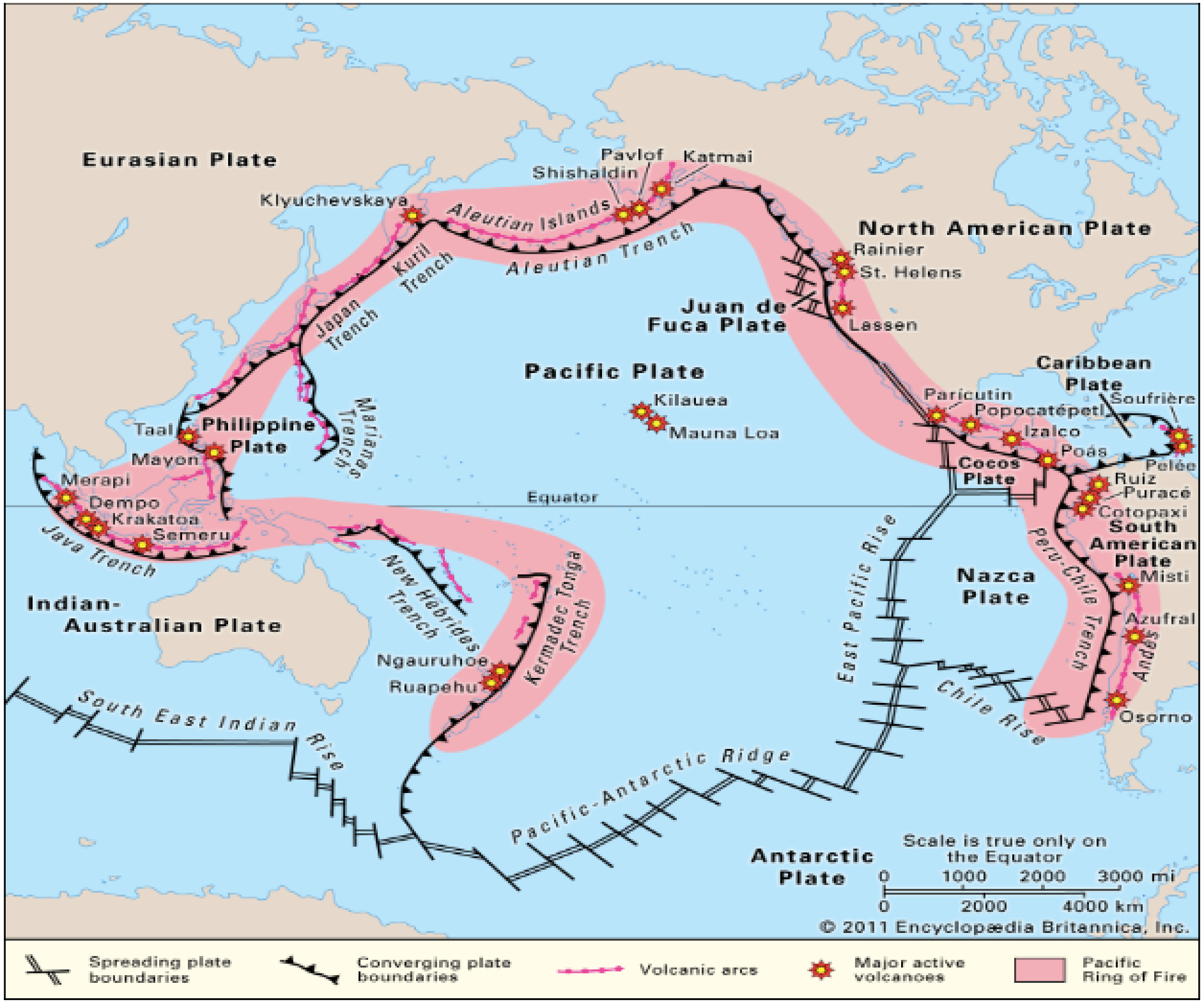
Alaska
1.2
1.5
3.7
3
5
1.5
CORDILLERAN
MOBILE
BELT
NORTH
AMERICAN
CRATON
PACIFIC
OCEAN
1.
4
9
1.1
1.3
2.0
Belt Basin
2.5
1.2
5.5
Canada
U.S.
1.4
5
7
Uinta Basin
1.2
2.1
0.6
Apache Basin



Eurasian Plate
Klyuchevskaya
Aleutian Islands
Pavlof
Shishaldin
Katmai
Aleutian Trench
Kuril Trench
Japan Trench
North American Plate
Rainier
St. Helens
Lassen
Juan de Fuca Plate
Pacific Plate
Kilauea
Mauna Loa
Caribbean Plate
Soufrière
Paricutin
Popocatépetl
Izalco
Poás
Pelée
Cocos Plate
Ruiz
Puracé
Cotopaxi
South American Plate
Taal
Philippine Plate
Mayon
Marianas Trench
Merapi
Dempo
Krakatoa
Semeru
Java Trench
Equator
New Hebrides Trench
Kermadec Tonga Trench
Ngauruhoe
Ruapehu
Indian-Australian Plate
East Pacific Rise
Nazca Plate
Peru-Chile Trench
Misti
Azufral
Andes
Chile Rise
Osorno
South East Indian Rise
Pacific-Antarctic Ridge
Antarctic Plate
Scale is true only on the Equator
0 1000 2000 3000 mi
0 2000 4000 km
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Spreading plate boundaries
Converging plate boundaries
Volcanic arcs
Major active volcanoes
Pacific Ring of Fire

North American Cordillera

The mountain chain system along the **Pacific coast** of the Americas begins with the Alaska Range and the Brooks Range in Alaska and runs through the Yukon into British Columbia. In the **United States**, the Cordillera branches include the **Rocky Mountains**, the **Sierra Nevada**, the **Cascades**, and various small Pacific **Coastal ranges**. The three main phases of the Cordilleran orogeny are the **Laramide**, **Sevier**, and **Nevadan** orogenies. The **Rocky Mountains** took shape during an intense period of plate tectonic activity of the Laramide orogeny, about 80–55 million years ago, responsible for raising the Rocky Mountains. It was the last of the three episodes of the **Cordilleran orogeny**.

- **Basin and Range extension-Miocene (17 Ma) - Present**
- **Columbia and Yellowstone plateau**


Brooks Range
Alaska Range
Coast Mountains
Cascade Range
Rockies
Sierra Nevada
Sierra Madre Occidental
Sierra Madre Oriental
Laurentian
mountains
Appalachians
Mauna Kea (Dormant Volcanic Mountain)


CASCADE RANGE
Coastal Ranges
ROCKY MOUNTAIN RANGES
GREAT PLAINS
CANADIAN SHIELD
GREAT BASIN
SIERRA NEVADA
CENTRAL LOWLANDS
APPALACHIAN MOUNTAINS
ATLANTIC COASTAL PLAIN
Coastal Ranges
GULF COASTAL PLAIN
Brooks Range
Alaska Range
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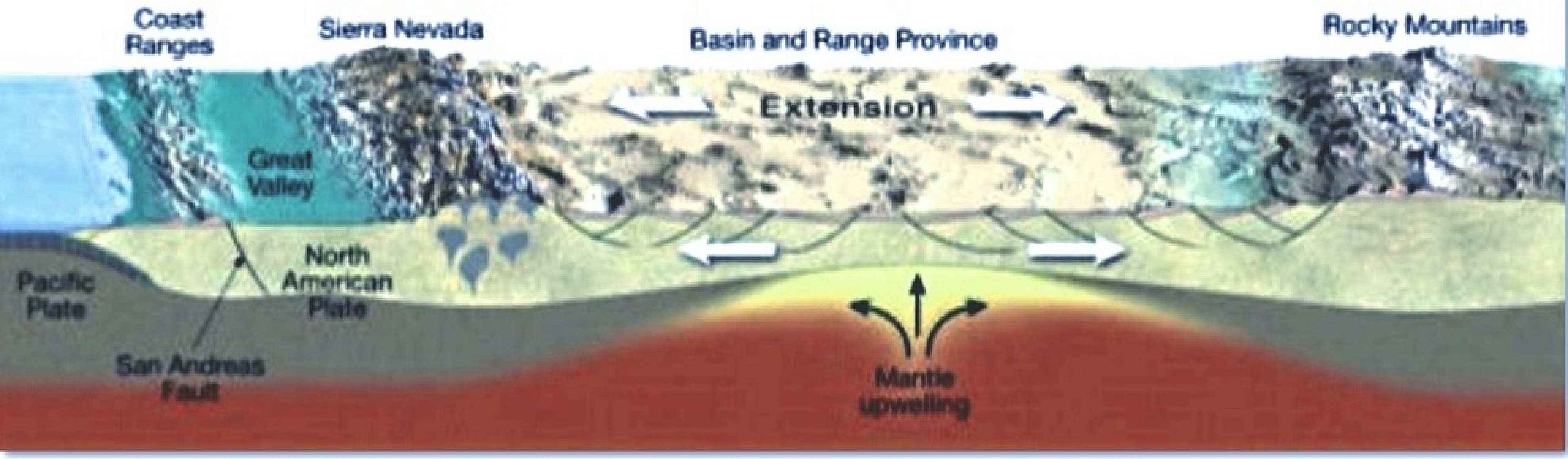

Source: *Basin and Range Province Cross Section,* Pearson Education


CANADA
MEXICO
Pacific Ocean
Atlantic Ocean
Gulf of Mexico
Rocky Mountains
Cascade Range
Sierra Nevada
Columbia Plateau
Colorado Plateau
Great Plains
Ozark Plateau
Edwards Plateau
Coastal Plain
Appalachian Mts.
Sonora Desert
Mt Whitney 4418
Snake R.
Colorado
Missouri
Arkansas
Red River
Mississippi
Ohio
Rio Grande
St. Lawrence
L. Superior
L. Michigan
L. Huron
L. Erie
L. Ont.
Seattle
Portland
San Francisco
San Jose
Los Angeles
San Diego
Las Vegas
Phoenix
Denver
Kansas City
Minneapolis
Milwaukee
Chicago
Detroit
Cleveland
Buffalo
St. Louis
Cincinnati
Memphis
Atlanta
Dallas
Houston
New Orleans
Miami
Boston
New York
Philadelphia
Baltimore
Washington D.C.
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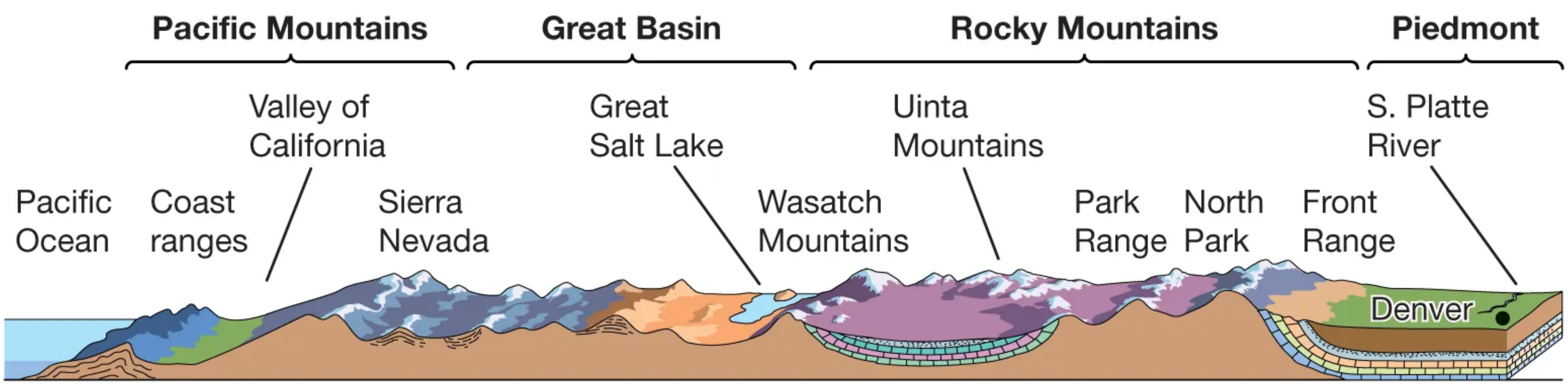


Pacific Mountains
Great Basin
Rocky Mountains
Piedmont
Valley of California
Great Salt Lake
Uinta Mountains
S. Platte River
Pacific Ocean
Coast ranges
Sierra Nevada
Wasatch Mountains
Park Range
North Park
Front Range
Denver

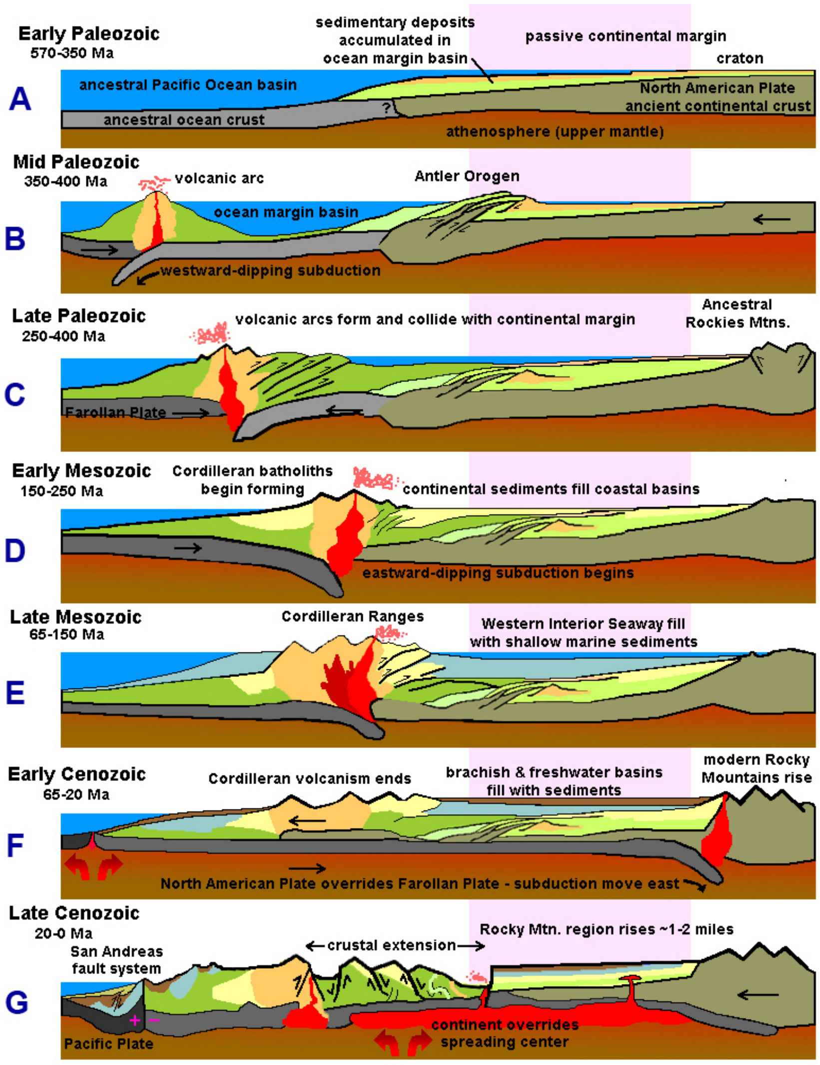
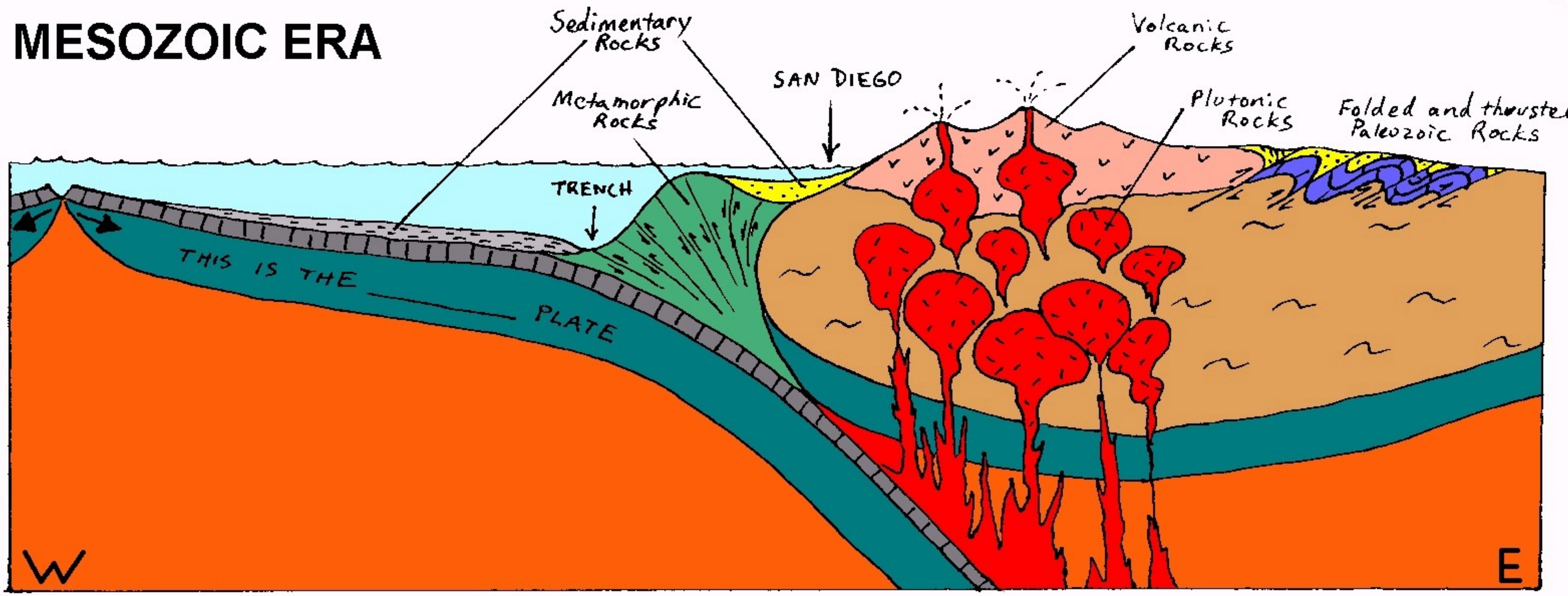


Fig. 105. Generalized geologic evolution of western United States from Late Precambrian time (1 billion years) to the present.

MESOZOIC ERA



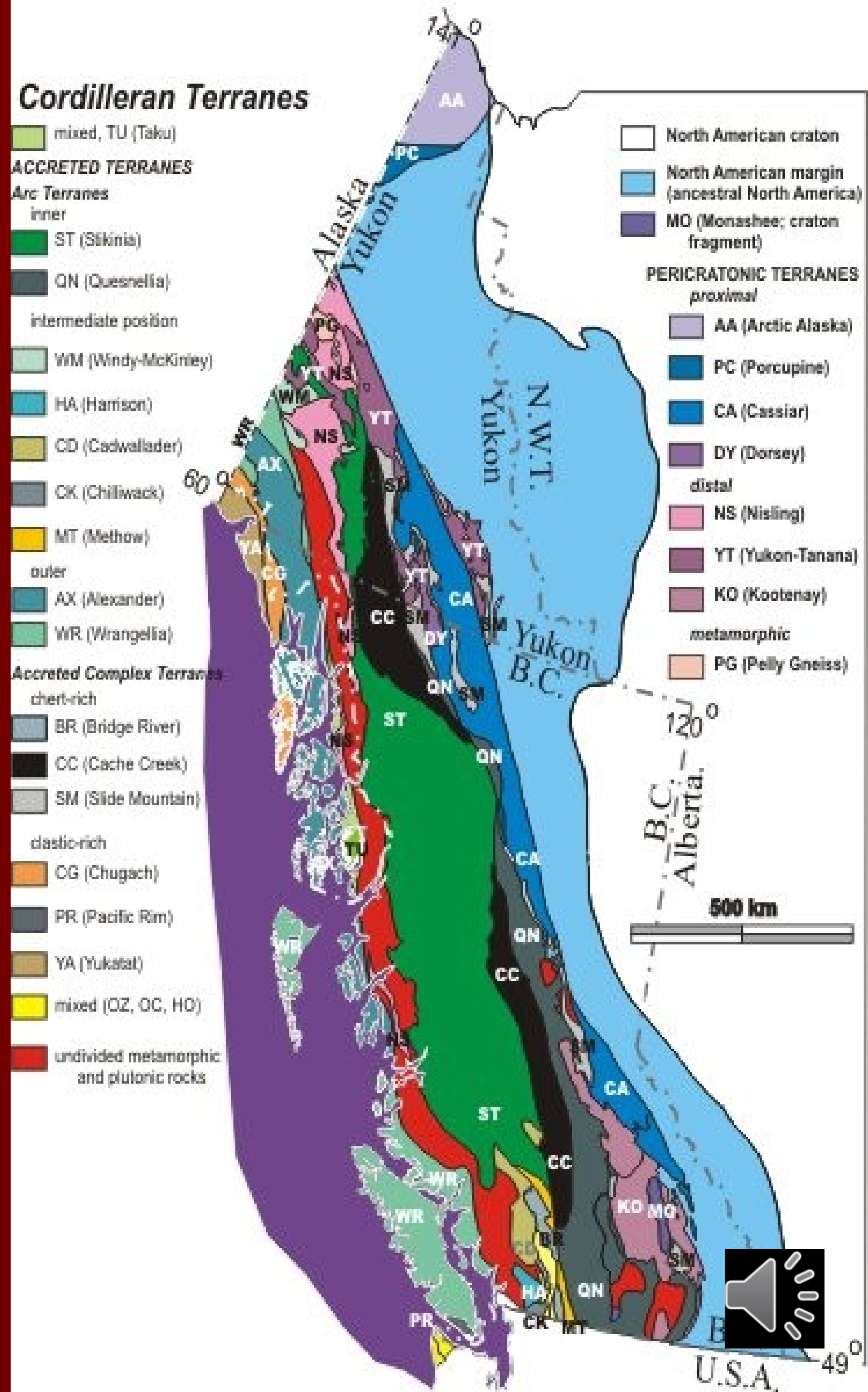
The Western Collage

- Cordillera an collage of microplates and arcs
  - accreted during the Paleozoic and Mesozoic
  - terrains have different rock types and fossil assemblages that cannot be correlated
  - suspect terrains--fault-bounded regions that cannot be correlated
  - exotic terrains--clearly from somewhere else

What is a Tectonostratigraphic Terrane?

Terranes can be:

- *Native* – showing shared traits with North American crust, indicating an origin adjacent to North America.
- *Exotic* – Far-traveled, not born adjacent to North America
- *Superterranes – amalgamated* with other terranes before *accretion* to the continental margin.



Accreted or “suspect” terranes

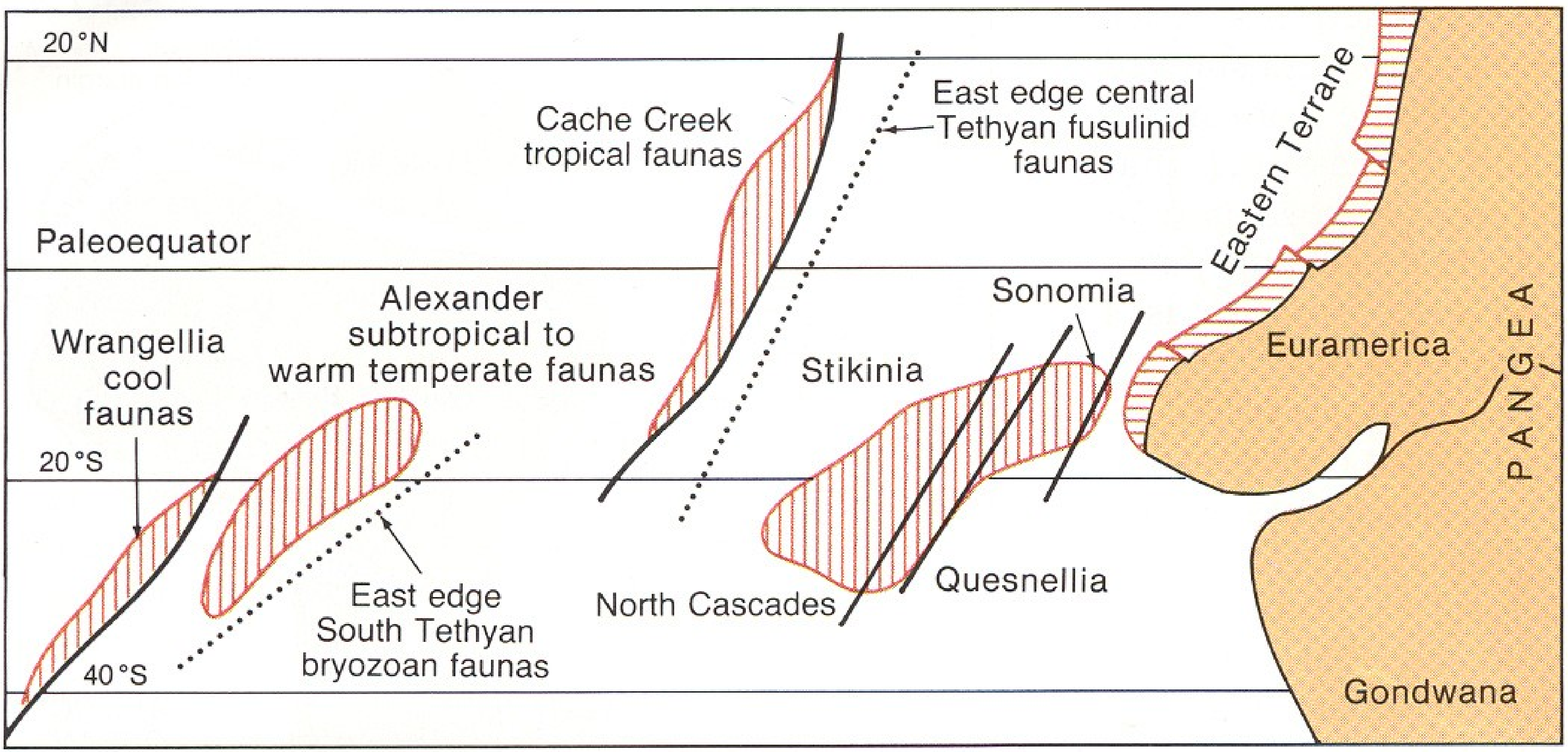
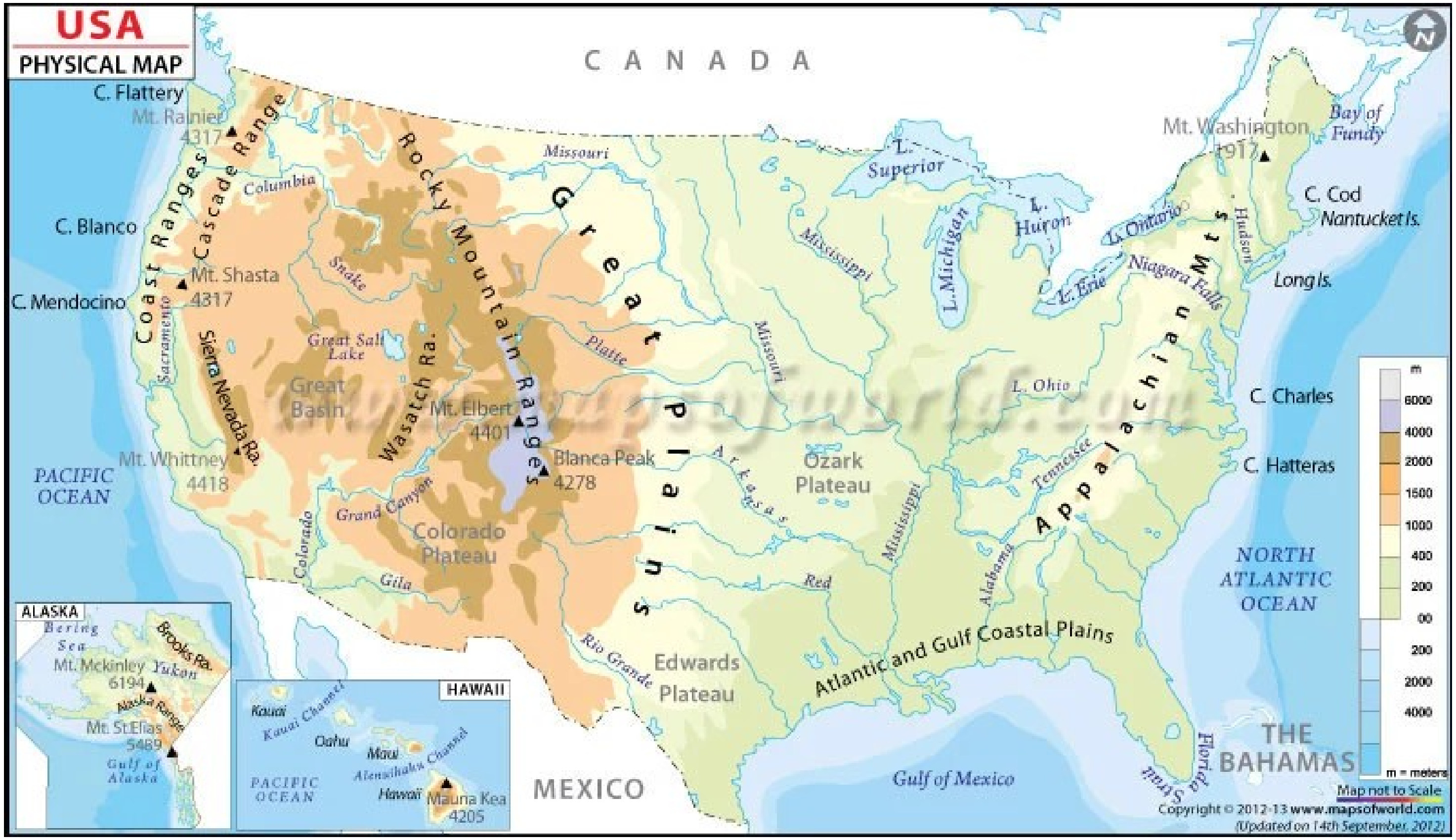


FIGURE 14.18

Dott & Prothero

United States Cordillera (without Alaska)

Coastal ranges
Cascades
Sierra Nevada
Rocky Mountains



Coastal Ranges
CASCADE RANGE
SIERRA NEVADA
GREAT BASIN
ROCKY MOUNTAIN RANGES
GREAT PLAINS
CANADIAN SHIELD
CENTRAL LOWLANDS
APPALACHIAN MOUNTAINS
ATLANTIC COASTAL PLAIN
GULF COASTAL PLAIN
Coastal Ranges
Brooks Range
Alaska Range
lizardpoint.com

KORDILERY

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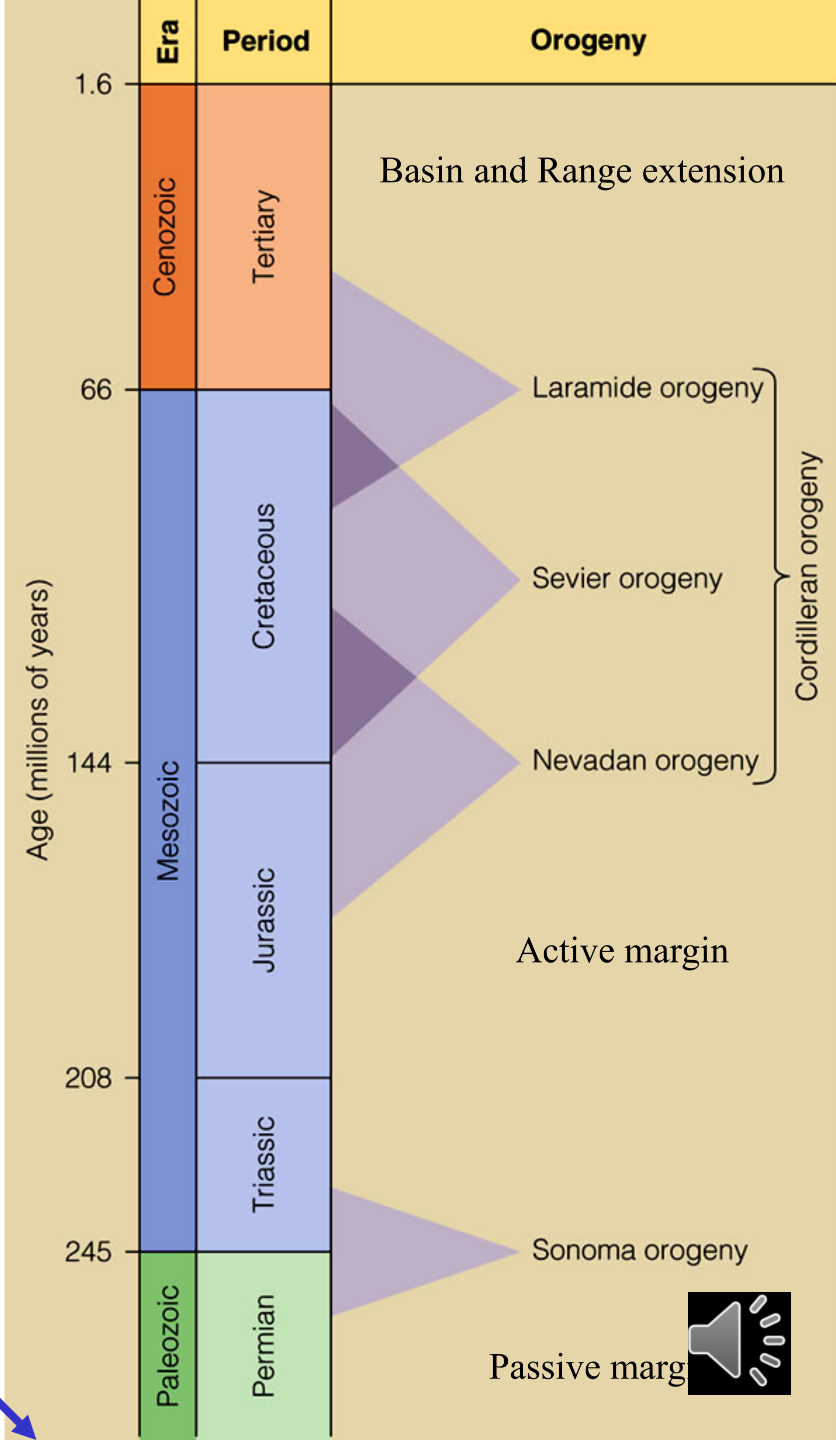
Antler Orogeny in Devonian-Carb.



Paleozoic Passive Margin

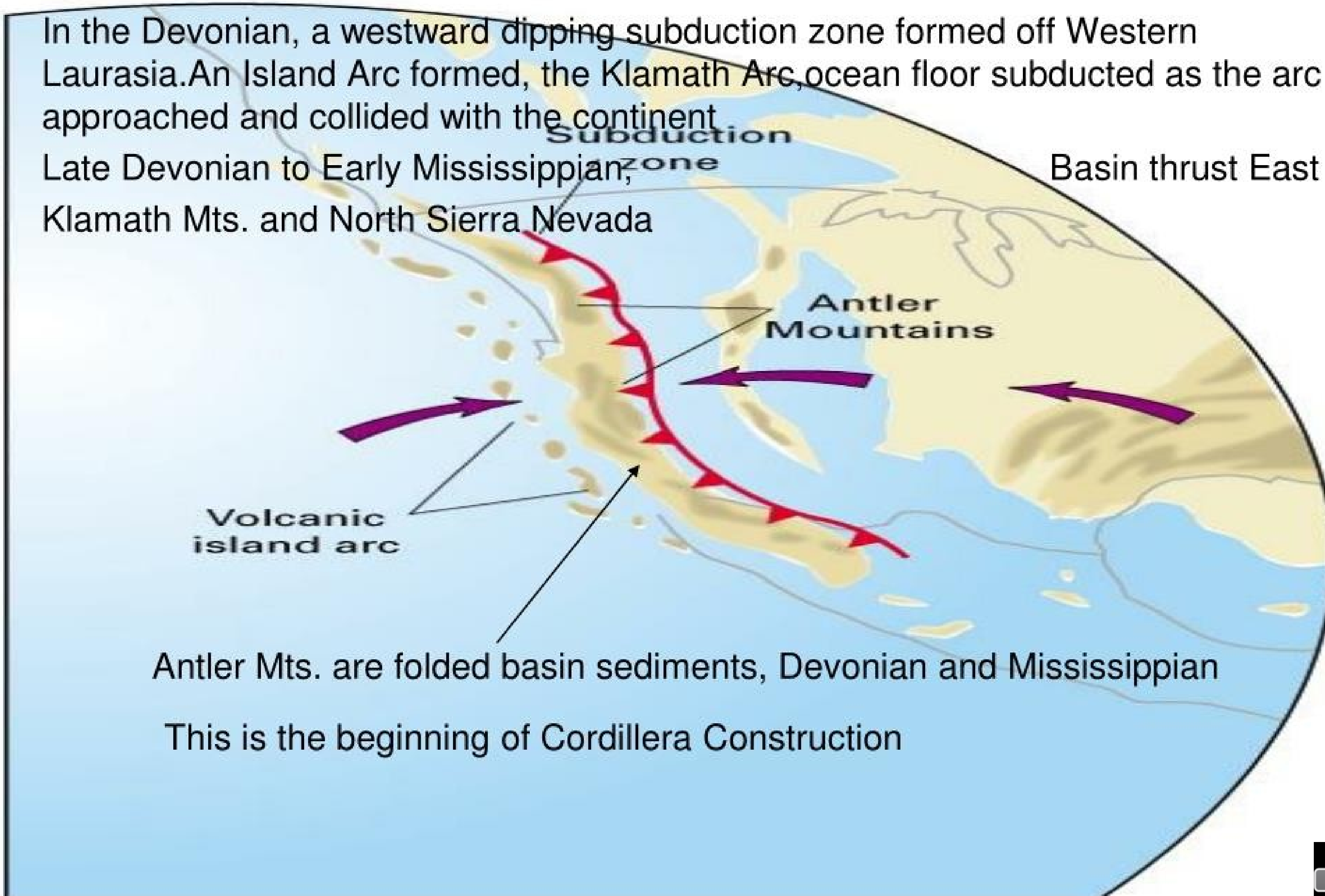
- Existed in Late Precambrian and Paleozoic
- Craton and cratonic basin deposits
- Miogeocline continental shelf deposits

Antler Orogeny (300-375 Ma)

- Late Devonian - Mississippian
- **Collision of the arc** with a passive margin
- **Roberts Mountain Allochton** thrust over the passive margin
- A series of foreland basins formed in eastern Nevada

Antler Orogeny

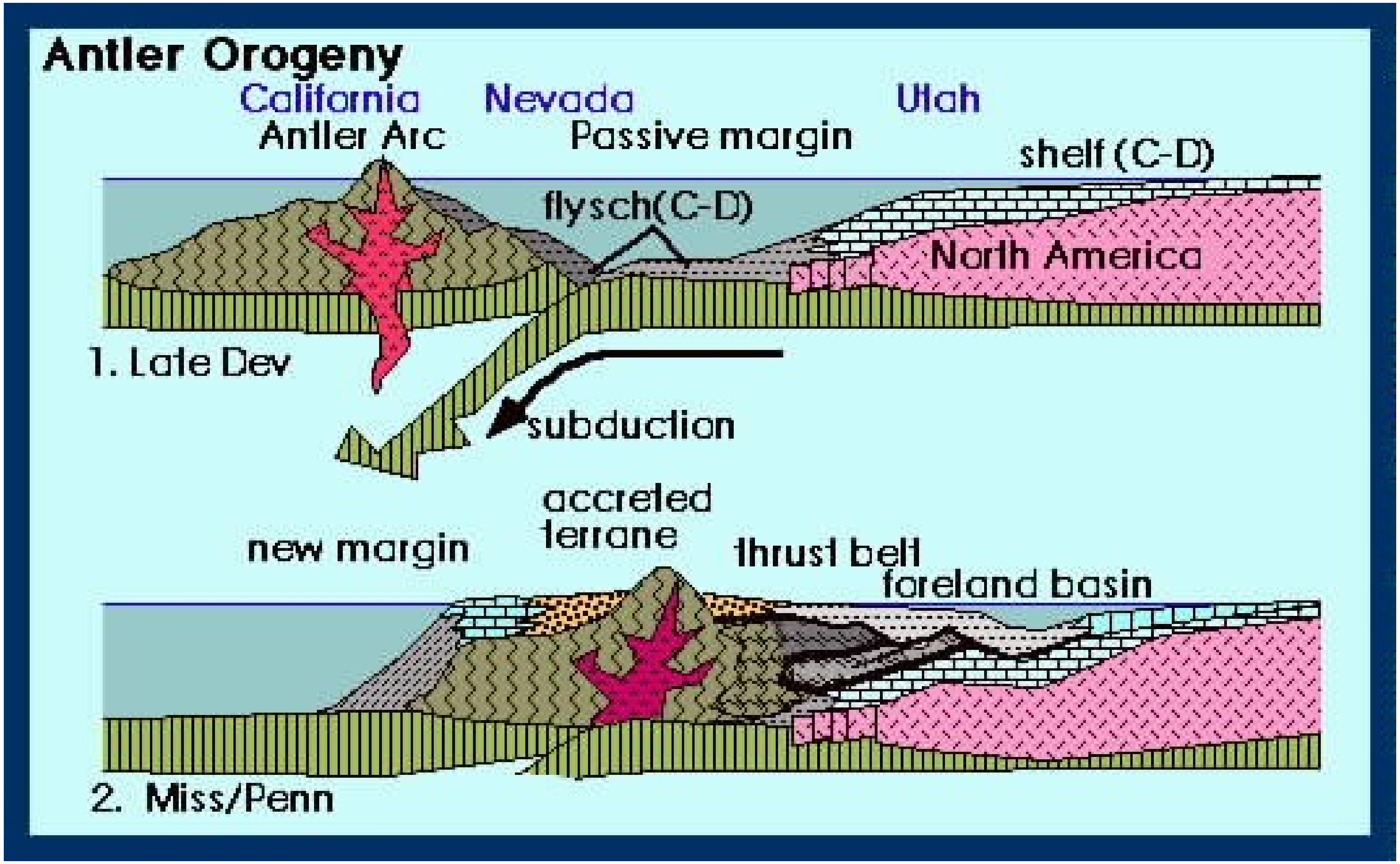
- In the Devonian, a westward dipping subduction zone formed off Western Laurasia.An Island Arc formed, the Klamath Arc,ocean floor subducted as the arc approached and collided with the continent
- Late Devonian to Early Mississippian, Basin thrust East
- Klamath Mts. and North Sierra Nevada



Antler Mts. are folded basin sediments, Devonian and Mississippian

This is the beginning of Cordillera Construction

Orogeneze: antlerská, kolize klamathského ostrovního oblouku v devonu a spodním karbonu



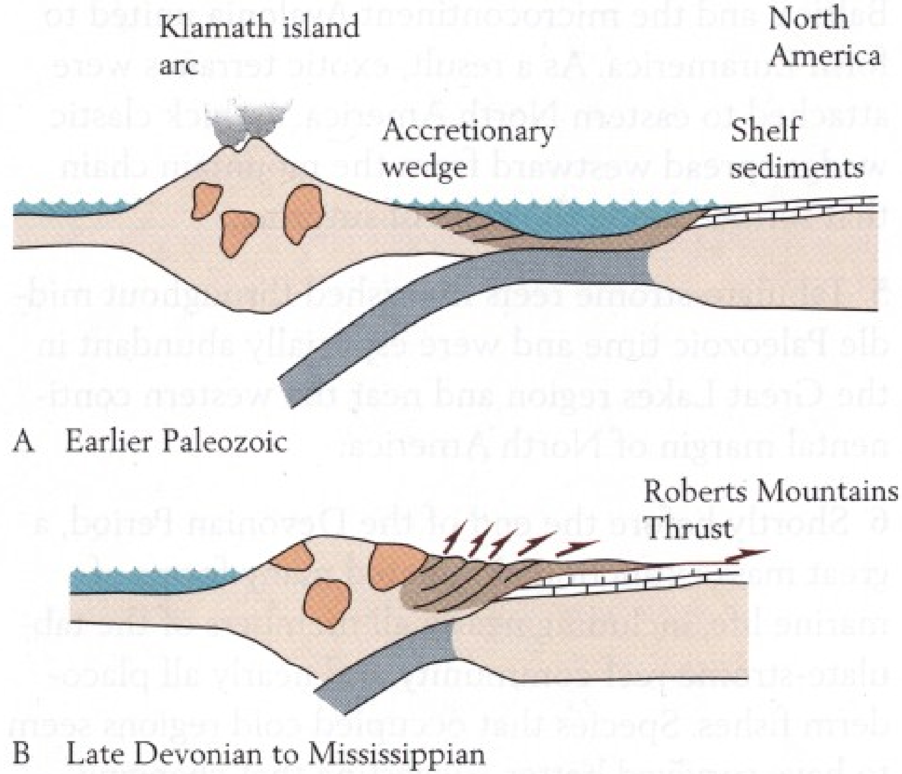


Figure 14-31 The likely mechanism by which the Klamath Arc was added to the North American continent by the Antler orogeny during Late Devonian and Mississippian time. The basin between the craton and the Klamath Arc *(A)* closed. As the continental crust was thrust beneath the volcanic crust of the Klamath Arc, deep-sea sediments slid onto shallow-water carbonates along the Roberts Mountains Thrust *(B)*.

