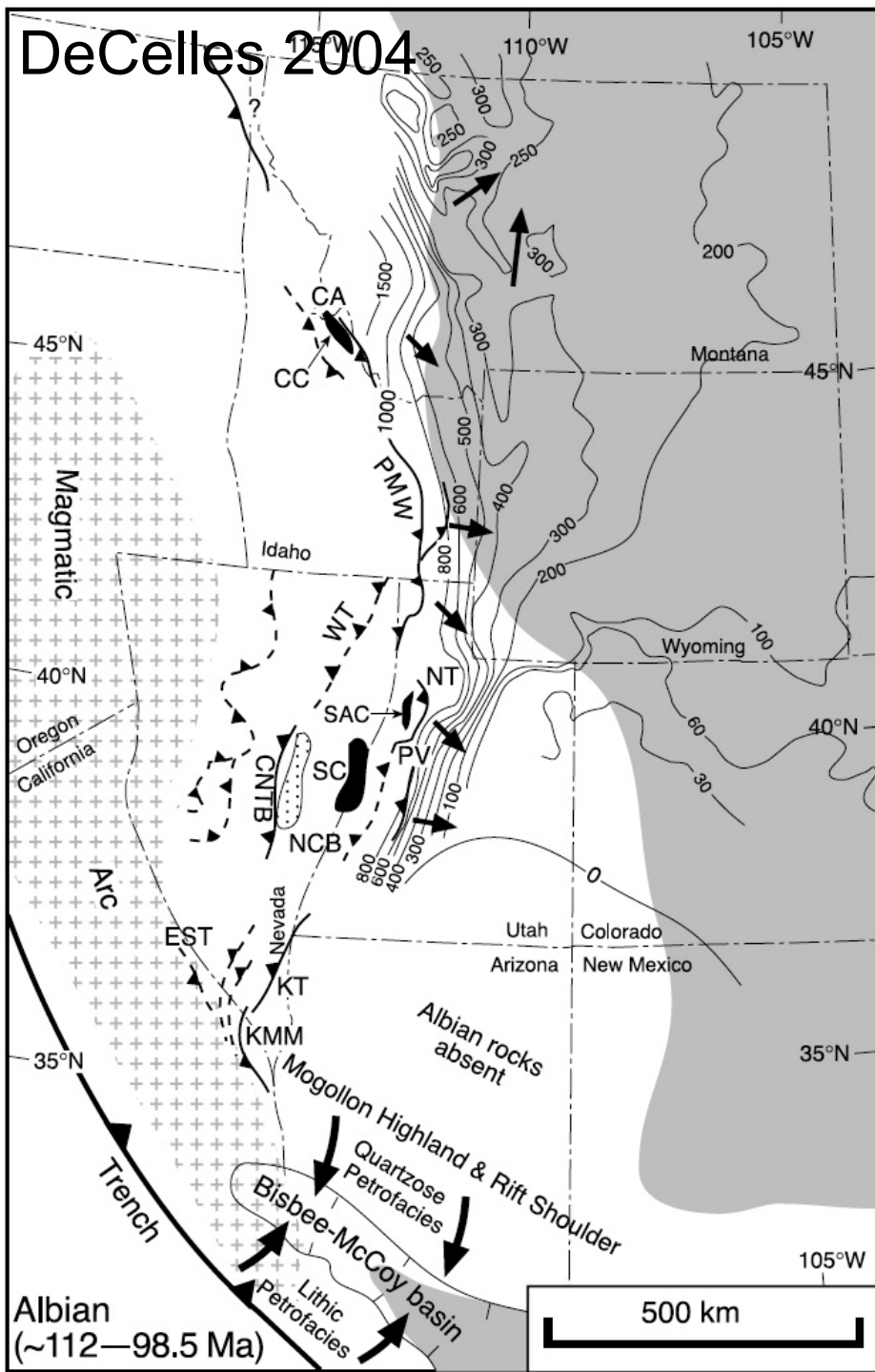
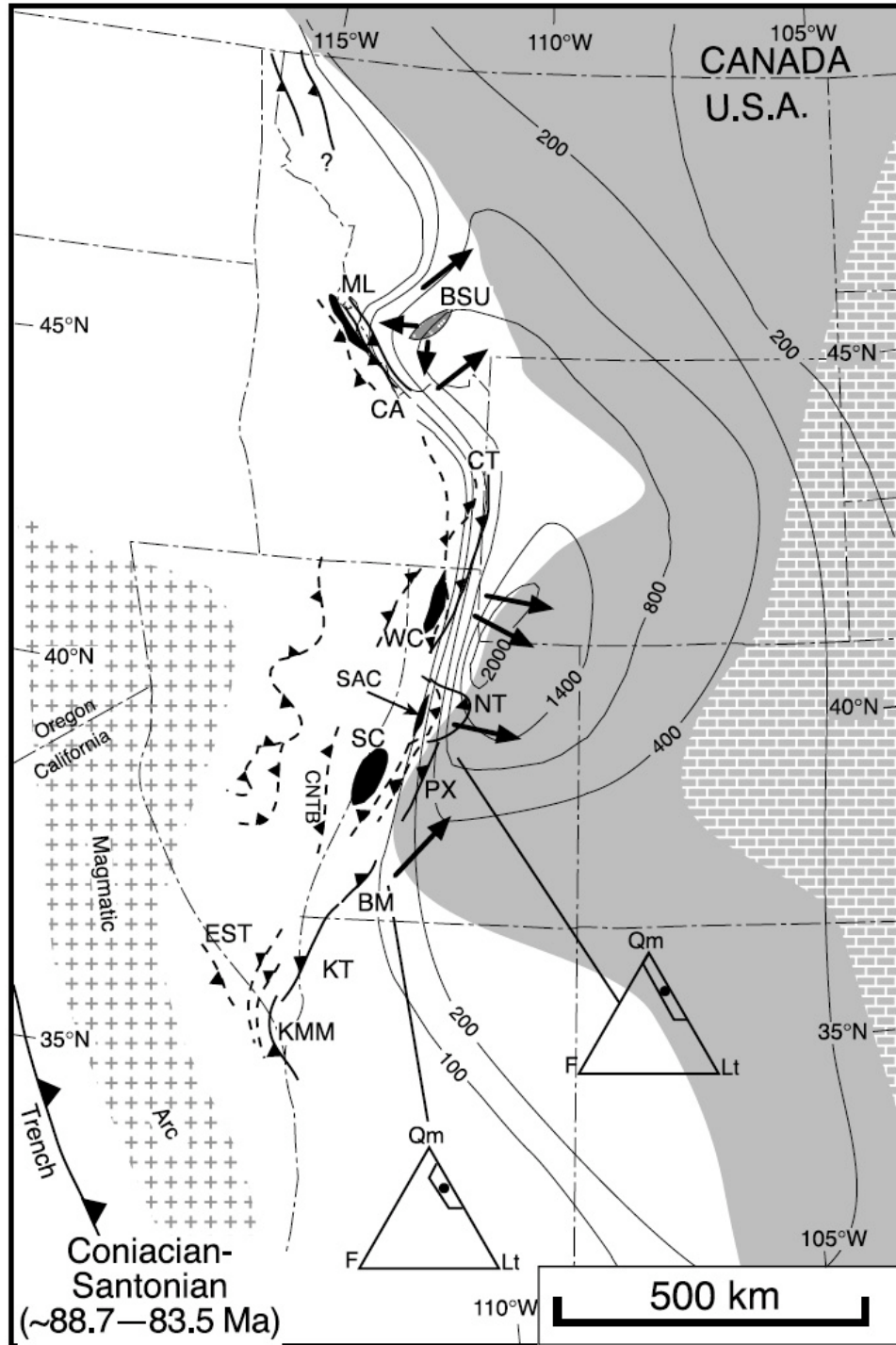
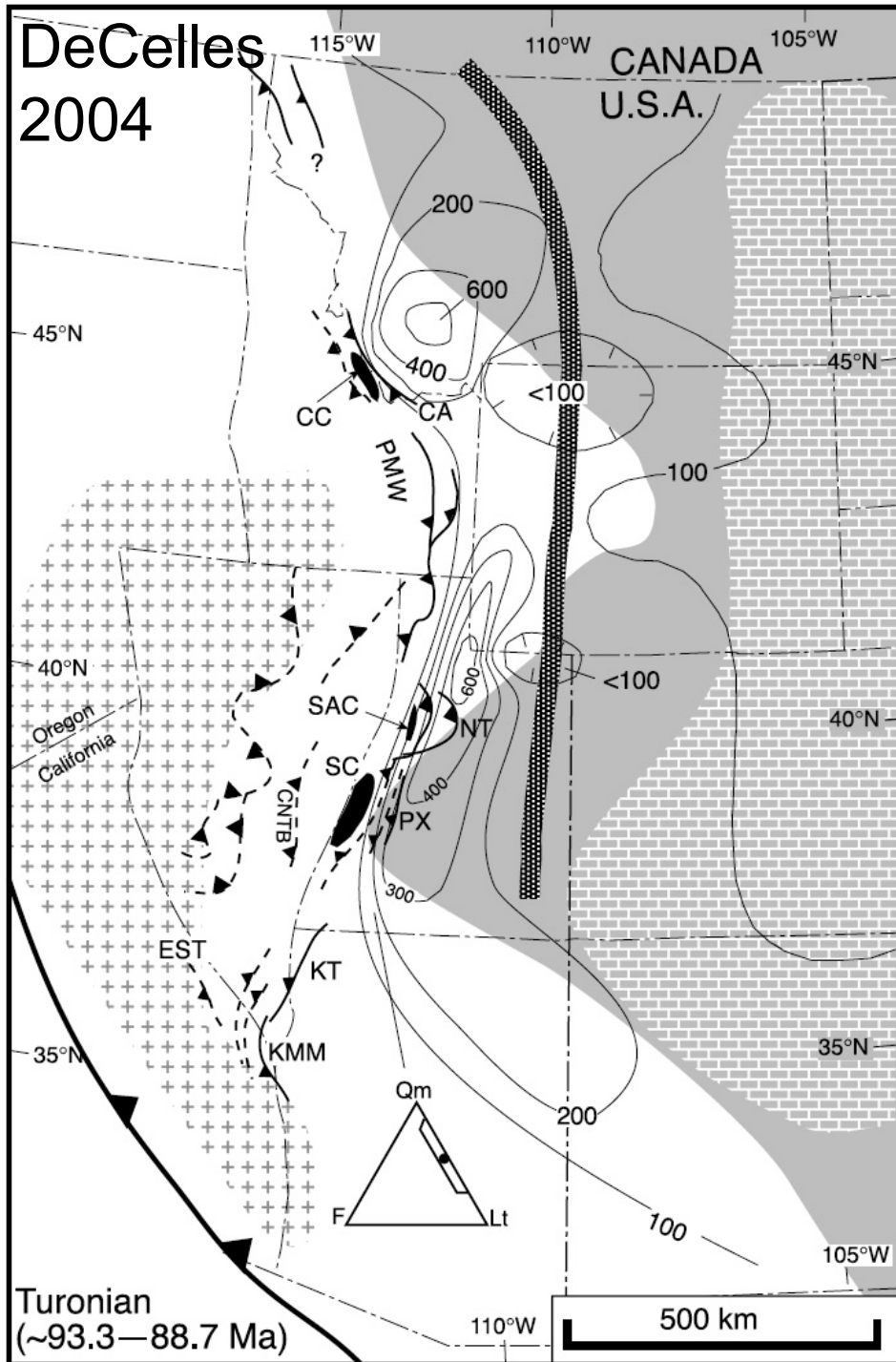