Fig. 3. Regional distribution of Antler Orogenic belt across West North America (Poole, 1974; Poole and Sanberg, 1977; Cook and Corboy, 2004).

Mesozoic reactivation of the Roberts Mountains thrust is a common feature

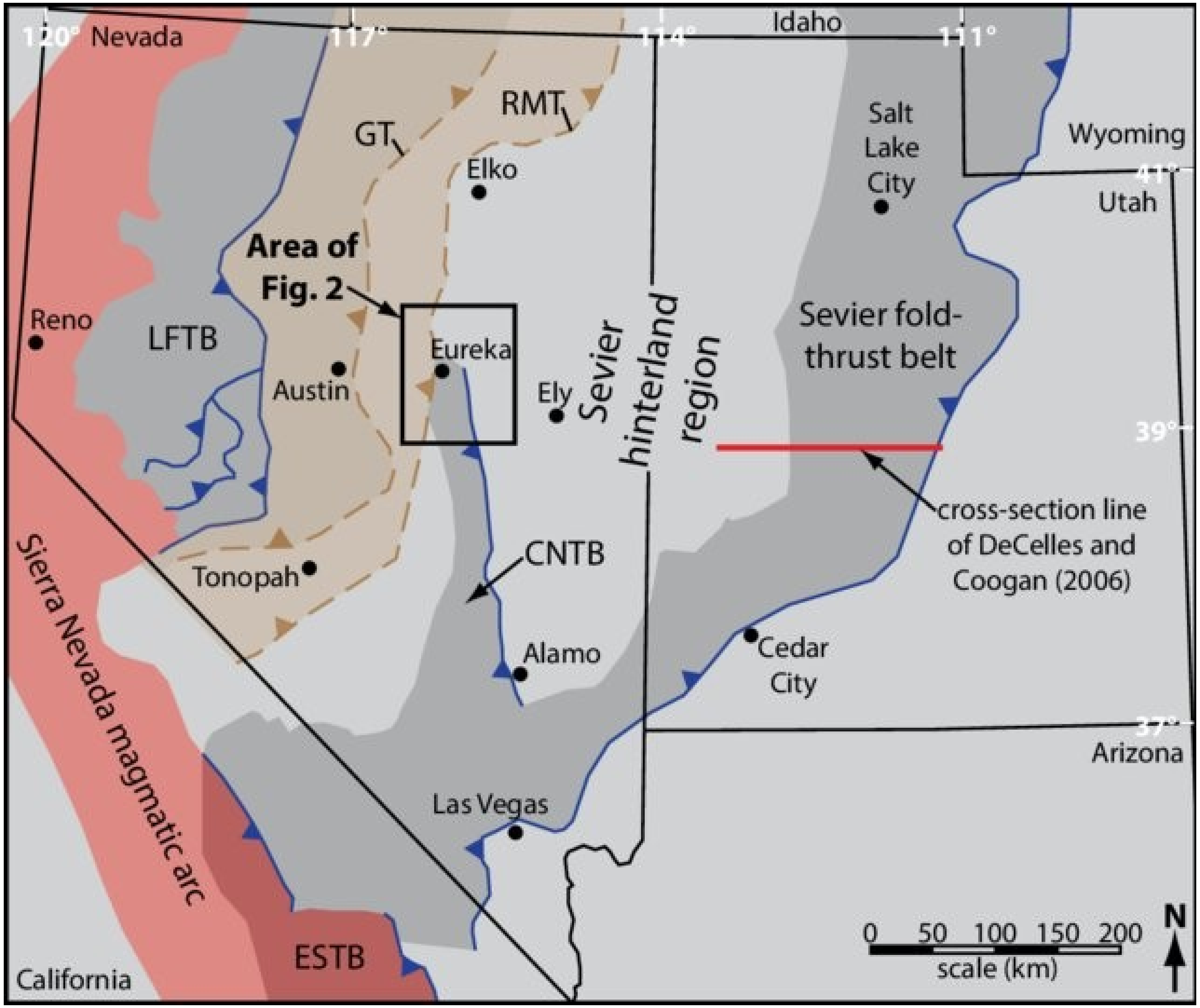
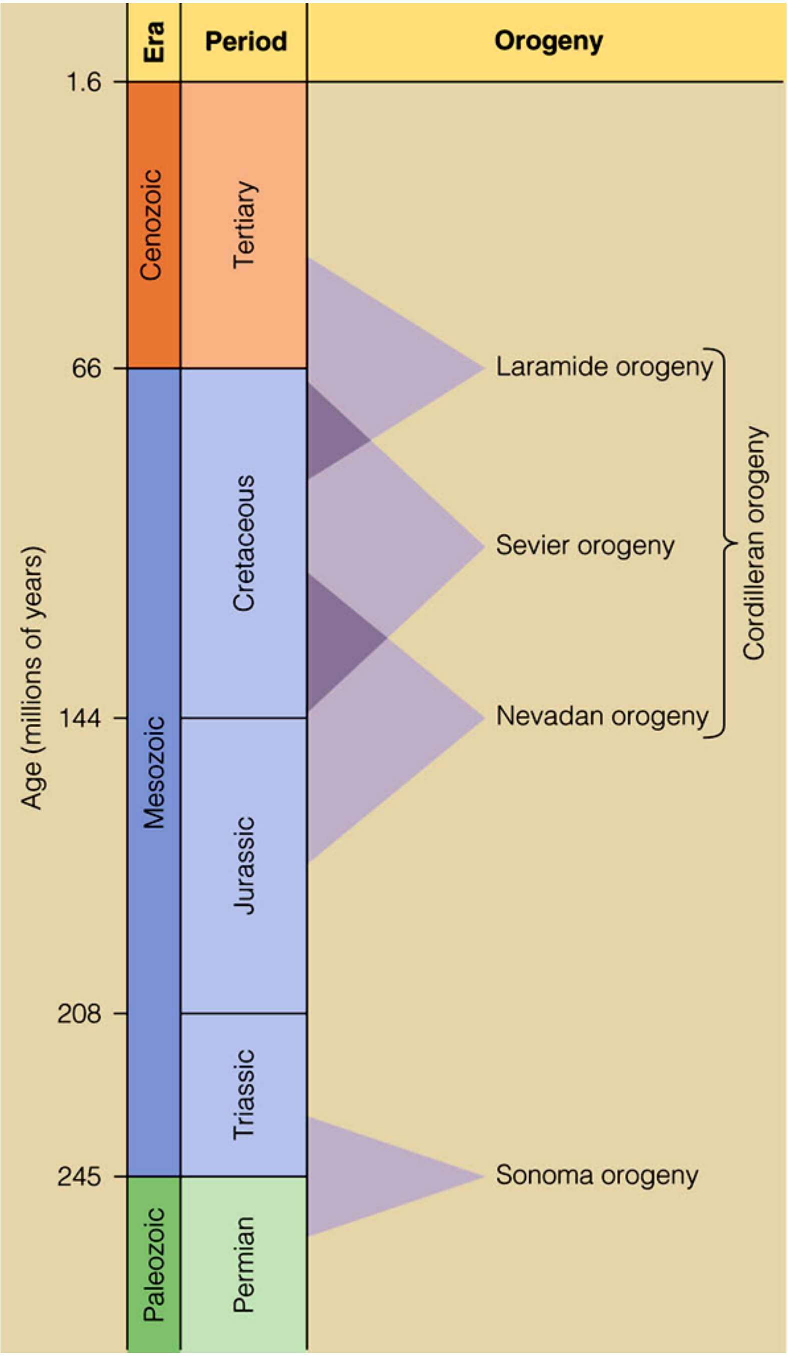


Figure 1. Map showing Paleozoic and Mesozoic thrust systems of Nevada, Utah, and southeast California (modifi ed from Long, 2012). Approximate deformation fronts of Paleozoic and Mesozoic thrust systems are shown in brown and blue, respectively, and spatial extents are shaded. Location of Sierra Nevada magmatic arc is from Van Buer et al. (2009) and DeCelles (2004). Abbreviations: GT—Golconda thrust; **RMT—Roberts Mountains thrust**; LFTB—Luning-Fencemaker thrust belt; CNTB—central Nevada thrust belt; ESTB—Eastern Sierra thrust belt.

Mesozoic

https://pages.uoregon.edu/ghump/Lectures_files/_wUS_history.pdf



Active margin

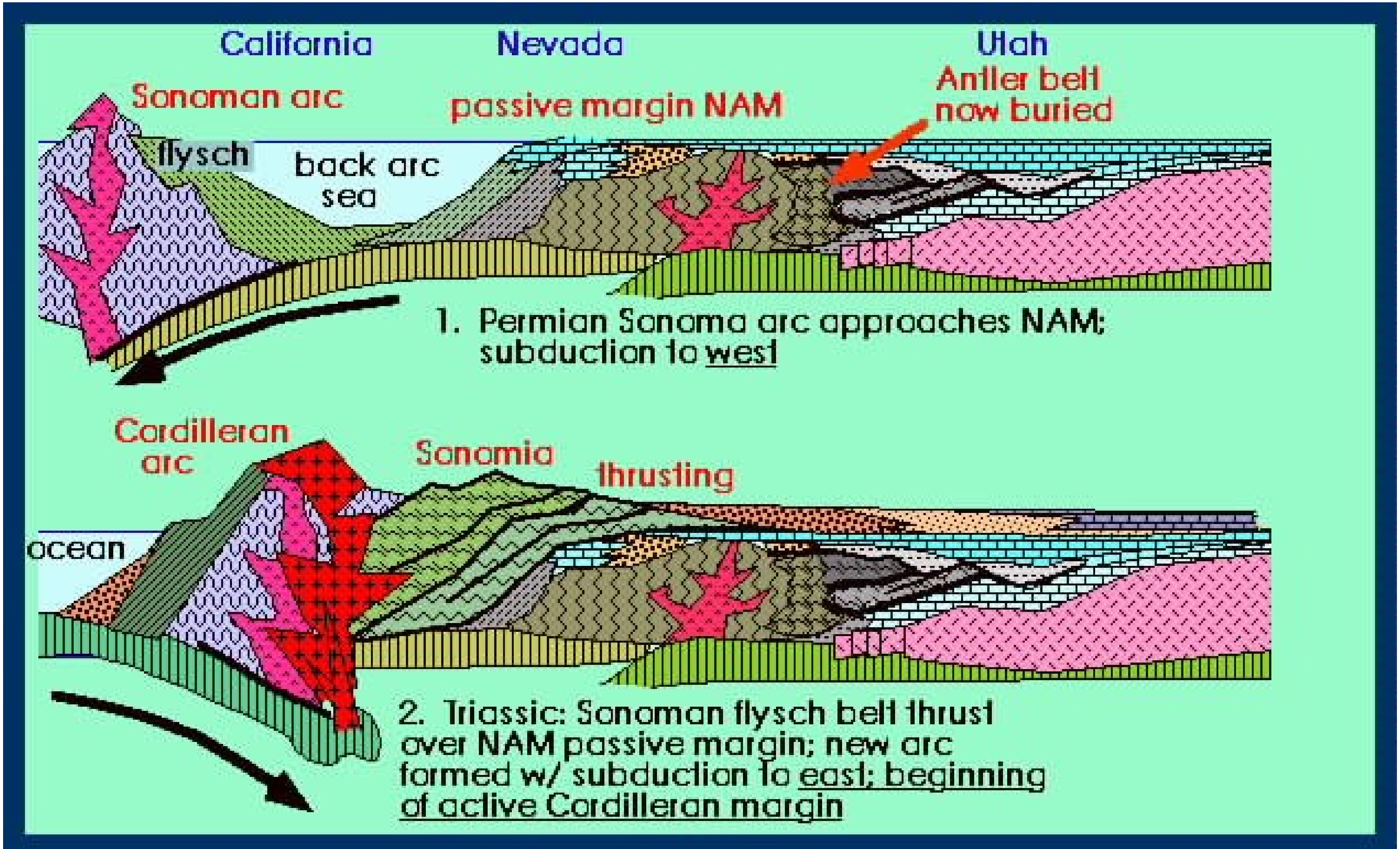
Passive margin

Sonoma Orogeny (200-280 Ma)

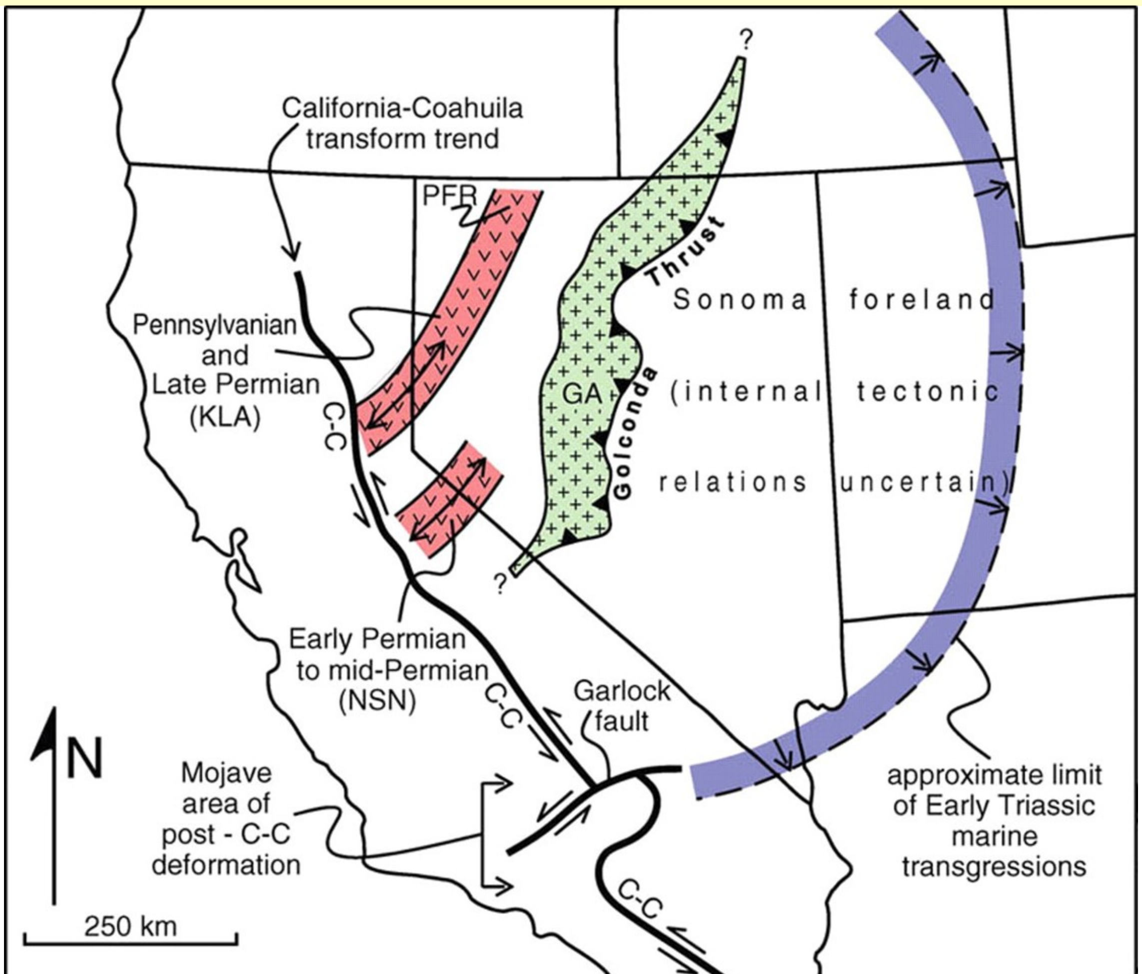
- Permo -Triassic
- Collision of Arc With **a Passive Margin**
- Island Arc Terrains Were Accreted
- **golconda allochthon**

Thrust Partly Over Roberts Mountain Antler allochtone

sonomská, kolize dalšího ostrovníhp oblouku na konci paleozoika



A hick oceanic sequence of Mississippian through Permian chert, limestone, conglomerate, siltstone, shale, lava flows and pyroclastics **accumulated in a trough west of the Antler orogenic belt**. This tectonic assemblage was **emplaced along the Golconda thrust, at least 60 miles (100 km) eastward** or inboard of the new continental margin, during the Late Permian through Early Triassic Sonoma Orogeny (Speed, 1983).



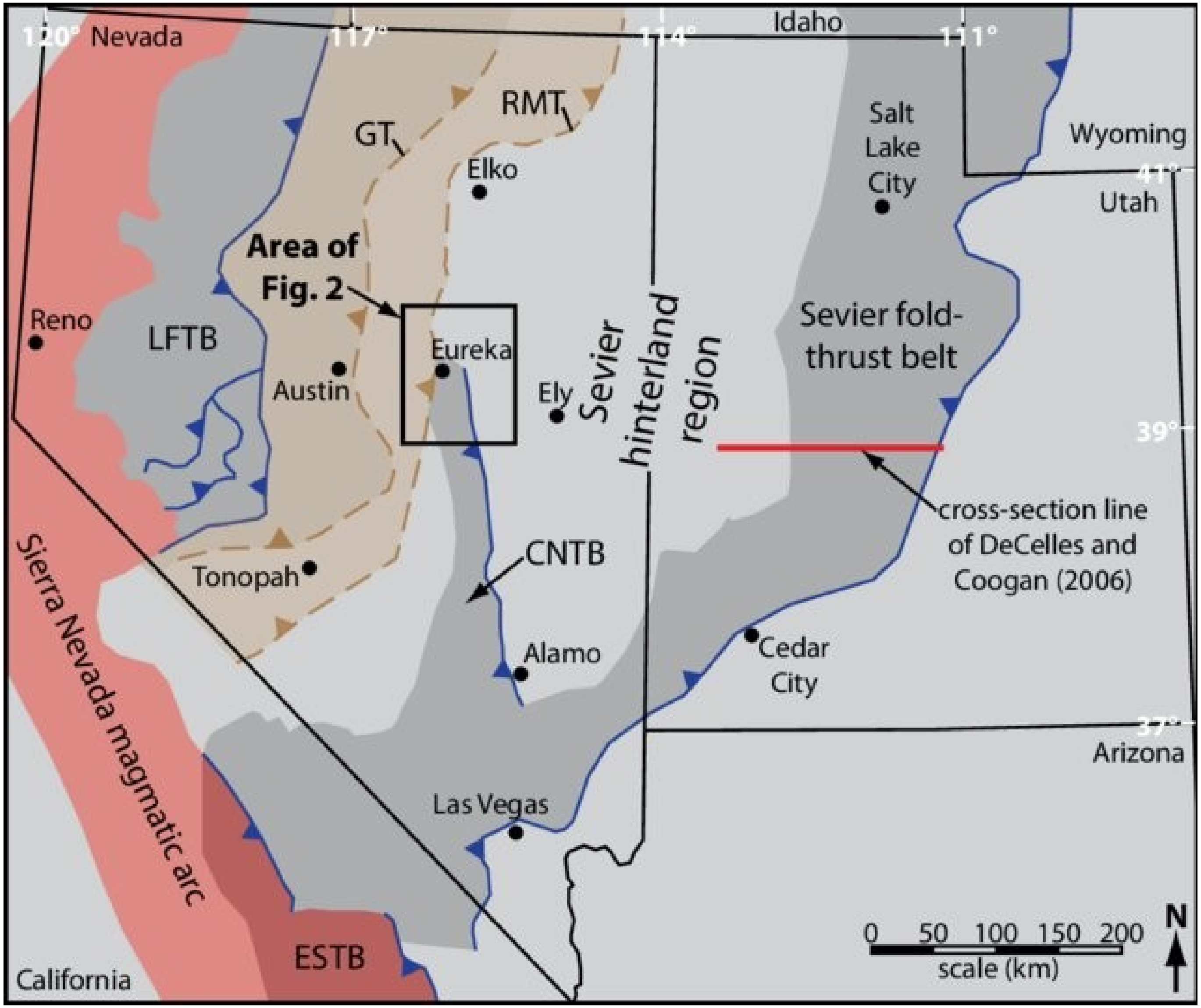
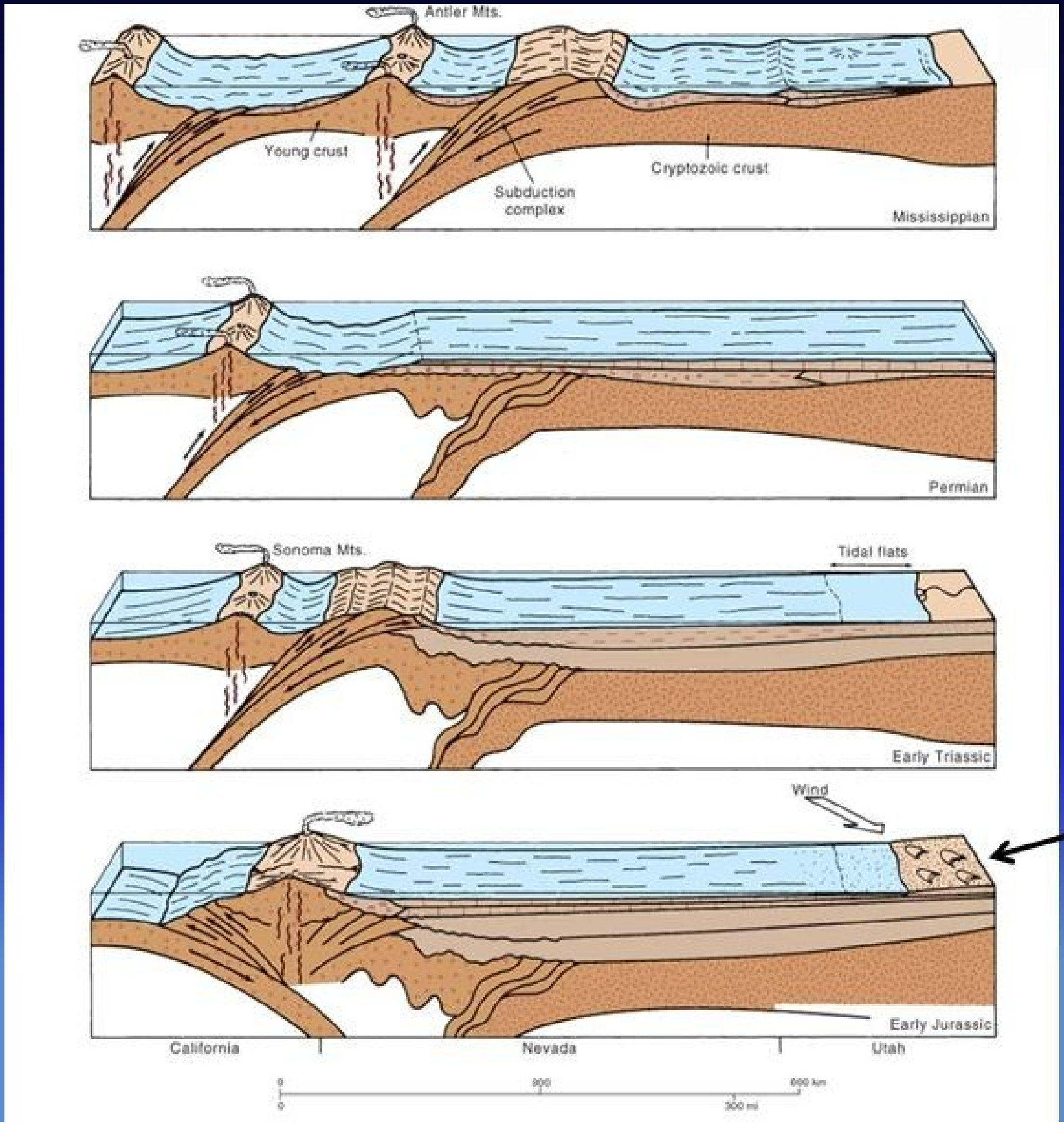


Figure 1. Map showing Paleozoic and Mesozoic thrust systems of Nevada, Utah, and southeast California (modifi ed from Long, 2012). Approximate deformation fronts of Paleozoic and Mesozoic thrust systems are shown in brown and blue, respectively, and spatial extents are shaded. Location of Sierra Nevada magmatic arc is from Van Buer et al. (2009) and DeCelles (2004). Abbreviations: **GT—Golconda thrust**; **RMT—Roberts Mountains thrust**; LFTB—Luning-Fencemaker thrust belt; CNTB—central Nevada thrust belt; ESTB—Eastern Sierra thrust belt.

Late Triassic Transition to Andean-type Margin



Antler Orogeny

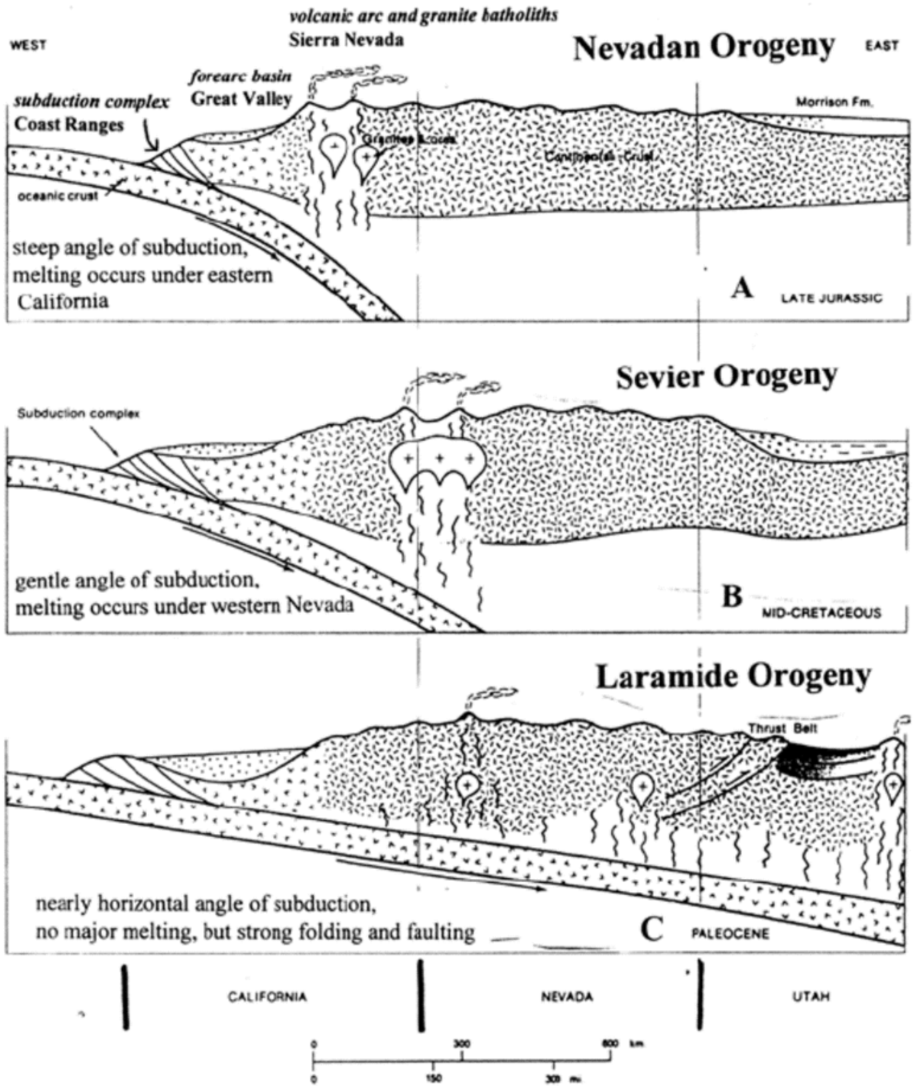
Accretion of Suspect/Exotic Terranes and Volcanic Arcs

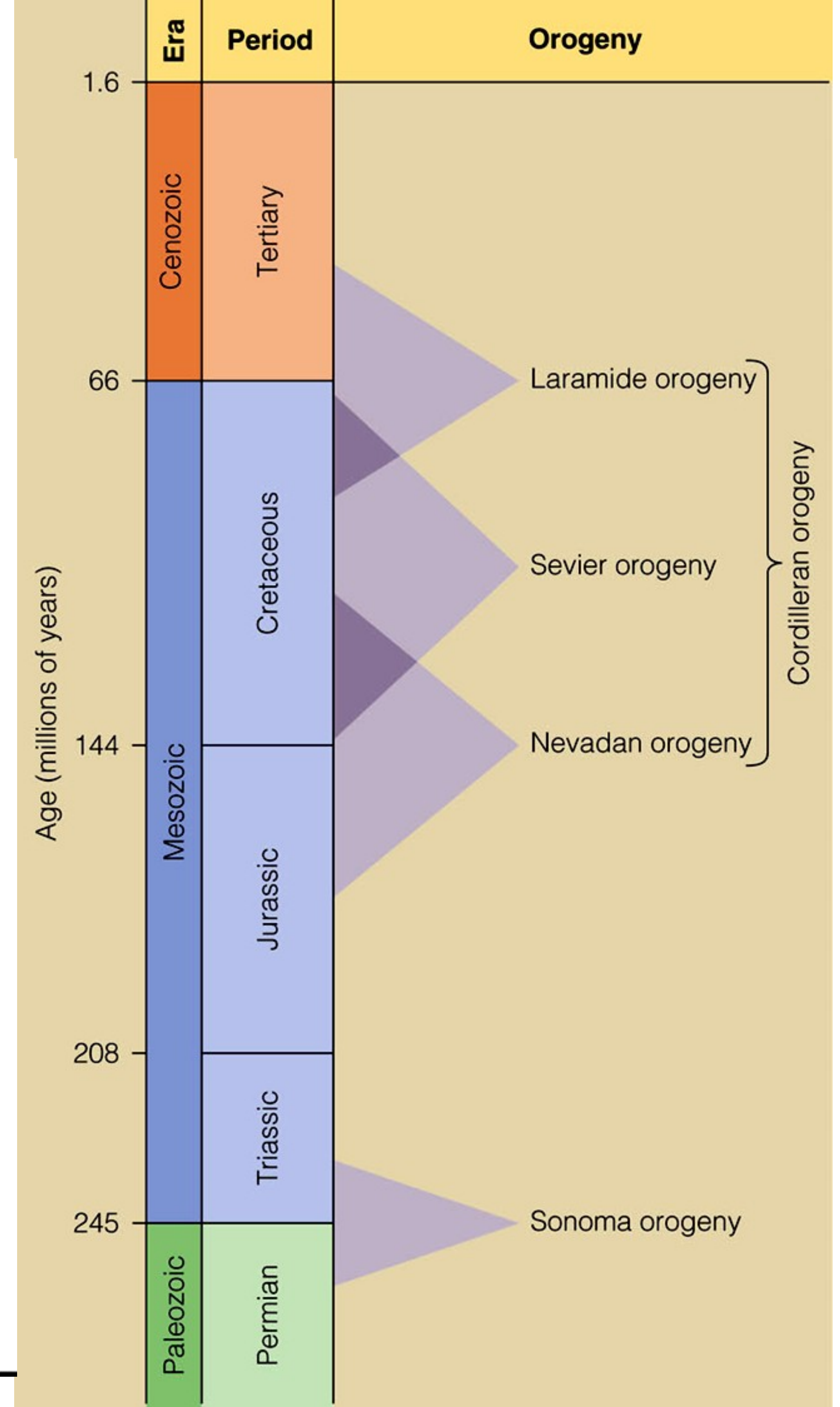
Sonoman Orogeny

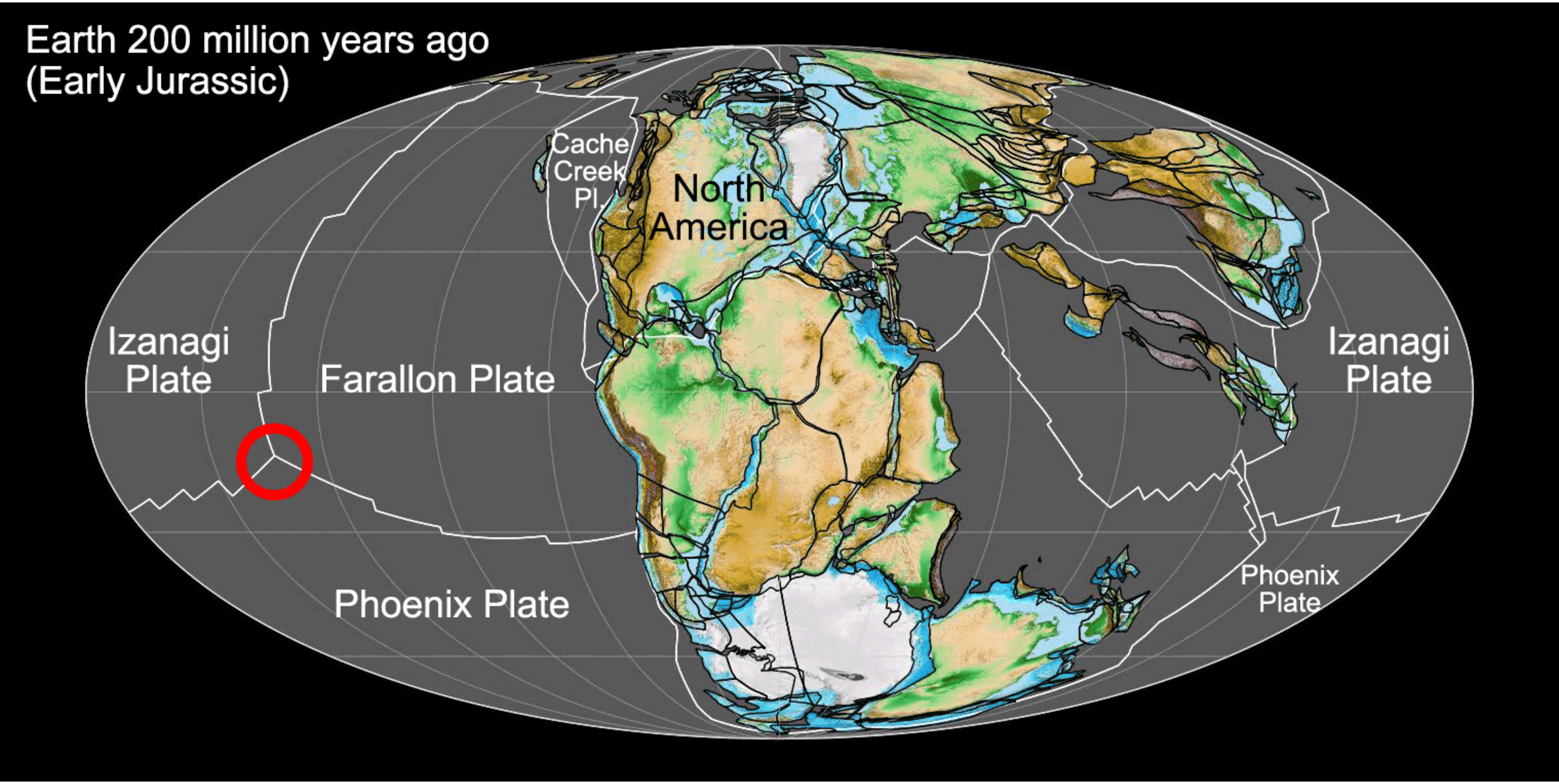
Navajo Sandstone

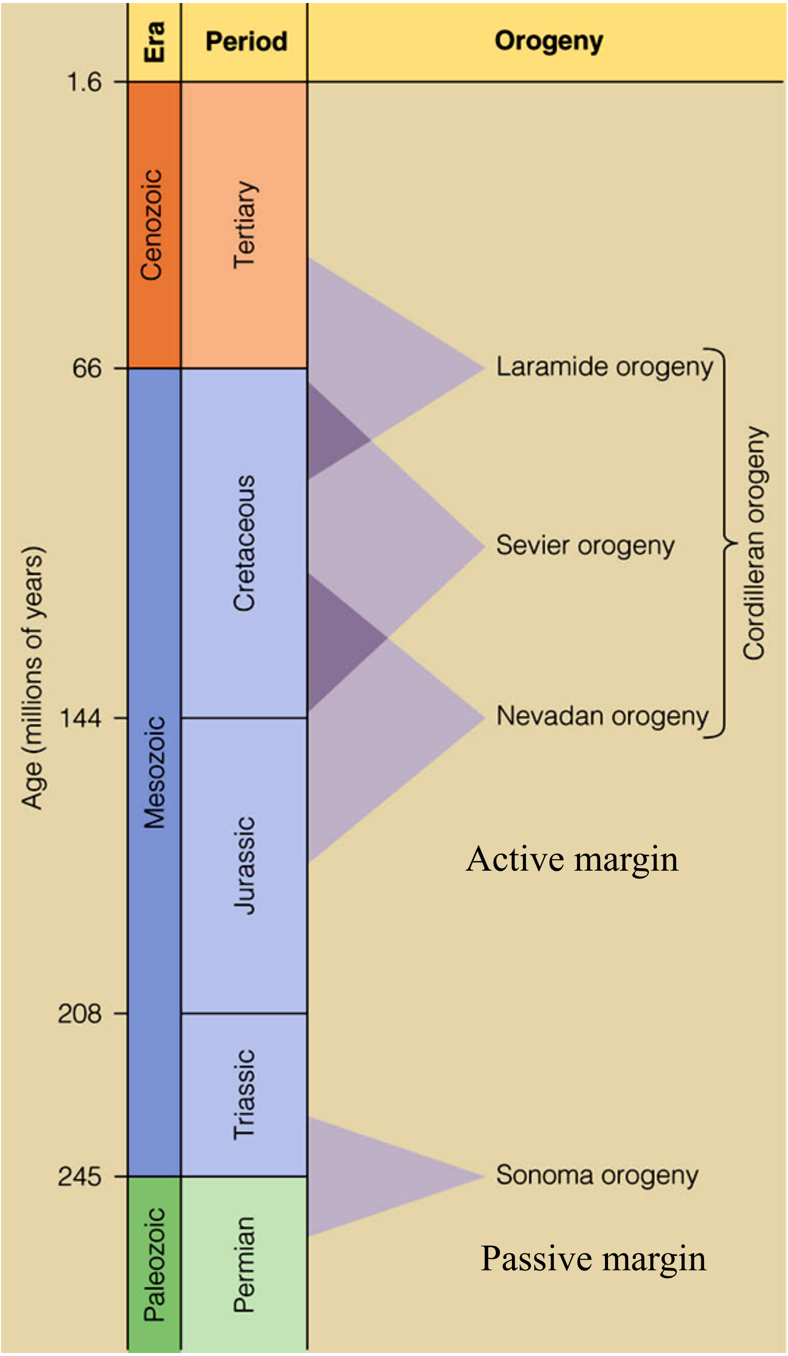
Sierran Orogeny

Cordilleran orogeny






Earth 200 million years ago
(Early Jurassic)
Cache Creek Pl.
North America
Izanagi Plate
Farallon Plate
Izanagi Plate
Phoenix Plate
Phoenix Plate

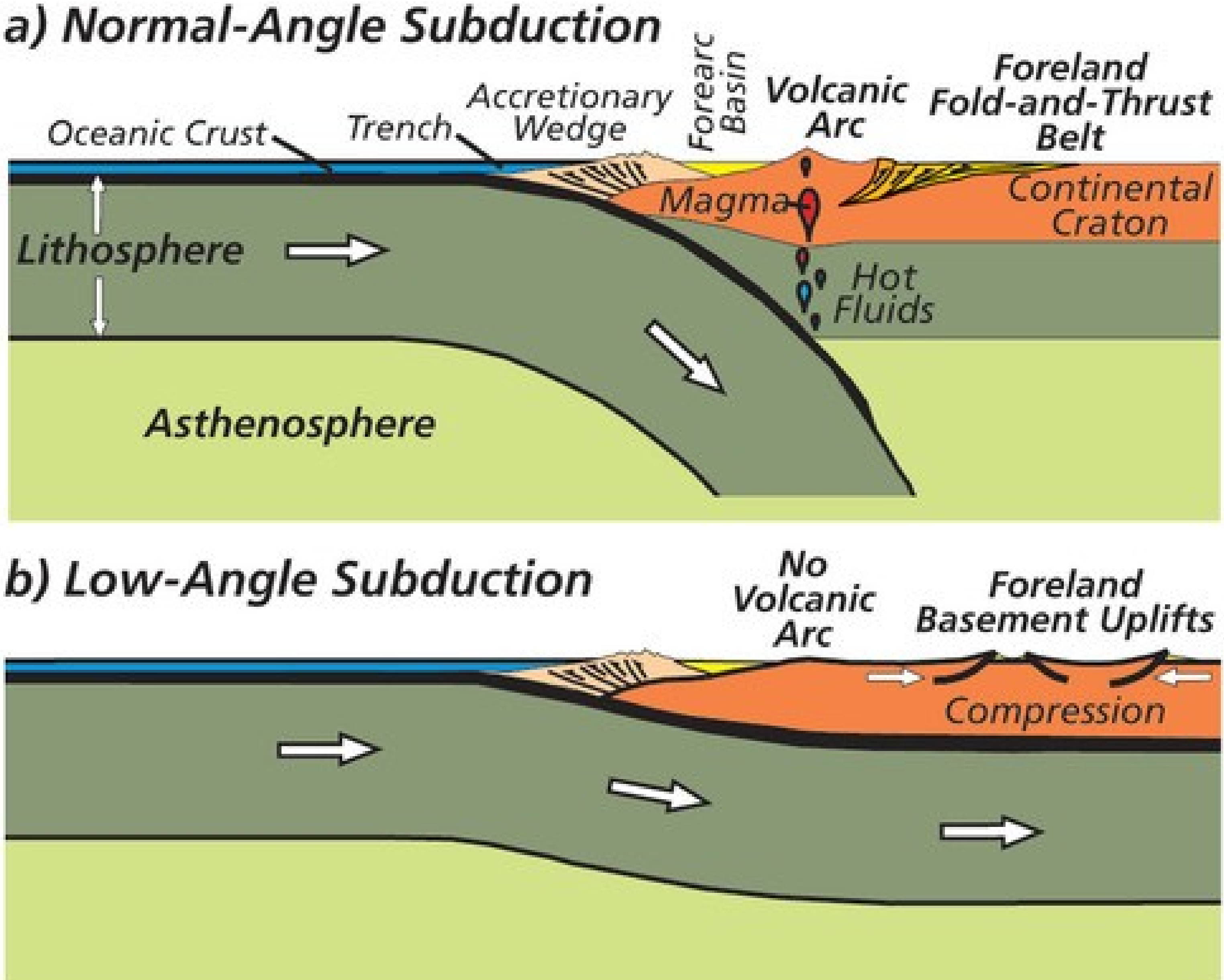


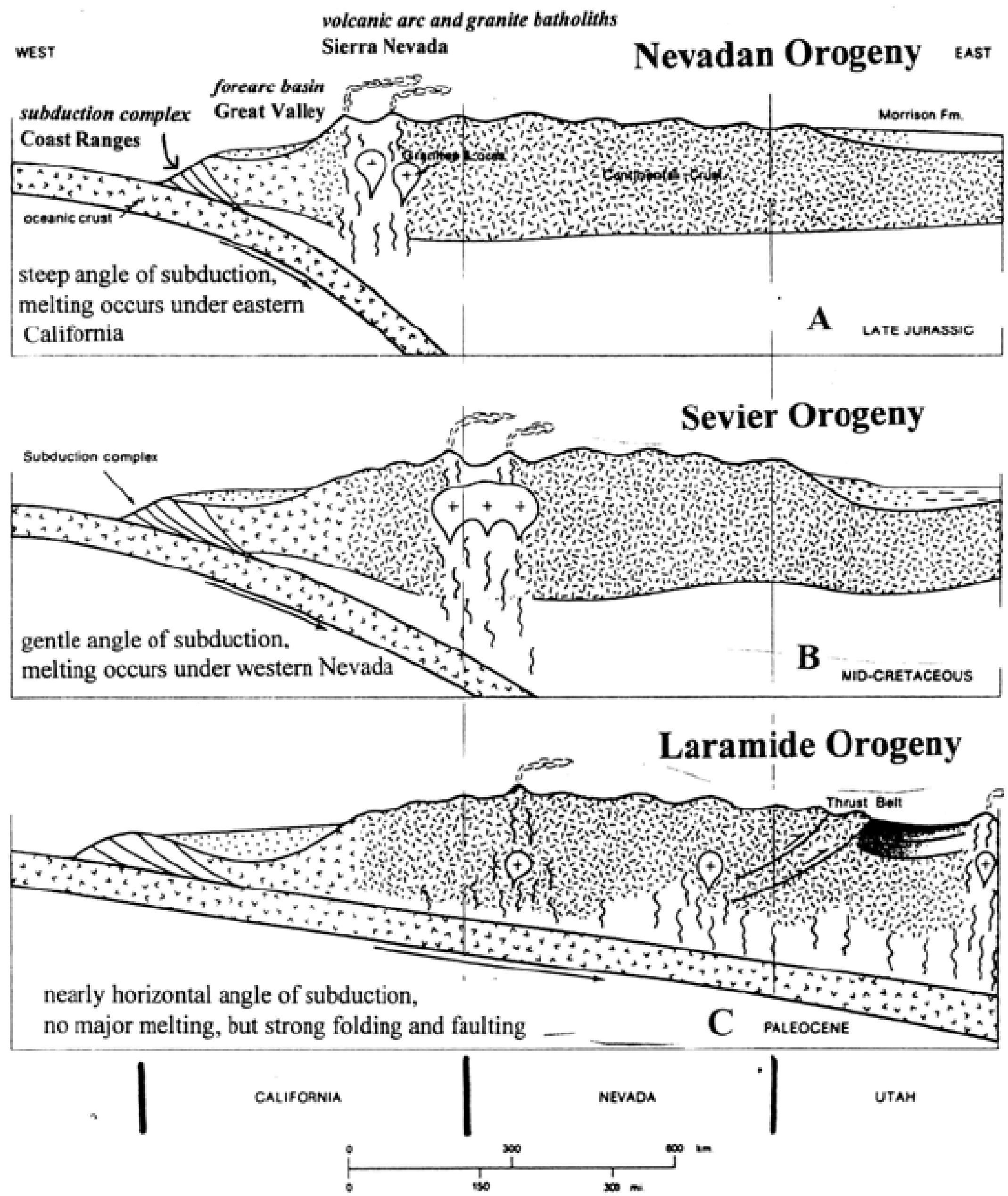
Cordilleran Orogeny components – Jurassic – Tertiary Periods

Nevadan – emplacements of large granite batholiths, Sierra Nevada, Idaho, S. California, Coast Ranges.

Sevier – Shallower sub-duction angle = igneous activity moves eastward.

Laramide – "Rocky Mts." – east of Sevier Orogeny – Cretaceous – Tertiary Periods


a) Normal-Angle Subduction
Oceanic Crust
Trench
Accretionary Wedge
Forearc Basin
Volcanic Arc
Foreland Fold-and-Thrust Belt
Magma
Continental Craton
Lithosphere
Hot Fluids
Asthenosphere
b) Low-Angle Subduction
No Volcanic Arc
Foreland Basement Uplifts
Compression


volcanic arc and granite batholiths
Sierra Nevada
WEST
Nevadan Orogeny
EAST
forearc basin
Great Valley
subduction complex
Coast Ranges
Morrison Fm.
oceanic crust
steep angle of subduction,
melting occurs under eastern
California
A
LATE JURASSIC
Sevier Orogeny
Subduction complex
gentle angle of subduction,
melting occurs under western Nevada
B
MID-CRETACEOUS
Laramide Orogeny
Thrust Belt
nearly horizontal angle of subduction,
no major melting, but strong folding and faulting
C
PALEOCENE
CALIFORNIA
NEVADA
UTAH
0
300
600 km
0
150
300 mi

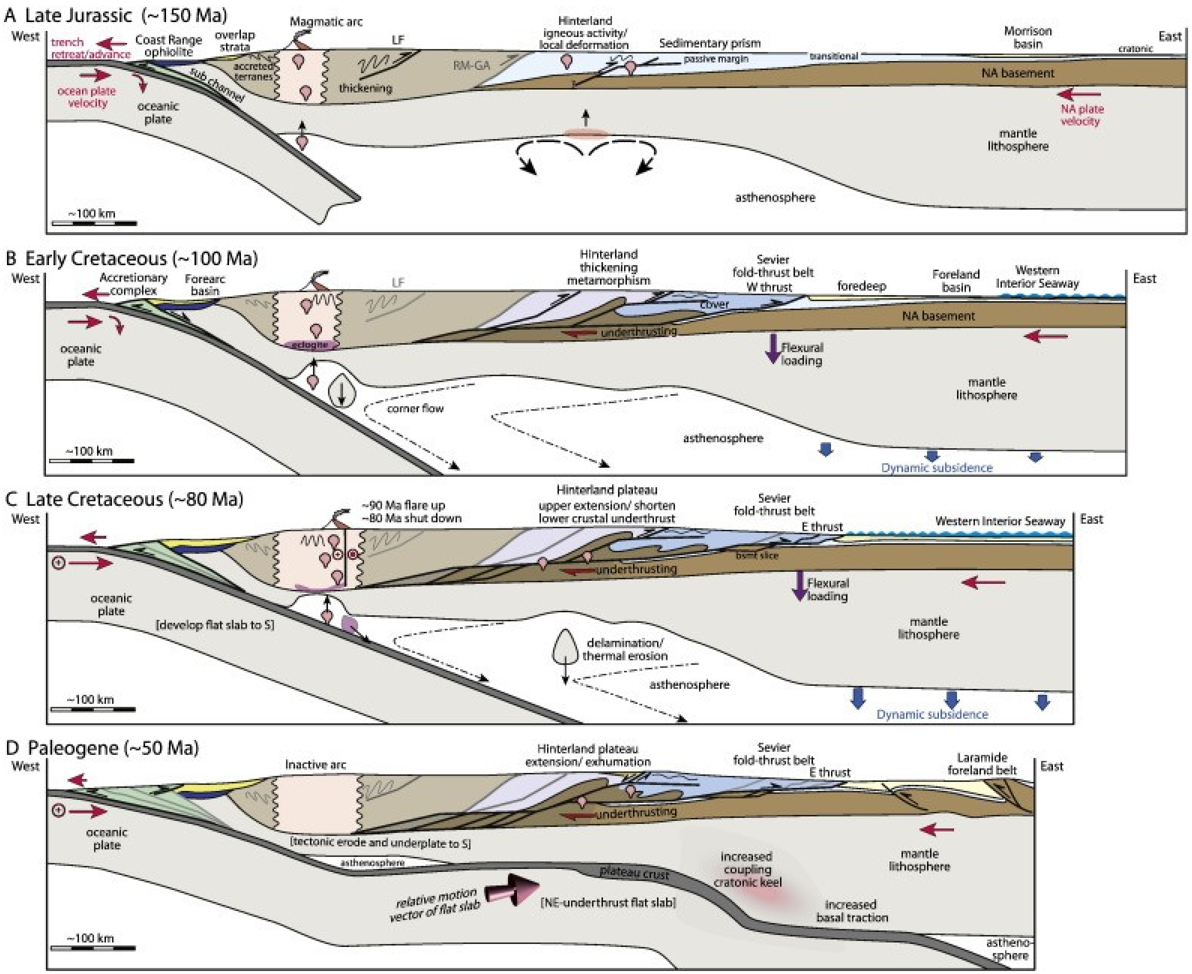
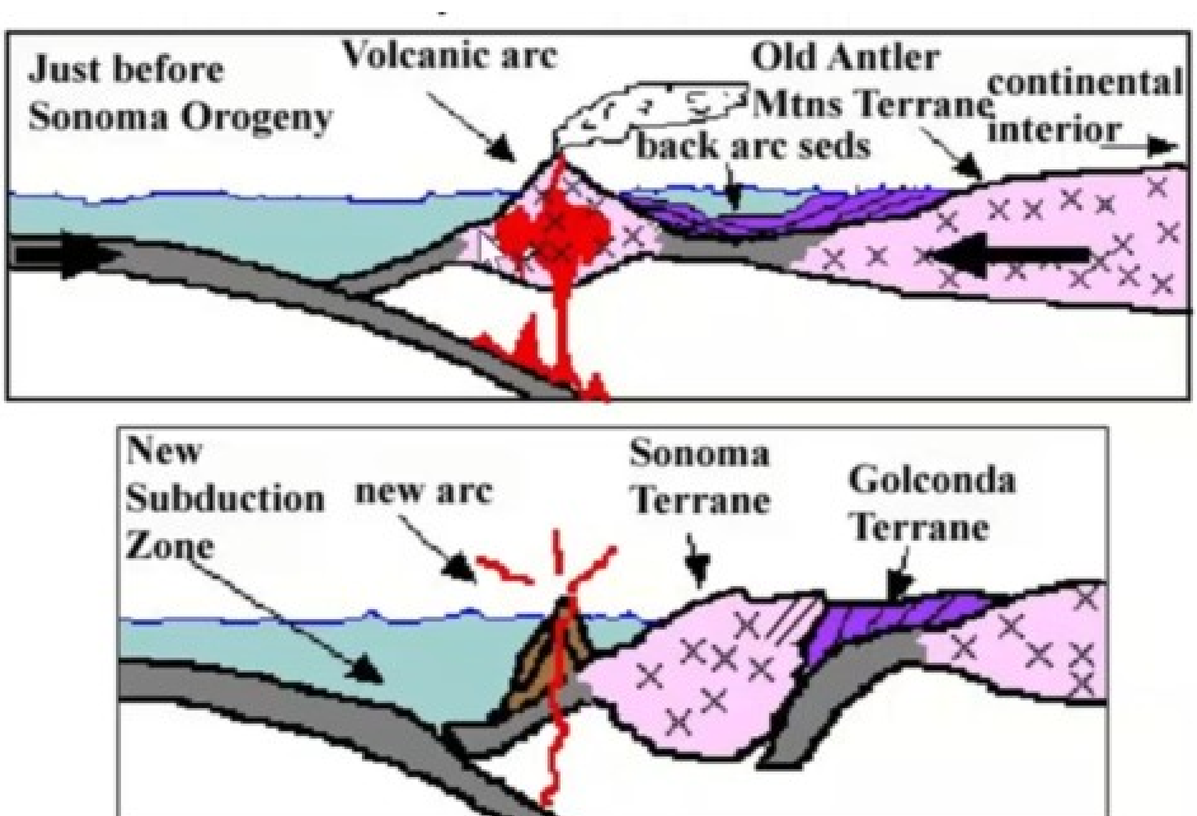


Fig. 6. Schematic lithospheric cross sections, shown for: A — Late Jurassic (~ 150 Ma); B — Early Cretaceous (~ 100 Ma); C — Late Cretaceous (~ 80 Ma); and D — Paleogene (~ 50 Ma) times. The Late Jurassic was marked by development of an E-dipping subduction zone, increased igneous activity along the magmatic arc, and initial shortening in the western part of the orogenic system. The Early Cretaceous included development of an accretionary complex, growth of the magmatic arc, crustal thickening in the hinterland, thin-skin shortening of the western Sevier belt, and sedimentation within a foreland basin. The Late Cretaceous included decreasing subduction angle (along with early development of a flat-slab segment to the south), a flare-up followed by shutdown of the magmatic arc, lower crustal thickening beneath a hinterland plateau, shortening in the eastern Sevier belt, and broad dynamic subsidence of the Western Interior Seaway. The Paleogene included rapid subduction and NE-underthrusting of the flat-slab segment, minor extension in the thickened hinterland, final shortening in the eastern Sevier belt, and uplift of Laramide arches that disrupted the foreland basin.

The Nevadan Orogeny

Marked by development of an E-dipping subduction zone, increased **igneous activity** along **the magmatic arc**, and initial **shortening in the western part of the orogenic system**.

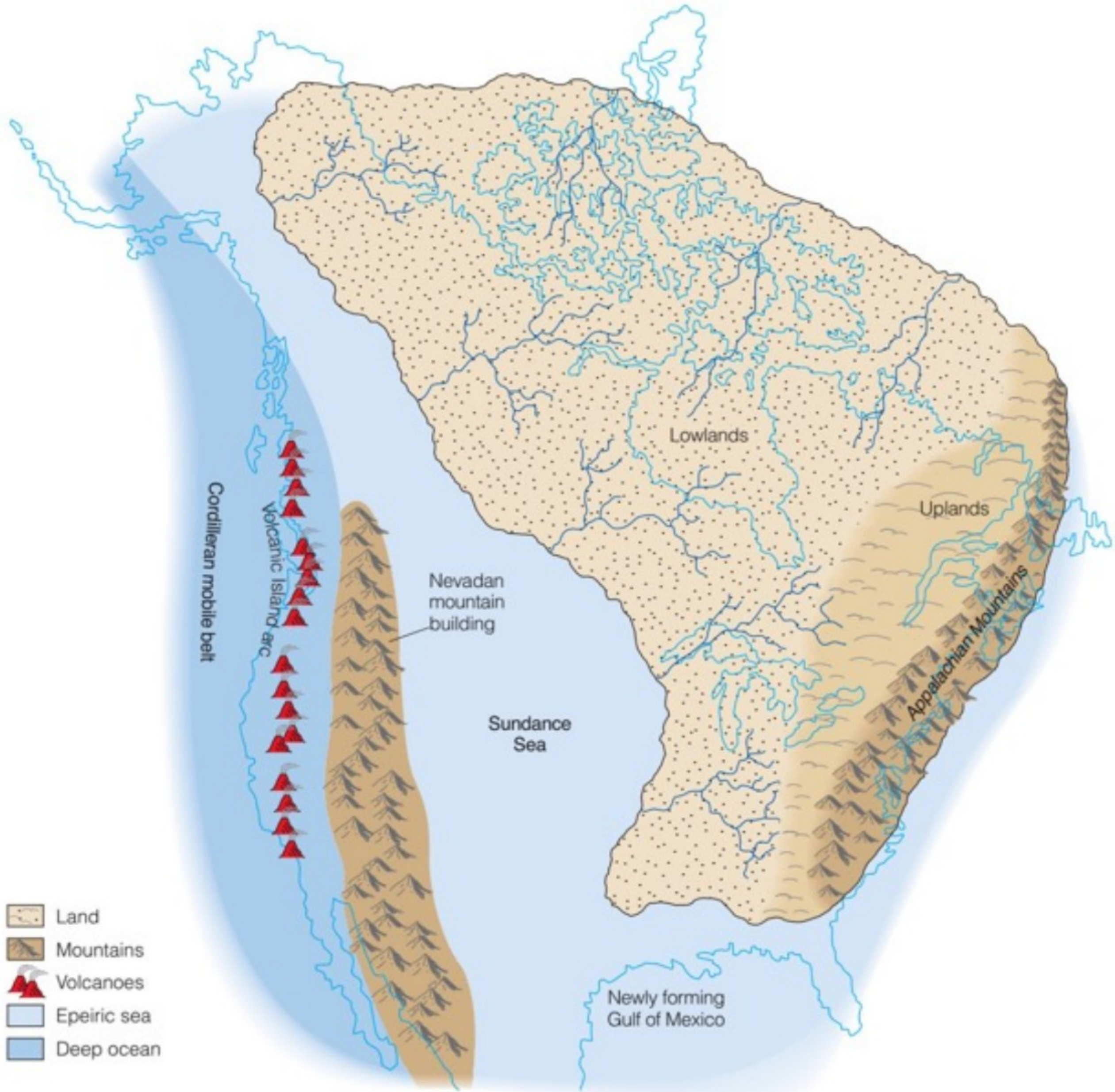


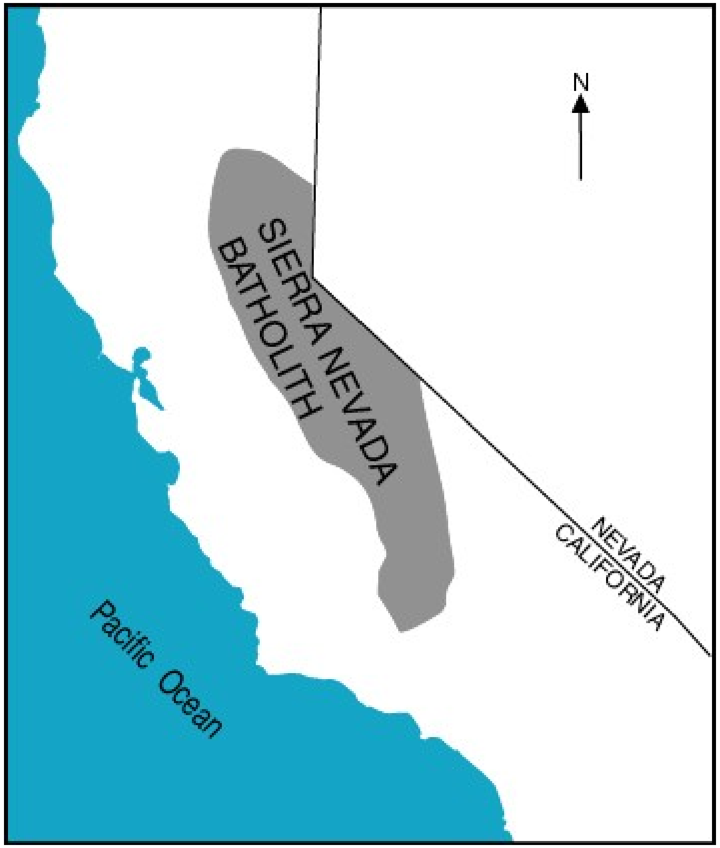
The Nevadan Orogeny

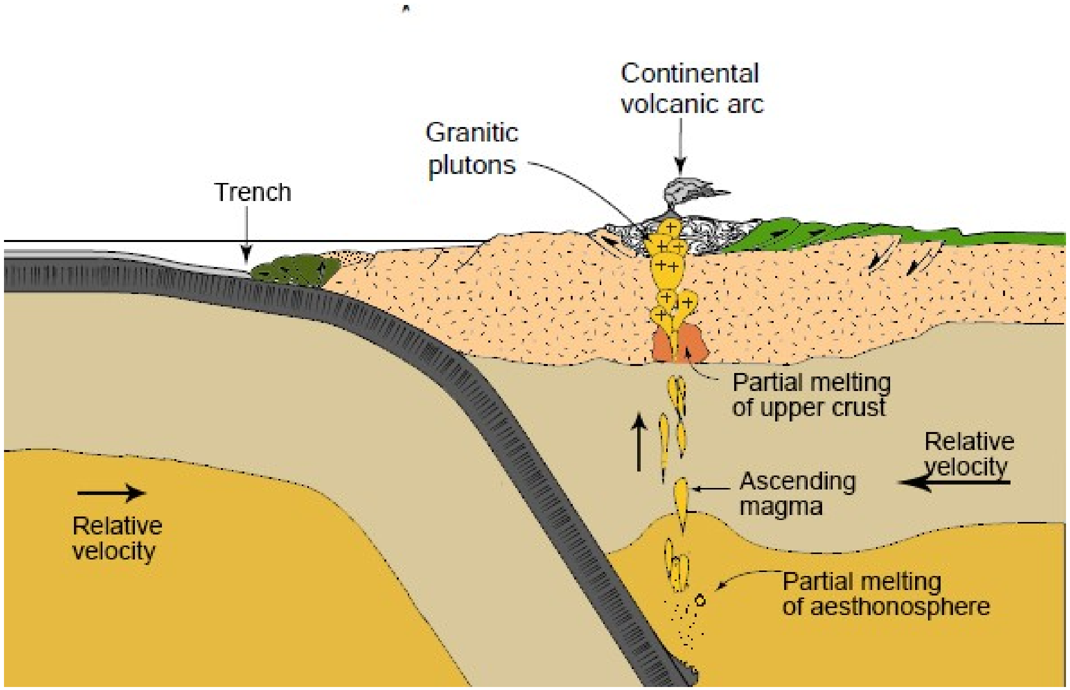
- Several Upper Jurassic **Arcs** Collided
- Cretaceous **Franciscan** Fm in the **accretionary prism**
- **Sierra Nevada** was the root zone of the arc

The **Nevadan Orogeny** was a major mountain building event that took place along the western edge of ancient North America between the **Mid to Late Jurassic** (between about 155 and 145 million years ago). The Sierra Nevada and the Klamath Mountains were the result of **continental magmatic arc** and then multiple **oceanic arcs** accretion. In comparison with other orogenic events, it appears that the Nevadan Orogeny occurred **rather quickly** (10 million years). During the **early stages** of orogenesis an "**Andean type**" **continental magmatic arc** developed due to subduction of the **Farallon oceanic plate** beneath the North American Plate. The **latter stages** of orogenesis, in contrast, saw **multiple oceanic arc terranes accreted** onto the western margin of North America in a "**Cordilleran type**" accretionary orogen. **Deformation** related to the accretion of these volcanic arc terranes is mostly **limited to the western regions** of the resulting mountain ranges (**Klamath Mountain range and Sierra Nevada**) and is absent from the eastern regions. The massive series of **exposed batholiths** that currently make up **most of the high Sierra Nevada** was formed during this event. **Due to the steep angle** of the subducted plate, these were located relatively **close to continent's edge**.

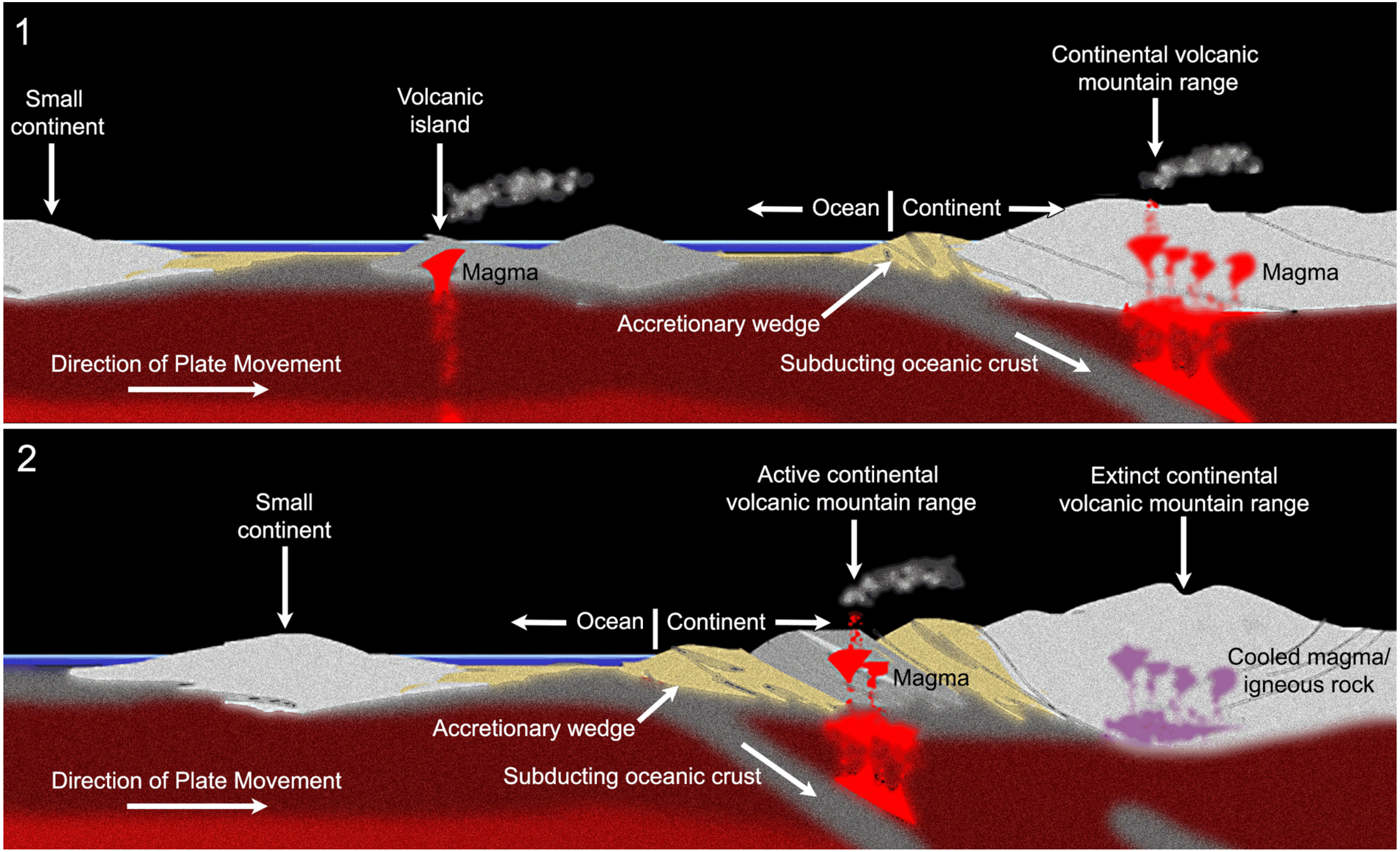
Zuni or Sundance Sea Transgression in the Jura



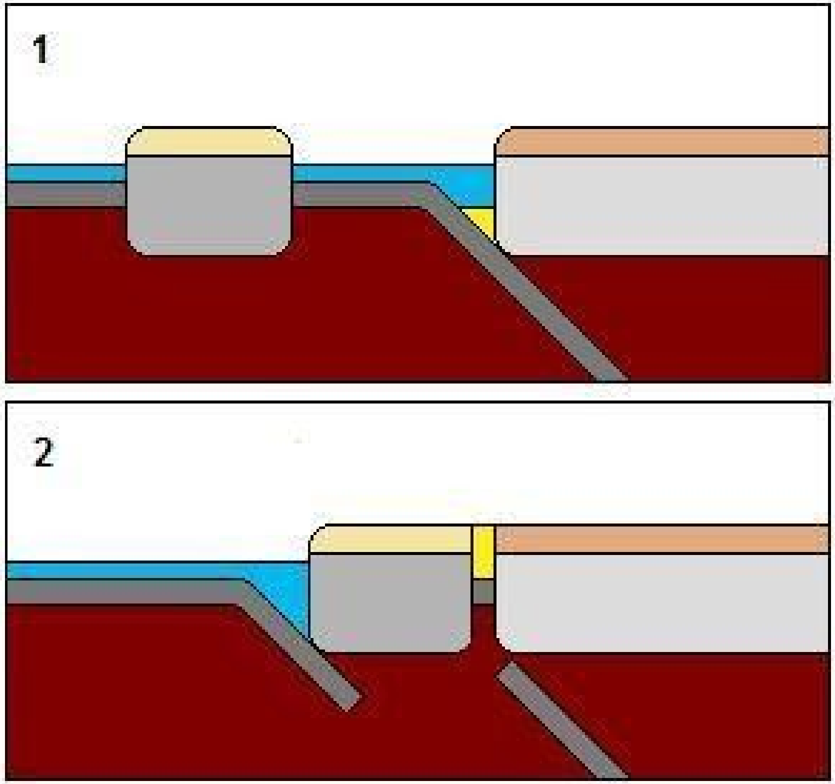




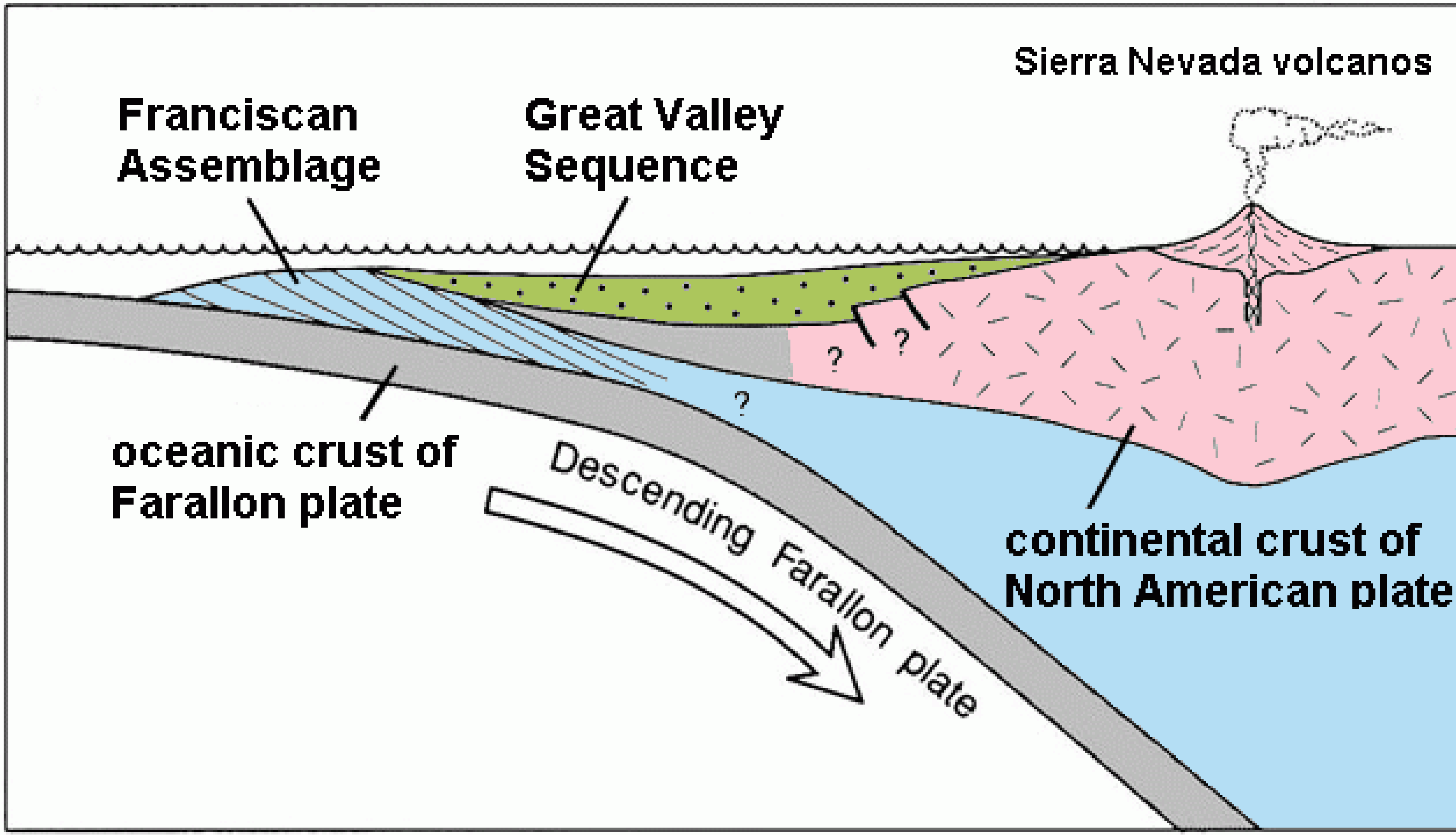
Andean" style of orogenesis involving the subduction of an oceanic plate beneath a continental plate causing partial melt of the asthenosphere wedge atop the down going plate. The partial melt then rises and causes volcanism to start to build up mountains through lava flows and deposits from eruptions.



Idealized diagram showing the docking and accretion of a volcanic island at the edge of a continent. Upper diagram (1): A volcanic island (center) on oceanic crust moves toward the edge of a large continent (right). As the oceanic crust is subducted, an accretionary wedge forms at the edge of the continent and the melting oceanic crust in the subduction zone produces magma, which rises through the continental crust and forms a volcanic mountain range. Lower diagram (2): The volcanic island has docked on the edge of the continent. The active subduction zone has moved seaward, meaning that the original continental volcanic mountain range has gone extinct and an active continental volcanic mountain range has formed near the new subduction zone. The old accretionary wedge is sandwich between the extinct volcanic mountain range and the new active continental volcanic mountain range. A new accretionary wedge has formed at the active subduction zone.

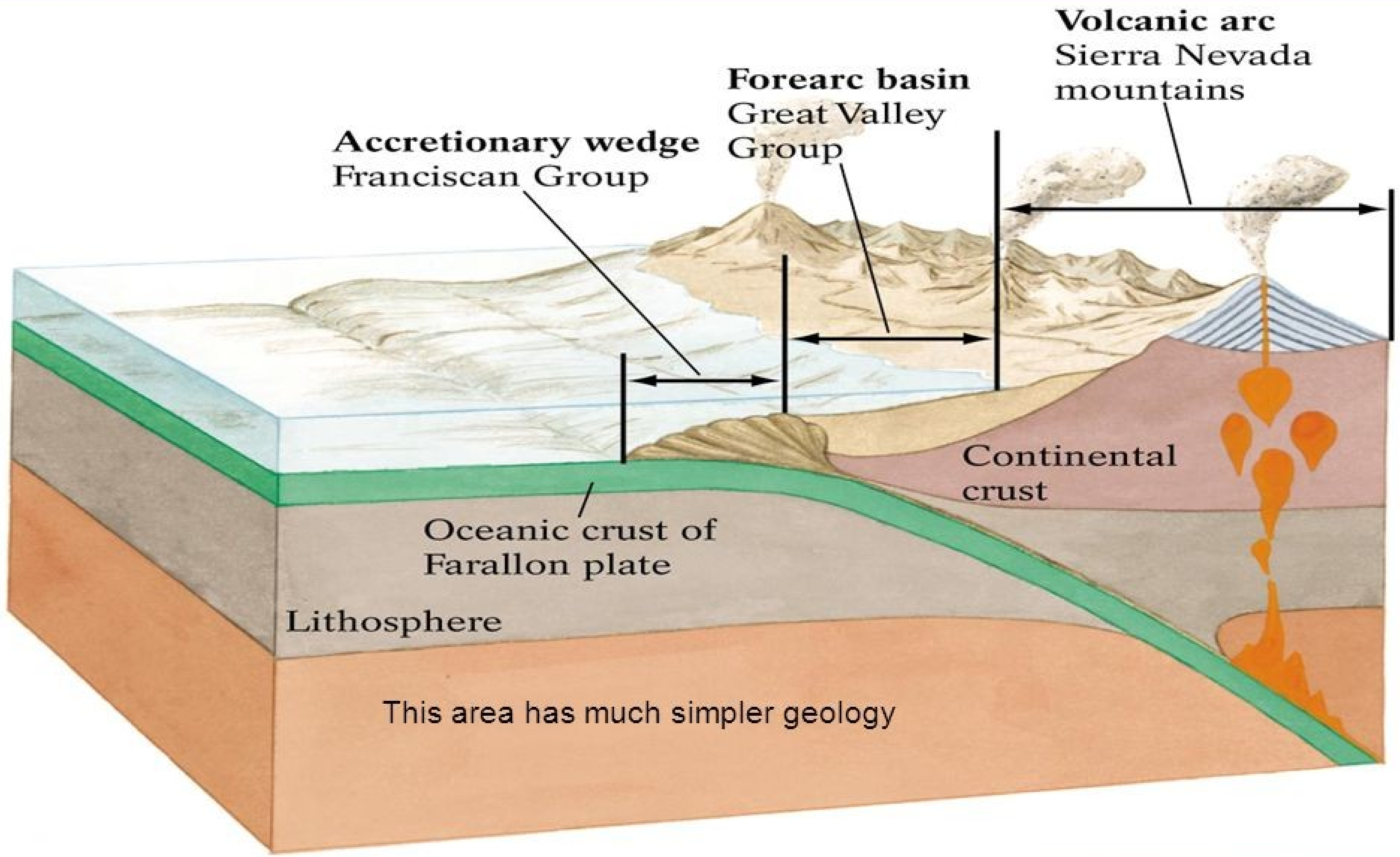


"Cordilleran" style of arc terrane accretion onto a continental land mass. Continued subduction transports the arc terrane to the margin of the continent where it is too buoyant to be subducted so it gets accreted to the continent



The **Franciscan Complex** is an assemblage of metamorphosed and deformed sediments and ophiolites, associated with **east-dipping subduction** zone. Although most of the Franciscan is **Early/Late Jurassic** through **Cretaceous** in age (150-66 Ma),[some Franciscan rocks are as old as early Jurassic (180-190 Ma) age and as young as Miocene (15 Ma). As oceanic crust descended beneath the continent, ocean floor basalt and sediments were subducted and then tectonically underplated to the upper plate.[10] This resulted in **widespread deformation** with the **generation of thrust faults** and **folding**, and caused **high pressure-low temperature regional metamorphism**. In the **Miocene**, the Farallon-Pacific spreading center reached the Franciscan trench and the relative motion between Pacific-North America caused the **initiation of the San Andreas Fault**.