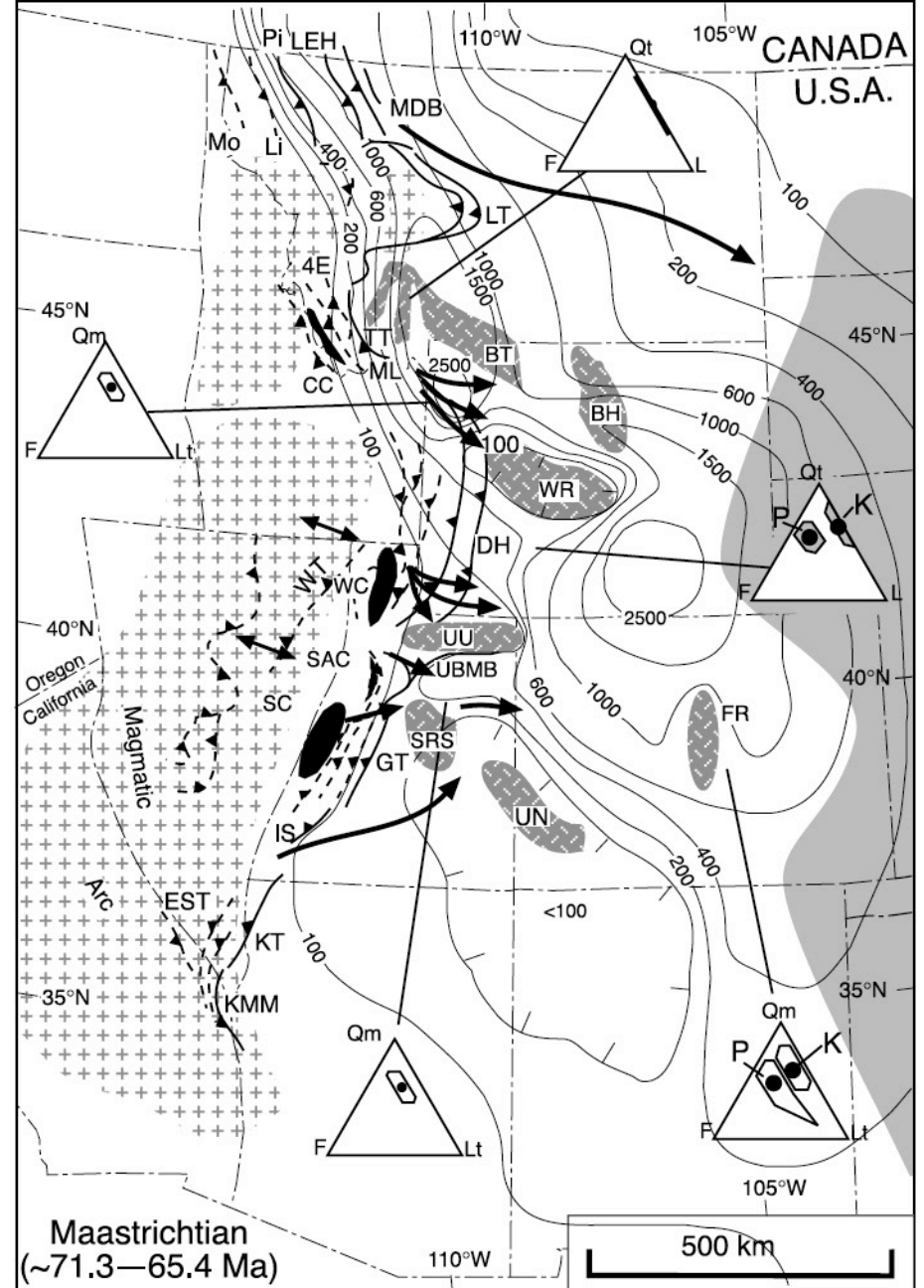
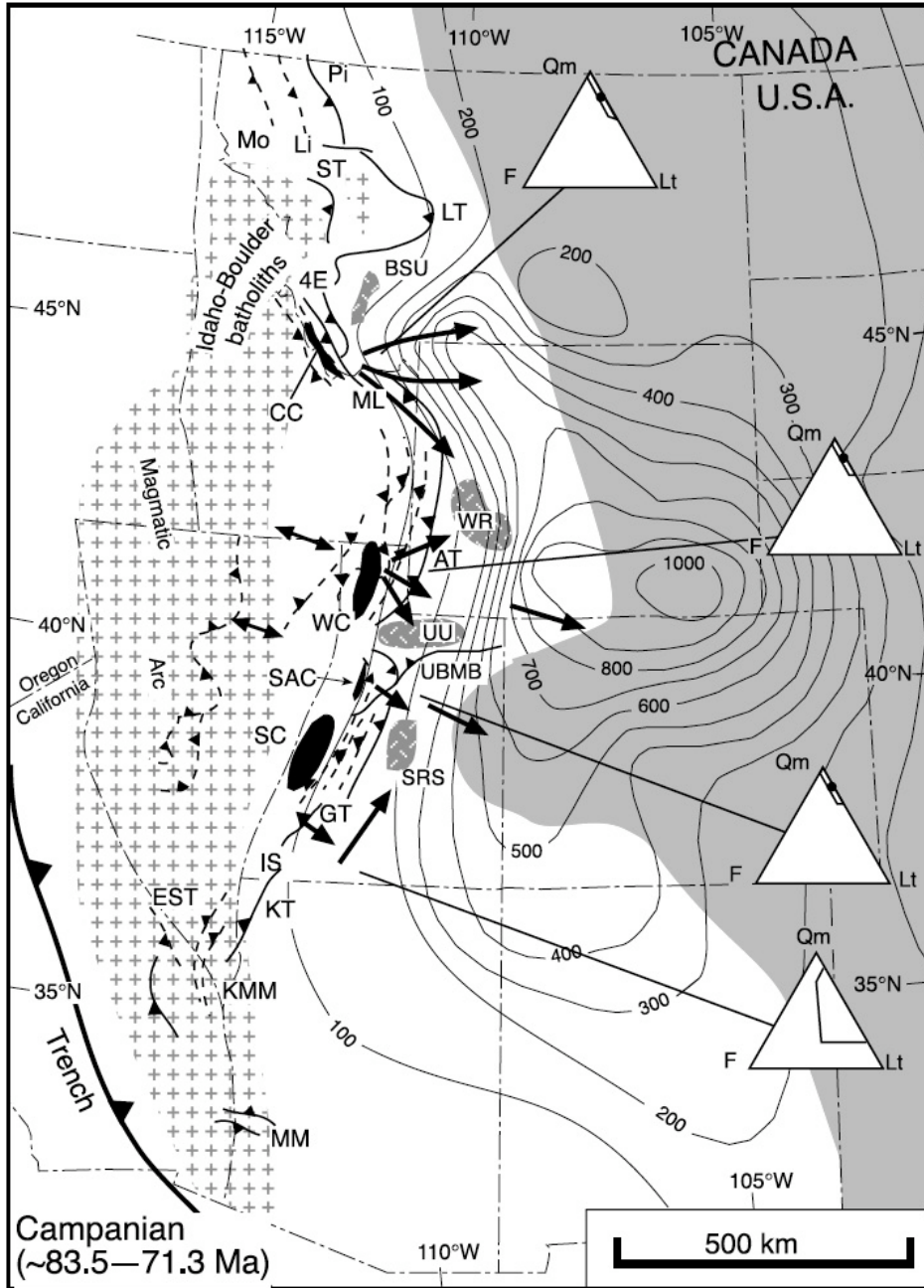
Figure 12. Schematic, reconstructed cross section of the Cordilleran orogenic belt at the latitude of central Utah during Late Cretaceous time. Geology beneath the magmatic arc is after Ducea (2001).



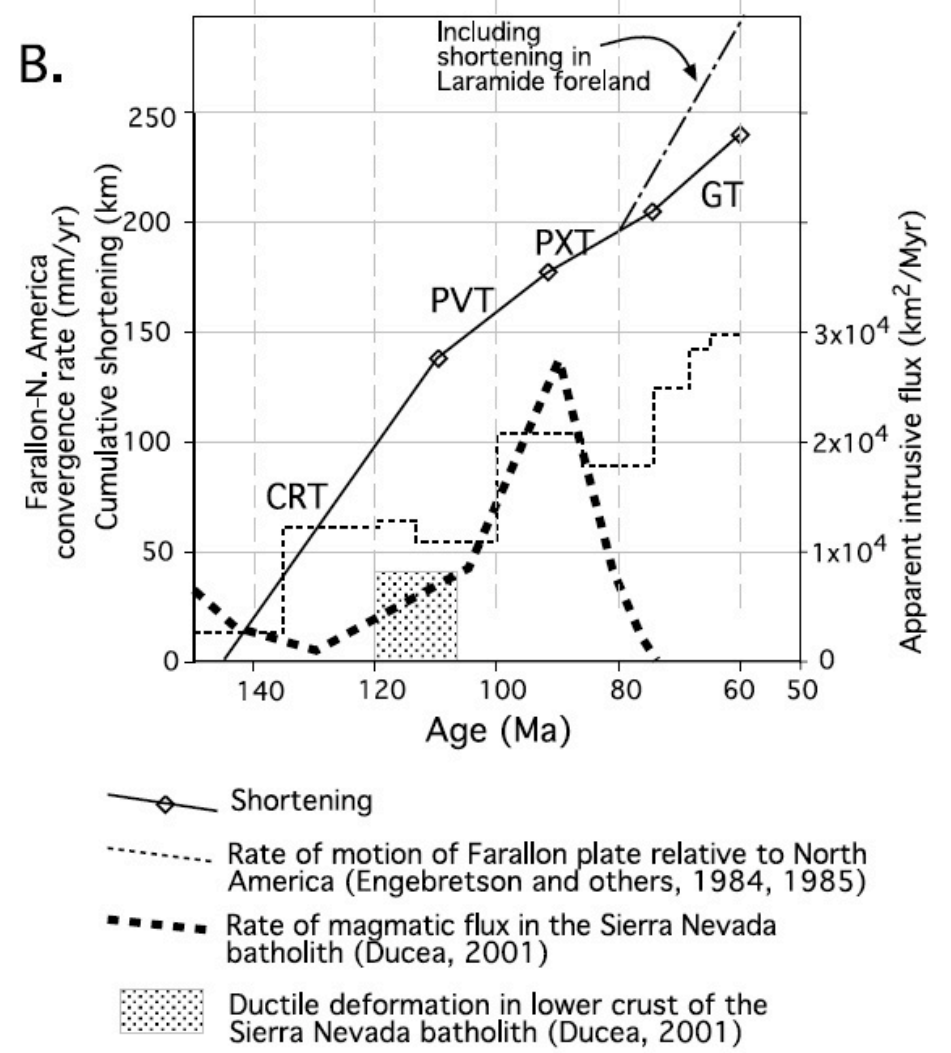
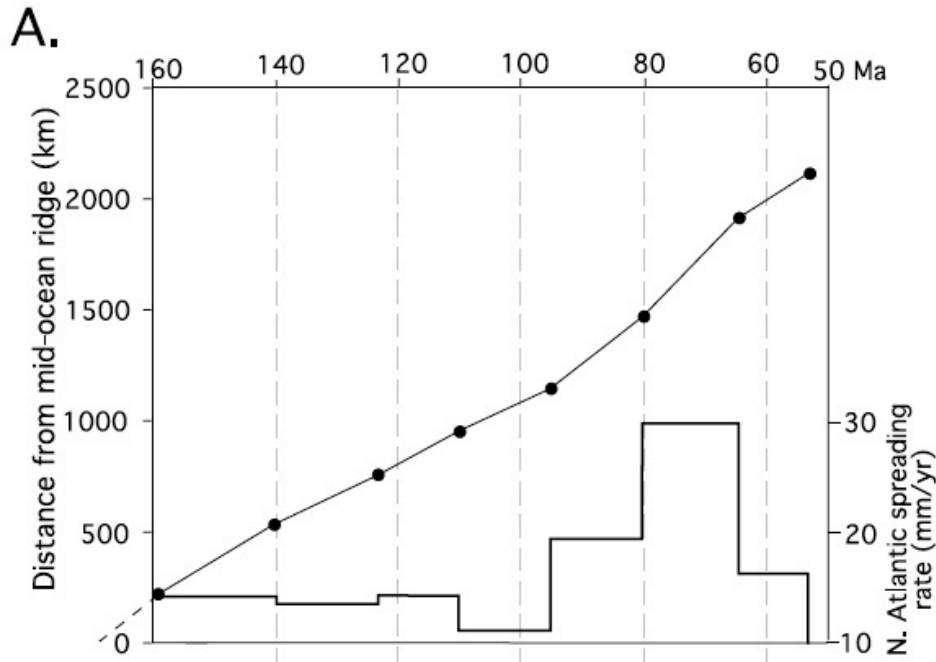
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- ◇— Shortening
- - - Rate of motion of Farallon plate relative to North America (Engebretson and others, 1984, 1985)
- - - Rate of magmatic flux in the Sierra Nevada batholith (Ducea, 2001)
- ▒ Ductile deformation in lower crust of the Sierra Nevada batholith (Ducea, 2001)