Look in detail at western plate margin



Franciscan Range, Great Valley Group, and Sierra Nevada Volcanics and Plutonics

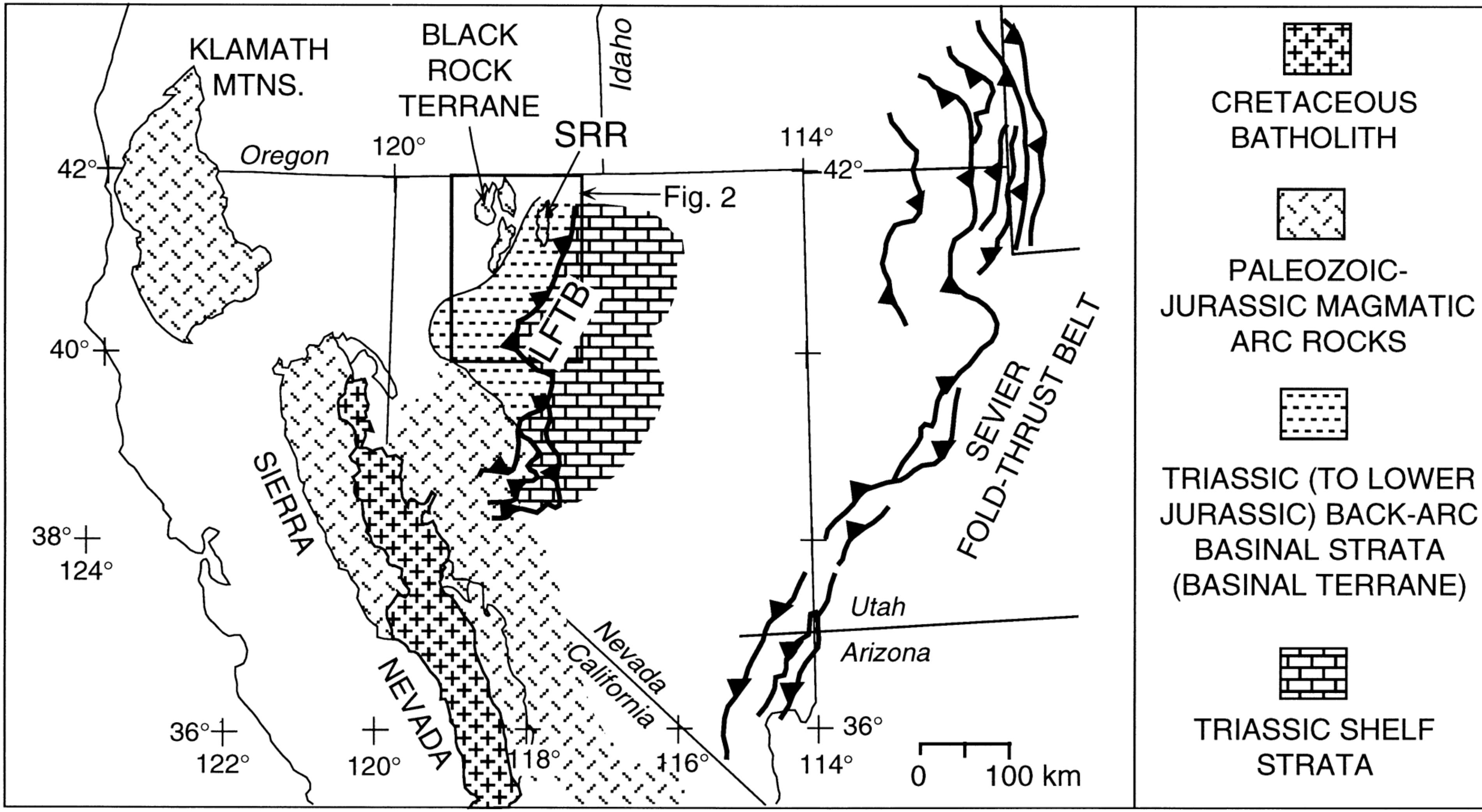
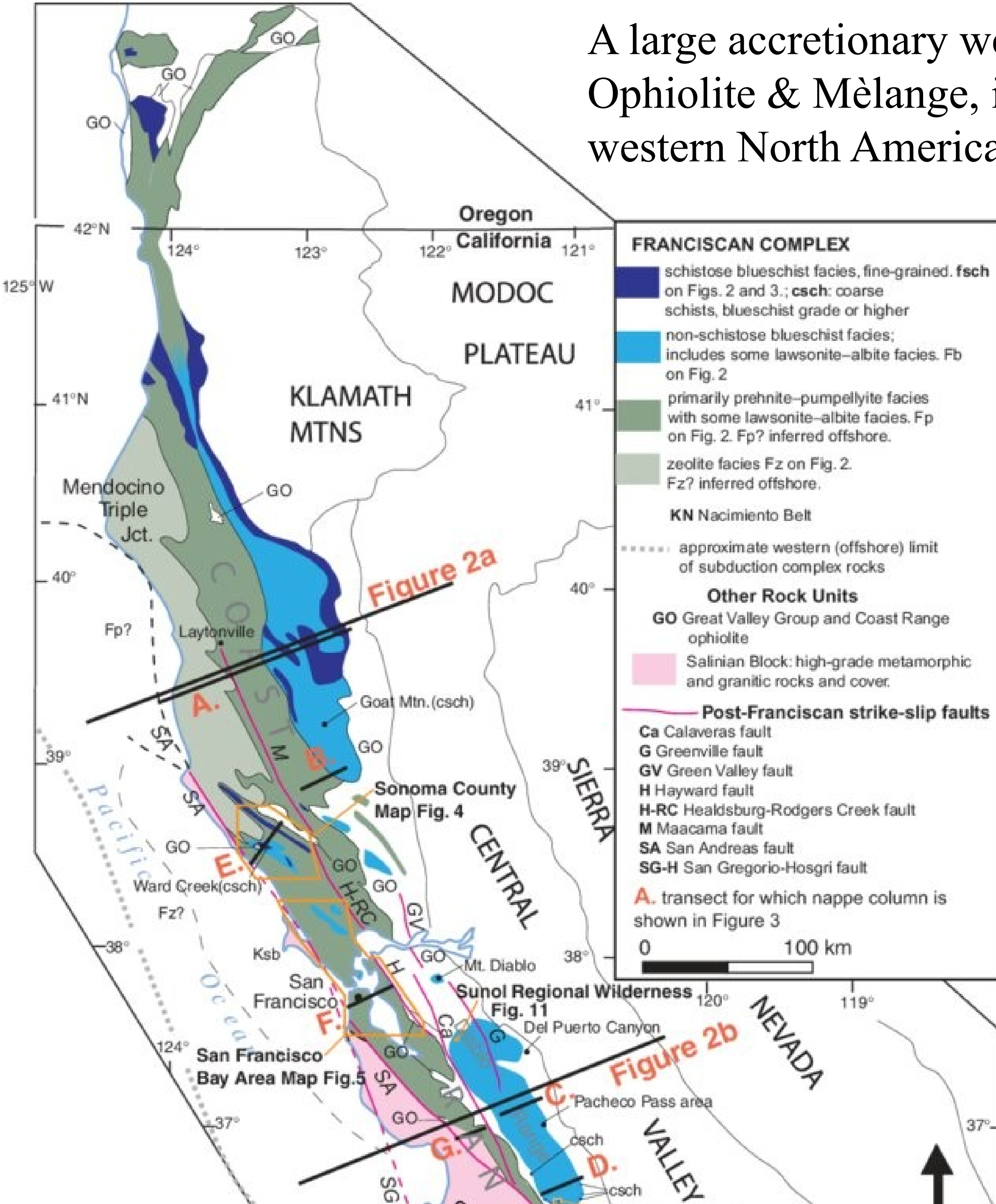
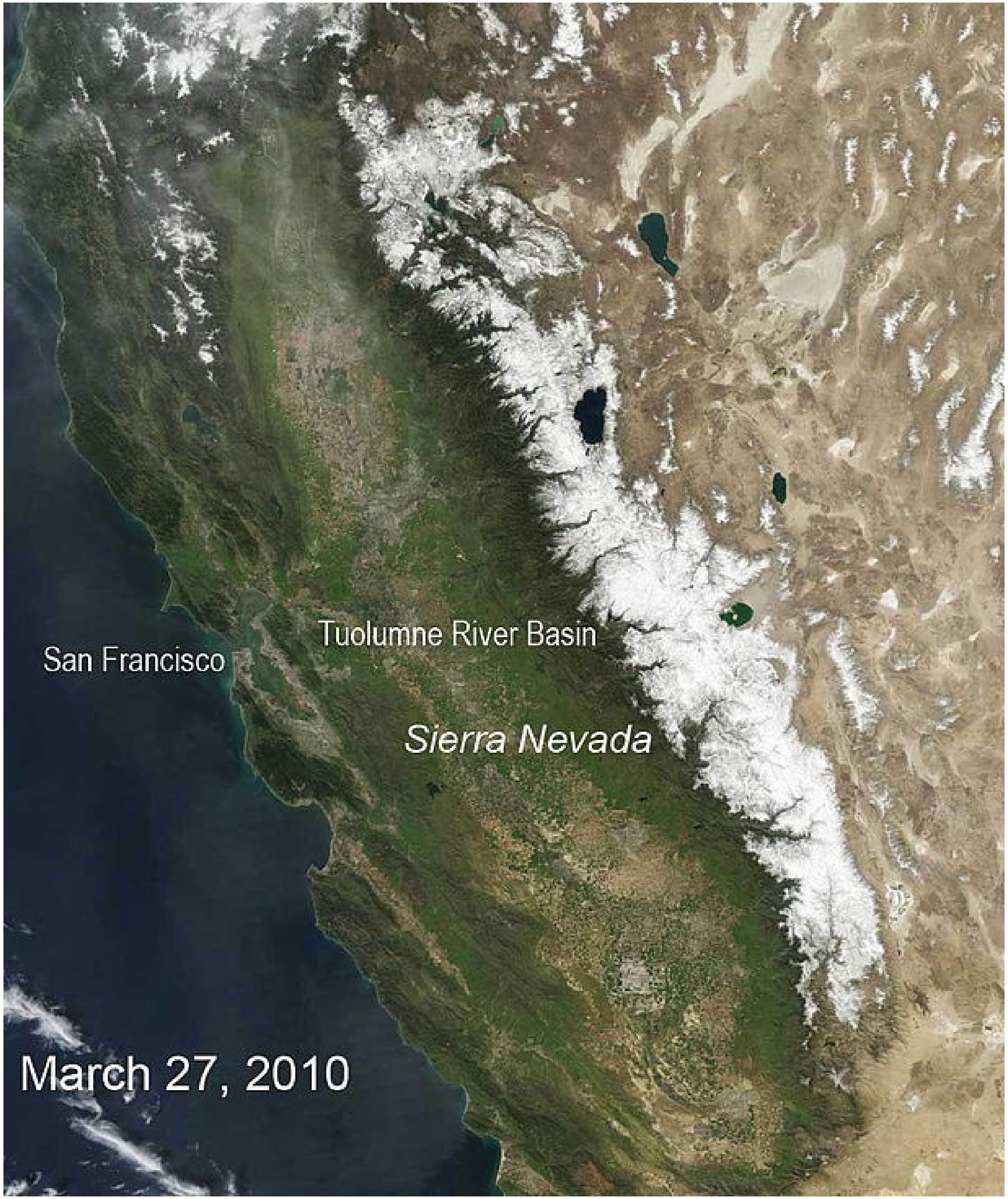


Fig. 1. Early Mesozoic rocks of the western US Cordillera, **Cretaceous batholith belt**, and location of major Mesozoic fold-and-thrust belts. The Jurassic to Cretaceous(?) **Luning–Fencemaker thrust belt (LFTB) encompasses the entire basinal terrane**; only frontal thrusts are shown (Oldow, 1984). Sevier fold-and-thrust belt is Cretaceous to Early Tertiary. SRR is the Santa Rosa Range.

A large accretionary wedge, the Franciscan Ophiolite & Mèlange, is thrust up onto western North America




Tuolumne River Basin
San Francisco
Sierra Nevada
March 27, 2010

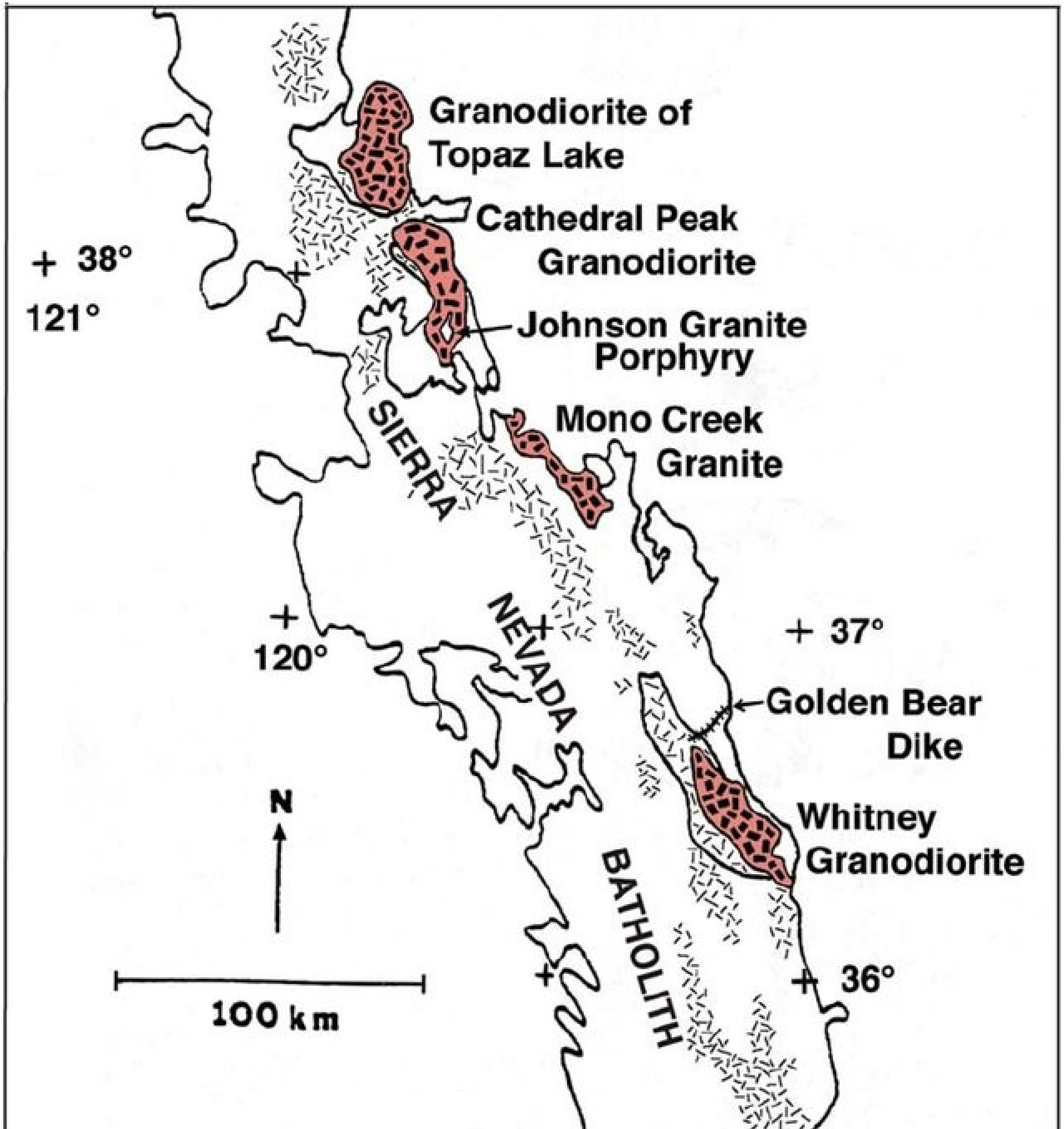
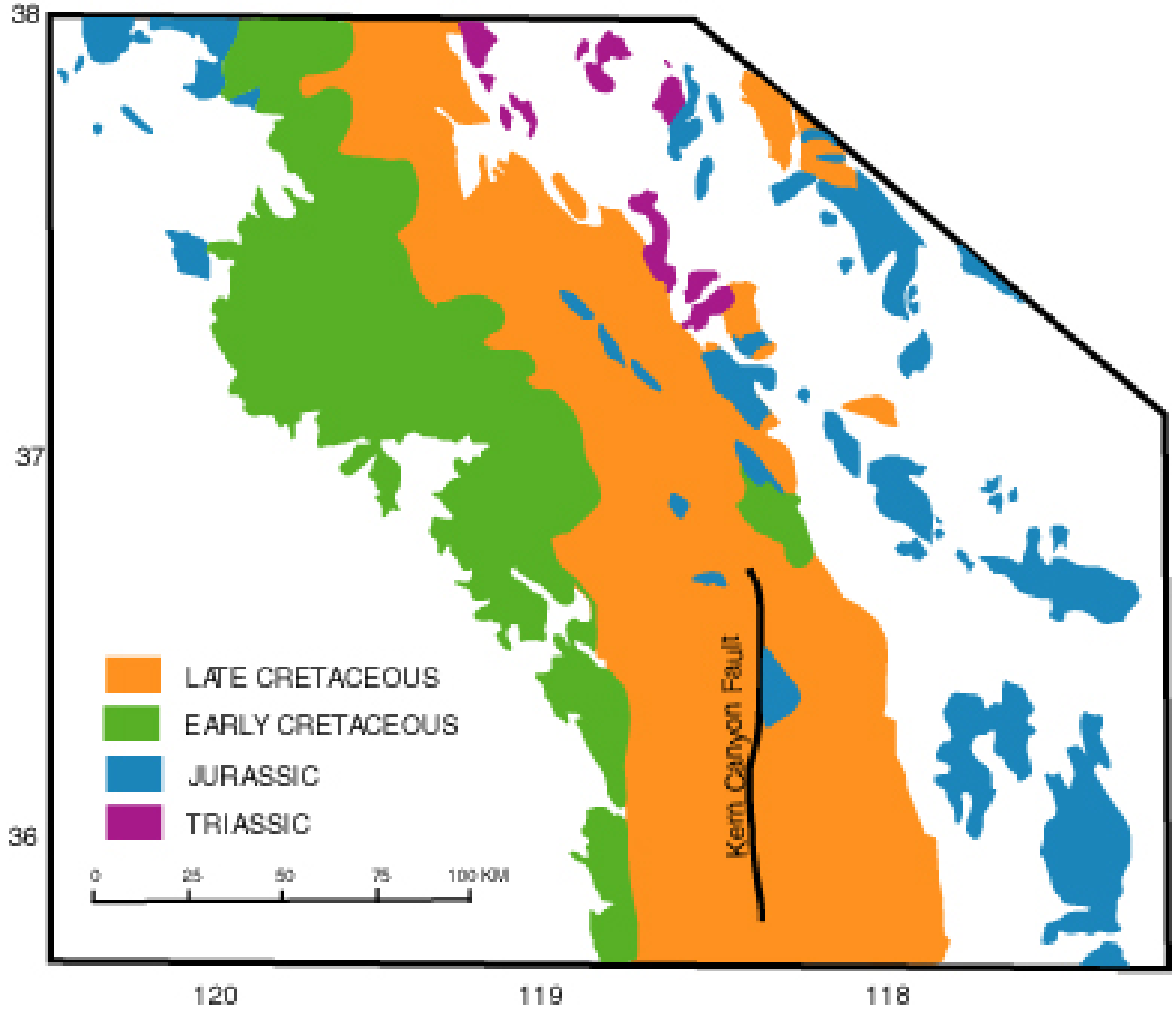


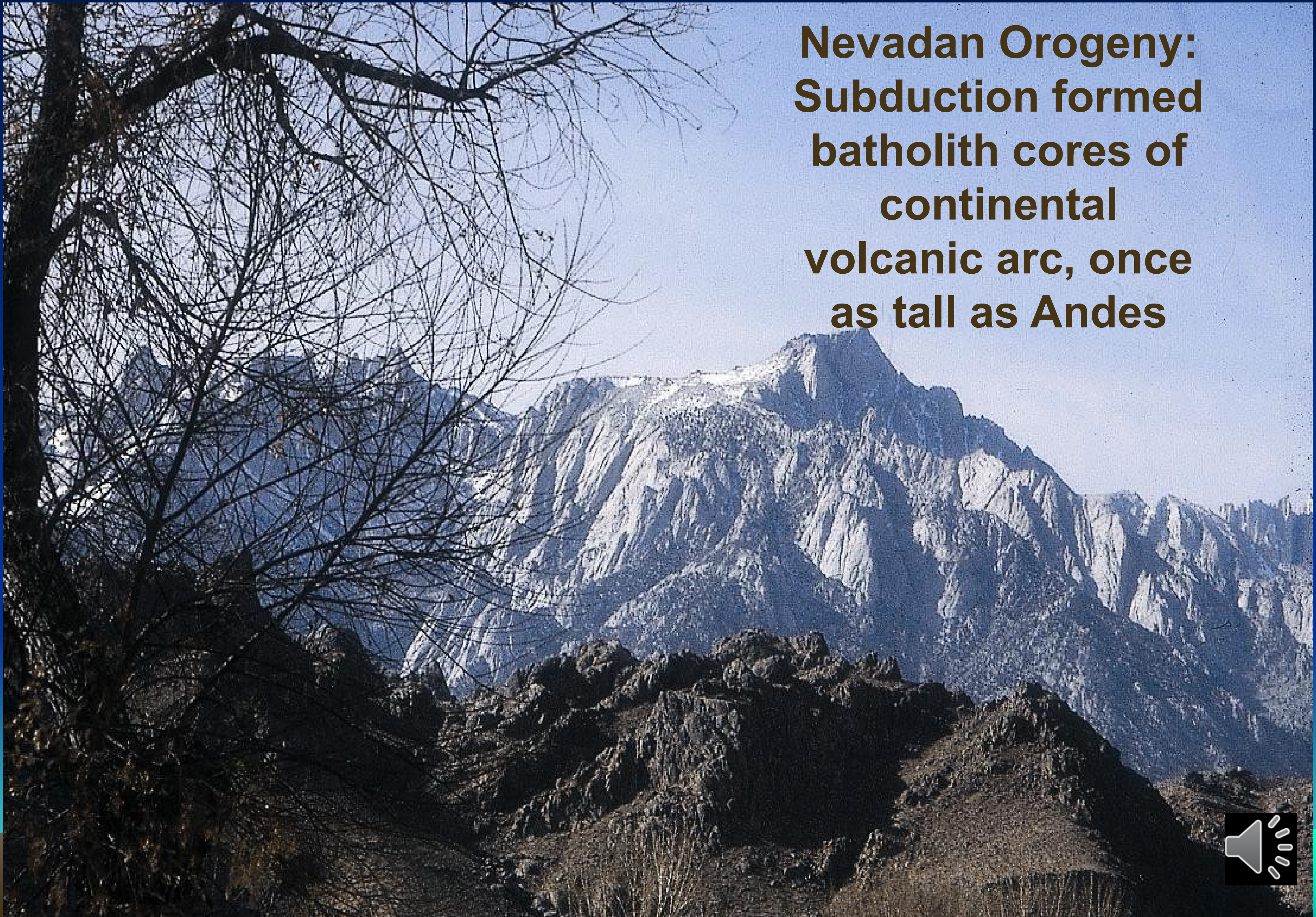
Figure 1. Map of Sierra Nevada batholith naming the four Cretaceous intrusive masses (plutons) that contain giant K-feldspar crystals (block pattern), and other less porphyritic plutons (cross-hatch pattern). In addition, two late porphyry intrusions are shown: the Johnson Granite Porphyry, cutting the Cathedral Peak Granodiorite, and the Golden Bear dike, apparently fed from the Whitney Granodiorite. Modifi ed from Kistler and Fleck (1994).



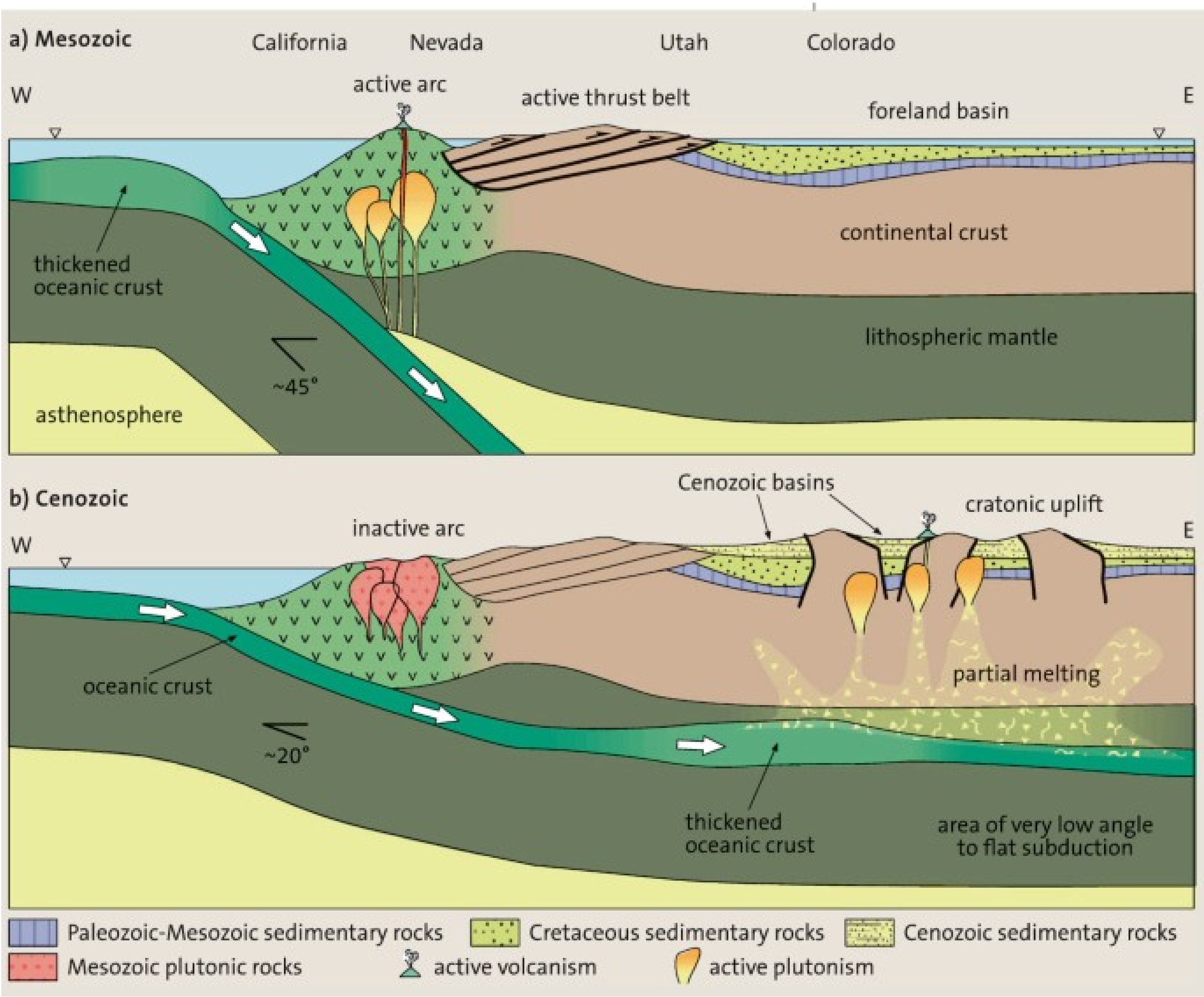
Modified from Chen and Tilton (1982). Showing the generalized age of granitic rocks.

~210 Ma on the east side of the batholith in a single, extensive Triassic sequence
186-155 Ma on both east and west margins of the batholith –Nevadan orogeny
125-88 Ma granitoids, which young eastward, in the axial part of the batholith

Sierra Nevada Mountains



Mount Whitney, the **highest mountain in the contiguous United States**, with an elevation of 14,505 feet (4,421.2 m) The raising of Whitney (and the downdrop of the Owens Valley) is due to the same geological forces that cause the Basin and Range Province: the crust of much of the intermontane west is slowly being stretched


a) Mesozoic
California
Nevada
Utah
Colorado
W
E
active arc
active thrust belt
foreland basin
continental crust
thickened
oceanic crust
lithospheric mantle
~45°
asthenosphere
b) Cenozoic
Cenozoic basins
cratonic uplift
inactive arc
W
E
oceanic crust
partial melting
~20°
thickened
oceanic crust
area of very low angle
to flat subduction
Paleozoic-Mesozoic sedimentary rocks
Cretaceous sedimentary rocks
Cenozoic sedimentary rocks
Mesozoic plutonic rocks
active volcanism
active plutonism

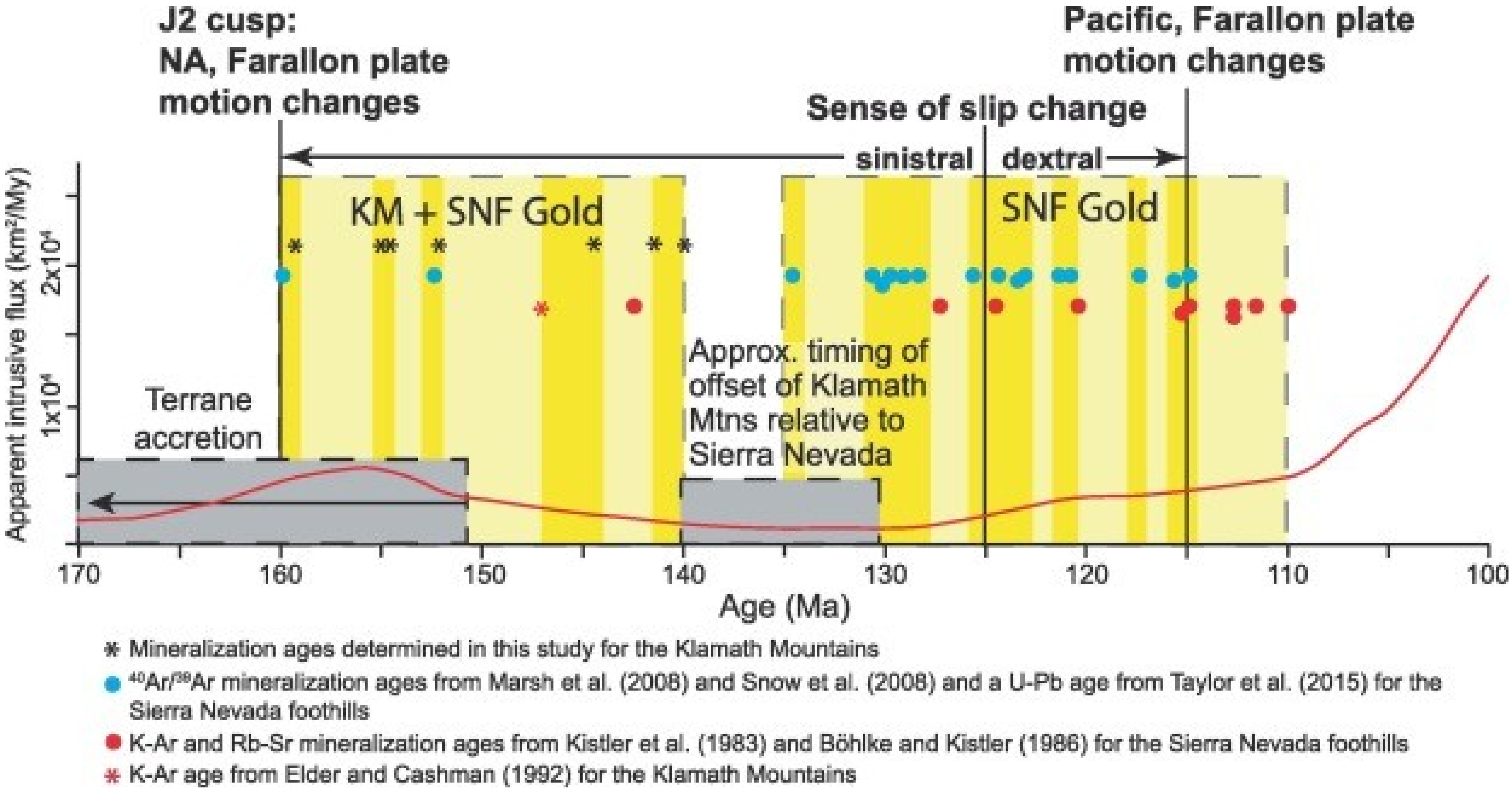
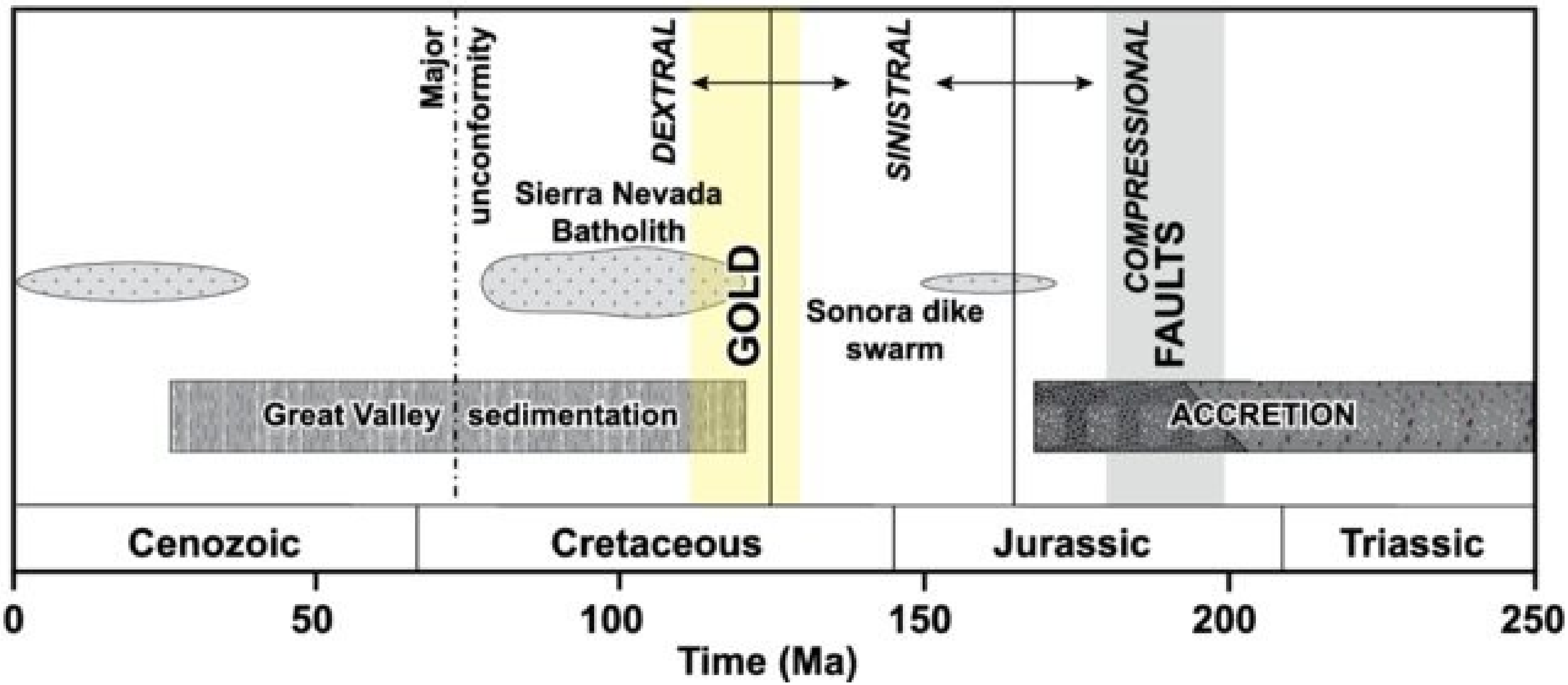


Fig. 7. Diagram showing a timeline of events from the Middle Jurassic through Early Cretaceous of California. The apparent **intrusive magma flux** of the Sierra Nevada is shown as the red line (from Ducea, 2001). The **light-yellow** boxes represent periods during which gold mineralization is **permissible**. The **dark-yellow** boxes represent times when gold mineralization has been **robustly dated** (see Table 4). The **age range that is permissible for gold mineralization** in the Klamath Mountains (KM) ranges from the beginning of orogenic gold mineralization in California at **160** Ma until the lateral offset of the Klamath Mountains from the active arc beginning around **140** Ma. The age range that is permissible for gold mineralization in the **Sierra Nevada** foothills (SNF) ranges from **160** Ma to approximately **115** Ma, or even as late as 110 Ma if younger K-Ar dates are proven reliable

Figure 2. Schematic diagram of major regional tectonic events in the Sierra Nevada Foothills metamorphic belt.



Strictly speaking, the Mother. Lode is a narrow belt of gold-bearing quartz veins extending for about. 120 miles through the Sierra Nevada foothills from Mariposa on the south to Georgetown on the north

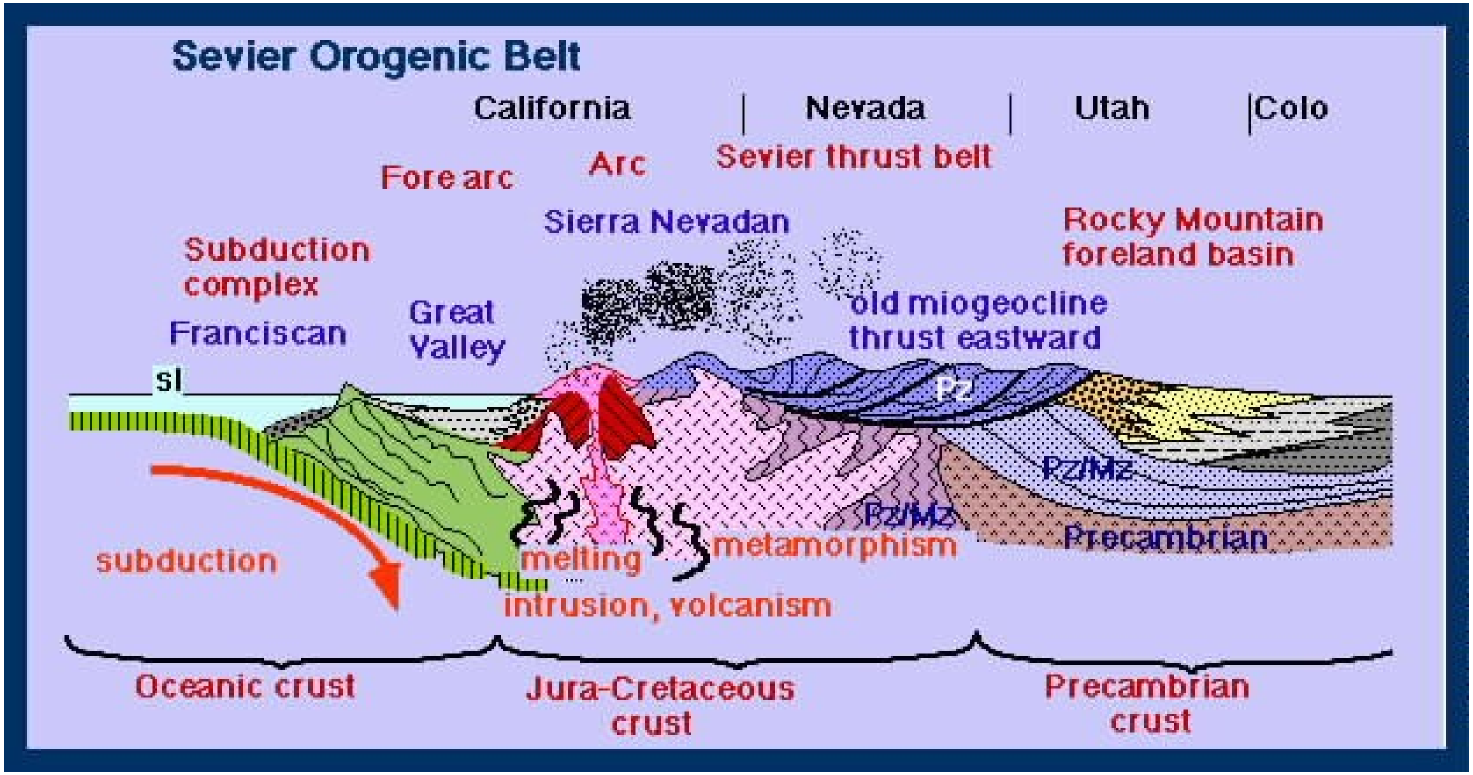
Along with the new data from Snow et al. (2008), our ages show clearly that the **bulk of the gold resource within the Mother Lode belt,** centered along the Melones fault system was deposited ca. **10** m.y. This overlaps with the final 10 m.y. of ductile **deformation** and regional **metamorphism** in the Sierra Nevada foothills, **post-dates the final major pulse of Jurassic foothills magmatism** by about 10 m.y., and pre-dates the onset of massive batholith emplacement by about 10 m.y. (e.g., Tobisch et al., 1989; Glazner, 1991)

https://www.researchgate.net/publication/292224558_New_constraints_on_the_timing_of_gold_formation_in_the_Sierra_Foothills_province_central_California

Sevier orogeny

Sevier Orogen (80 Sevier Orogen (50- 130 Ma)

- Fold-thrust belt behind the arc
- Eastward directed thin skinned thrusts
- Franciscan complex and Great Valley fore arc basins
- Cretaceous
- Batholithic intrusions



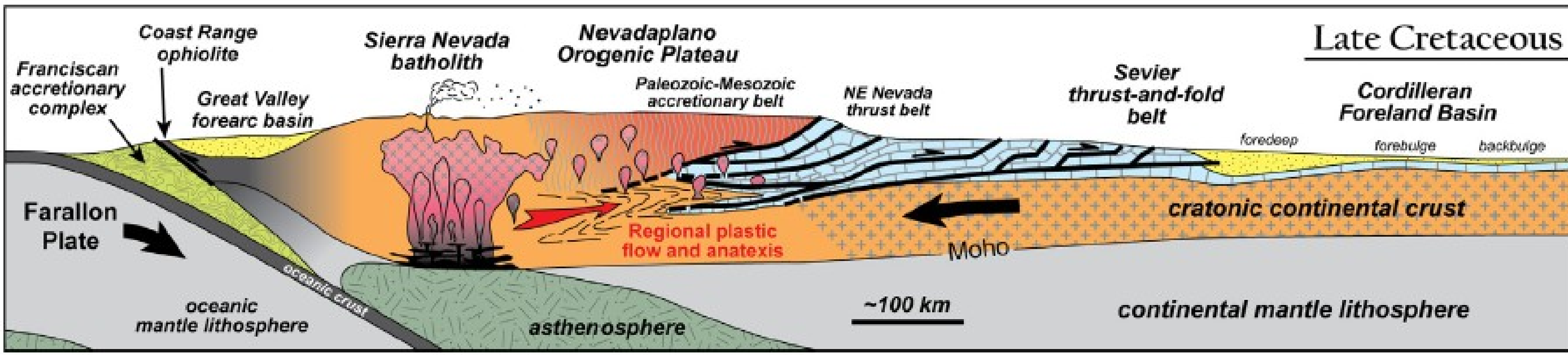


Fig. 5 Schematic Late Cretaceous cross-section of the Central Cordillera, showing the relationship between the Sevier fold-and-thrust belt and Cordilleran foreland basin on the east, metamorphic and igneous rocks of the hinterland, Sierra Nevada batholith, Great Valley forearc basin, and Franciscan accretionary complex on the west.

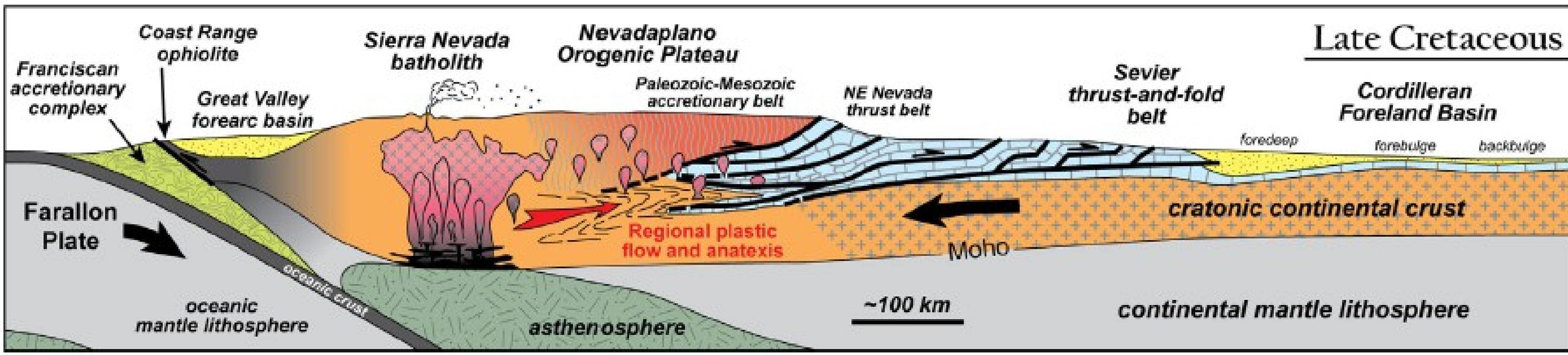
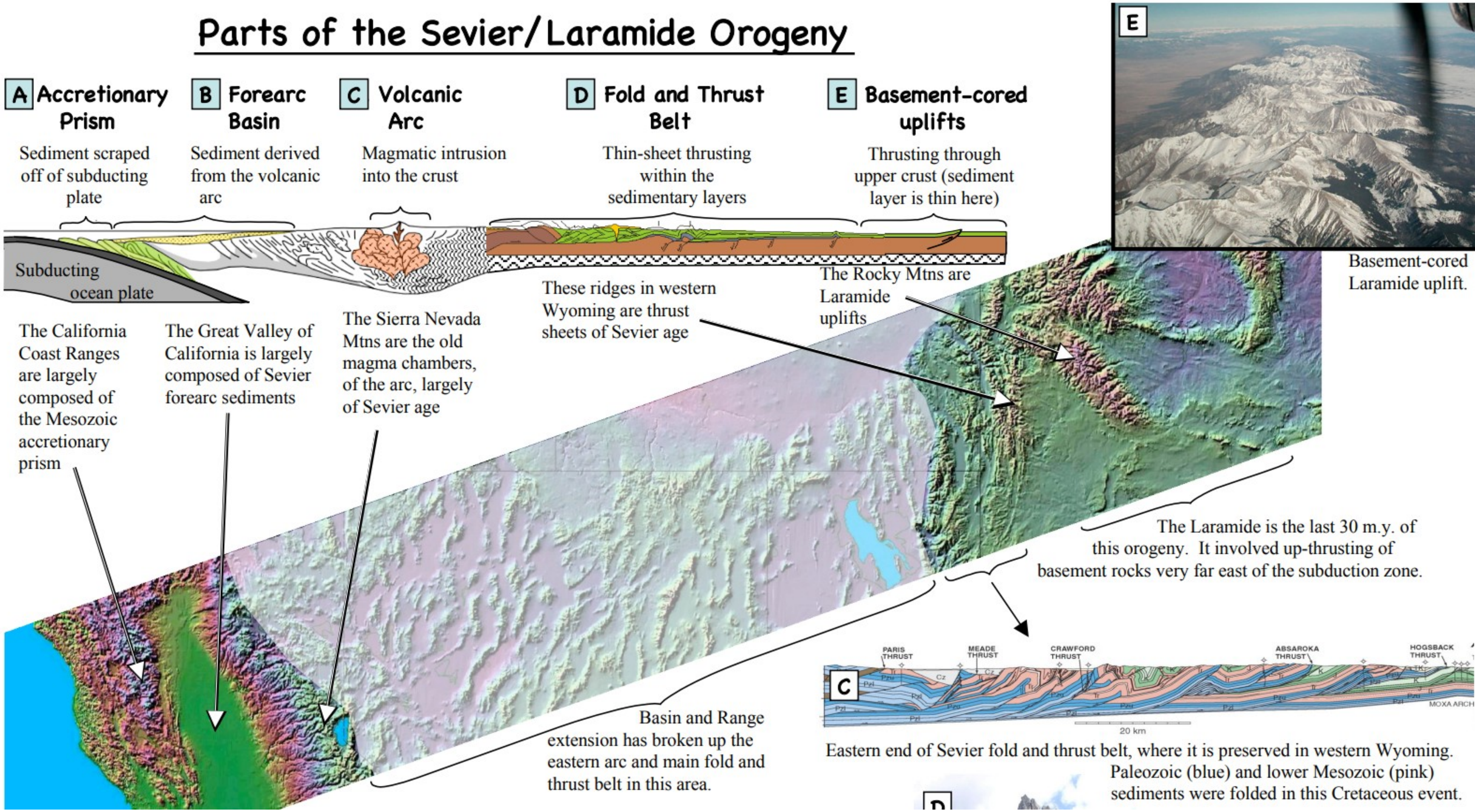
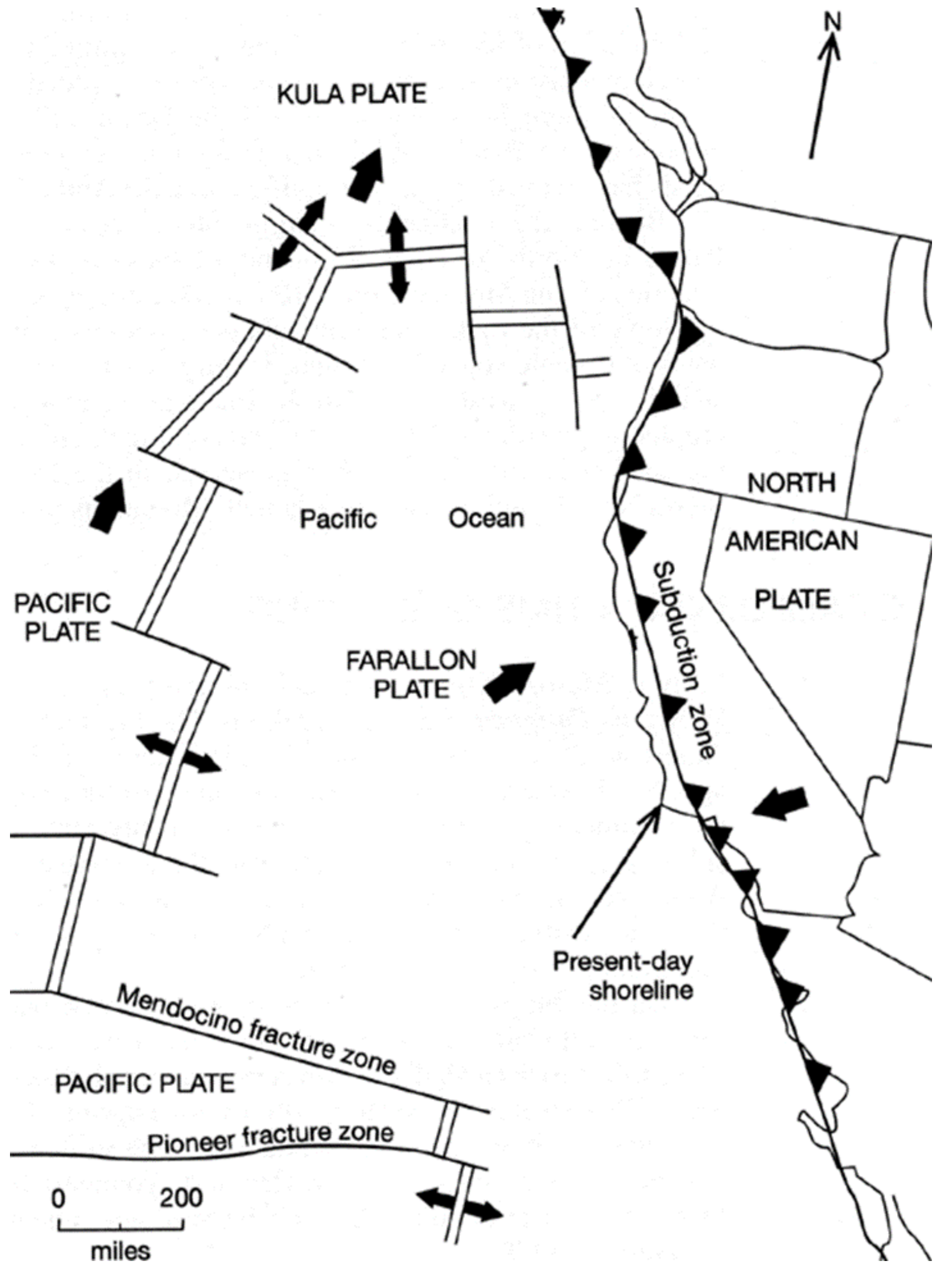


Fig. 5 Schematic Late Cretaceous cross-section of the Central Cordillera, showing the relationship between the Sevier fold-and-thrust belt and Cordilleran foreland basin on the east, metamorphic and igneous rocks of the hinterland, Sierra Nevada batholith, Great Valley forearc basin, and Franciscan accretionary complex on the west.

Parts of the Sevier/Laramide Orogeny





N
KULA PLATE
Pacific
Ocean
PACIFIC
PLATE
FARALLON
PLATE
NORTH
AMERICAN
PLATE
Subduction zone
Present-day
shoreline
Mendocino fracture zone
PACIFIC PLATE
Pioneer fracture zone
0
200
miles

The **Sevier orogeny** was the result of convergent boundary tectonic activity, and deformation occurred from approximately 160 million years (Ma) ago to around 50 Ma. This orogeny was caused by the **subduction of the oceanic Farallon Plate** underneath the continental North American Plate. Voluminous volcanism is also associated with the Sevier Orogeny.

The **Sevier orogeny partially overlapped** in time and space **with the Laramide** orogeny. There is evidence that suggests late **Sevier faults were active during the early Laramide**. Sevier thrusts may have remained **active until the Eocene** while **Laramide** deformation **began in the Late Cretaceous**

In general the Sevier orogeny defines **compressional event** that took advantage of **weak bedding planes in overlying Paleozoic and Mesozoic sedimentary rock**. As the crust was shortened, pressure was transferred eastward along the weak sedimentary layers, producing **"thin-skinned" thrust faults** that generally get **younger to the east**. In contrast, the **Laramide orogeny** produced **"basement-cored" uplifts** that often took advantage of pre-existing **faults** that **formed** during **rifting** in the late **Precambrian** during the breakup of the supercontinent Rodinia or during the Ancestral Rocky Mountains orogeny

The Sevier Fold and Thrust Belt extends from southern California near the Mexican border to Canada

Location of the Sevier Fold and Thrust Belt (highlighted in red). After Yonkee and Weil (2015)

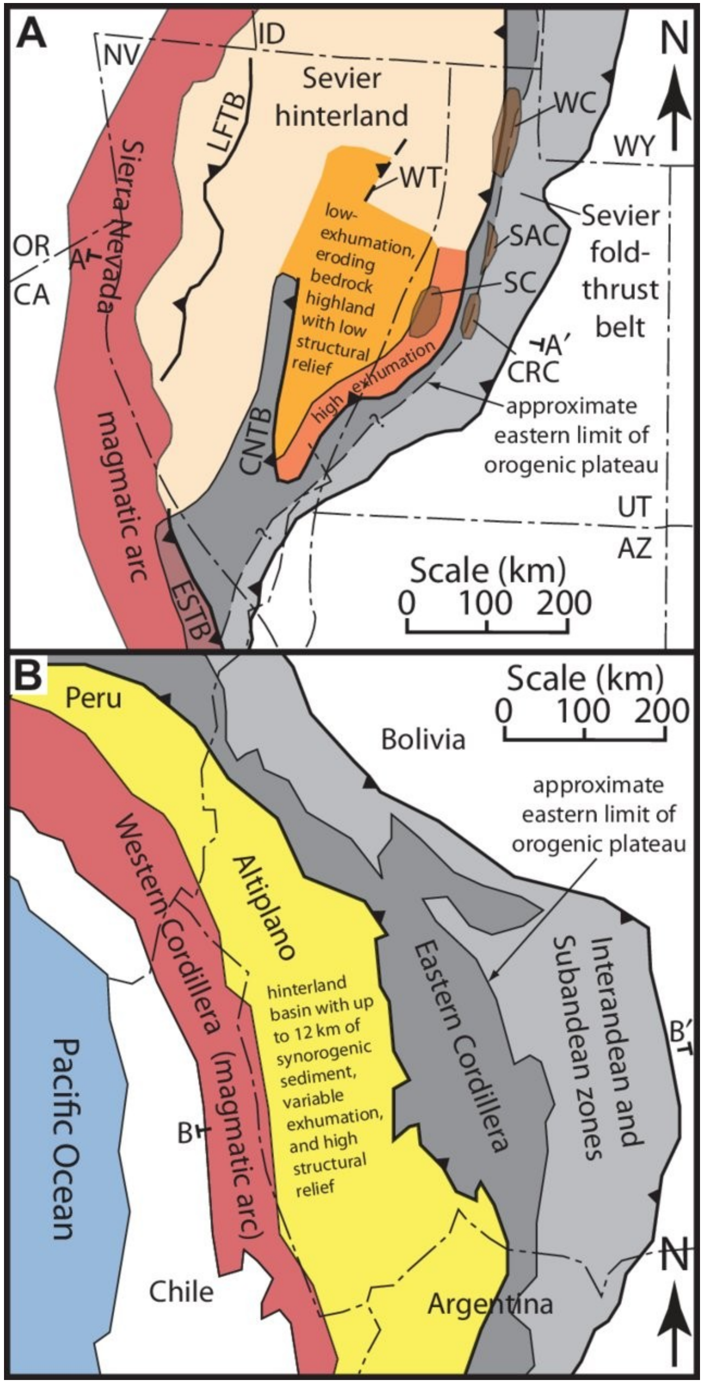


Figure 3. (A) Generalized geologic map of the Sevier orogenic belt, approximately restored for Cenozoic extension (base map modifi ed from DeCelles, 2004). Mesozoic thrust systems: LFTB—Luning-Fencemaker thrust belt, CNTB—central Nevada thrust belt, ESTB—eastern Sierra thrust belt, WT—Windermere thrust. Structural culminations in Utah: SC— Sevier culmination, CRC—Canyon Range culmination, SAC—Santaquin culmination, WC—Wasatch culmination. Approximate eastern limit of orogenic plateau based on position of Wasatch hingeline and positions of culminations (queried where unknown) (e.g., DeCelles, 1994, 2004; DeCelles and Coogan, 2006). Line A–A′ delineates approximate crosssection line of Figure 4A. Note that exhumation magnitudes outside of the map area in this study are not quantifi ed.

Luning-Fencemaker fold and thrust belt was active from the Middle or Late Jurassic through the. Early Cretaceous – Nevadan orogeny

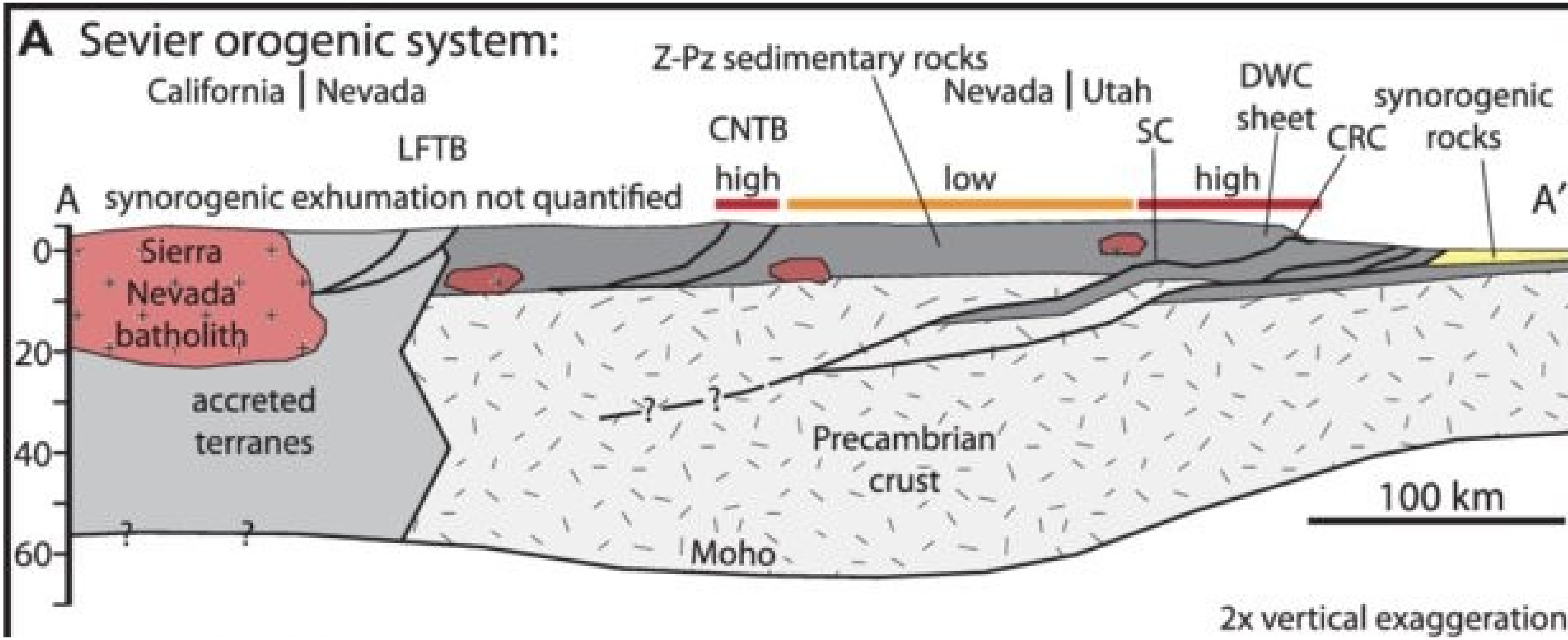
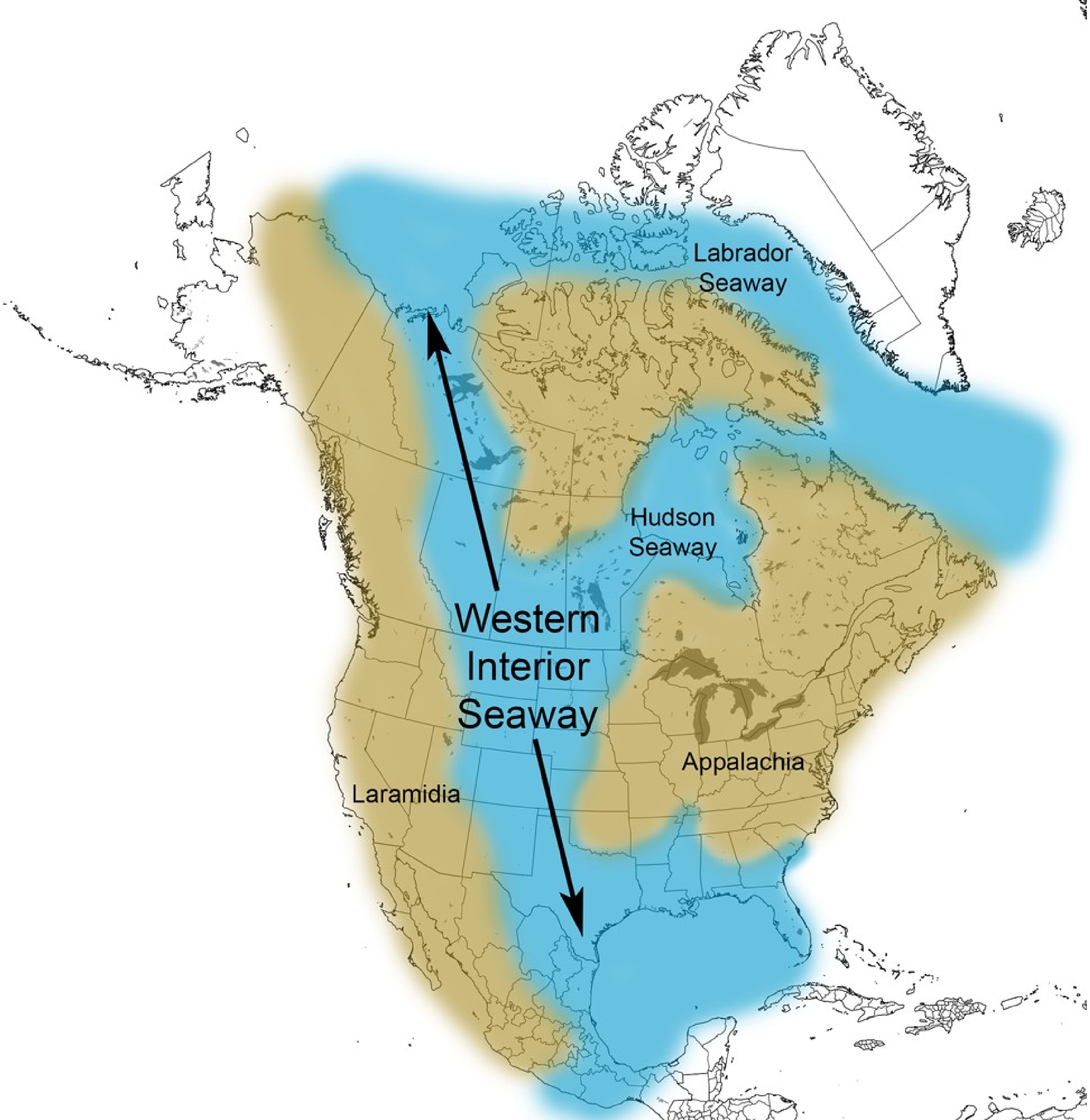


Figure 4. Schematic cross sections comparing deformation geometries and exhumation patterns between the Sevier orogenic systems. Approximate cross-section lines are shown in Figure 3. (A) Schematic preextensional geometry of the Sevier orogenic system, modifi ed from Allmendinger et al. (1987) and Best et al. (2009). Placements of individual structures and plutons are largely schematic, and are meant to show only general locations. Eastern limit of high topography is placed above the Canyon Range culmination (DeCelles and Coogan, 2006). Generalized exhumation magnitudes are shown by red and orange bars. **LFTB—Luning-Fencemaker thrust belt**, CNTB—central Nevada thrust belt, SC—Sevier culmination, CRC—Canyon Range culmination, DWC—Delamar–Wah Wah– Canyon Ra
Z–Pz—Neoproterozoic–Paleozoic..


Labrador Seaway
Hudson Seaway
Western Interior Seaway
Appalachia
Laramidia

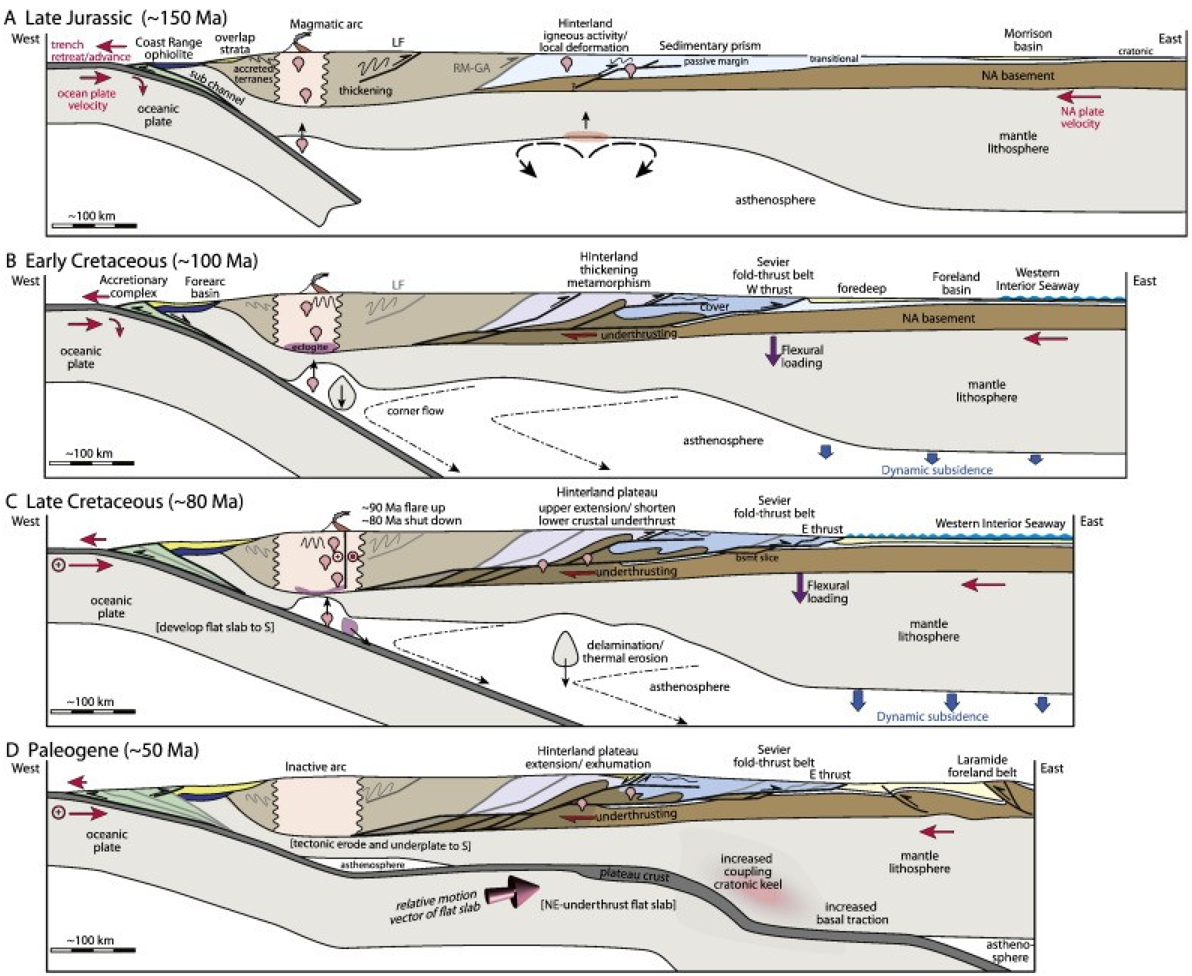
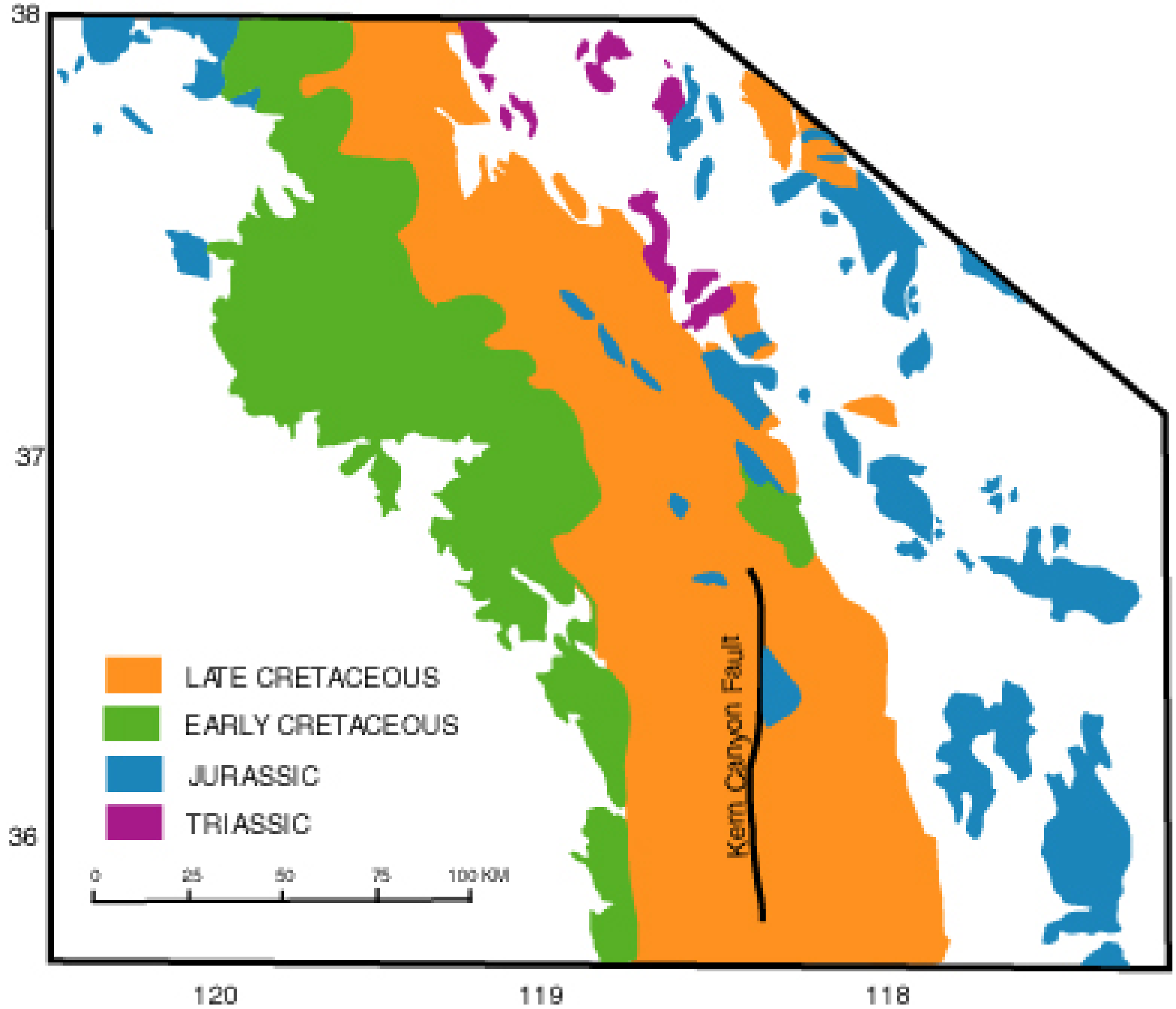


Fig. 6. Schematic lithospheric cross sections, shown for: A — Late Jurassic (~ 150 Ma); B — Early Cretaceous (~ 100 Ma); C — Late Cretaceous (~ 80 Ma); and D — Paleogene (~ 50 Ma) times. The Late Jurassic was marked by development of an E-dipping subduction zone, increased igneous activity along the magmatic arc, and initial shortening in the western part of the orogenic system. The Early Cretaceous included development of an accretionary complex, growth of the magmatic arc, crustal thickening in the hinterland, thin-skin shortening of the western Sevier belt, and sedimentation within a foreland basin. The Late Cretaceous included decreasing subduction angle (along with early development of a flat-slab segment to the south), a flare-up followed by shutdown of the magmatic arc, lower crustal thickening beneath a hinterland plateau, shortening in the eastern Sevier belt, and broad dynamic subsidence of the Western Interior Seaway. The Paleogene included rapid subduction and NE-underthrusting of the flat-slab segment, minor extension in the thickened hinterland, final shortening in the eastern Sevier belt, and uplift of Laramide arches that disrupted the foreland basin.



Modified from Chen and Tilton (1982). Showing the generalized age of granitic rocks.

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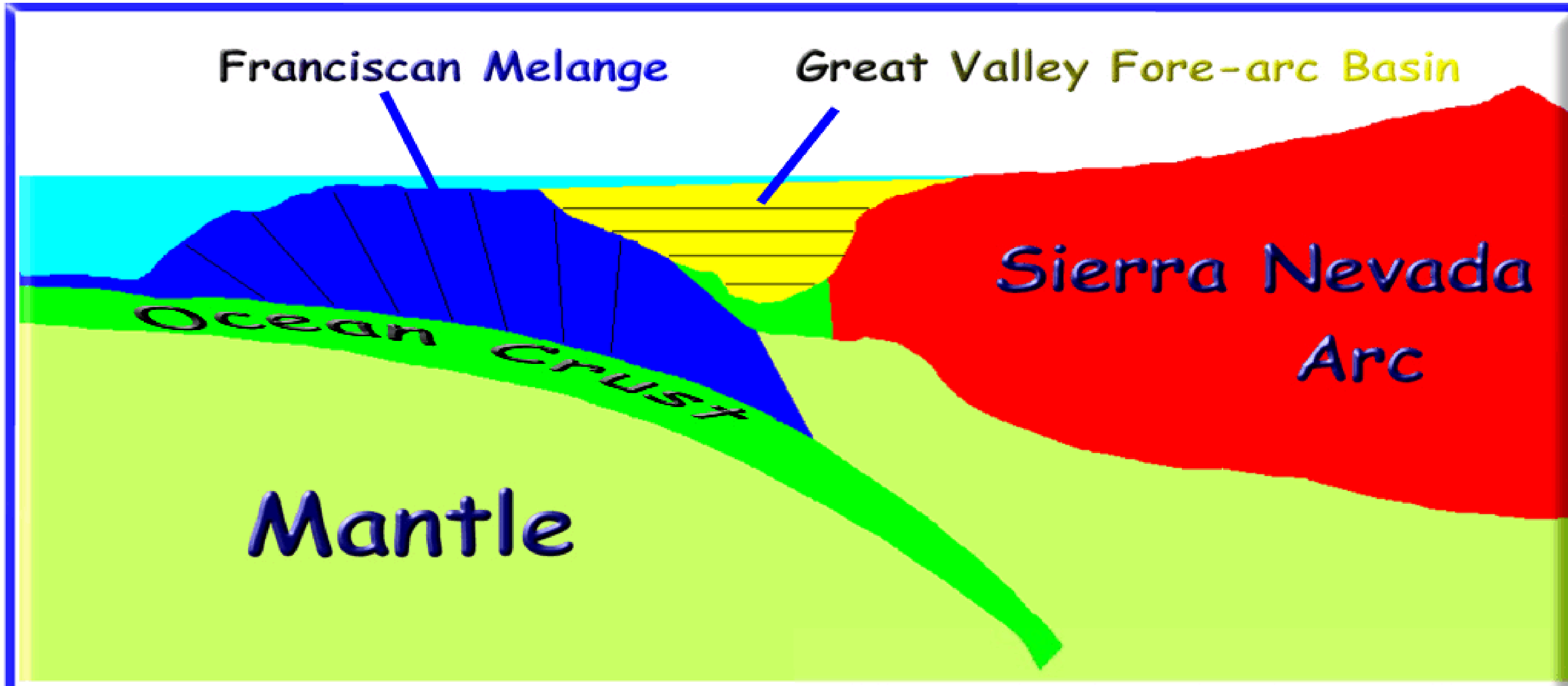
186-155 Ma on both east and west margins of the batholith –Nevadan orogeny

125-88 Ma granitoids, which young eastward, in the axial part of the batholith



Jurrassic Subduction
California

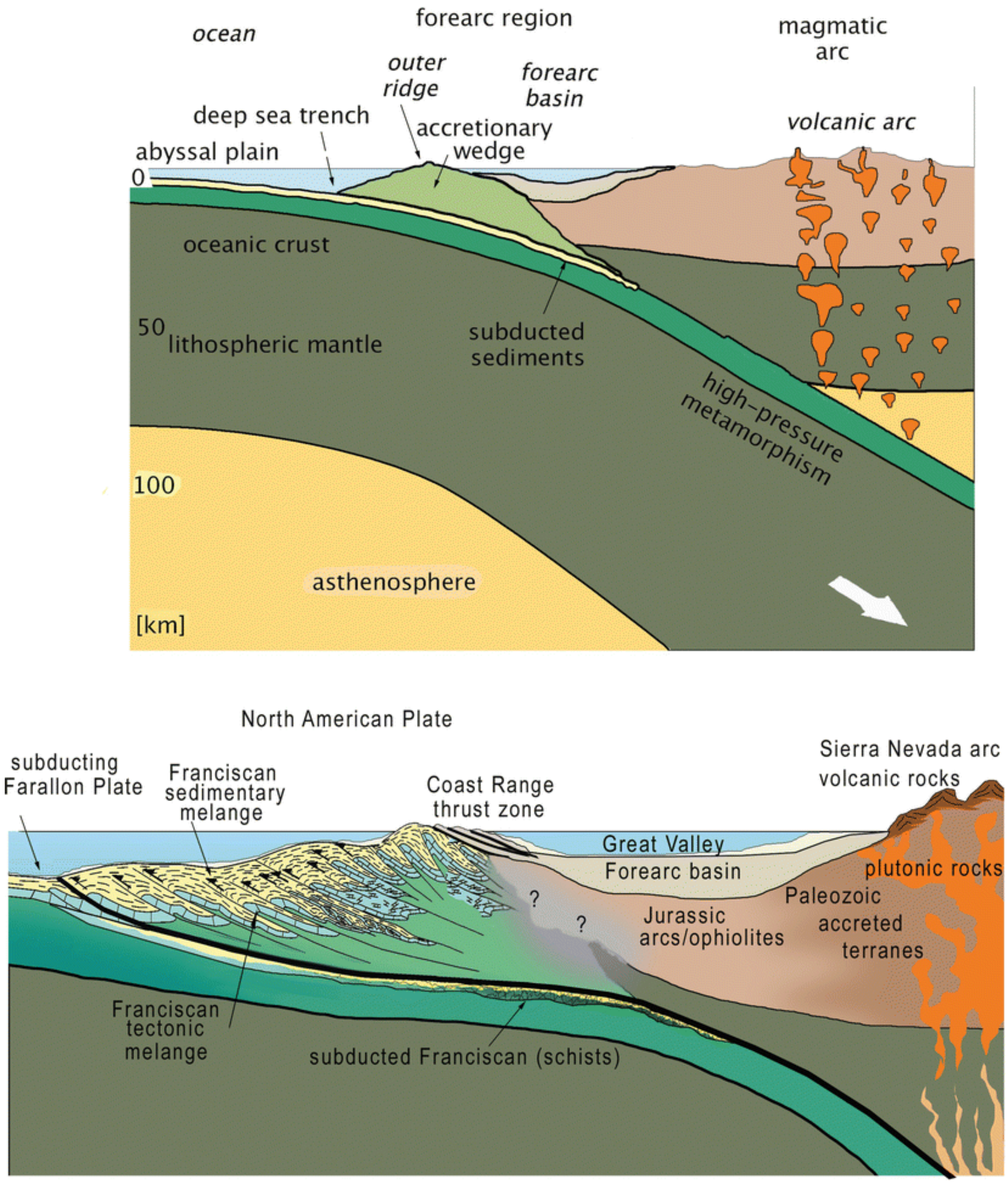
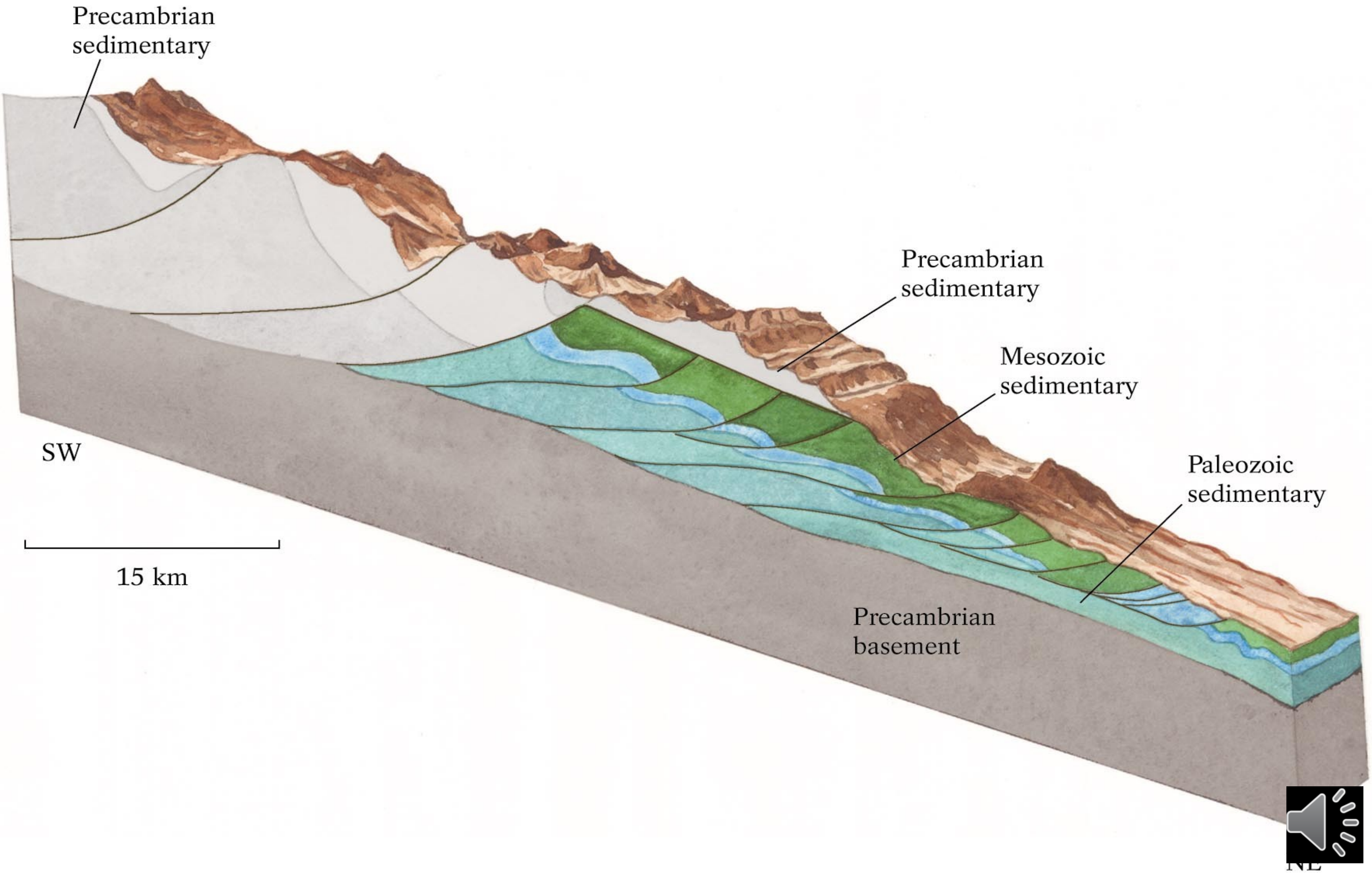
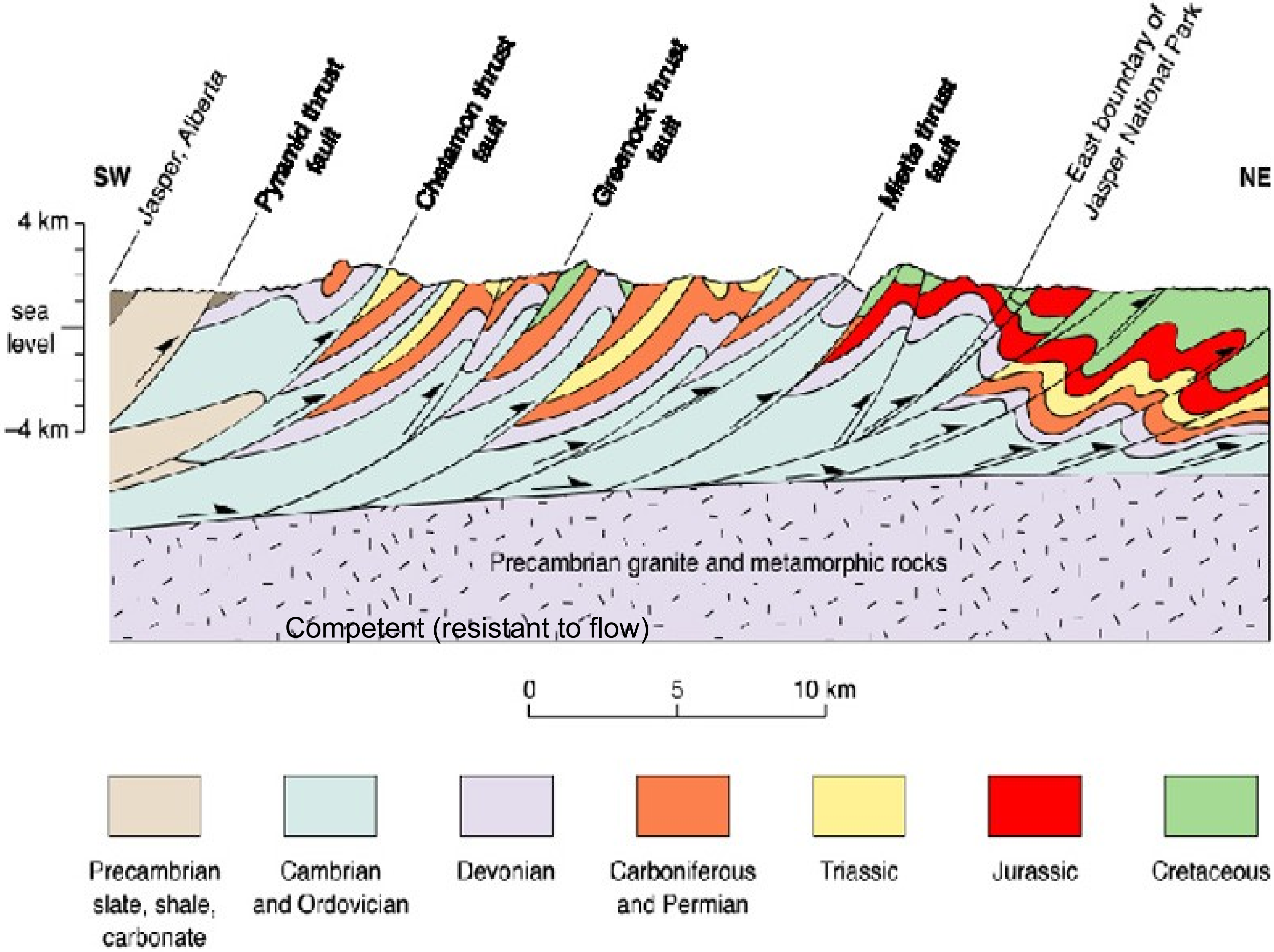