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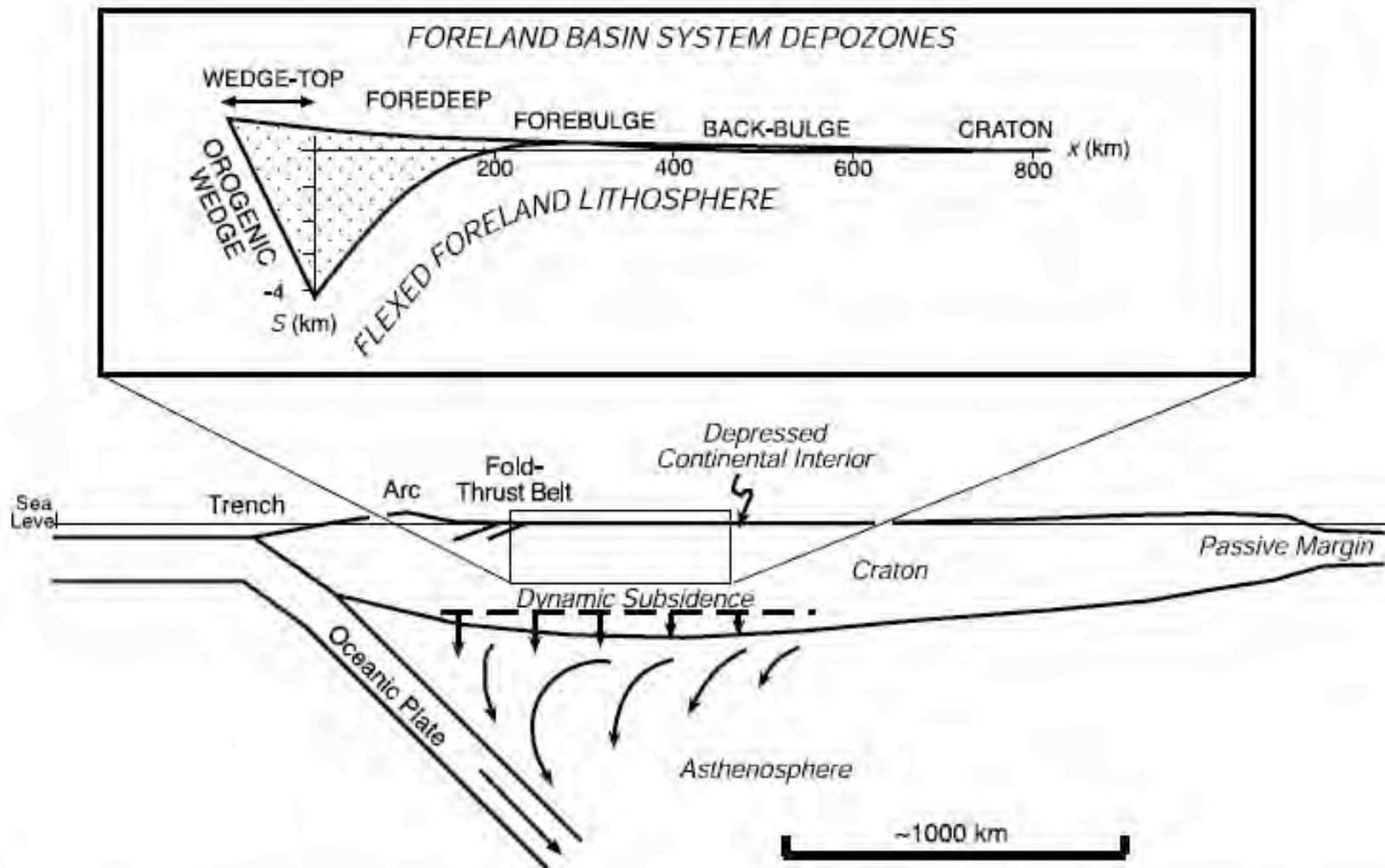
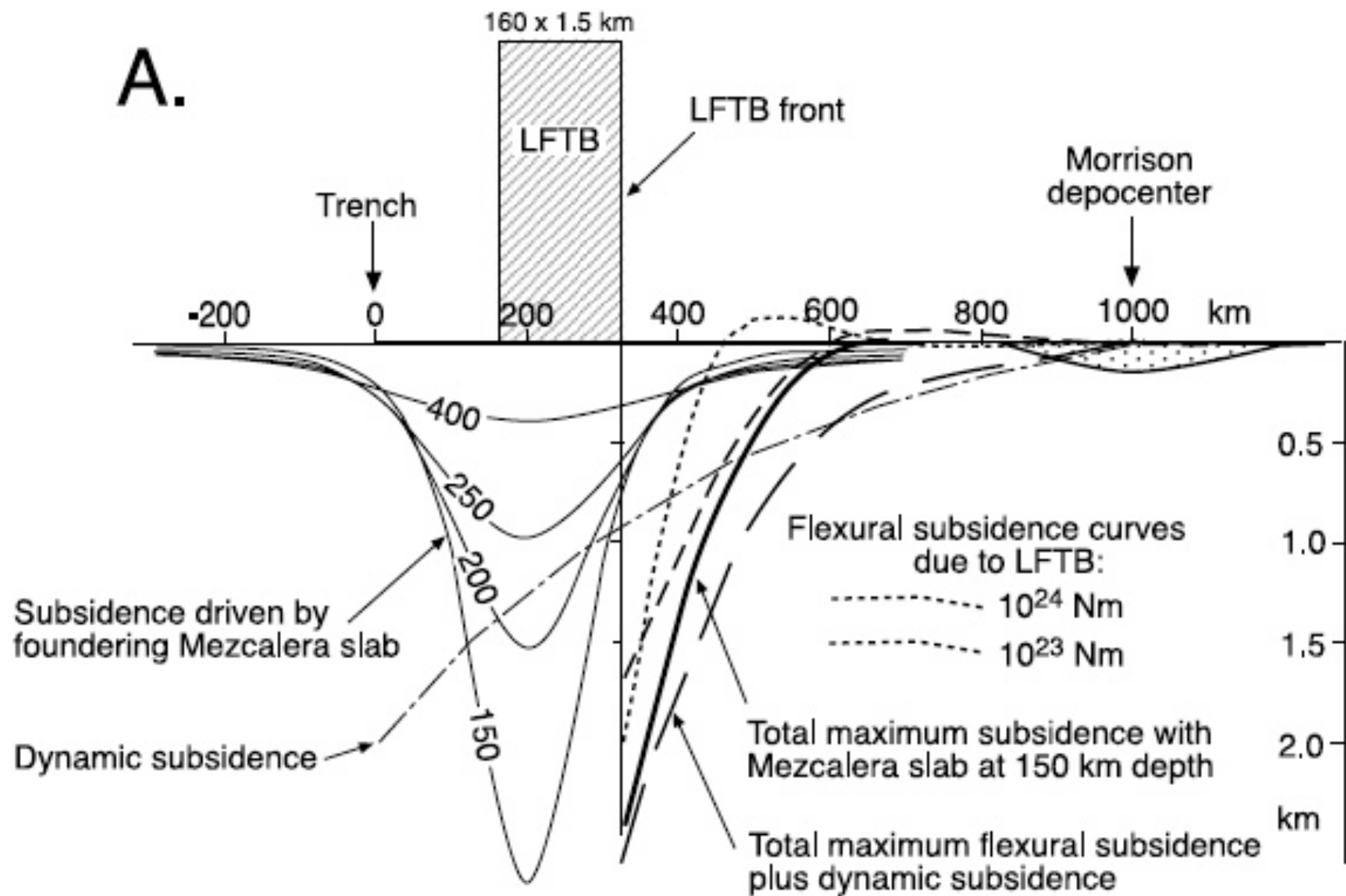


Fig. 6. Schematic cross sections illustrating the principal mechanisms of subsidence in retroarc foreland basins (modified from DeCelles and Giles, 1996). Lower panel shows the effect of long-wavelength dynamic subsidence (Gurnis, 1992), which tilts the craton downward toward the trench. Upper panel depicts shorter-wavelength flexural subsidence ( $S$ ) versus lateral distance ( $x$ ) owing to the topographic load of the orogenic wedge, and the four depozones that characterize many foreland basin systems. Note the extreme vertical exaggeration in the upper panel.