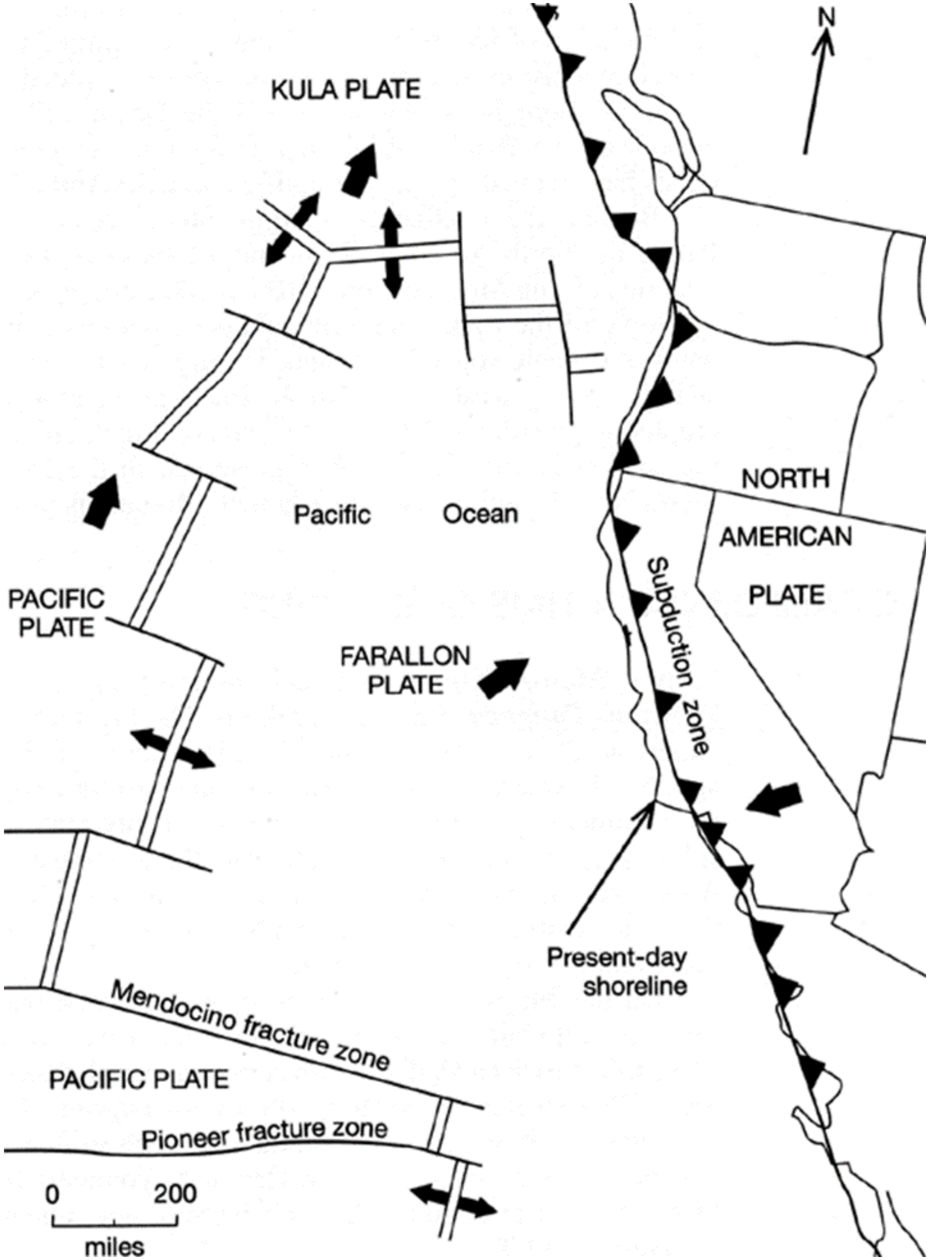
Fig. 8.5 Cross sections of the forearc region. Upper: general cross section of typical Cordilleran margin showing tectonic and sedimentary elements and geomorphic settings. Lower: details of forearc setting typical of the Late Jurassic through Paleocene of Central California showing tectonic and sedimentary setting of Franciscan and Great Valley sedimentary rocks. Light tan shows zones of active sedimentation. Note that most Franciscan deposits are bathyal to abyssal and that Great Valley deposits range from shoreline to abyssal. The contact between Franciscan and Great Valley rocks is everywhere tectonic – usually the Coast Range Fault zone. Queried areas have uncertain relations. Over long periods of geologic time, the entire forearc region became new continental crust added to western North America; Cenozoic sedimentary basins and associated volcanic rocks were developed across the forearc region during the ensuing compressional, transpressional, and transform tectonic [illegible]s (Modified after Frisch et al. 2011)

Sevier thin-skinned deformation





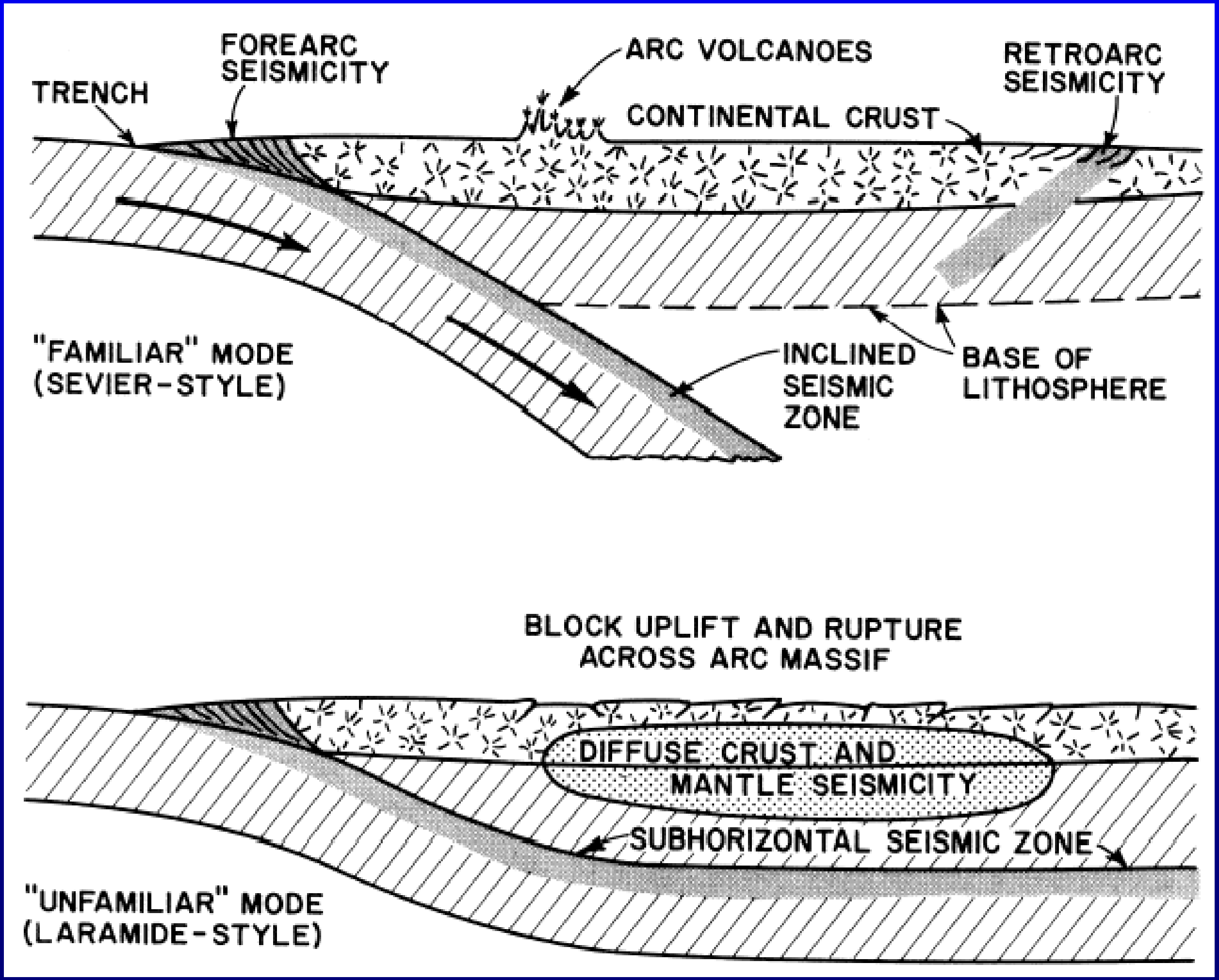
SW
NE
Jasper, Alberta
Pyramid thrust fault
Chetamon thrust fault
Greenock thrust fault
Miette thrust fault
East boundary of Jasper National Park
4 km
sea level
–4 km
Precambrian granite and metamorphic rocks
Competent (resistant to flow)
0
5
10 km
Precambrian slate, shale, carbonate
Cambrian and Ordovician
Devonian
Carboniferous and Permian
Triassic
Jurassic
Cretaceous



100 Million Years Ago

~50 Ma: End of subduction

- In the Cenozoic, the slab became completely horizontal, probably due to progressive decrease in age of the subducting Farallon Plate as the ridge approached the trench. Results include end of calc-alkaline volcanism, major compressive orogeny far inland (Laramide orogeny of the Rocky Mountains) and emplacement of Pelona and related schists under Southern California

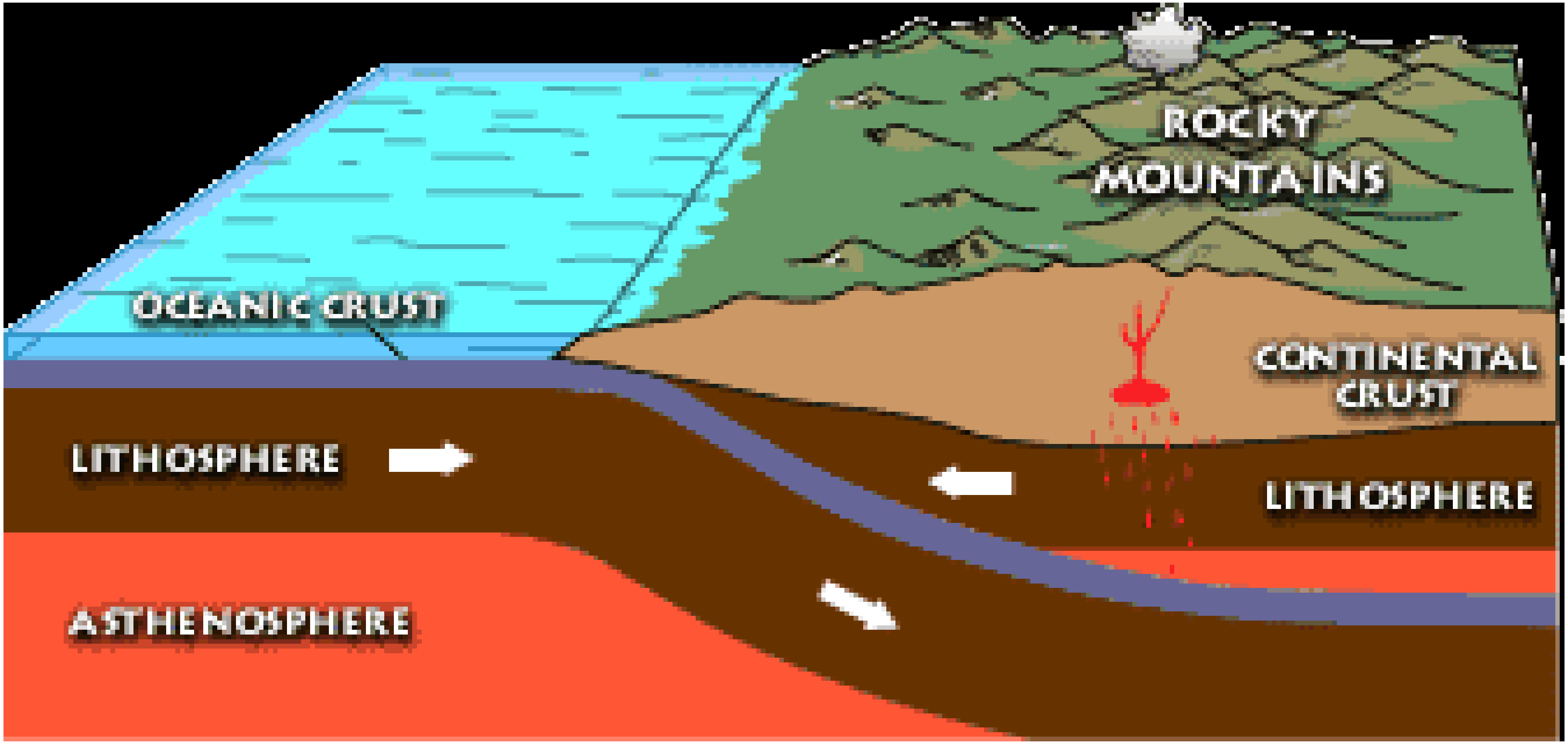


Laramide Orogeny (50- 80 Ma)

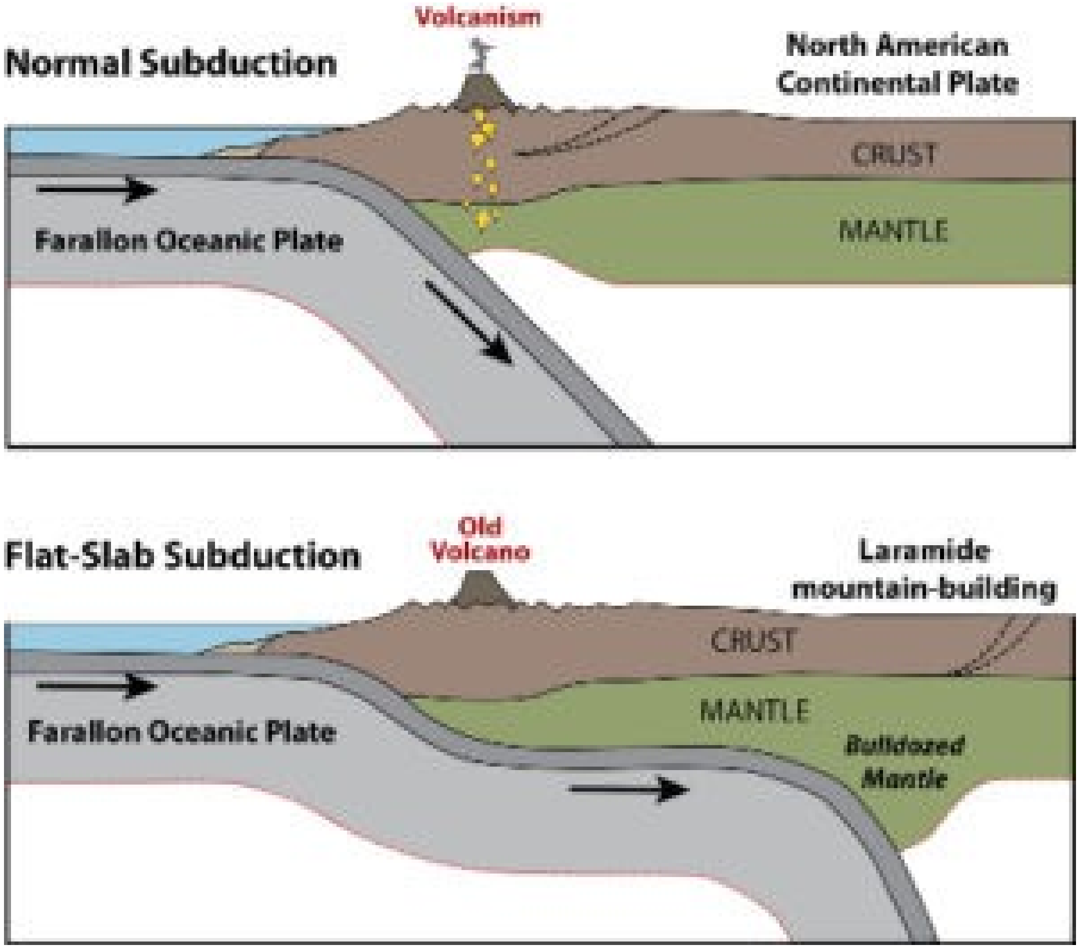
- Late Cretaceous - Early Eocene
- Deformation shifted eastward following
- Magmatism – Coast Range Arc
- Thick-skinned tectonics

The Laramide orogeny occurred in a series of pulses, with quiescent phases intervening. The major feature that was created by this orogeny was **deep-seated, thick-skinned deformation**, with evidence of this orogeny found from Canada to northern Mexico. Most hypotheses propose that the **angle of subduction became shallow**. One cause for shallow subduction may have been an **increased rate of plate convergence**.The Laramide Orogeny lasted about 30 million years during which the **Rocky Mountain foreland ranges were pushed up**. The area affected by the Laramide Orogeny includes the central and southern Rockies and the Colorado Plateau.

Dynamic processes that propagate deformation across the strong and broad plateau far into the foreland and produce thick-skinned tectonics in the case of the Laramide orogeny are still largely debated

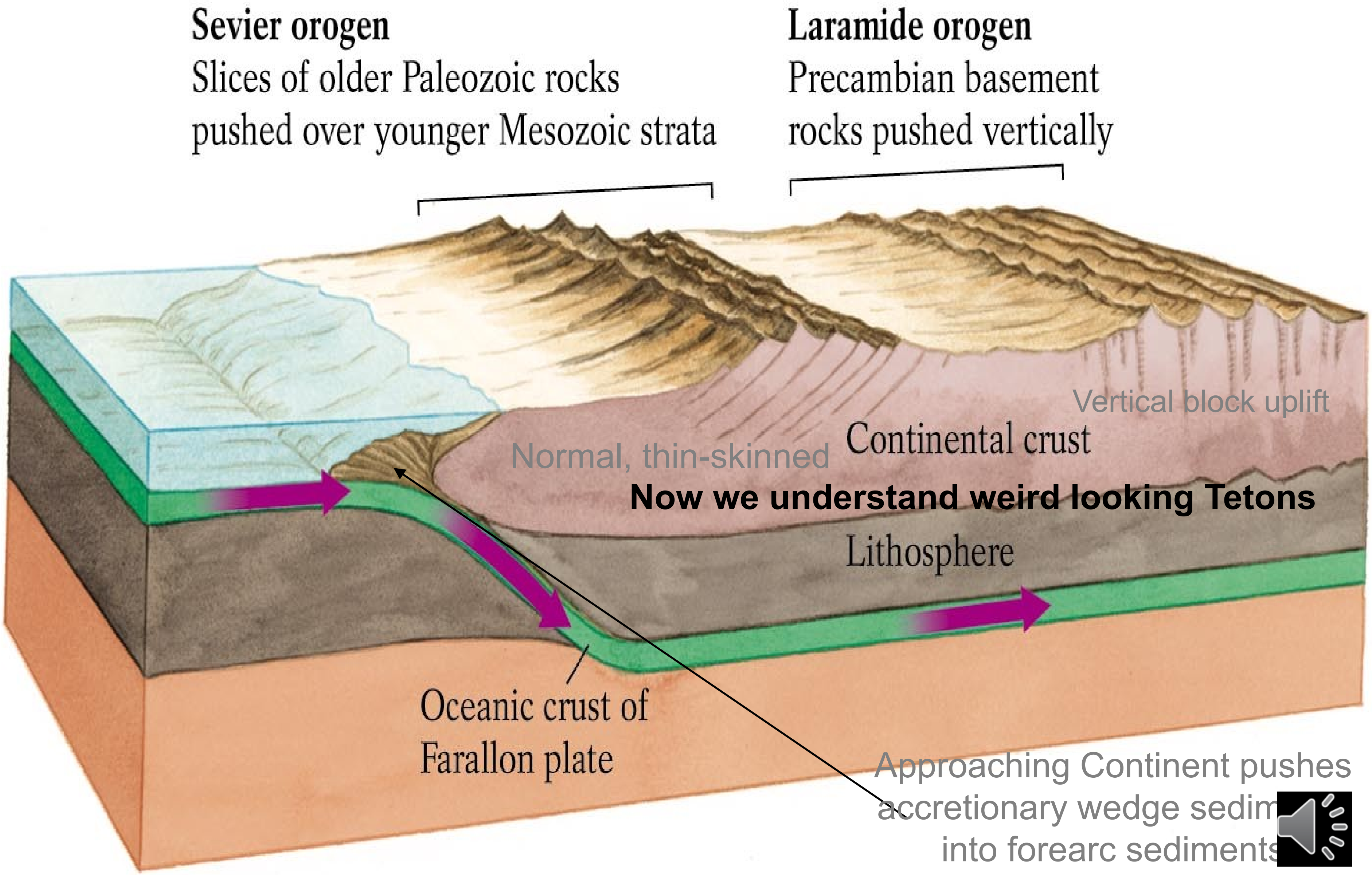


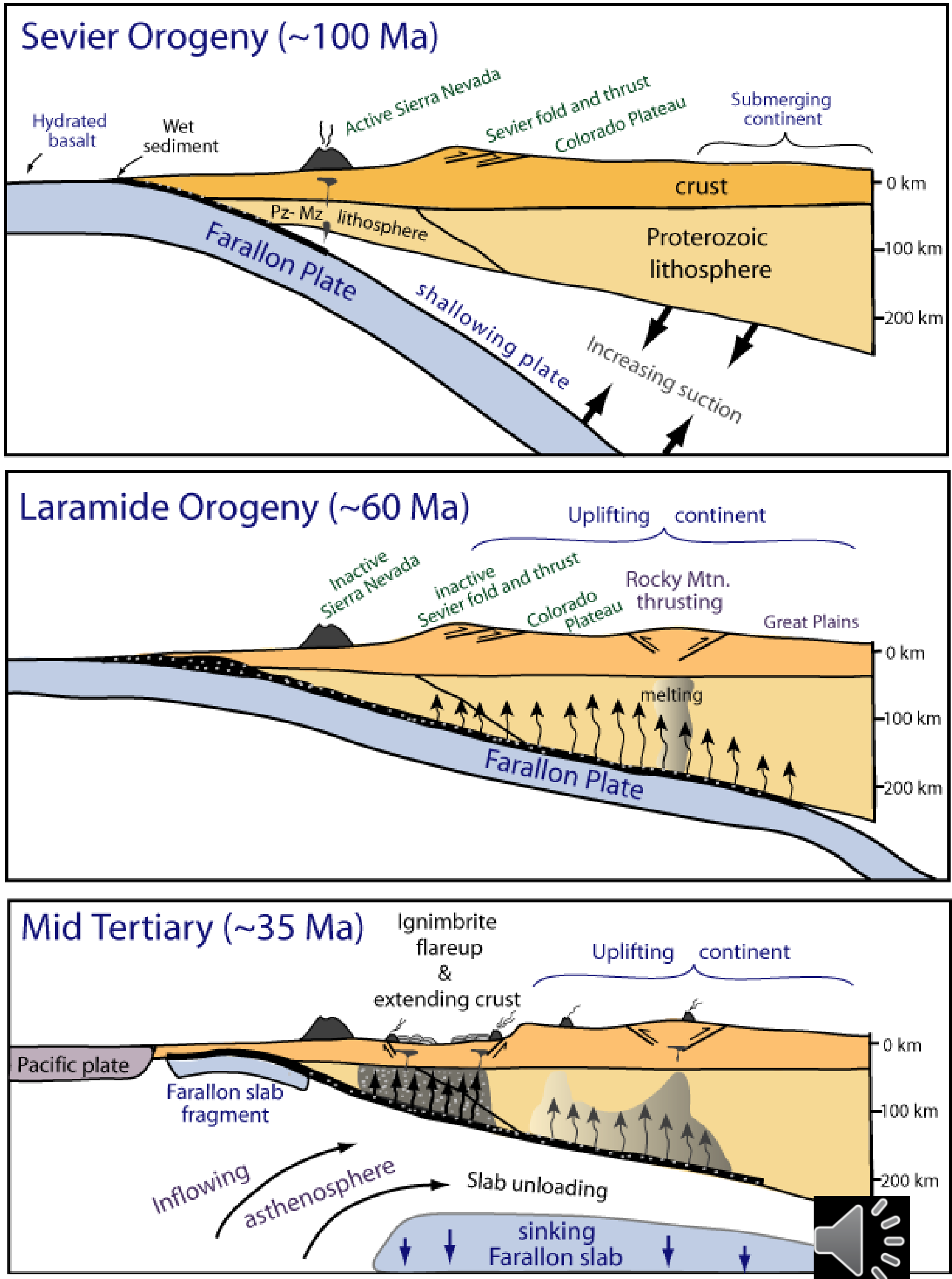
The Laramide orogeny was caused by subduction of a plate at a shallow angle. The Laramide Orogeny lasted about 30 million years during which the Rocky Mountain foreland ranges were pushed up. The area affected by the Laramide Orogeny includes the central and southern Rockies and the Colorado Plateau.



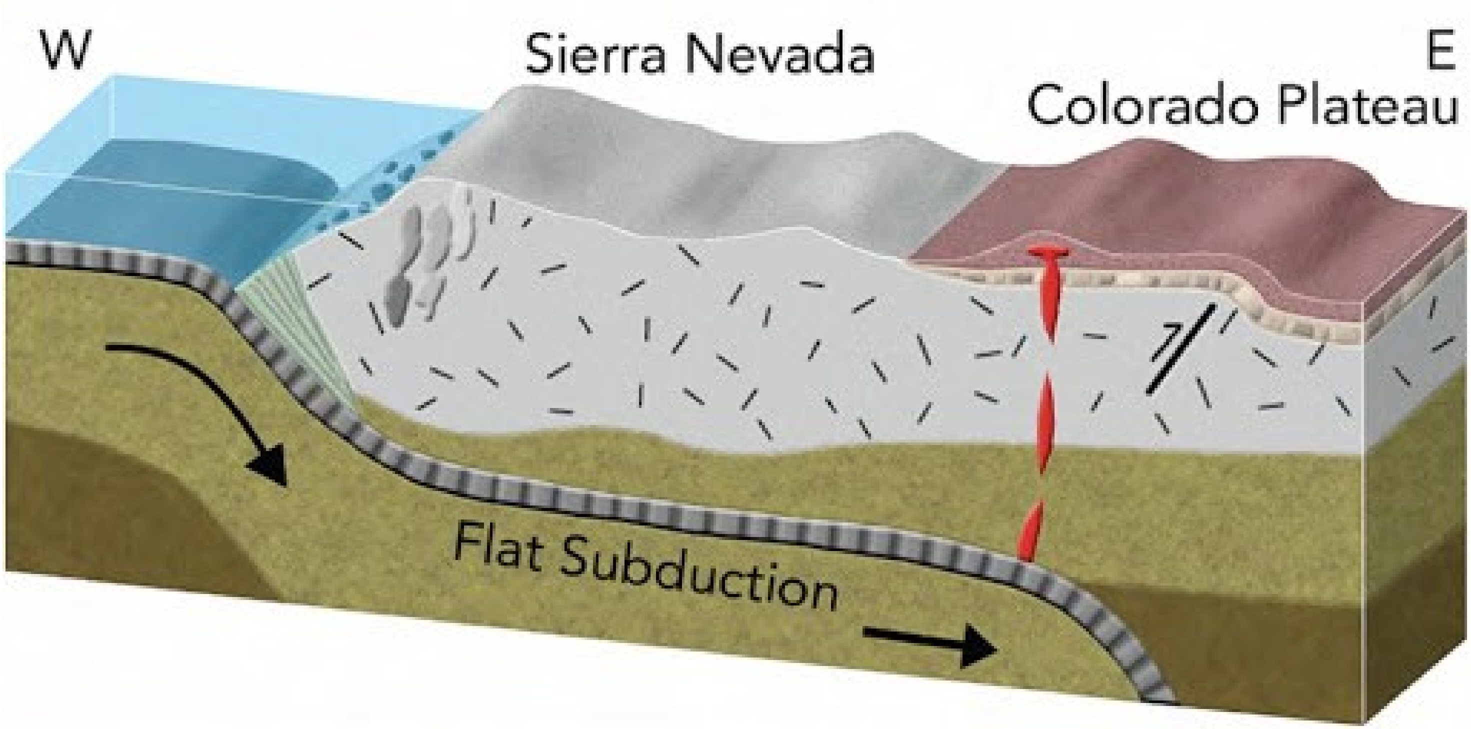
Below, an image prepared by Clair Currie, University of Alberta, showing the difference between subduction prior to Laramide time (above) and during Laramide.

Buoyant Subduction Laramide Orogeny





Humphreys et al., 2003



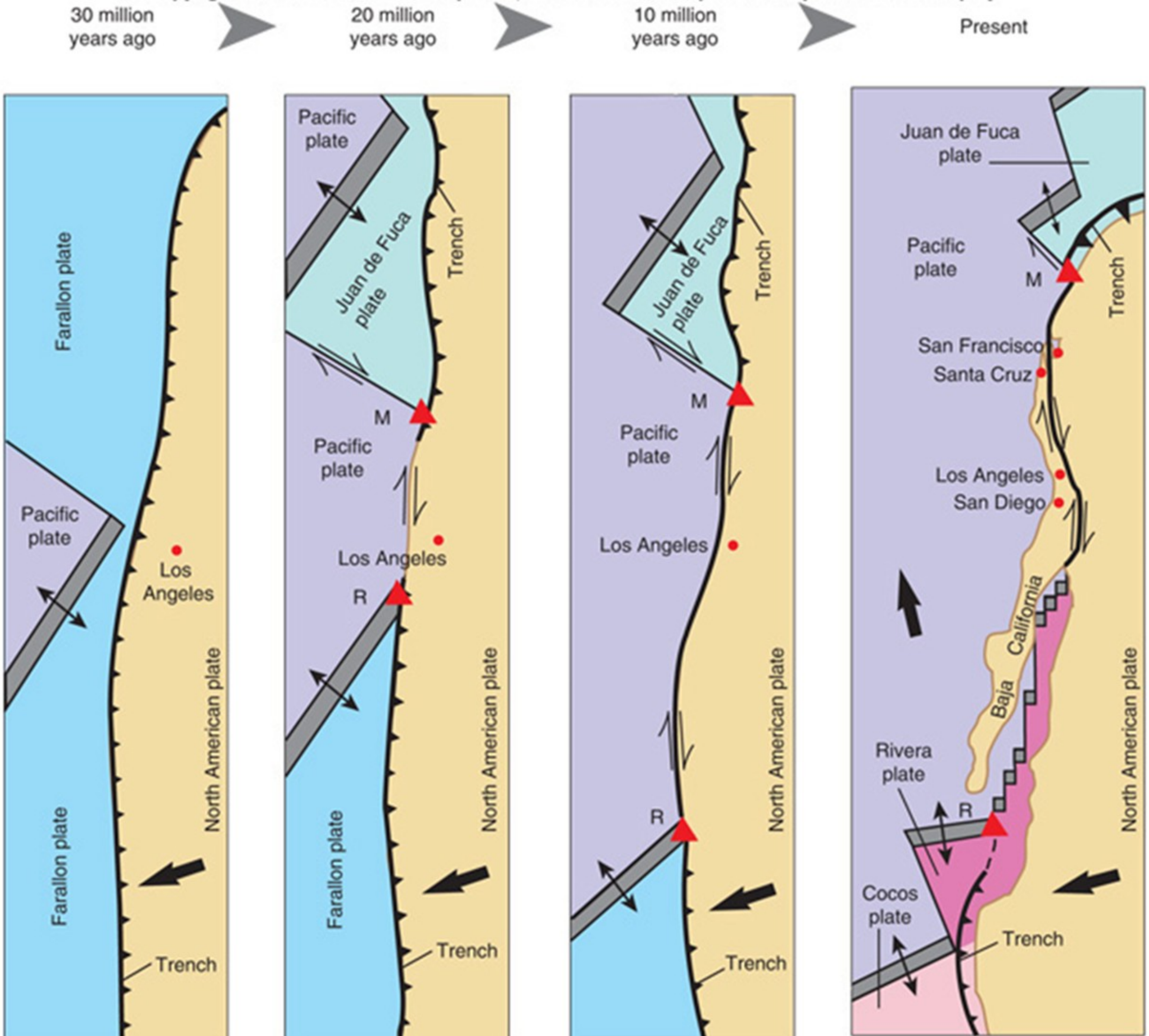
deformation landward of the relatively undeformed Colo-
rado Plateau

Mount Elbert is the highest summit of the Rocky Mountains of North America. With an elevation of 14,438 feet (4400.58 m), https://www.youtube.com/watch?v=tJk9cFz152s

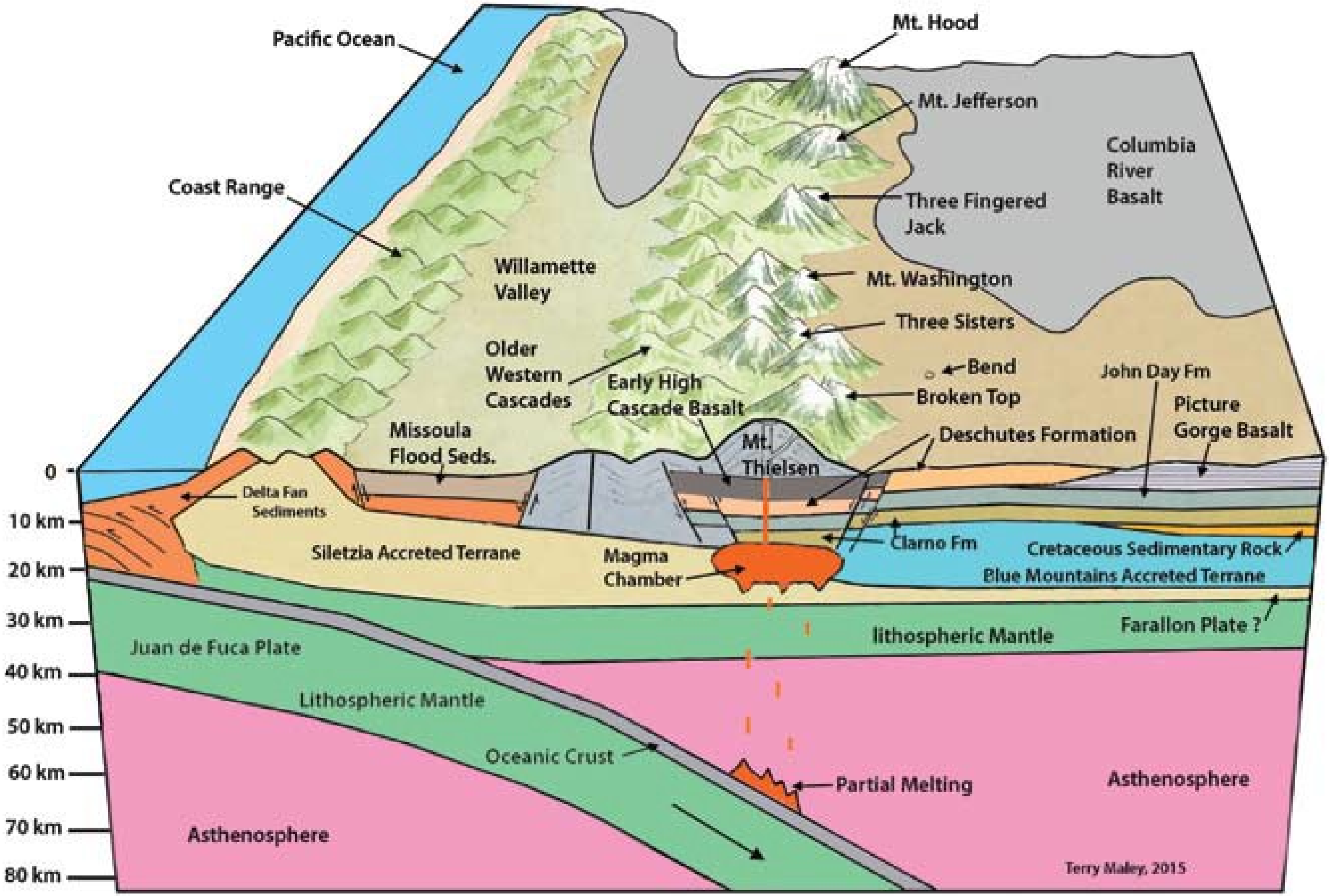
https://www.youtube.com/watch?v=74TEQfw6L60

Tertiary Postlaramide evolution

- **Faralon plate** partly **subducted. San Andreas Fault** system was formed, tangential motion and expansion replaced convergent motion as the North American plate began **interacting with the Pacific plate**.
- **Cascades orogeny – subduction of fragments of Faralon plate 42Ma-today**
- **Basin and Range extension-Miocene (17 Ma) - Present**
- **Columbia and Yellowstone plateau**
- **Coast ranges - accretionary wedge complex formed as the Juan de Fuca and North American plates collided.**



Kious, W.J., and Tilling, R.I., *This Dynamic Earth*. US Geological Survey, p.77



Block diagram showing a cross section across the **Coast Range**,Willamette Valley, older **Western Cascades**, **High Cascades** and the High Lava Plateau of northern Oregon.

Cascades

The Cascade Range extends from British Columbia, Canada, south to northern California where it meets the Sierra Nevada. The **North Cascades** span from the Canadian province of British Columbia to the U.S. state of Washington and are often officially named as the **Cascades**. The **South Cascades** in California is bounded on the west by the Sacramento Valley and the **Klamath Mountains**, and on the east by the Great Basin,

The **Cascade** Region is divided, physiographically, into the Western Cascades and the High Cascades. The **Western Cascades**, or **Ancestral Cascades** encompasses volcanic rocks as old as 45 million years. The **High Cascades** or **Modern Cascades** are much younger dating from 5-7 million years to just a few hundred years The Cascades are primarily composed of **volcanic** igneous rock, the youngest of which is found in the active volcanoes of the **High Cascades**—strikingly large stratovolcanoes that rise high above the landscape of the range. The tallest of the High Cascades is **Mt. Rainier**, which rises to **4392** meters (14,410 feet) above sea level. The most common rock produced by these volcanoes is andesite, a fine-grained rock of intermediate silica content. Another common rock is dacite, a gray volcanic rock that lies between andesite and rhyolite in terms of its silica content

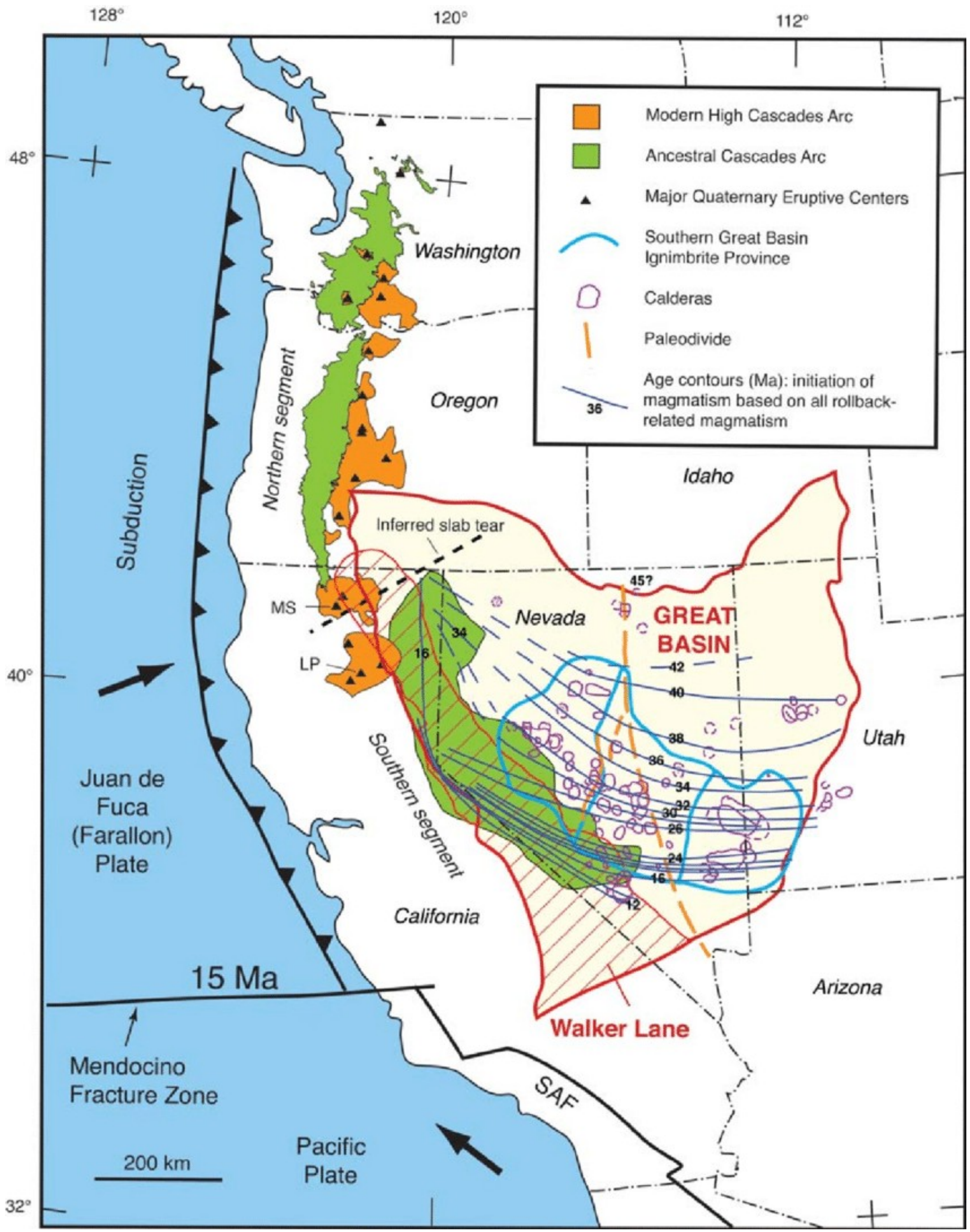


Figure 1. Index map of the western US showing the **Ancestral Cascade** and **High Cascade** arcs, the southern Great Basin ignimbrite province, and outlines of the Henry and John (2013). Age contours show approximate location of the initiation of slab rollback magmatism at time indicated as inferred from locally sourced volcanic and intrusive rocks (Henry and John, 2013). East-west line labeled 15 Ma shows approximate location of the Mendocino fracture zone (southern edge of the Farallon plate, which was being subducted beneath North America) at 15 Ma (Atwater and Stock, 1998). The southern terminus of the southern segment of the ancestral Cascade arc gradually migrated north in concert with northerly migration of the Mendocino fracture zone. Accordingly, the southern limit of Farallon

Cascade Range, segment of the Pacific mountain system of western North America. The Cascades extend northward for more than 700 miles (1,100 km) from Lassen Peak, in northern California, U.S., through Oregon and Washington to the Fraser River in southern British Columbia, Canada. **Many peaks exceed 10,000 feet (3,000 metres)**, including Mount Hood (11,235 feet [3,424 metres], highest point in Oregon) and **Mount Rainier** (14,410 feet [4,392 metres], highest in Washington and in the Cascade Range). **Most of the summits are extinct volcanoes**, but Lassen Peak (10,457 feet [3,187 metres]) and several others have erupted in the **recent past**. **Mount Baker** (10,778 feet [3,285 metres]) steamed heavily in 1975, and **Mount St. Helens** (8,365 feet [2,550 metres]) erupted in 1980 and again in 1981.

Mt. Rainier 4,392 metres is a steep-sided composite volcano composed of numerous andesite lava flows and volcanic mudflows and covered by glaciers.

Northern Cascade Range is almost entirely volcanic in origin

The Cascadia subduction zone is a convergent plate boundary that stretches from northern Vancouver Island in Canada to Northern California in the United States. It is a very long, sloping **subduction zone where the** Explorer, Juan de Fuca, and Gorda plates (**segments of Faralon plate**) move to the east and slide below the much larger mostly continental North American Plate**.**

The Cascade Arc was created after accretion of the **Siletzia oceanic plateau** perhaps by about 42 million years ago **ended a period of flat-slab subduction**.

The **Western Cascades (Ancestral Cascades)** began to form **40** million years ago with eruptions from a chain of volcanoes near the **Eocene shoreline**. Around **10 million years ago**, the **Modern (High) Cascade arc** became active. This renewed period of volcanism and mountain building is believed to be related to **changes in the orientation** or **water content** of the **subducting tectonic plate**. Major eruption of **Mount St. Helens in 1980.**

Tectonic processes active in the Cascadia subduction zone region include **accretion**, **subduction**, deep **earthquakes**, and active **volcanism** of the Cascades. The **Juan de Fuca plate** is **moving** at a rate of about 1.6 inches (4 cm) per year. This subduction zone is responsible for the **Cascade magma arc**.