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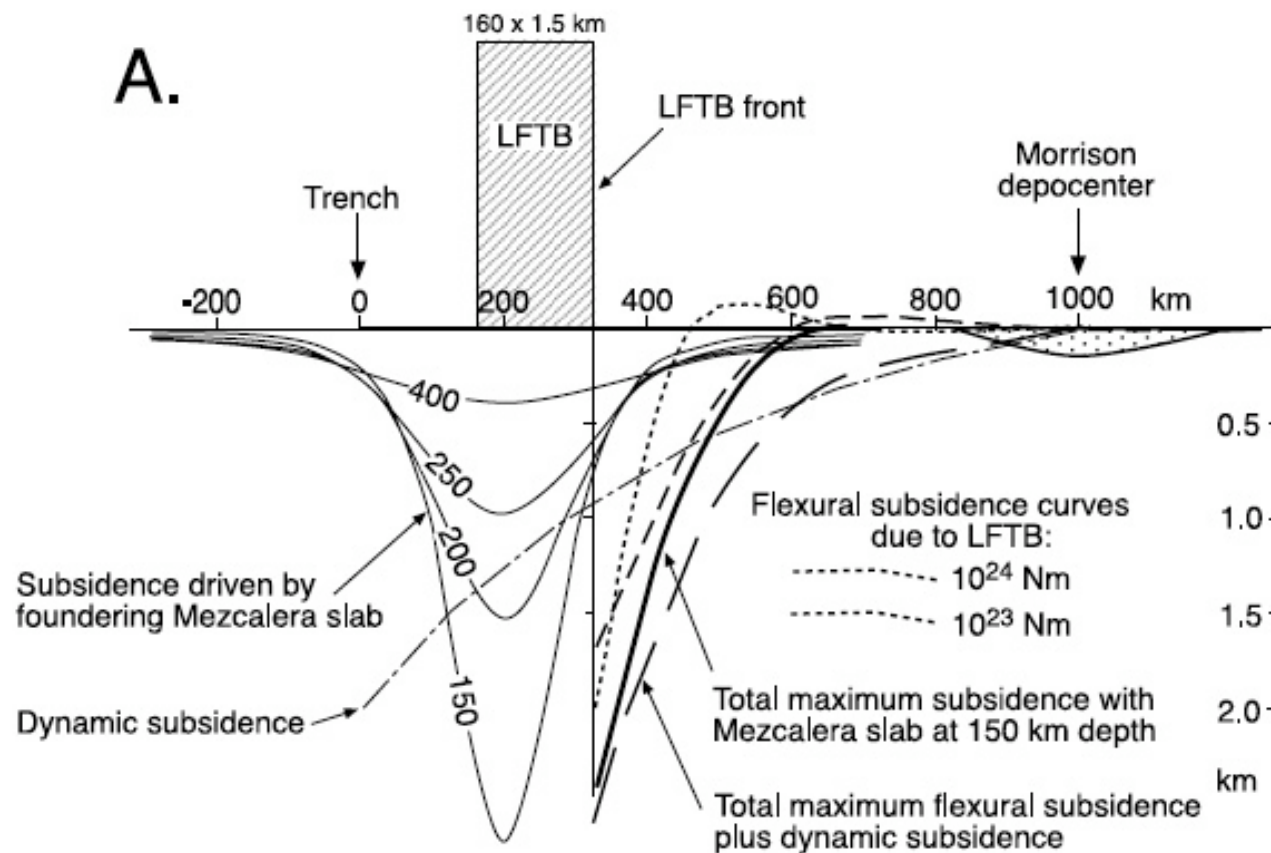
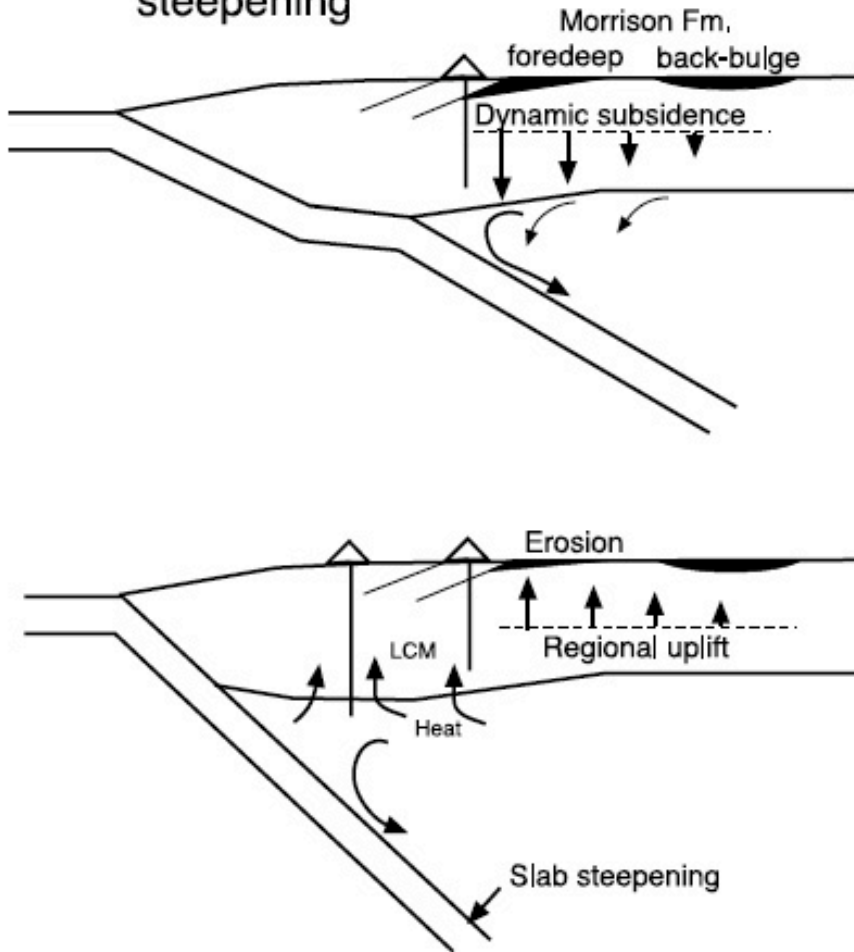


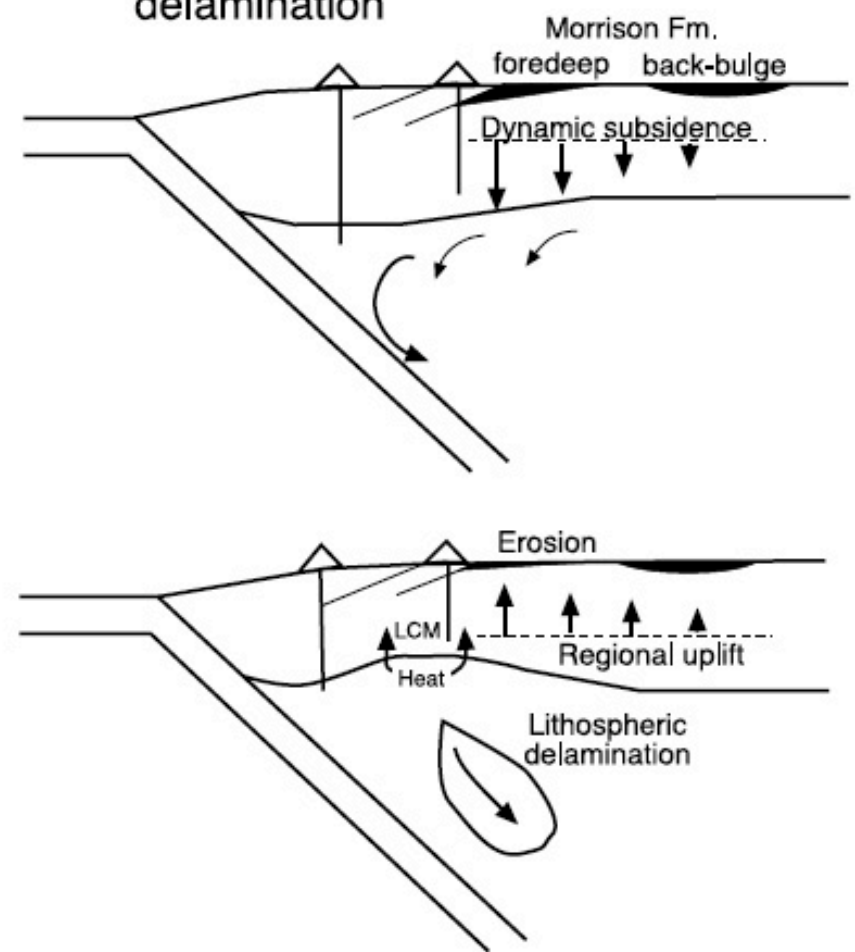
Fig. 8. (A) Comparison of predicted flexural subsidence owing to the surface load of the Luning-Fencemaker thrust belt (LFTB) (dashed and dotted curves, for different flexural rigidities using equations of Turcotte and Schubert, 2002), subsidence driven by viscous foundering of a hypothetical Mezcalera slab at depths of 150 km, 200 km, 250 km, and 400 km (calculated according to Morgan, 1965, assuming a spherical geometry with a diameter of 200 km), and dynamic subsidence driven by viscous coupling between the subducting Farallon slab and North American craton (after Gurnis, 1992). The origin of the horizontal scale is the approximate location of the trench during Late Jurassic time. Thick line represents sum of the subsidence owing to Mezcalera slab foundering (when the slab was at only 150 km depth) and flexure of lithosphere with flexural rigidity of  $10^{24}$  Nm. The distribution of the Morrison Formation is shown at  $\sim 1000 \pm 200$  km from trench. Note that the Morrison depocenter is situated approximately where a back-bulge depocenter is predicted for flexed lithosphere of rigidity =  $10^{24}$  Nm. Predicted subsidence driven by the foundering Mezcalera slab is several hundred kilometers farther west. The long dashed curve is the sum of subsidence for flexed lithosphere of rigidity =  $10^{24}$  Nm and dynamic subsidence. (B) and (C)

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## B. Slab flattening and steepening



## C. Partial lithospheric delamination



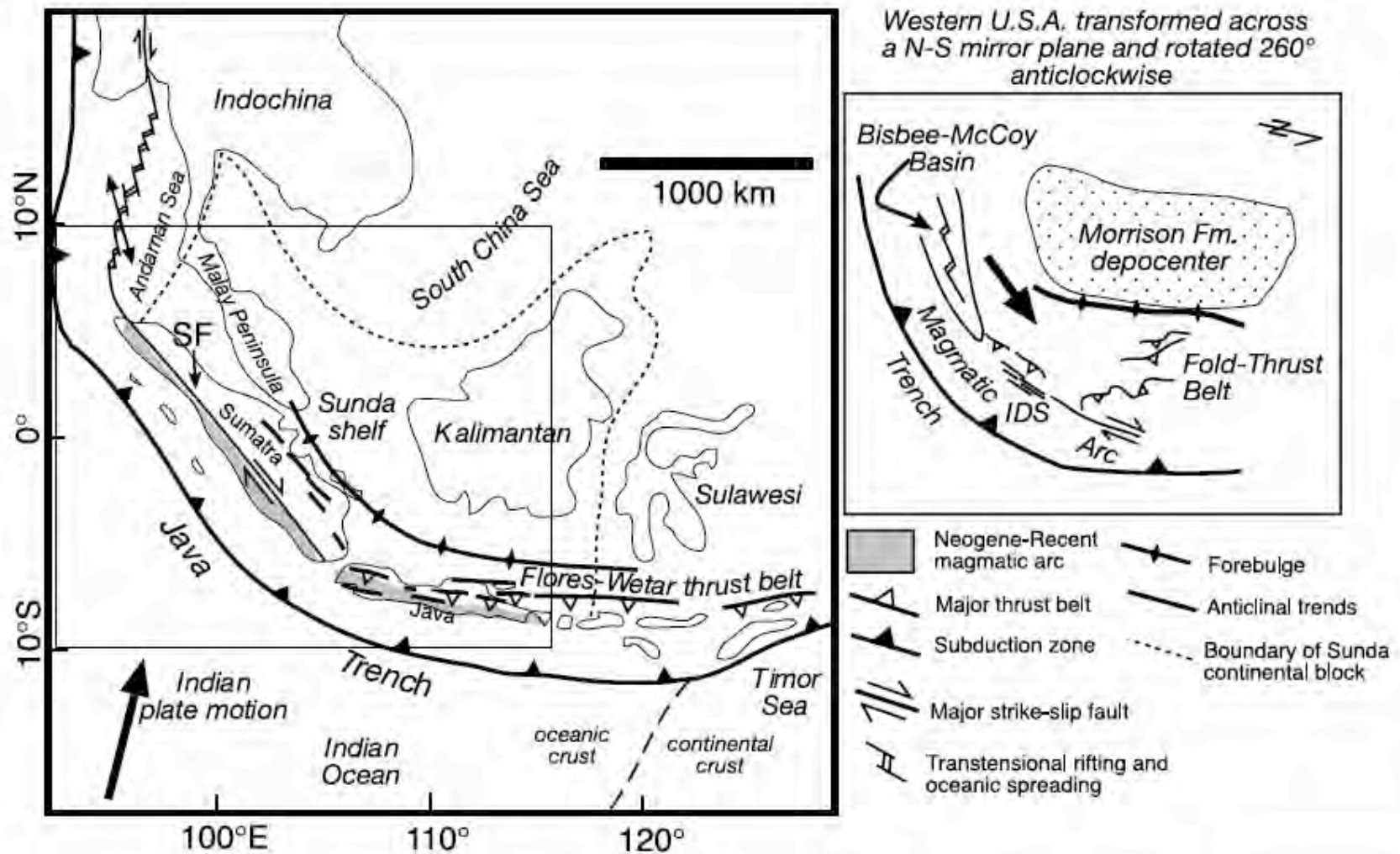


Fig. 9. Generalized tectonic maps (at same scale) of the Indonesian orogenic system (left) and western U.S.A. Cordilleran orogenic system during Late Jurassic time (right). The box in the Indonesian map indicates the same-sized region as depicted in the Late Jurassic map. Abbreviations: SF, Sumatran fault system; IDS, Independence dike swarm. Large arrows indicate relative plate convergence directions. The Late Jurassic map has been simplified from figure 6 and transformed as indicated in title. The Indonesian map is after Hamilton (1979), Silver and others (1983), McCaffrey and Nabelek (1987), and Lee and Lawver (1995).

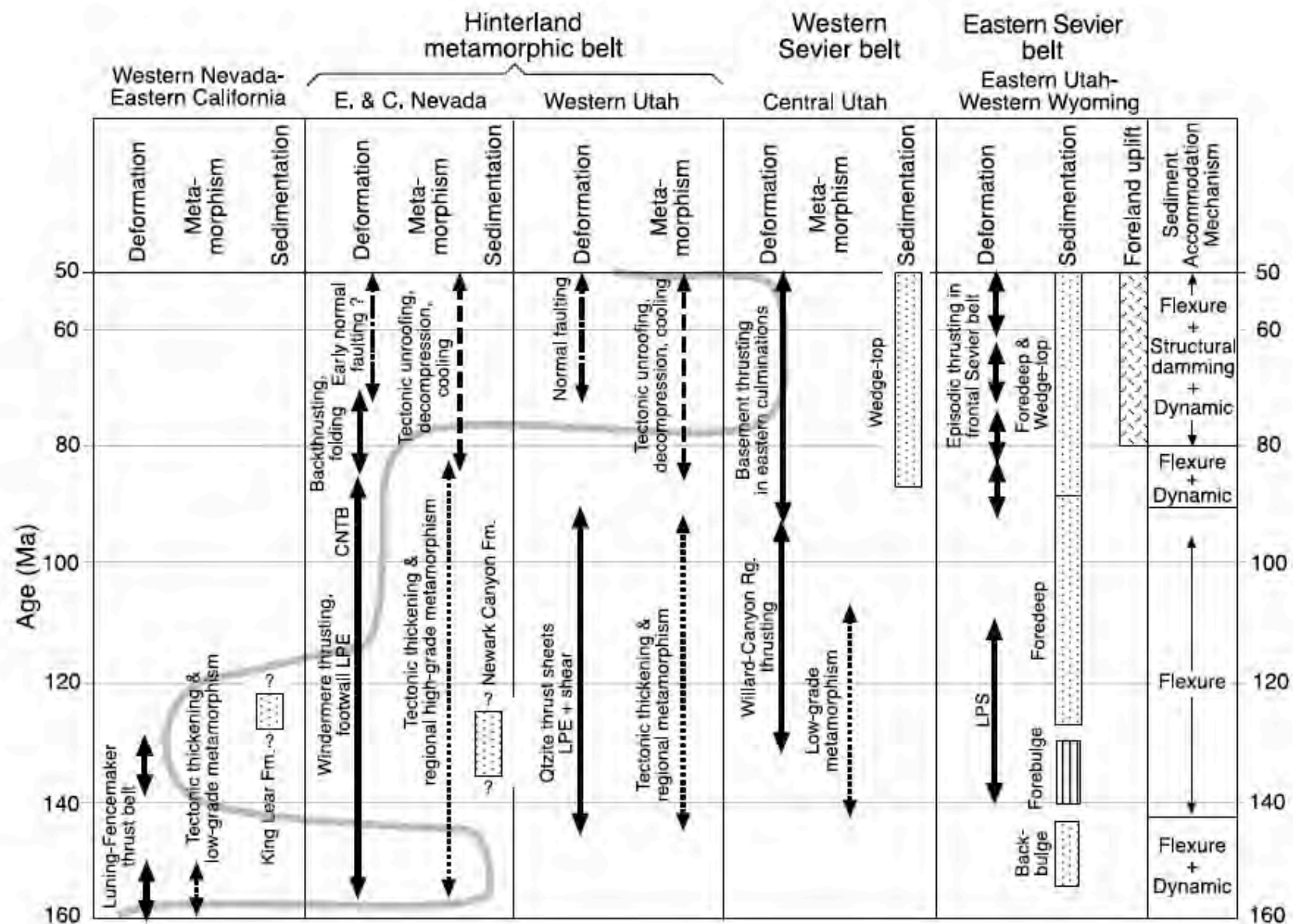
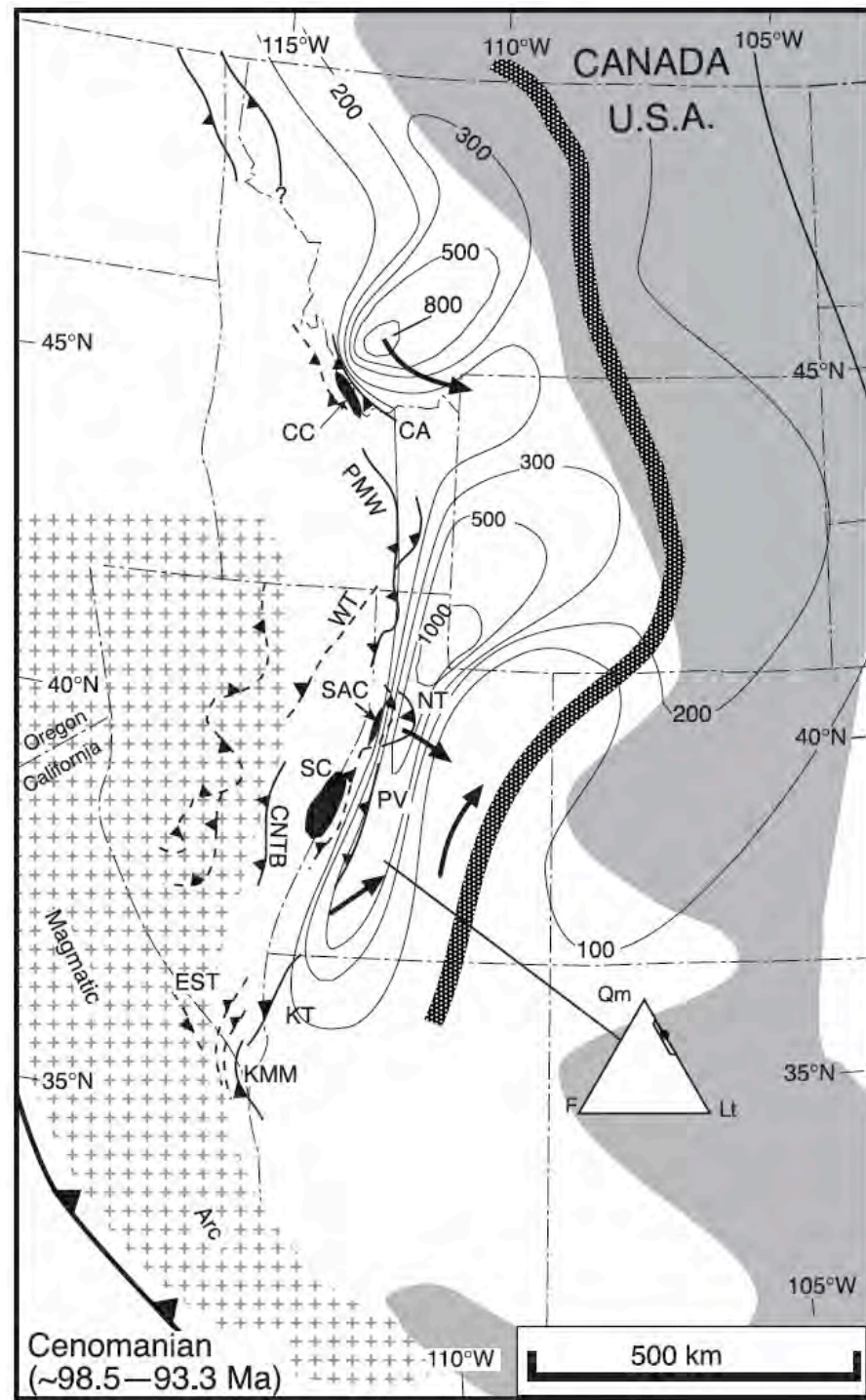
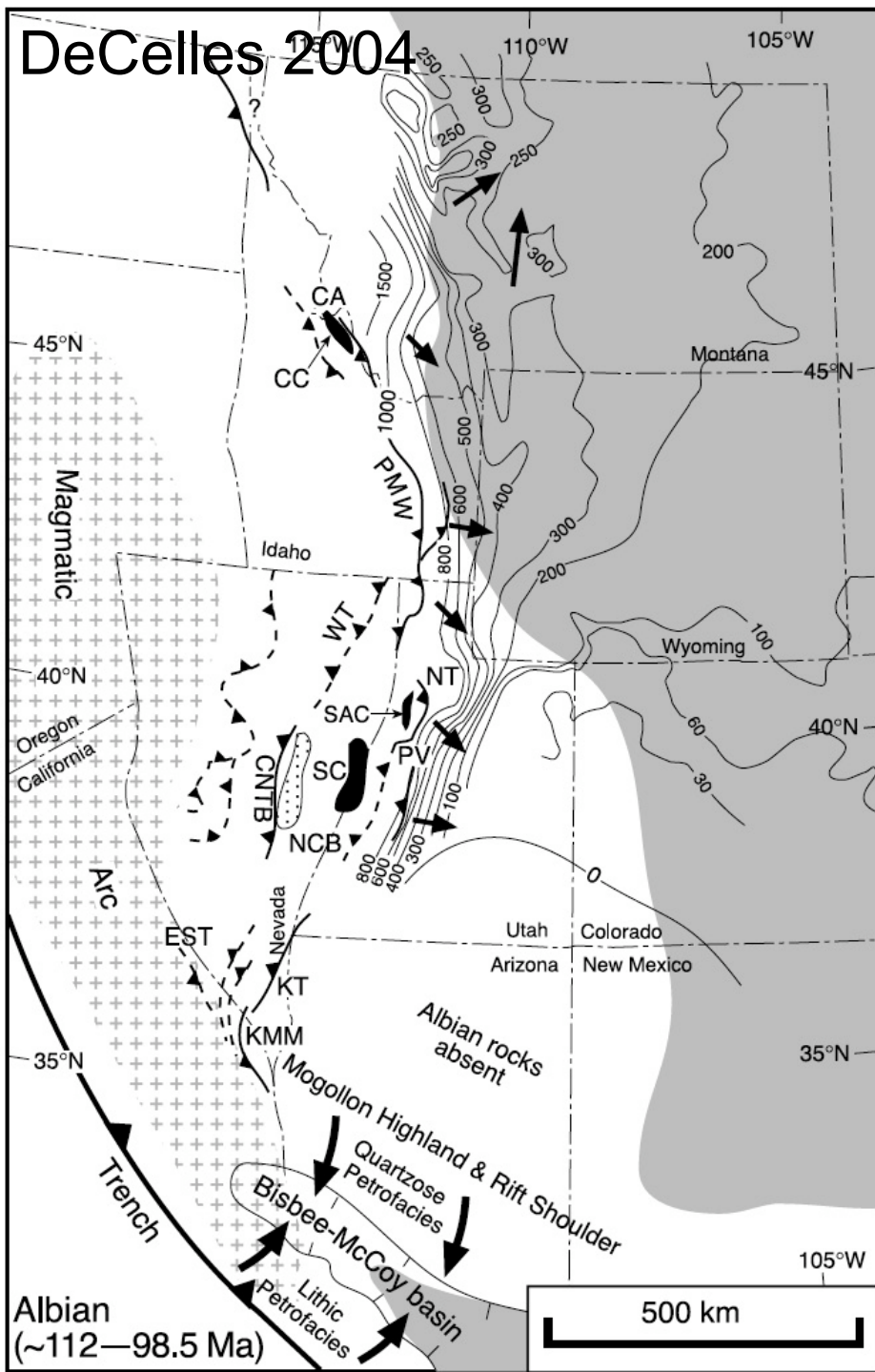
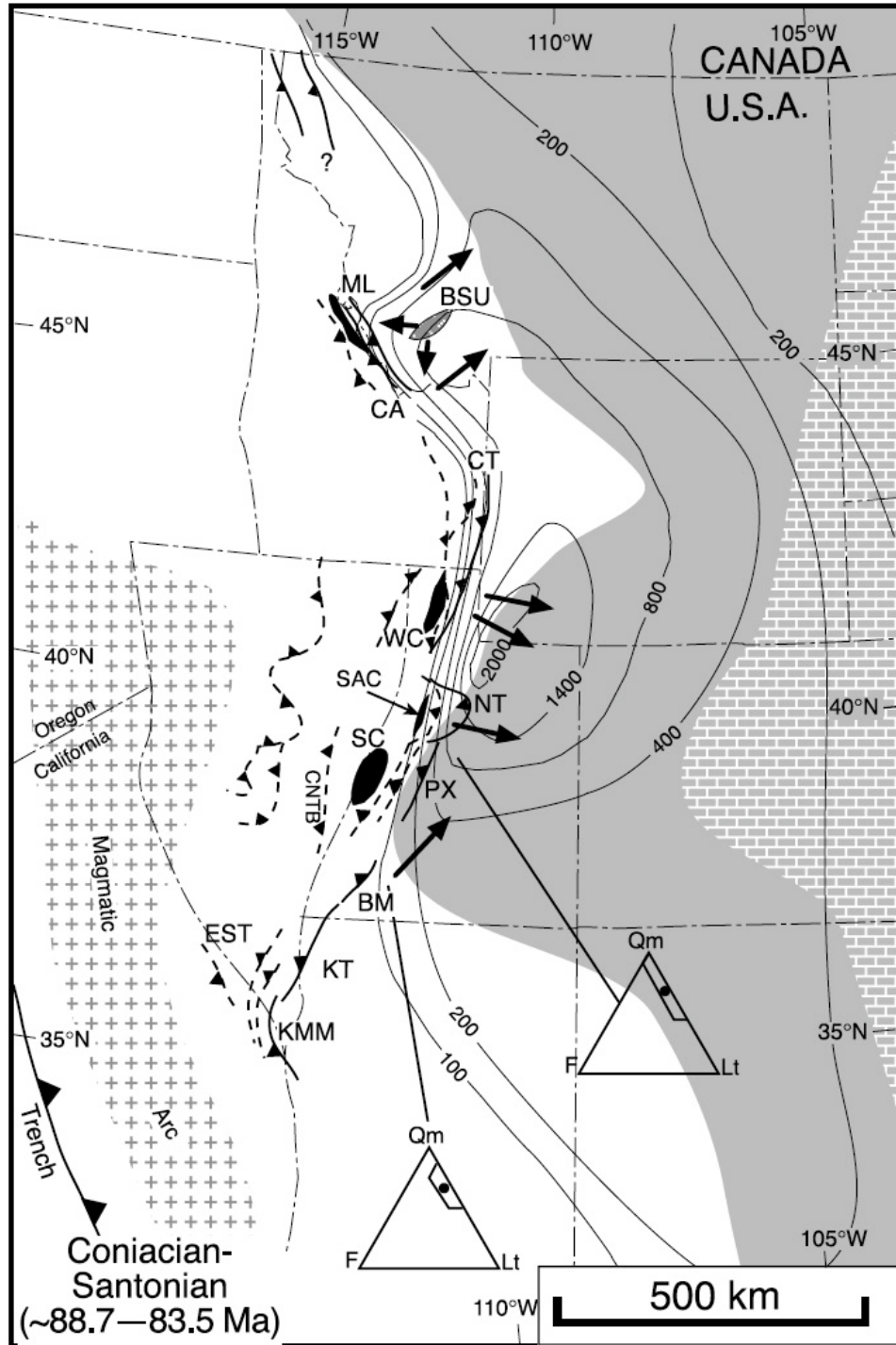