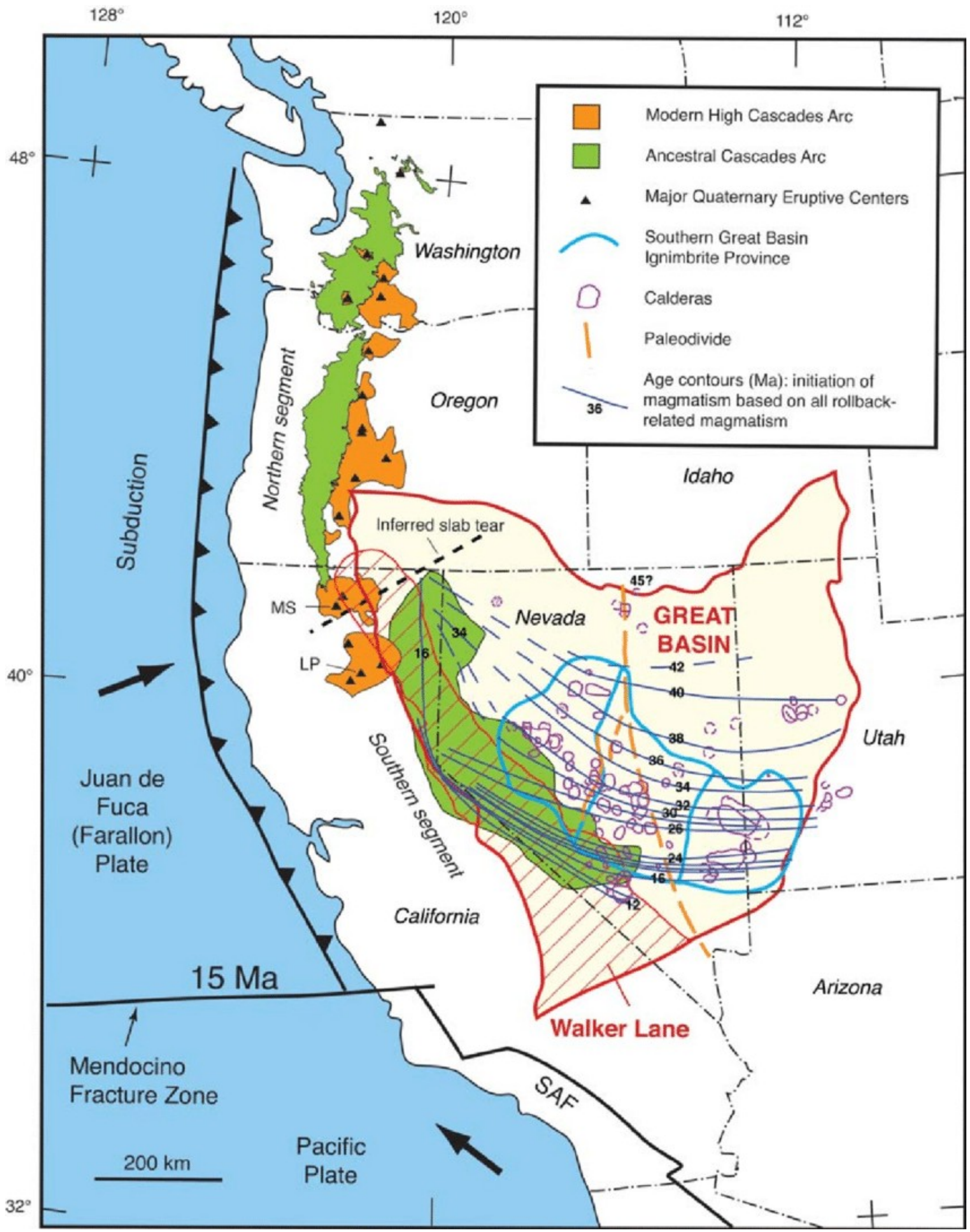


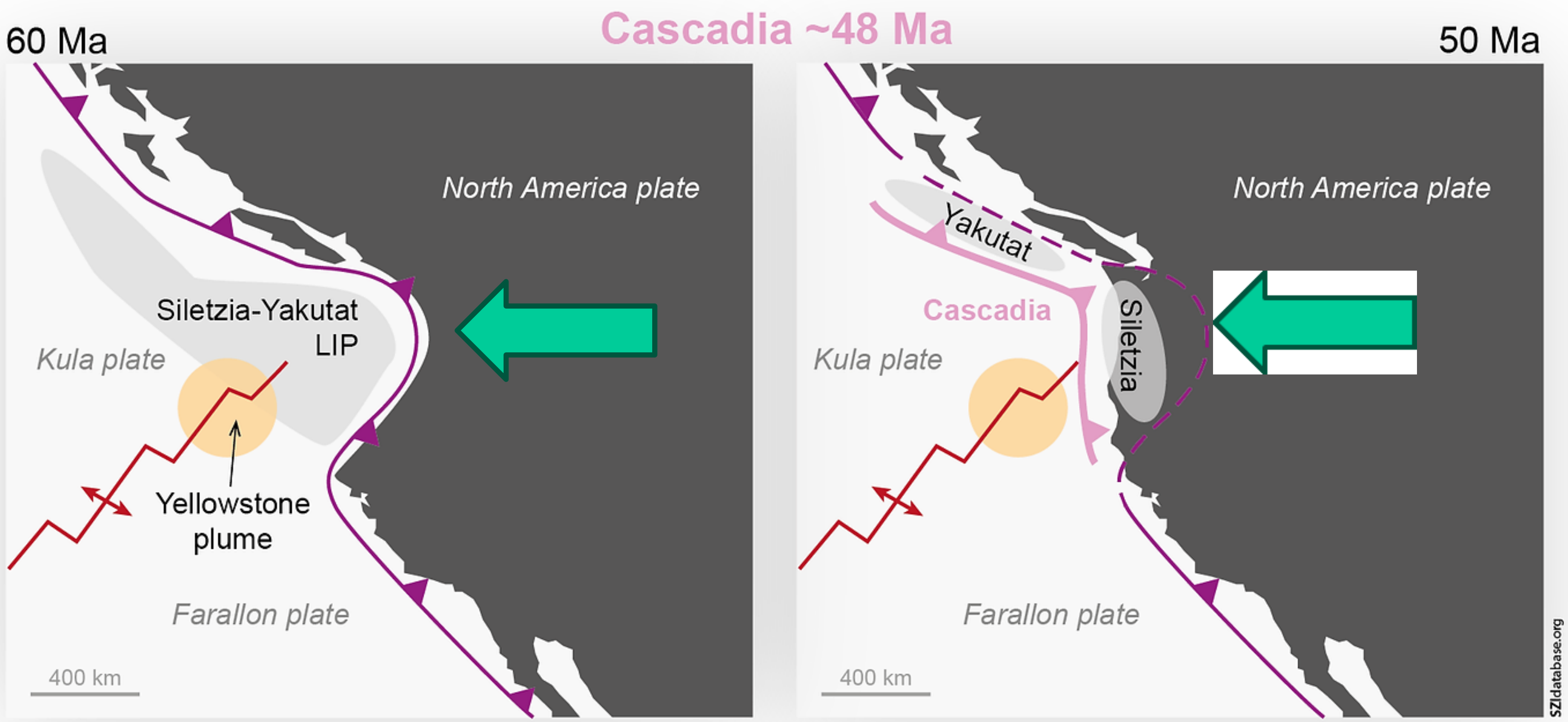
Figure 1. Index map of the western US showing the **Ancestral Cascade** and **High Cascade** arcs, the southern Great Basin ignimbrite province, and outlines of the Henry and John (2013). Age contours show approximate location of the initiation of slab rollback magmatism at time indicated as inferred from locally sourced volcanic and intrusive rocks (Henry and John, 2013). East-west line labeled 15 Ma shows approximate location of the Mendocino fracture zone (southern edge of the Farallon plate, which was being subducted beneath North America) at 15 Ma (Atwater and Stock, 1998). The southern terminus of the southern segment of the ancestral Cascade arc gradually migrated north in concert with northerly migration of the Mendocino fracture zone. Accordingly, the southern limit of Farallon

Silverthrone Caldera
British Columbia
Franklin Glacier Volcano
Mount Meager
Mount Cayley
Mount Garibaldi
Explorer Ridge
Explorer Plate
Mount Baker
Glacier Peak
Juan de Fuca Ridge
Washington
Mount Rainier
Mount St. Helens
Mount Adams
Juan de Fuca Plate
Mount Hood
Mount Jefferson
Three Sisters
Newberry Volcano
Blanco Fracture Zone
Crater Lake
Oregon
Gorda Ridge
Gorda Plate
Mount Shasta
Medicine Lake Volcano
Lassen Peak
Mendocino Fracture Zone
California

Models of **how Siletzia formed** are of two general types:[73] (1) **Formation well offshore** (possibly as **seamounts**, like the **hotspot** Hawaiian-Emperor seamount chain, or a **hotspot at a spreading ridge**, like Iceland) and then accretion to the continent; (2) **formation inshore**, on or near the continental margin (perhaps as a result of **transcurrent extension**, or of a **slab window**).

Soon afterwards, **Siletzia** entered the preexisting, east-dipping Cordilleran **subduction zone and caused it to fail**, accreting to North America and **causing the new east-dipping Cascadia subduction zone** to form outboard of Siletzia

Accounting for the observed **volumes of basalt** requires an enhanced magmatic source, for which most models invoke either the presence of the **Yellowstone hotspot**, or **slab windows.** The **latter** would have resulted from the **subduction of** the **Kula-Farallon** (or possibly Farallon—**Resurrection**) **spreading ridge**. The relation with the Kula-Farallon spreading ridge is an important element in all models, though its location through that epoch is not well determined



Schematic tectonic reconstruction of the Cascadia SZI event (modified from Stern and Dumitru et al., 2019 and Wells et al., 2014). **A trench jump occurred due to the accretion of the Siletzia** and Yakutat large igneous province (LIP) formed by the Yellowstone plume, initiating the new Cascadia subduction zone. Shown are the new subduction zone (pink line), other active (solid purple lines) and inactive (dashed purple lines) subduction zones, and spreading ridges (solid red lines).

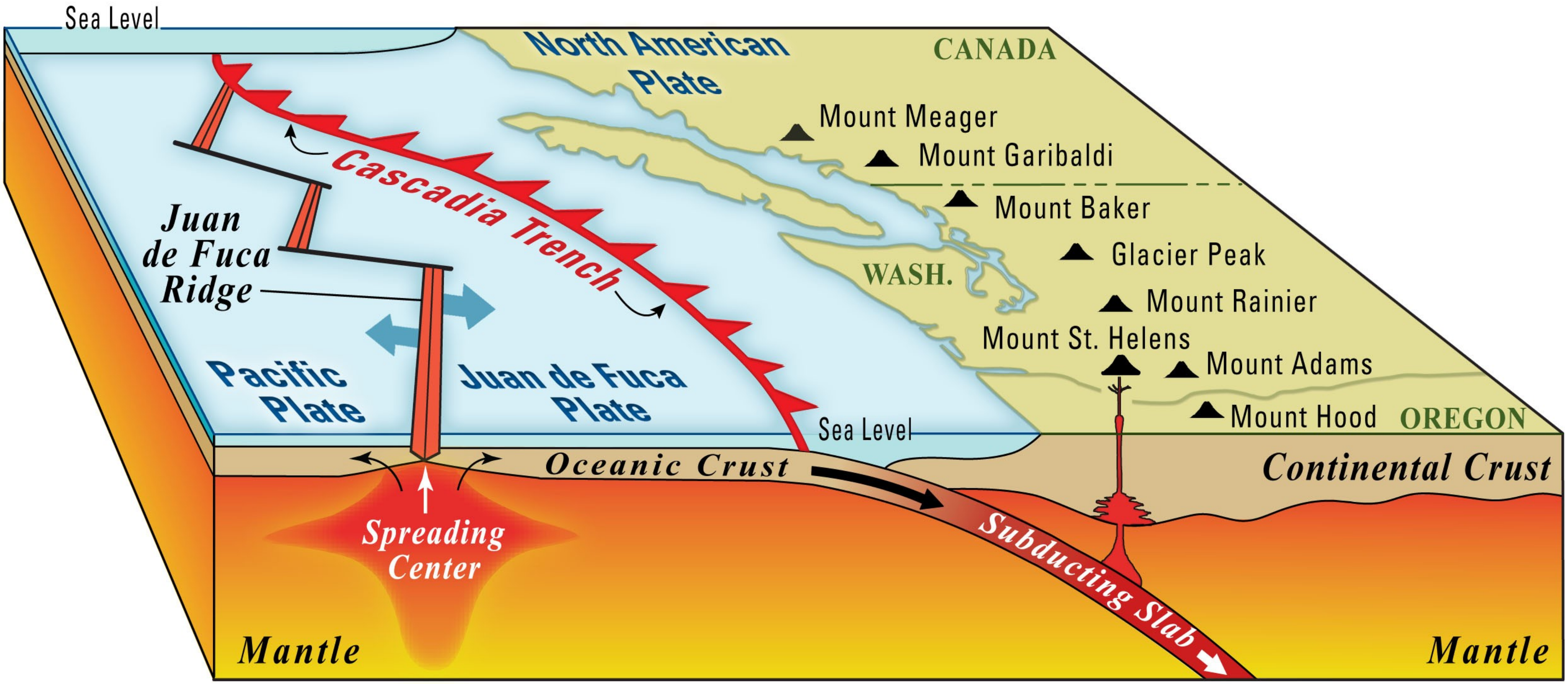
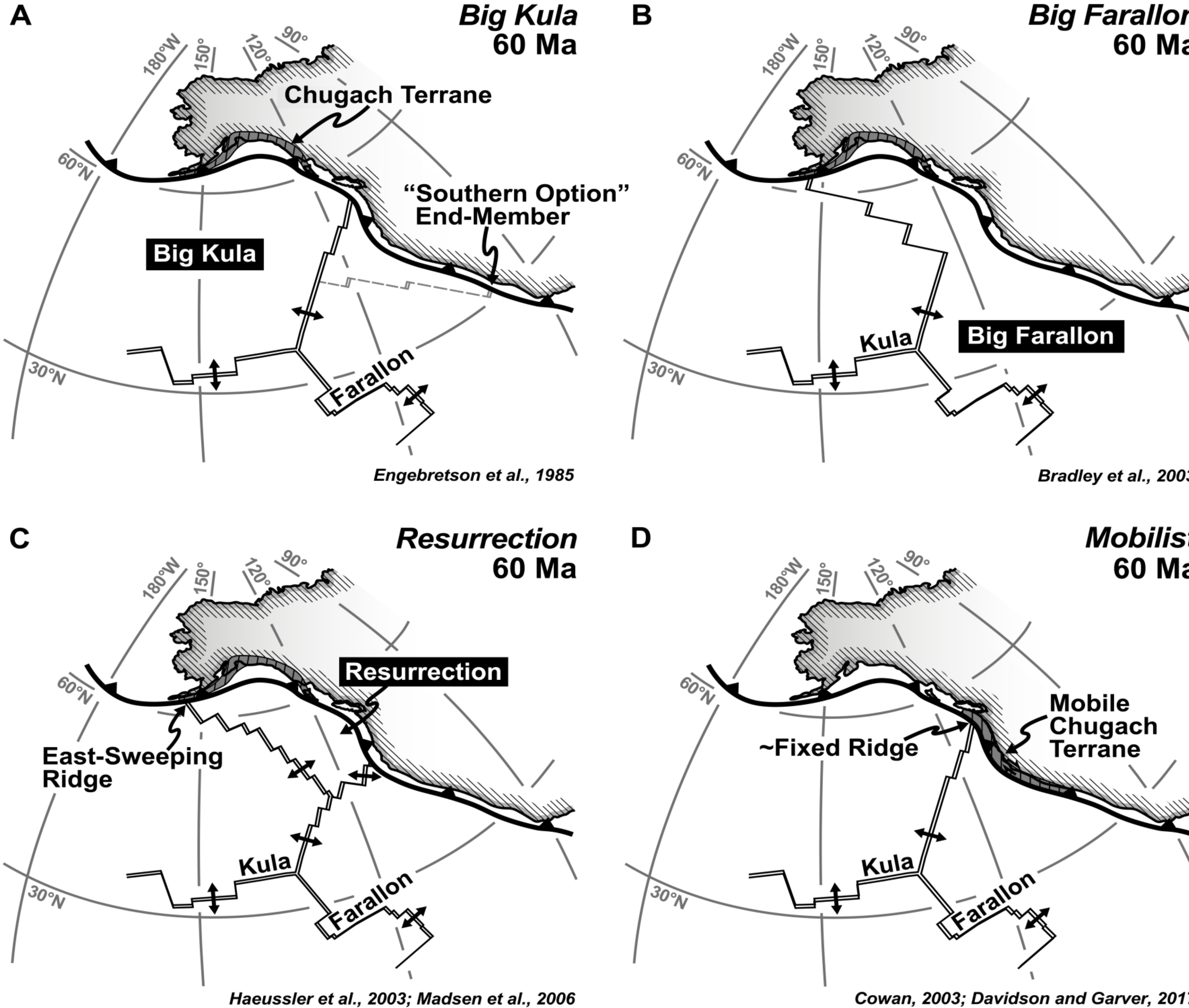


Diagram of the northern portion of the Cascadia Subduction Zone.

Siletzia is a massive formation of early to middle Eocene epoch marine basalts and interbedded sediments in the forearc of the Cascadia subduction zone,

a large fragment of Farallonoceanic lithosphere



A
Big Kula
60 Ma
180°W
150°
120°
90°
60°N
30°N
Chugach Terrane
"Southern Option" End-Member
Big Kula
Farallon
Engebretson et al., 1985
B
Big Farallon
60 Ma
Kula
Big Farallon
Bradley et al., 2003
C
Resurrection
60 Ma
Resurrection
East-Sweeping Ridge
Kula
Farallon
Haeussler et al., 2003; Madsen et al., 2006
D
Mobilist
60 Ma
Mobile Chugach Terrane
~Fixed Ridge
Kula
Farallon
Cowan, 2003; Davidson and Garver, 2017

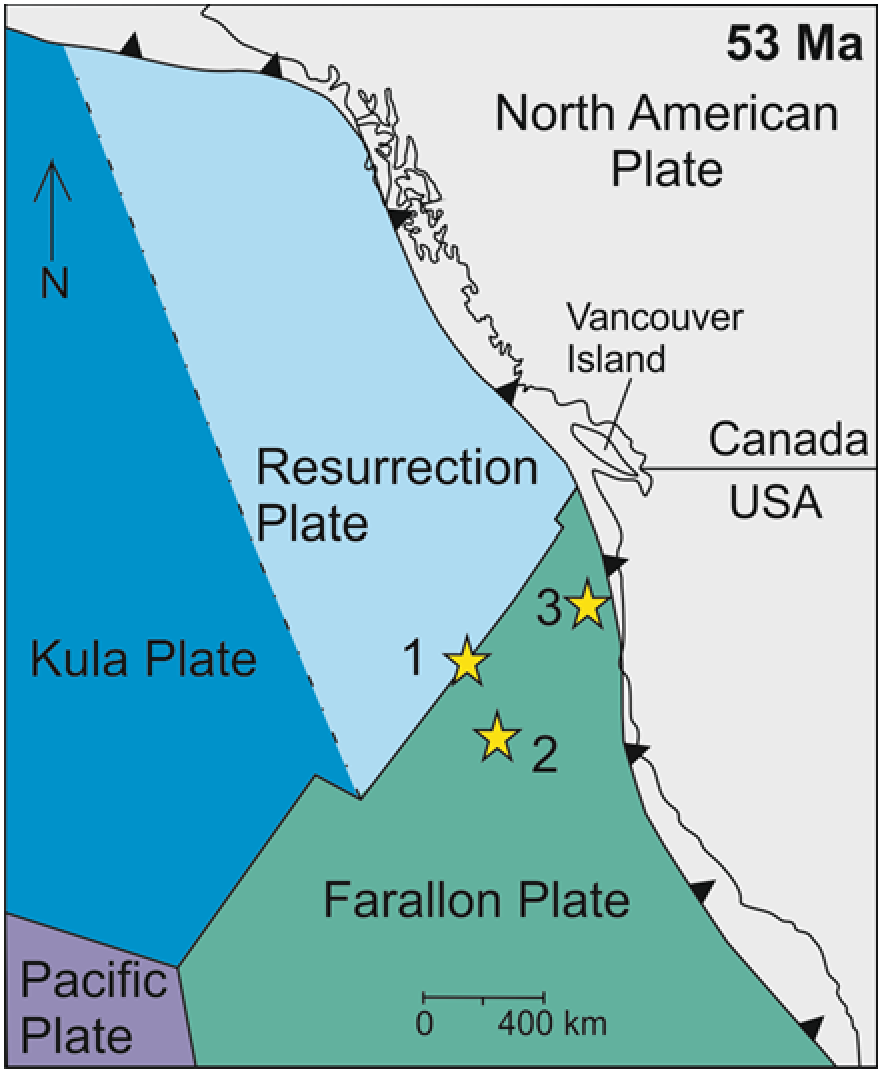
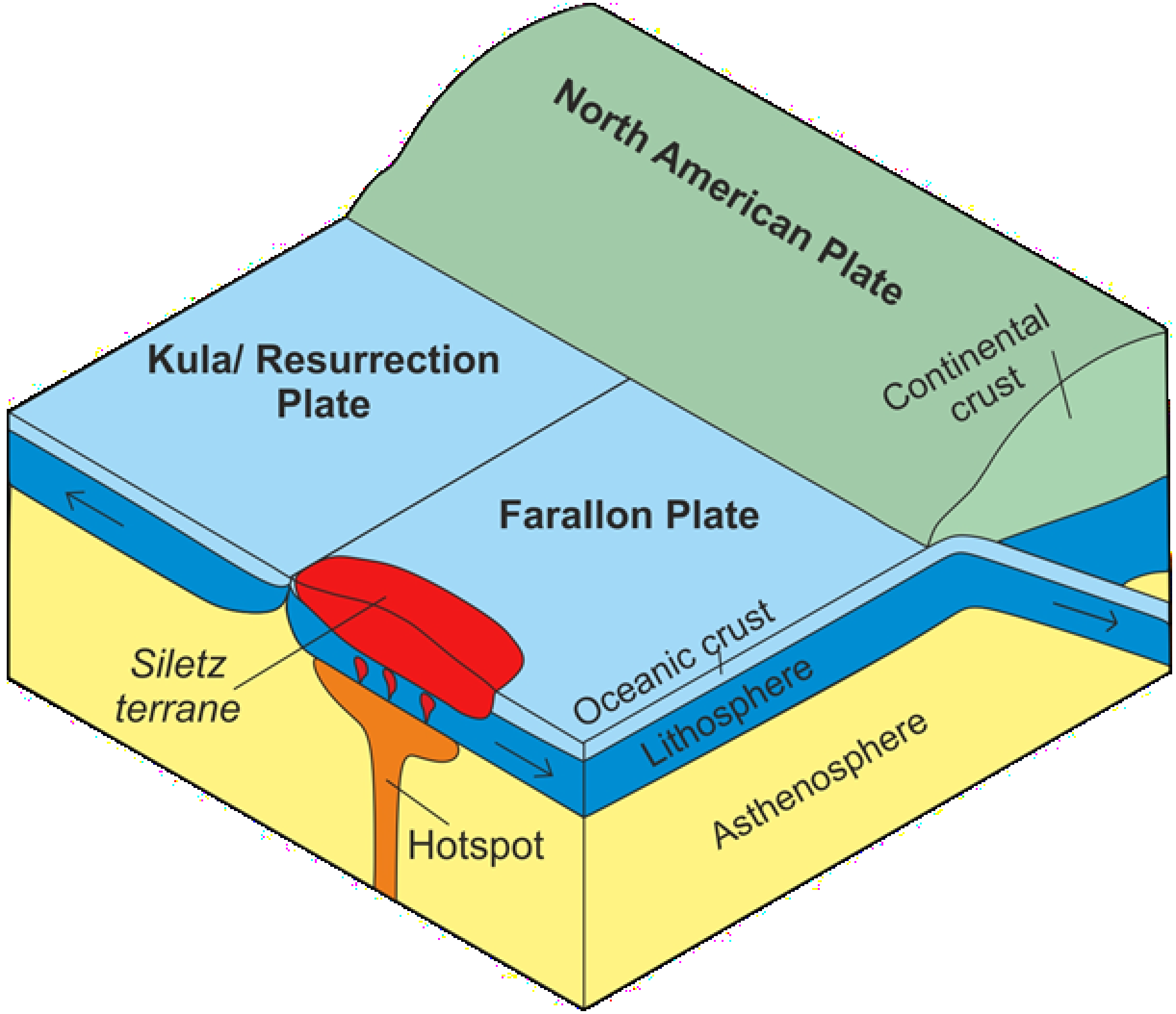
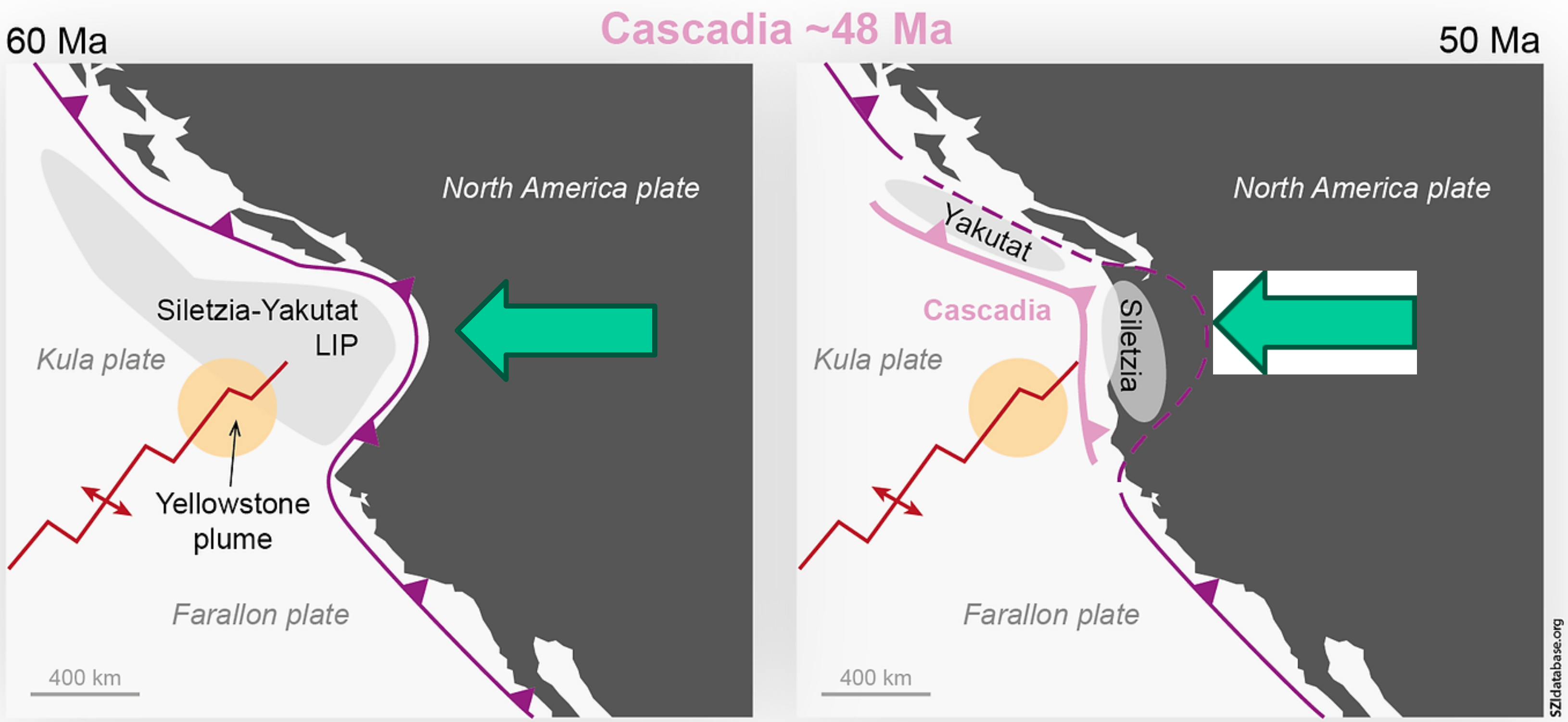


Fig. 2. Suggested plate configuration map at 53 Ma. Adapted from Haeussler et al. (2003), Seton et al. (2012) and Wells et al. (2014), where the stars represent the proposed positions of the Yellowstone hotspot; 1 (O'Neill et al. (2005), 2 (Doubrovine et al., 2012) and 3 (Müller et al., 1993).


North American Plate
Kula/ Resurrection Plate
Farallon Plate
Continental crust
Oceanic crust
Lithosphere
Asthenosphere
Siletz terrane
Hotspot



Schematic tectonic reconstruction of the Cascadia SZI event (modified from Stern and Dumitru et al., 2019 and Wells et al., 2014). **A trench jump occurred due to the accretion of the Siletzia** and Yakutat large igneous province (LIP) formed by the Yellowstone plume, initiating the new Cascadia subduction zone. Shown are the new subduction zone (pink line), other active (solid purple lines) and inactive (dashed purple lines) subduction zones, and spreading ridges (solid red lines).

The Cascadia SZI (subduction zone **initiation**) event formed the **currently active Cascadia subduction zone** at around 53 - 43 Ma (Hyndman et al., 1990; Priest, 1990; Schmandt and Humphreys, 2011; Stern and Dumitru, 2019) and **induced subduction of the Farallon and Kula plates below the North America plate**. **The Cascadia SZI event** is believed to have occurred as an episodic subduction via a **trench jump** after the large igneous province (LIP) **Siletzia accreted at the previous trench** of the Farallon/Cordilleran subduction zone (Wells et al., 2014; Stern and Dumitru, 2019). There is also an indication of the presence of the prominent **Yellowstone mantle plume** during the time of the onset, which might have been facilitated by the breaking of the intact subducting plate. It is worth noting that at the time of the trench jump there was ongoing subduction to the north and south of the Cascadia subduction zone. Although the **accretion of the Siletzia block is likely to be the main cause of the trench jump**, the nearby subduction zones in the north and south might therefore also have had a role in this SZI event.

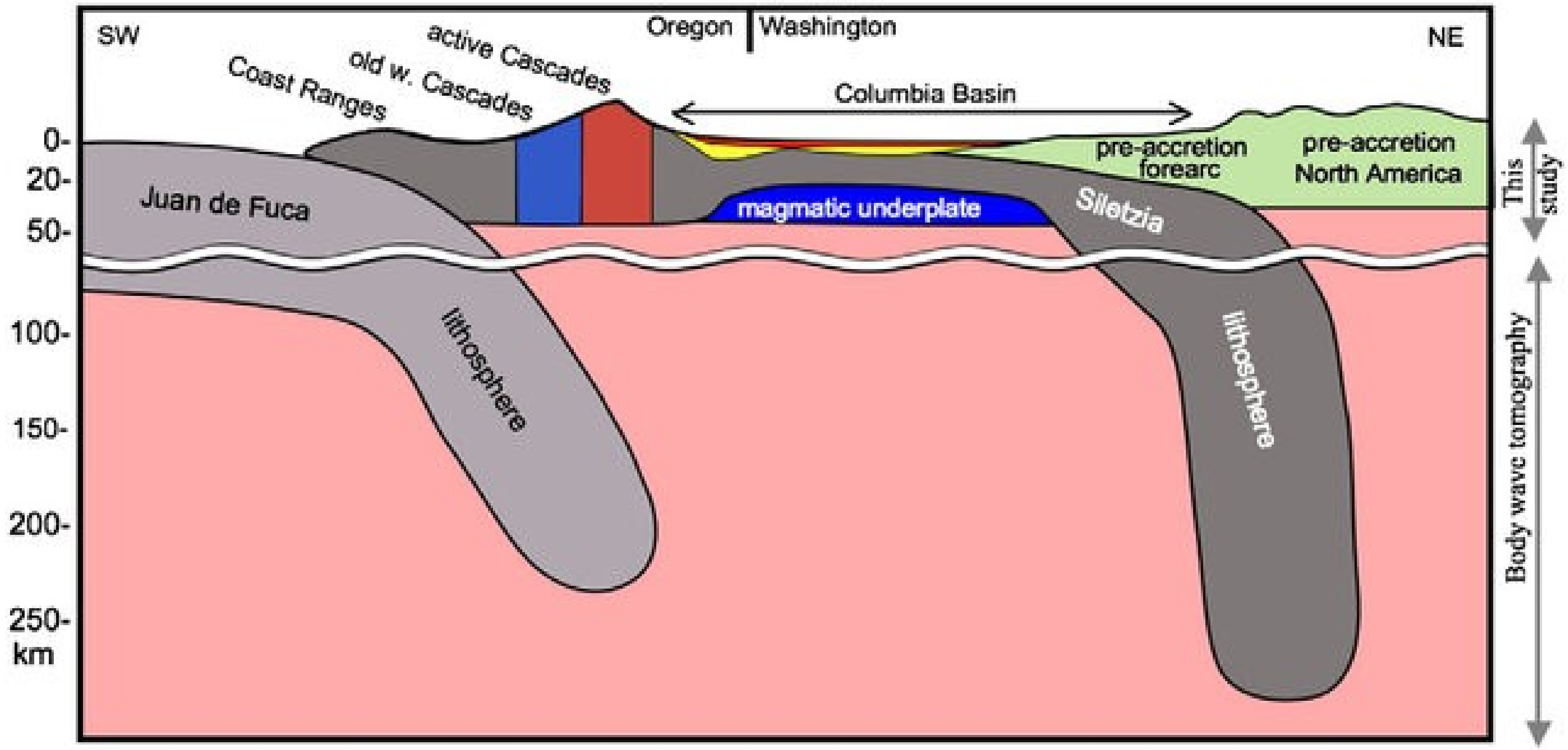
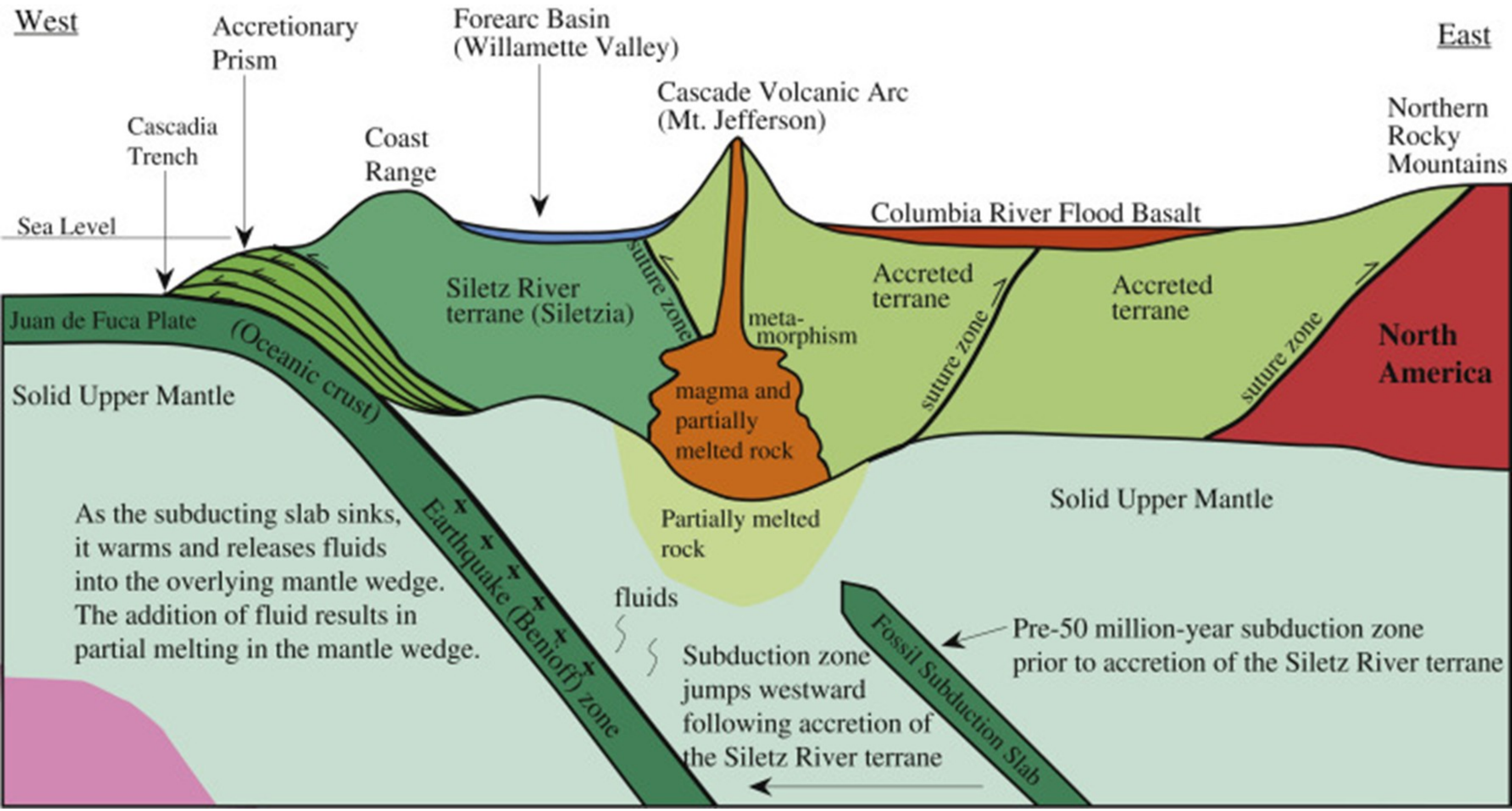
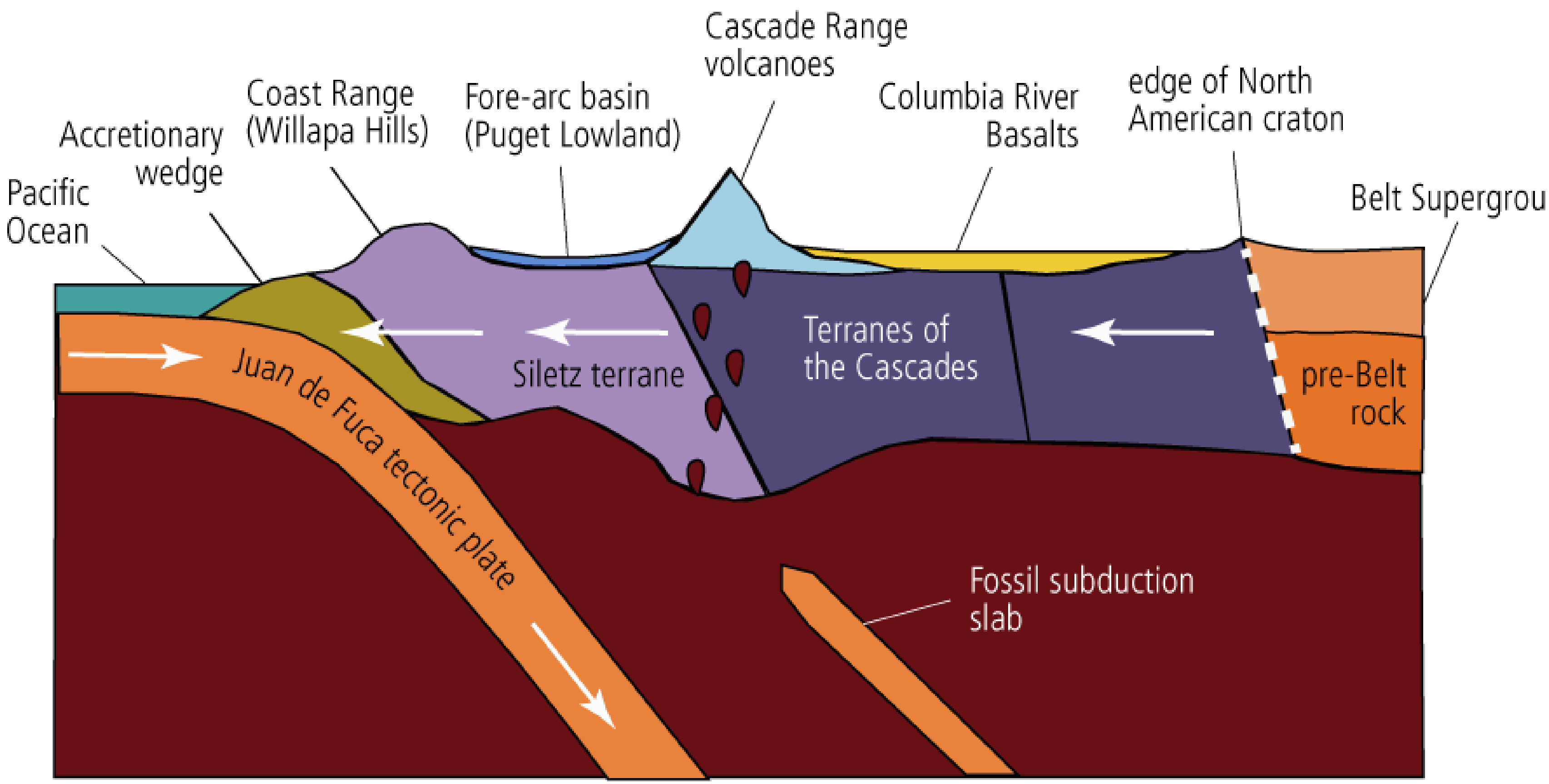


Fig. 8. Cartoon cross section illustrating the major structures inferred from our ambient-noise tomography, emphasizing the inferred distribution of S**iletzia lithosphere (dark gray).** Cross section location shown in Fig. 2.. The western **Columbia Basin** is underlain by the Columbia River ood basalts (red), deep sediment filled Eocene basins (yellow), extended **Siletzia** lithosphere, and magmatic underplate (dark blue). Below the northeastern Columbia Basin, Siletzia lithosphere is shown below the pre-accretion North America crust. From the body wave tomography, Siletzia lithosphere is thought to descend vertically beneath mountainous northeastern Washington.



Siletzia is a massive formation of early to middle Eocene epoch marine basalts and interbedded sediments in the forearc of the Cascadia subduction zone, on the west coast of North America.