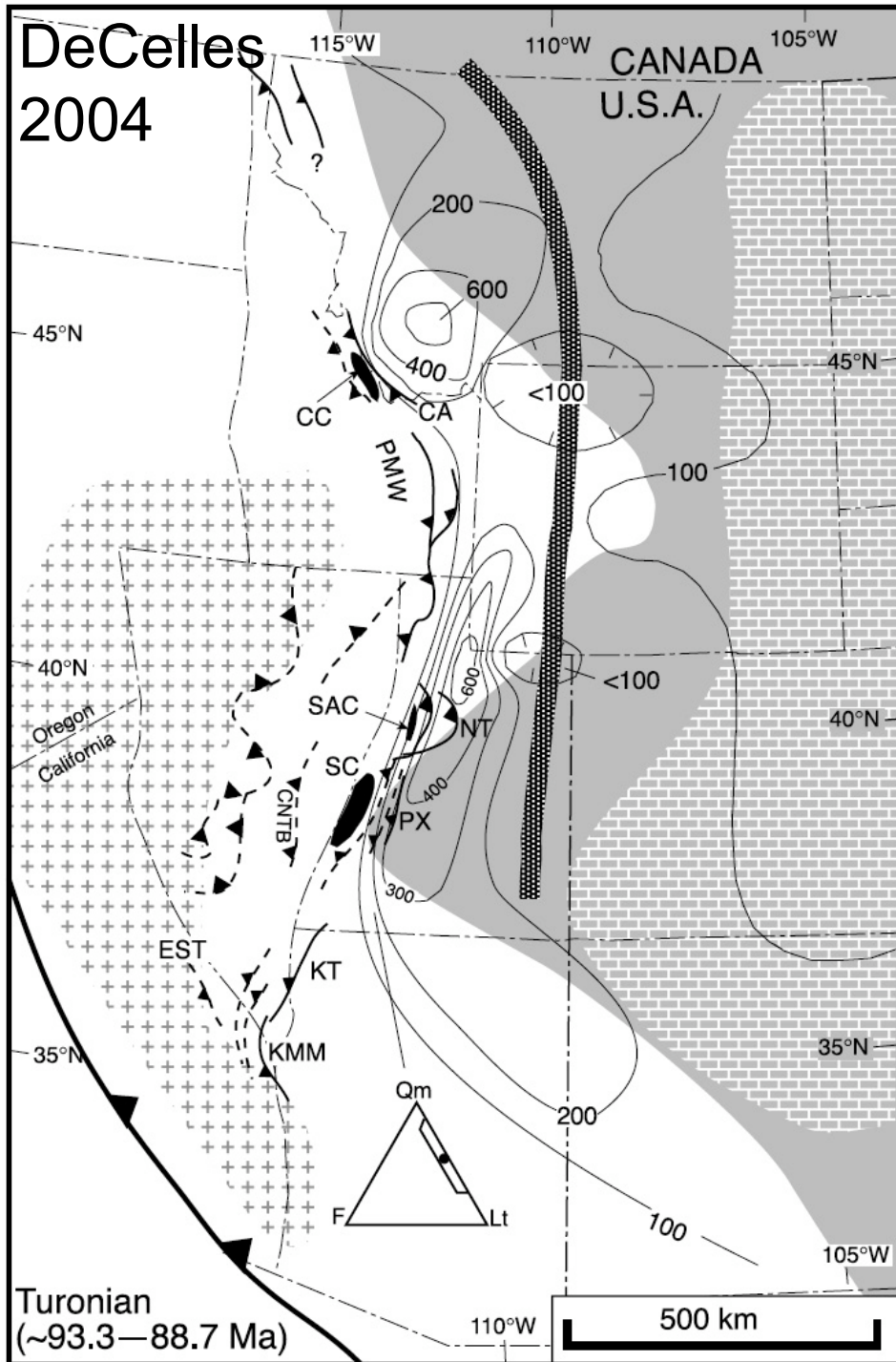
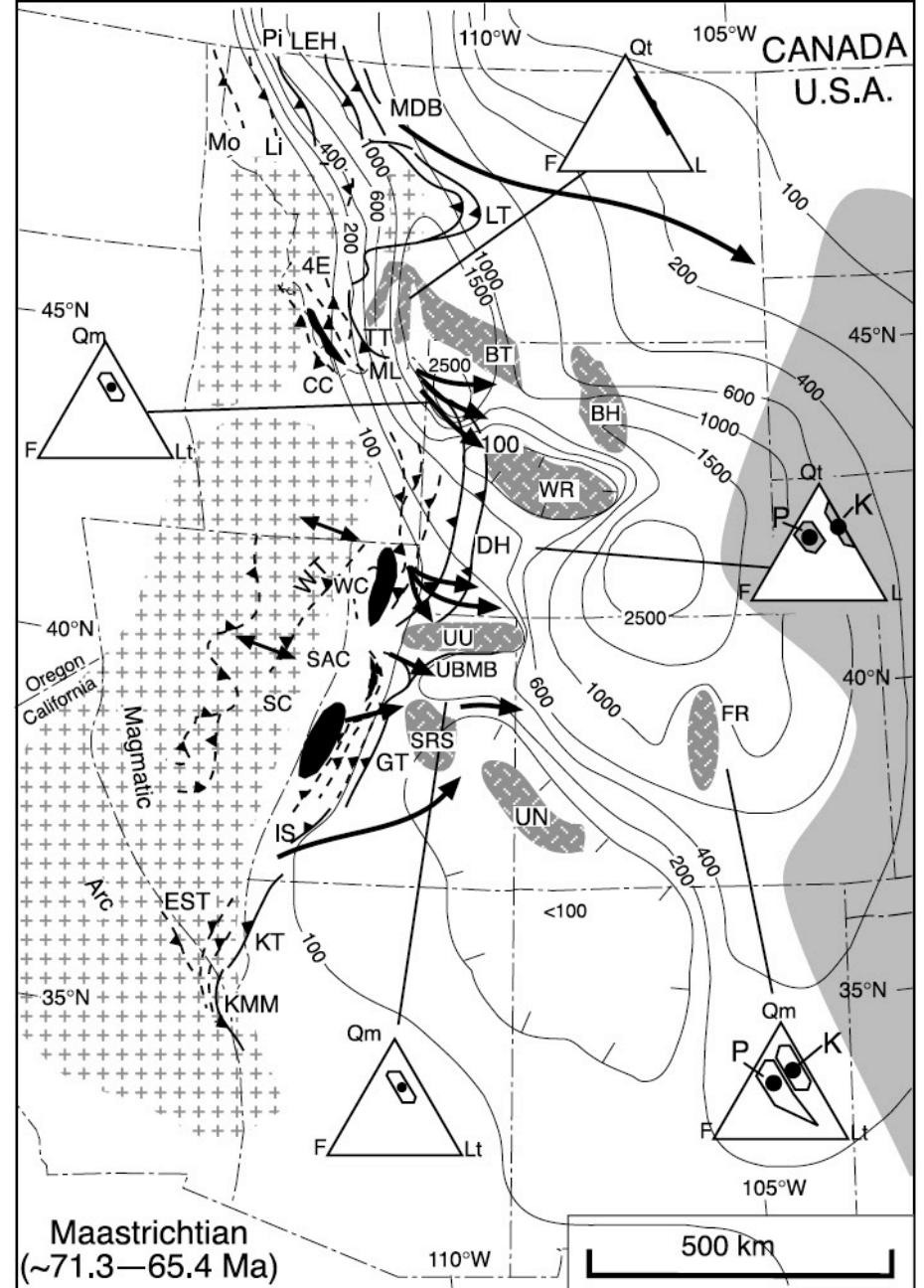
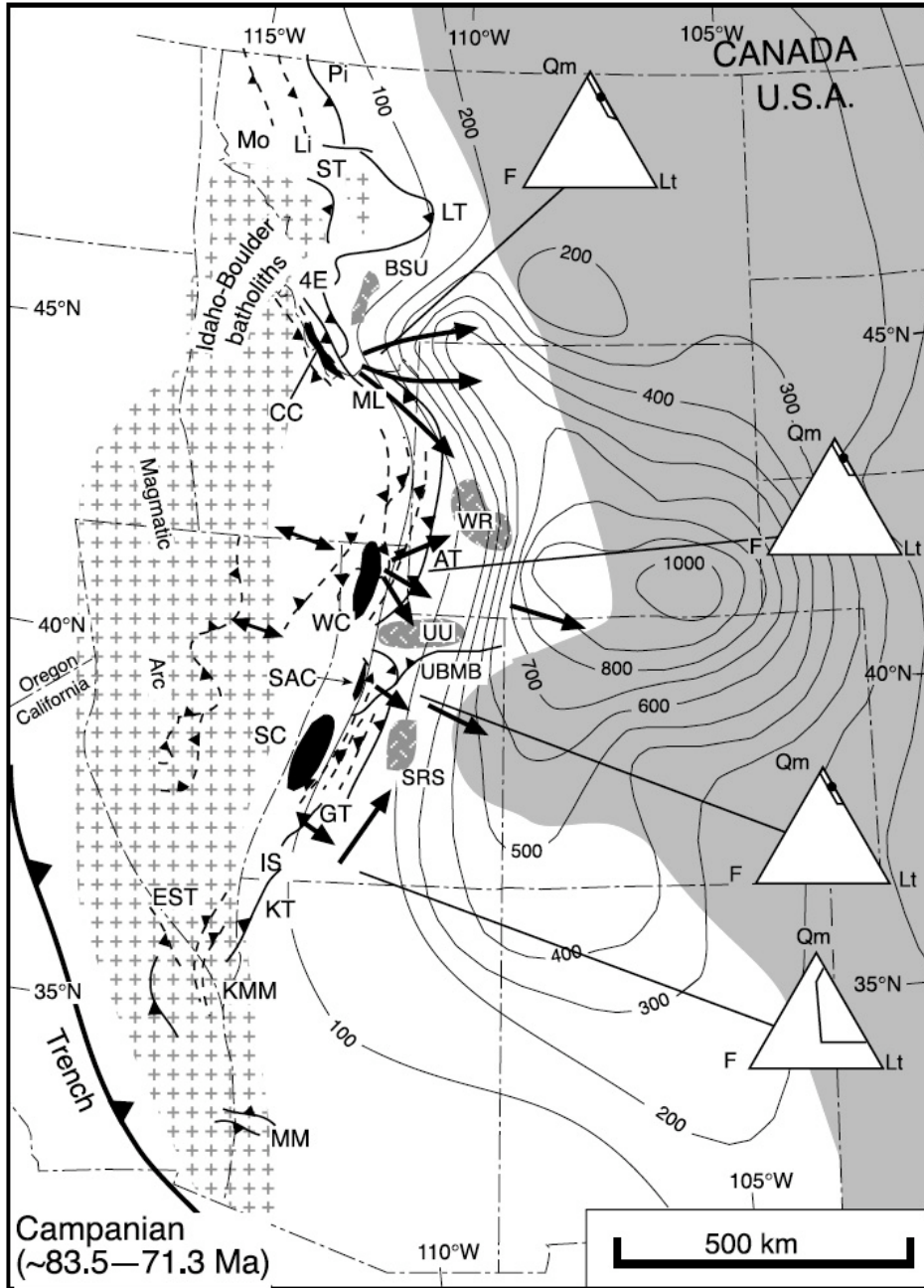


Fig. 17. Diagram illustrating timing of major tectonic, metamorphic, and depositional events in an east-west transect across the Cordilleran orogenic belt and foreland basin system at the approximate latitude of 41°N (northern Utah). Compiled from sources discussed in the text and previous figures. Gray line indicates the approximate eastern front of magmatic activity (after Christiansen and others, 1994).







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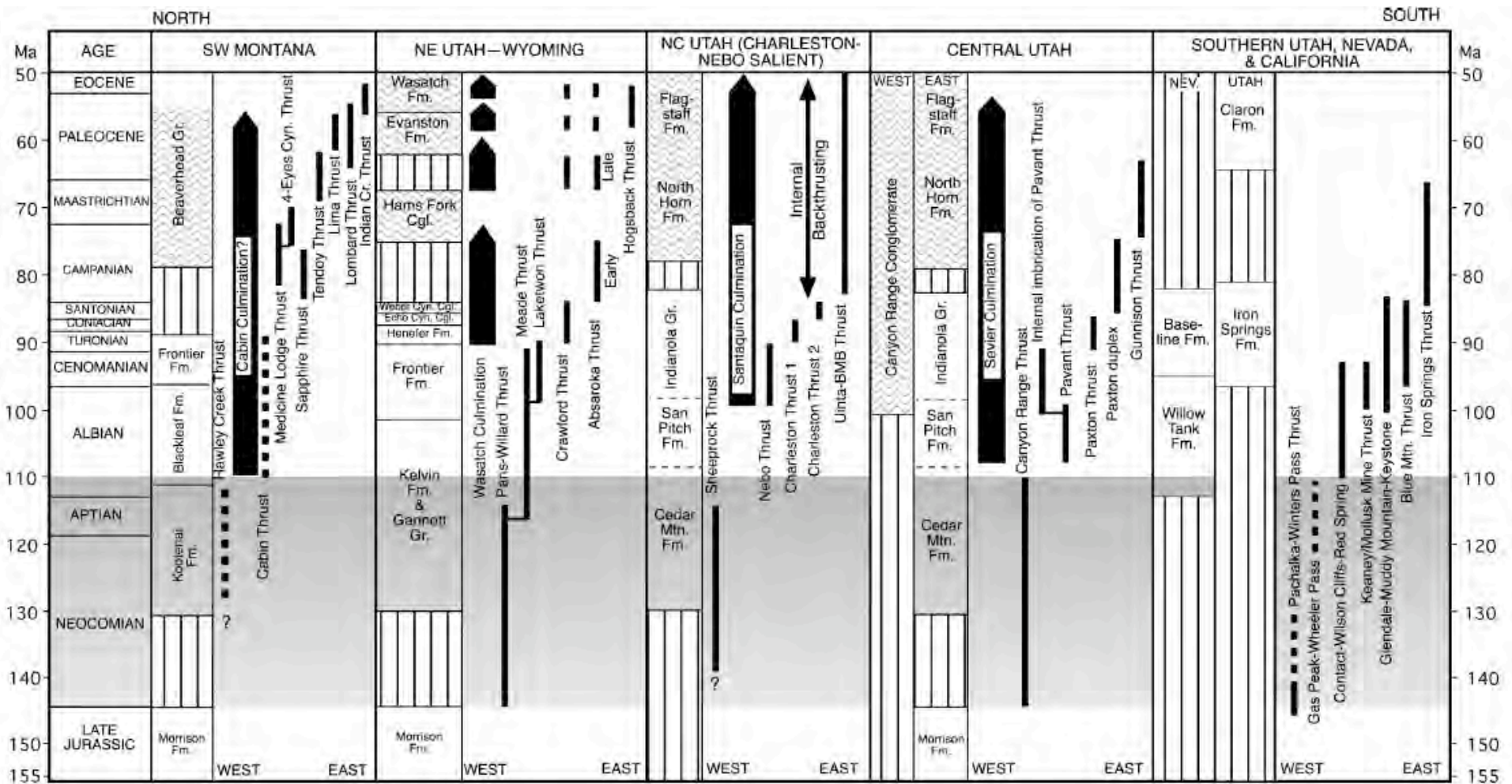
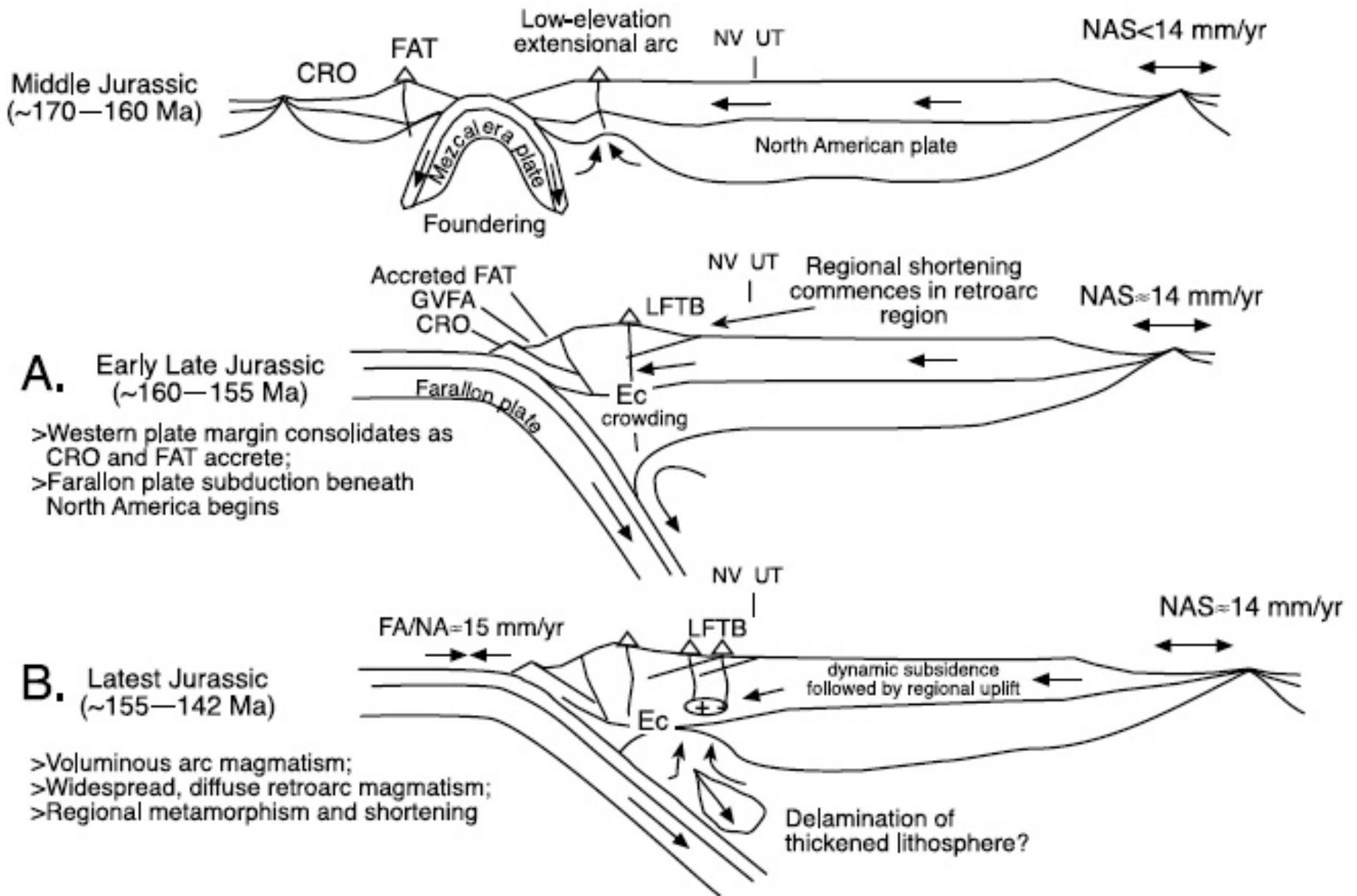
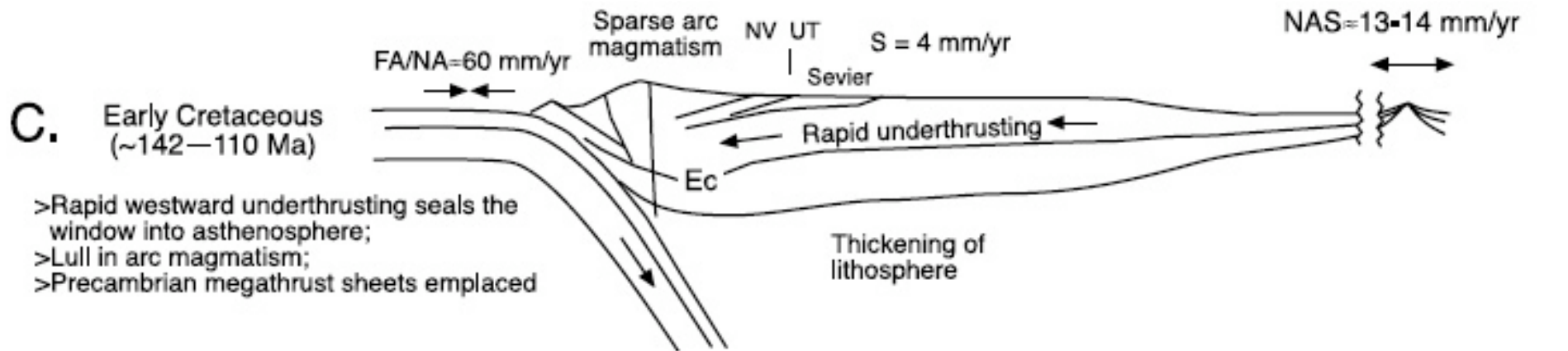


Fig. 18. Diagram illustrating the kinematic history in five selected segments of the frontal (Sevier belt) part of the Cordilleran thrust belt. The gray shaded area in lower part of the diagram indicates the period of emplacement of the Precambrian quartzite megathrust sheets. Black vertical lines indicate general estimates of timing of thrust displacement; dashed vertical lines (in southwest Montana panel) are speculative. Thick vertical arrows represent times of active uplift in basement culminations.

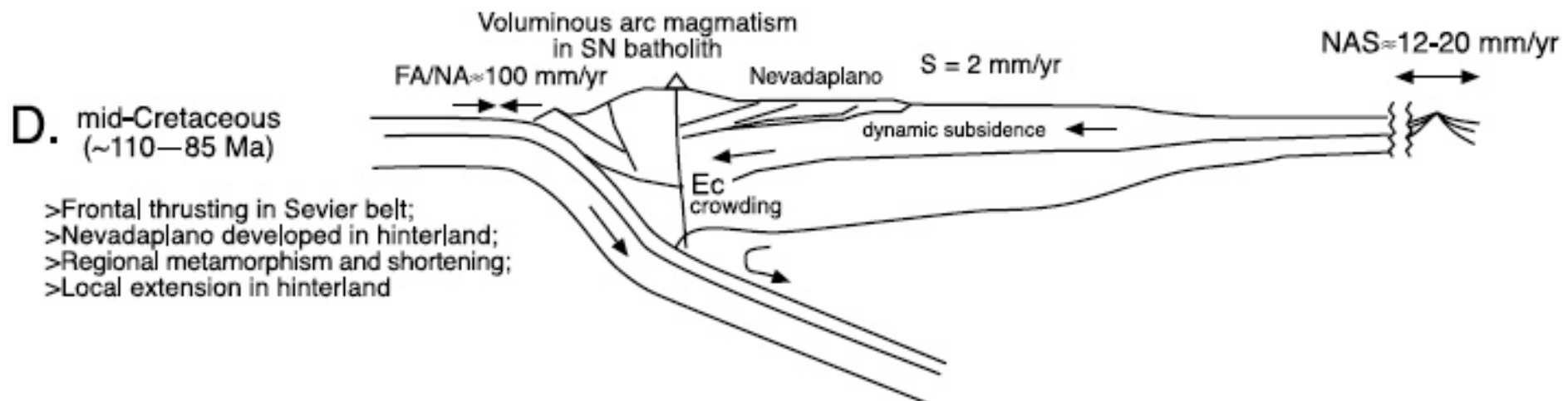




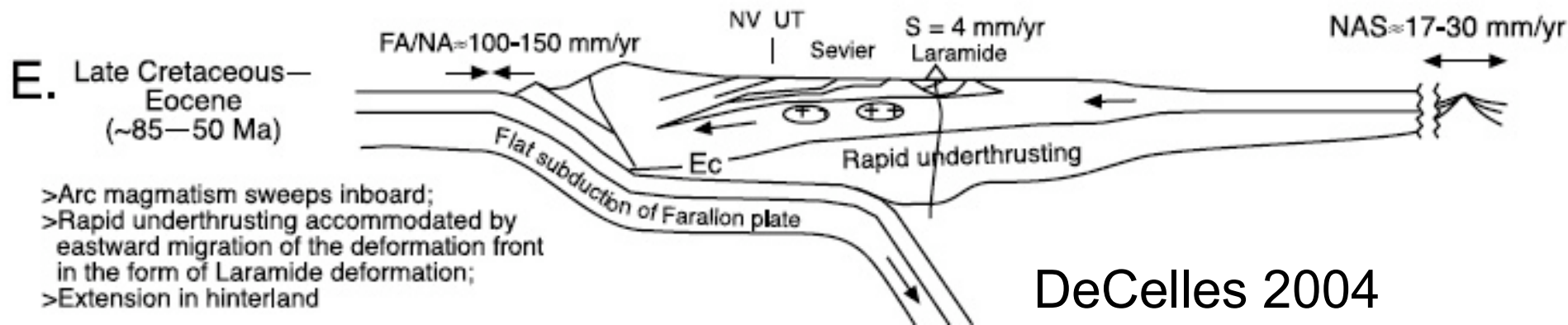
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- >Rapid westward underthrusting seals the window into asthenosphere;
- >Lull in arc magmatism;
- >Precambrian megathrust sheets emplaced



- >Frontal thrusting in Sevier belt;
- >Nevadaplano developed in hinterland;
- >Regional metamorphism and shortening;
- >Local extension in hinterland



- >Arc magmatism sweeps inboard;
- >Rapid underthrusting accommodated by eastward migration of the deformation front in the form of Laramide deformation;
- >Extension in hinterland

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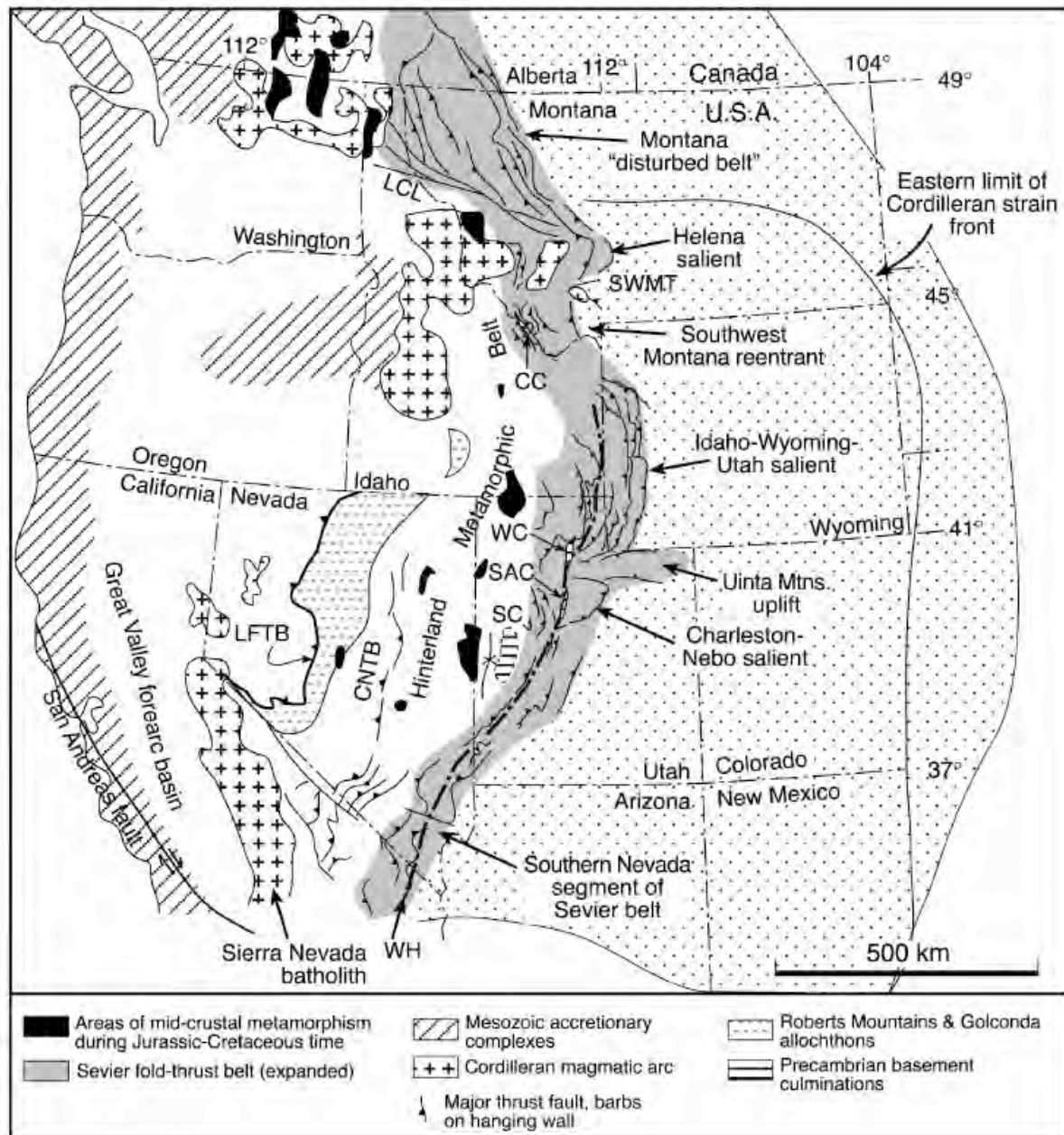


Fig. 5. Simplified version of figure 2, showing some of the major tectonic features in the Cordilleran thrust belt discussed in the text. Abbreviations as follows: LCL, Lewis and Clark line; SWMT, Southwest Montana transverse zone; CC, Cabin culmination; WC, Wasatch culmination; SAC, Santaquin culmination; SC, Sevier culmination; CNTB, Central Nevada thrust belt; LFTB, Luning-Fencemaker thrust belt; WH, Wasatch hinge line. Stippled region represents Cordilleran foreland basin system.

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