Cascade Range
volcanoes
Coast Range
(Willapa Hills)
Fore-arc basin
(Puget Lowland)
Columbia River
Basalts
edge of North
American craton
Accretionary
wedge
Pacific
Ocean
Belt Supergroup
Terranes of
the Cascades
Siletz terrane
pre-Belt
rock
Juan de Fuca tectonic plate
Fossil subduction
slab

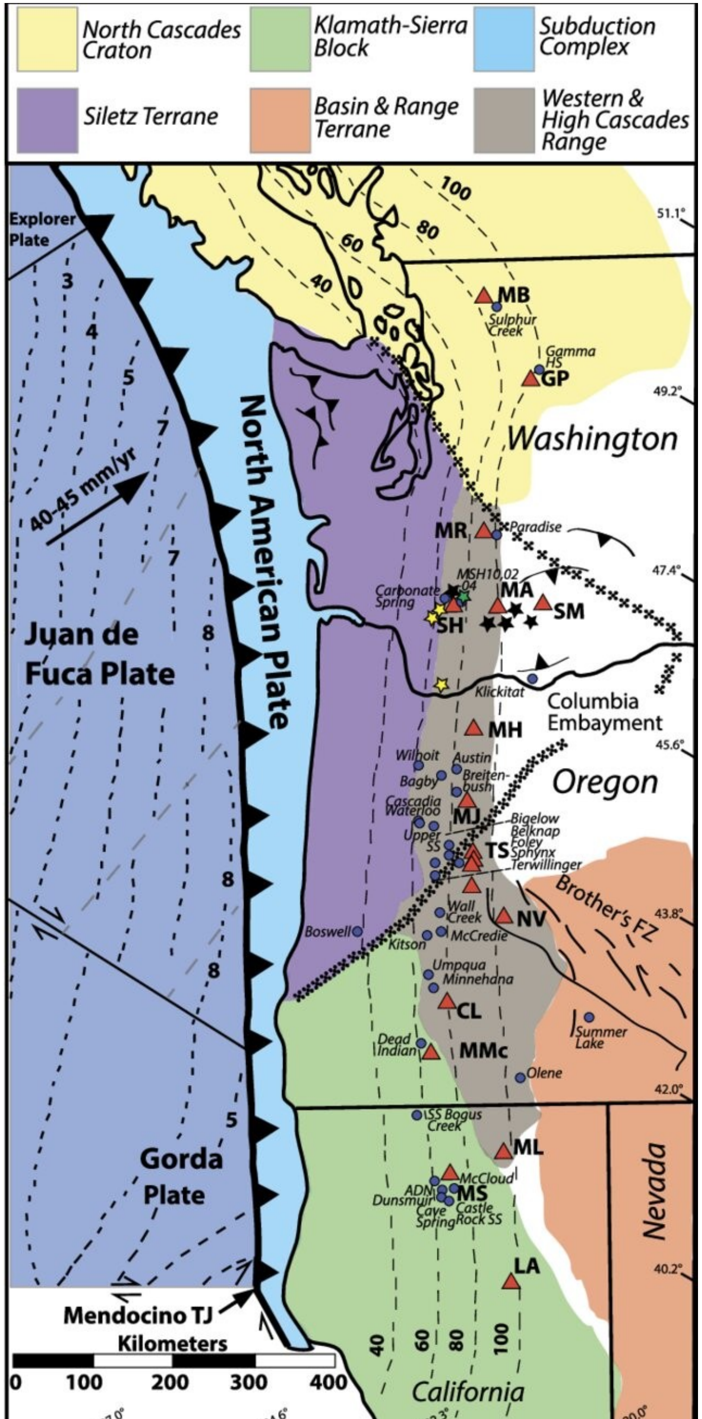


Fig. 1. Map of isotopically distinguishable terranes along the **Cascade volcanic arc** as outlined by Schmidt et al. (2008). Dashed contours show approximate depths to the slab in km (McCrory et al., 2004). Dashed lines on oceanic plates are magnetic anomalies (Wilson, 1988). Major volcanoes are illustrated as red triangles: (LA) Lassen, (MS) Mt. Shasta, (ML) Medicine Lake, (MMc) Mt. McLaughlin, (CL) Crater Lake, (NV) Newberry Volcano, (TS) Three Sisters, (MJ) Mt. Jefferson, (MH) Mt. Hood, (SH) Mt. St. Helens, (MA) Mt. Adams, (SM) Simcoe, (MR) Mt. Rainer, (GP) Glacier Peak, (MB) Mt. Baker, (MG), Mt. Garibaldi, (MC). Mt. Cayley, (MM) Mt. Meager.

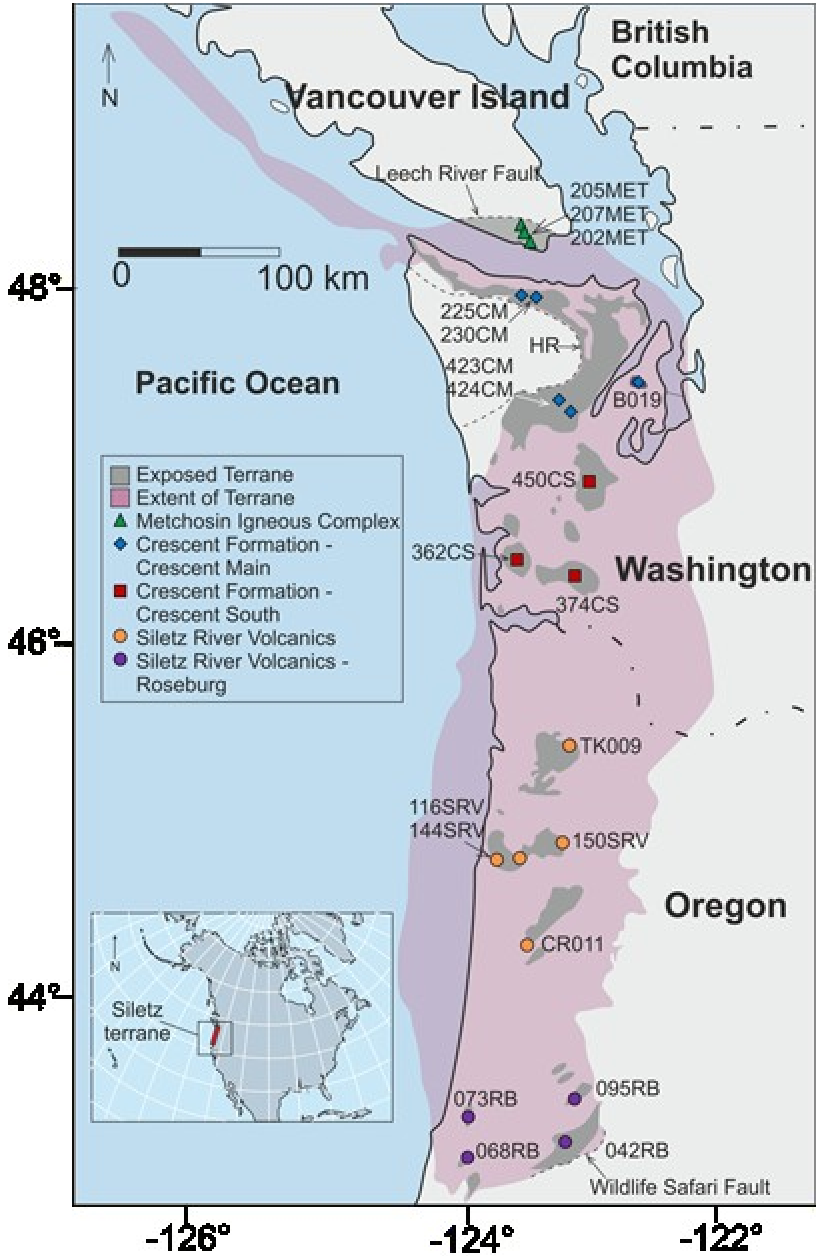


Fig. 1. Map of the extent and exposed areas of the Siletz Terrane, adapted from McCrory and Wilson (2013). HR – Hurricane Ridge Fault.

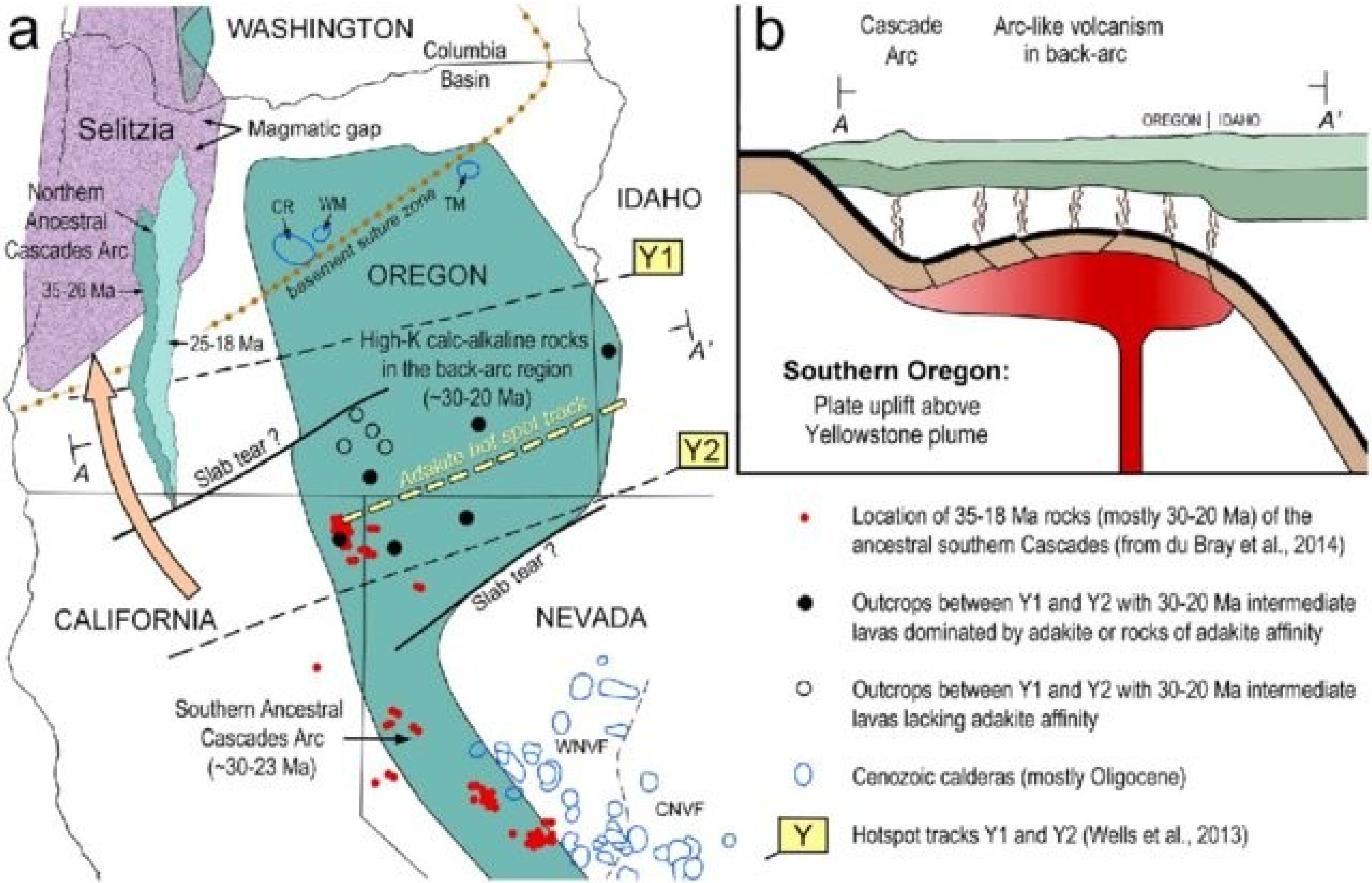
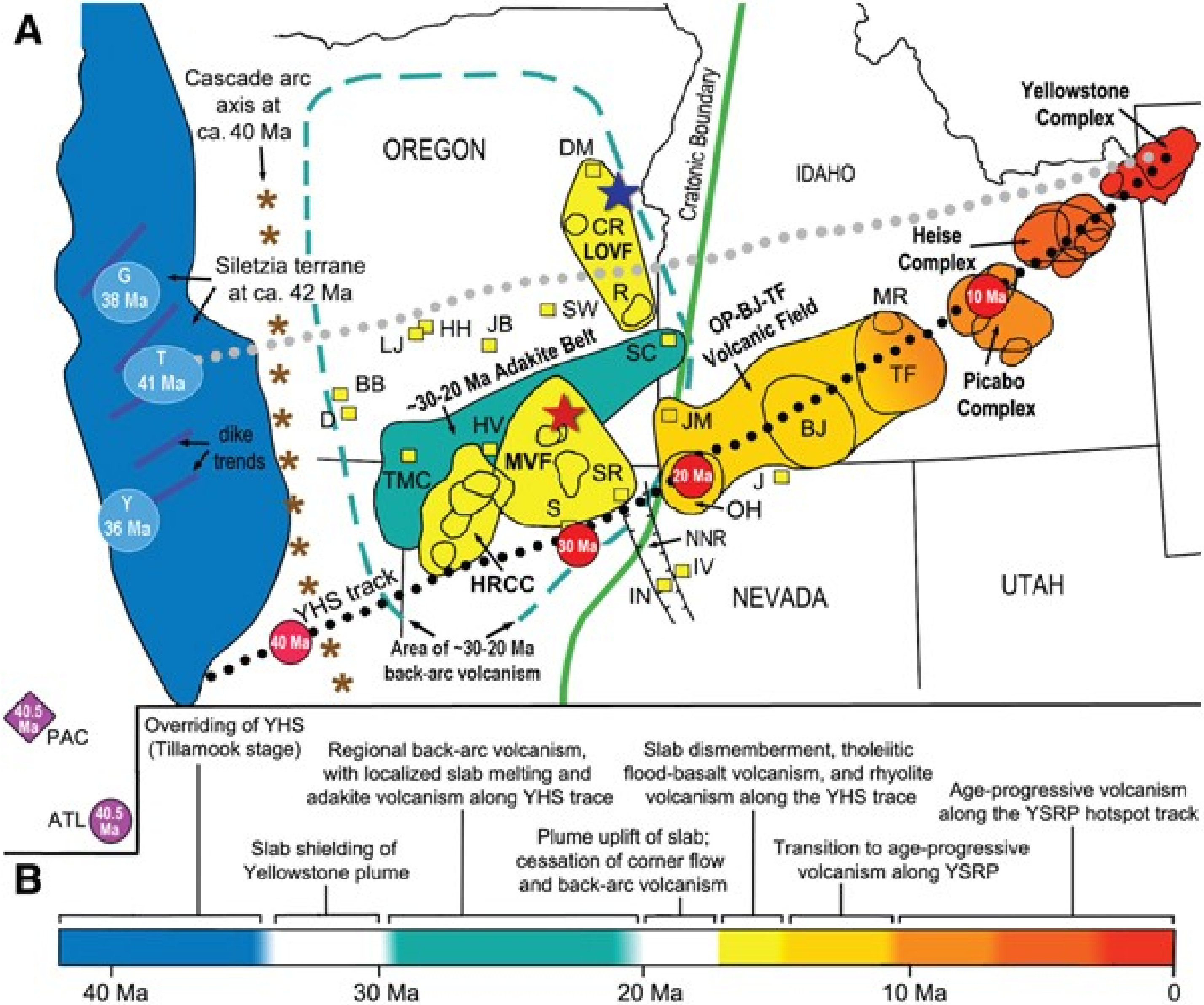
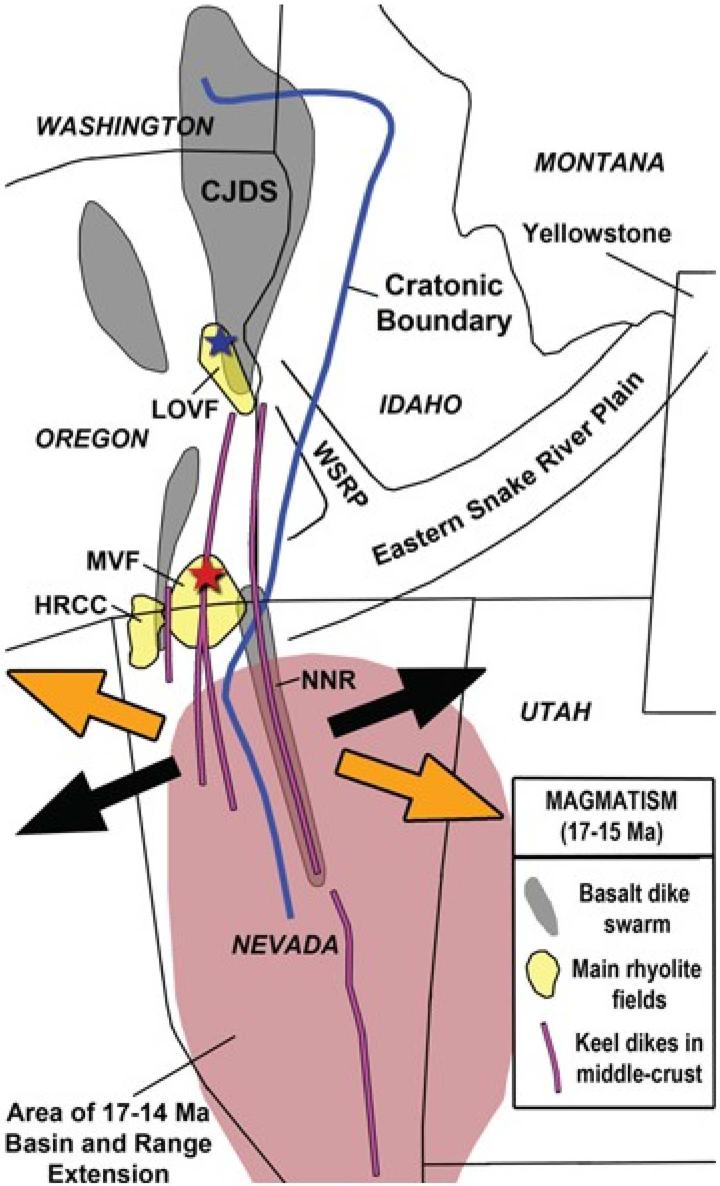


Figure 12. (a) Distribution of Oligocene to early Miocene volcanism in the ancestral Cascade arc and back-arc regions.



They suggest that the Siletzia basalts are a product of the Yellowstone Hot Spot before the North American Plate moved on it. The relatively thin oceanic crust would have been more easily pierced by the upward-welling plume, resulting in prodigious underwater lava flows. Hence, Siletzia. This illustration, from Camp and Wells' article, shows their idea:



Palinspastic reconstruction of bimodal volcanism along the Nevada–Columbia Basin magmatic belt from ca. 17–15 Ma, with southernmost extension based solely on aeromagnetic data. See Figure 1 for definition of red and blue stars and volcanic fields HRCC, MVF, LOVF, and NNR. Orange arrows depict the orientation of mid-Miocene Basin-and-Range extension; black arrows depict the overall dilation direction of coeval mid-Miocene dikes. CJDS–Chief Joseph dike swarm, where 85% of the Columbia River Basalt Group volume erupted. Area of 17–14 Ma extension from Colgan and Henry (2009). WSRP—Western Snake River Plain.

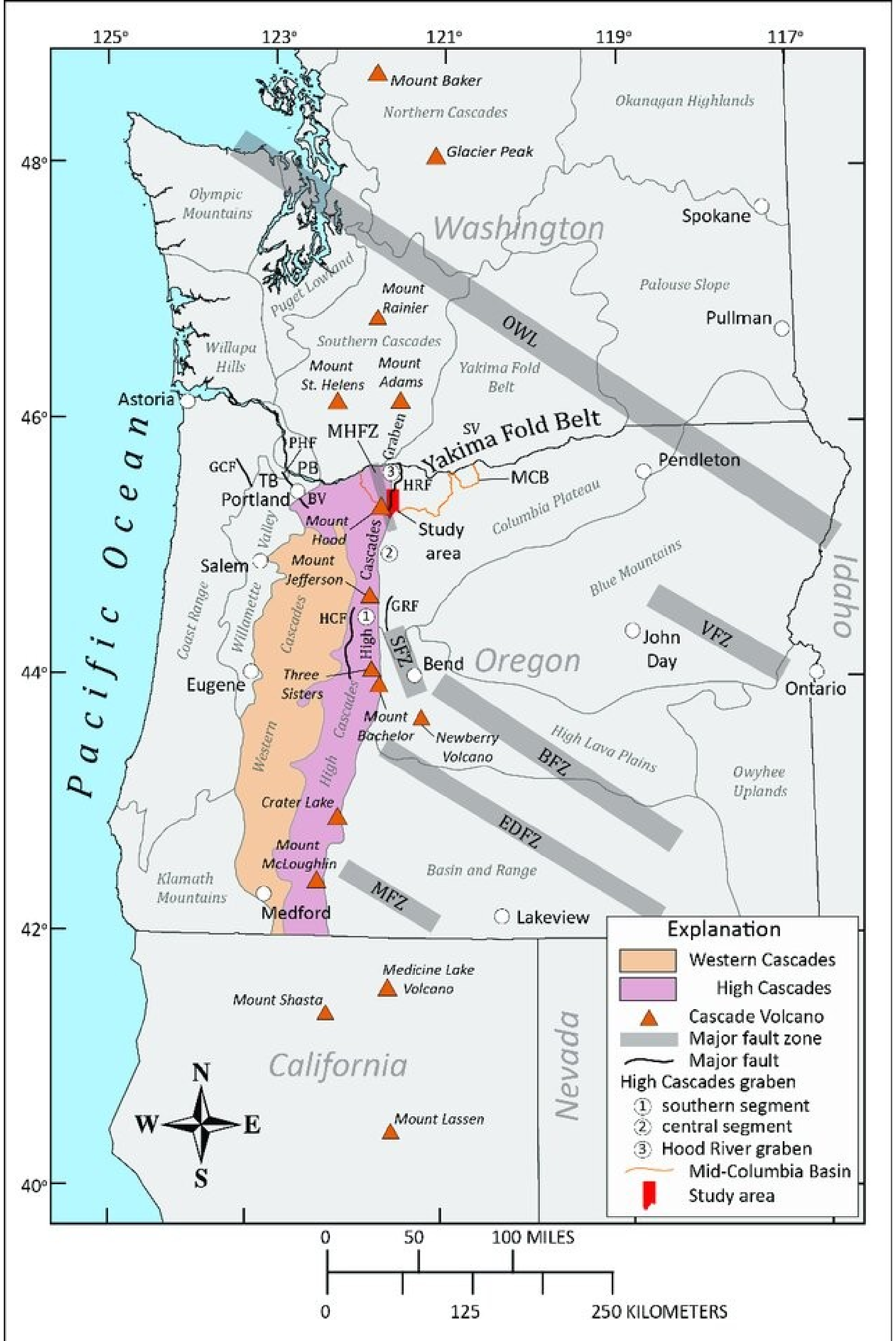


Figure 5-2. Map of the Cascade Range in the Pacific Northwest showing geographic locations, approximate extent of Western (tan) and High Cascades (purple), and the spatial relationships of some major structural features in Oregon. Note that the names Western Cascades and High Cascades are not used in Washington or south of Mount Shasta in California.

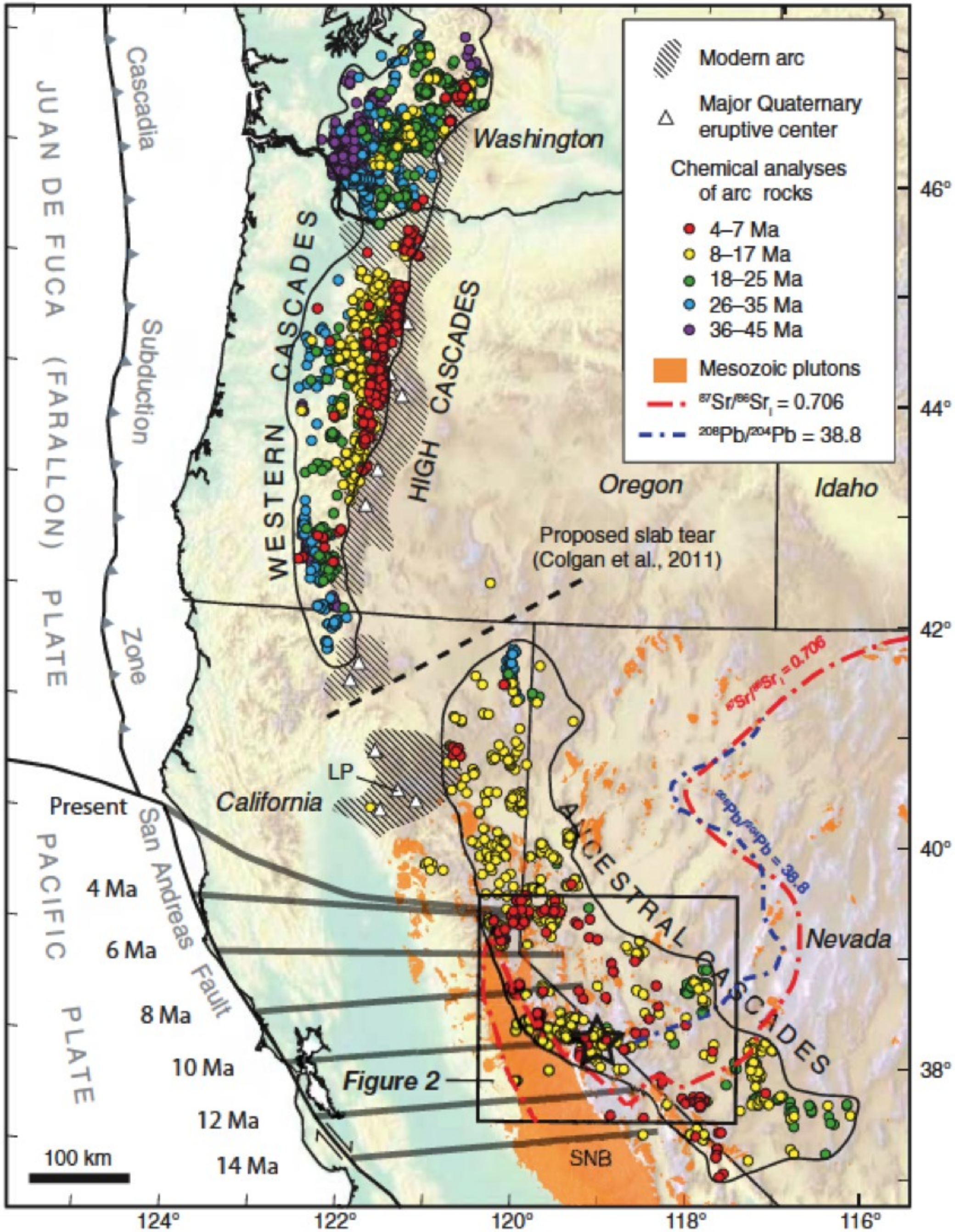
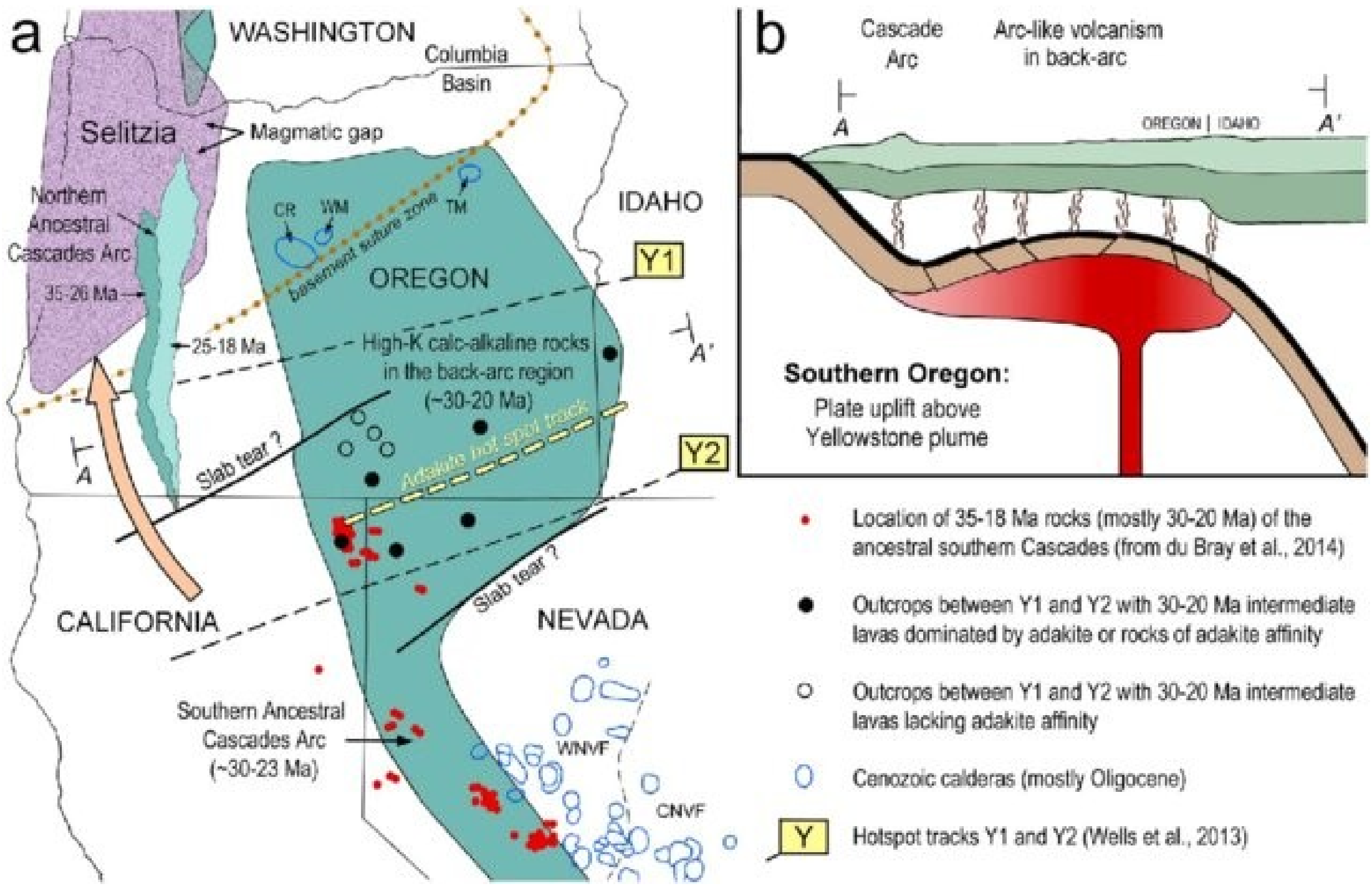
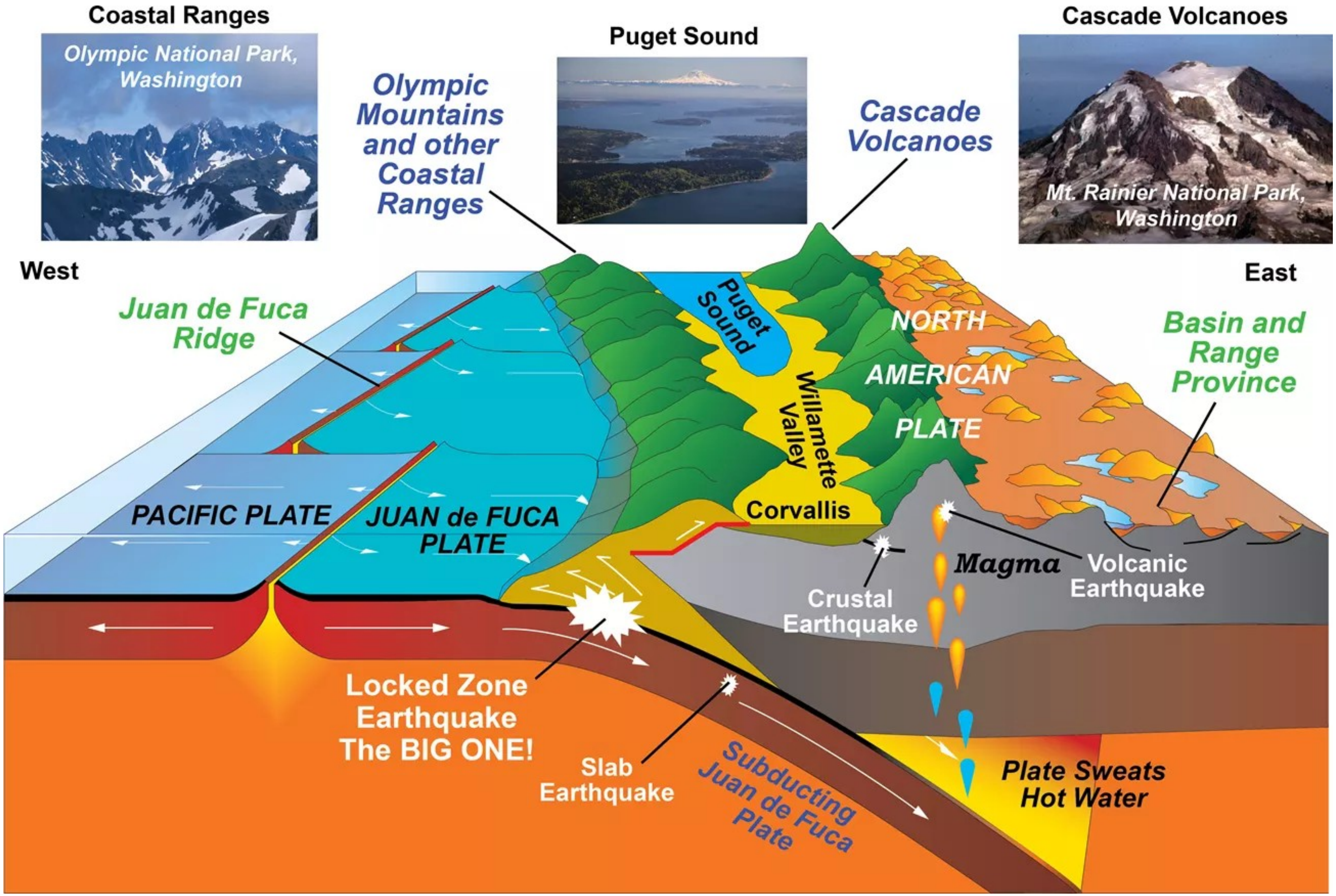


Figure 1. Map showing the locations of dated Ancestral Cascade deposits along the west coast. From John et al. 2012.

Southern ancestral Cascades

Low-angle subduction prior to ca. 52 Ma began to roll back, causing a magmatic migration across the Great Basin that culminated with Oligocene–Miocene ancestral Cascade arc activity in Nevada and southern California





Subduction of the Juan de Fuca Plate results in the formation of the Coastal Ranges and Cascade Volcanoes, as well as a variety of earthquakes, in the Pacific Northwest. Olympic and Mt. Rainier national parks showcase the contrasting landscapes of the two parallel mountain ranges.

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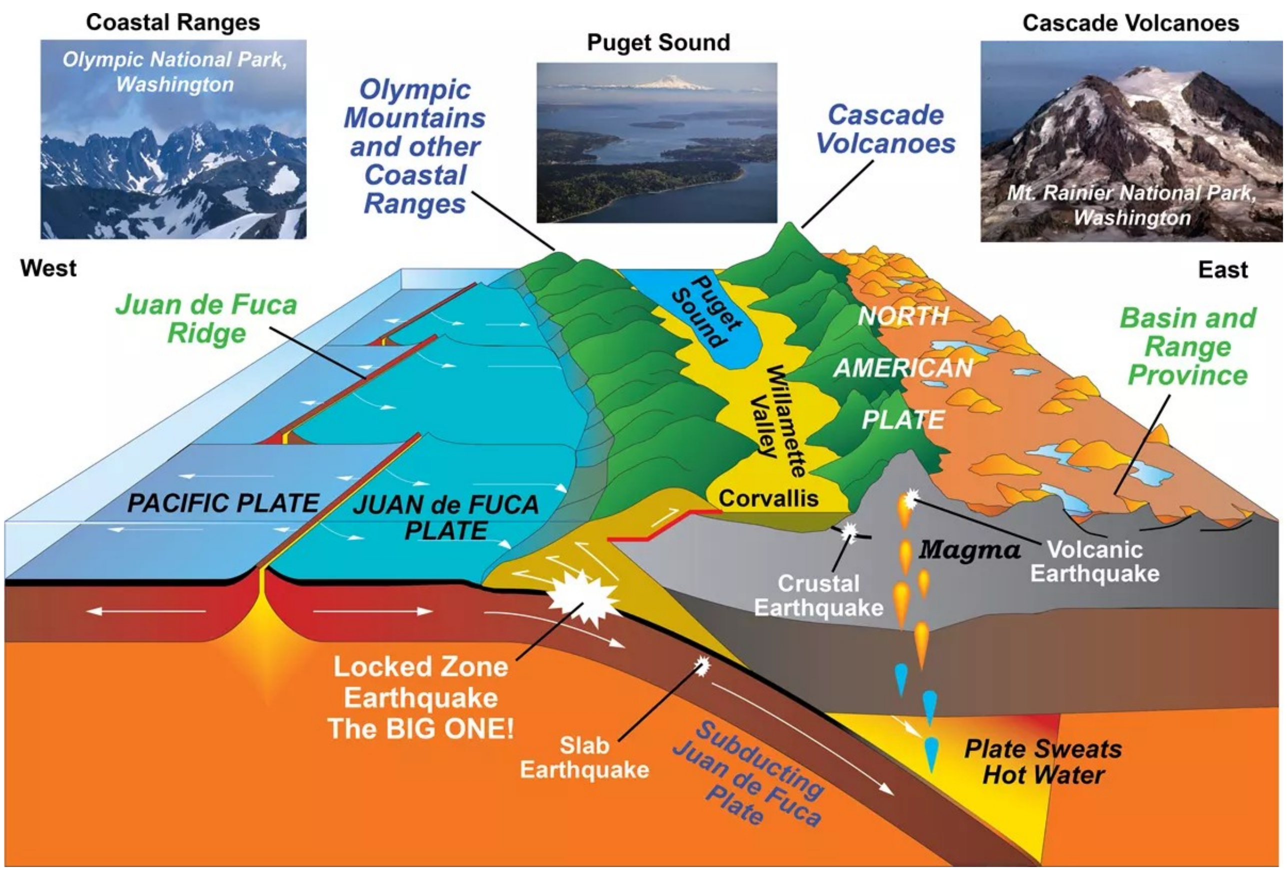
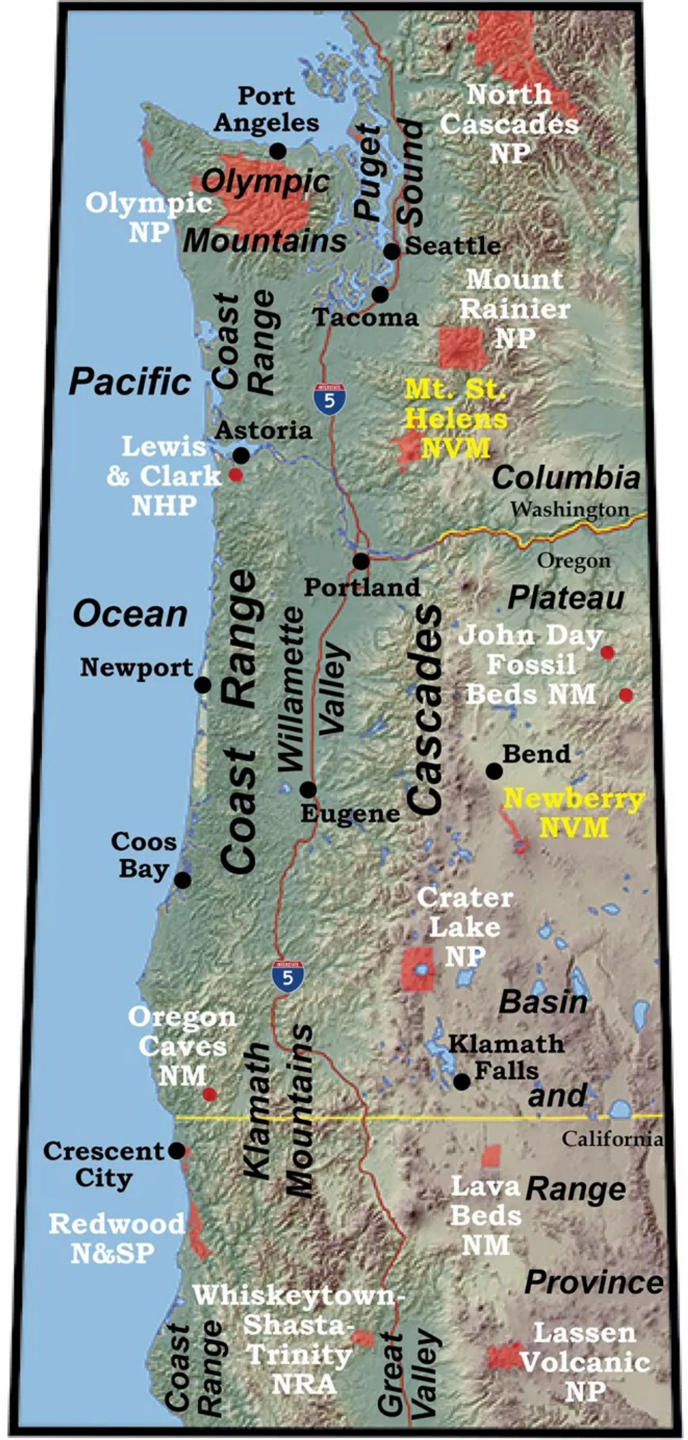
Coast Range

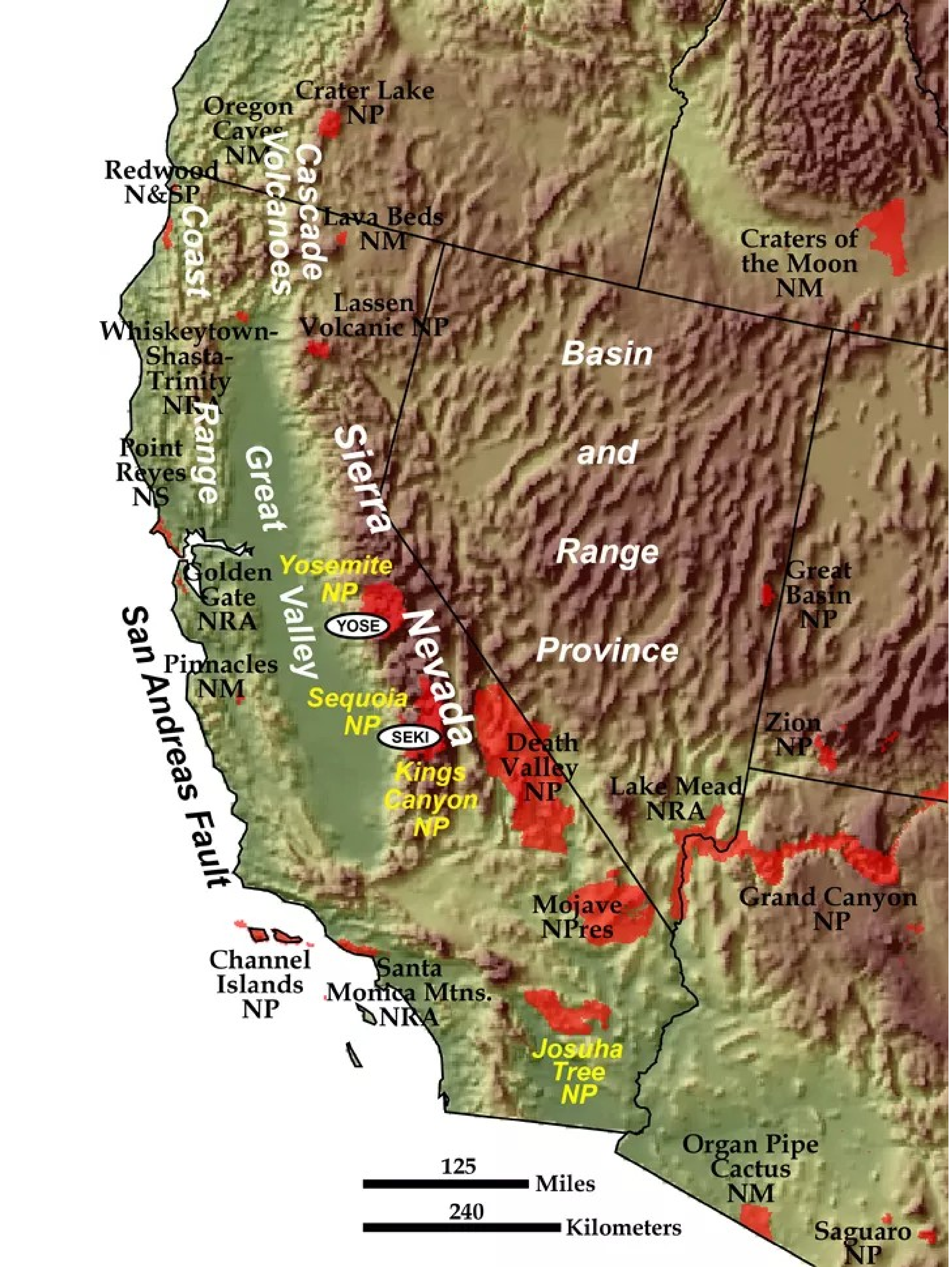
The Coast Range (including the Olympic Mountains) consists of sedimentary rock layers and hard crust scraped off the ocean floor where the Juan de Fuca Plate begins to dive downward.



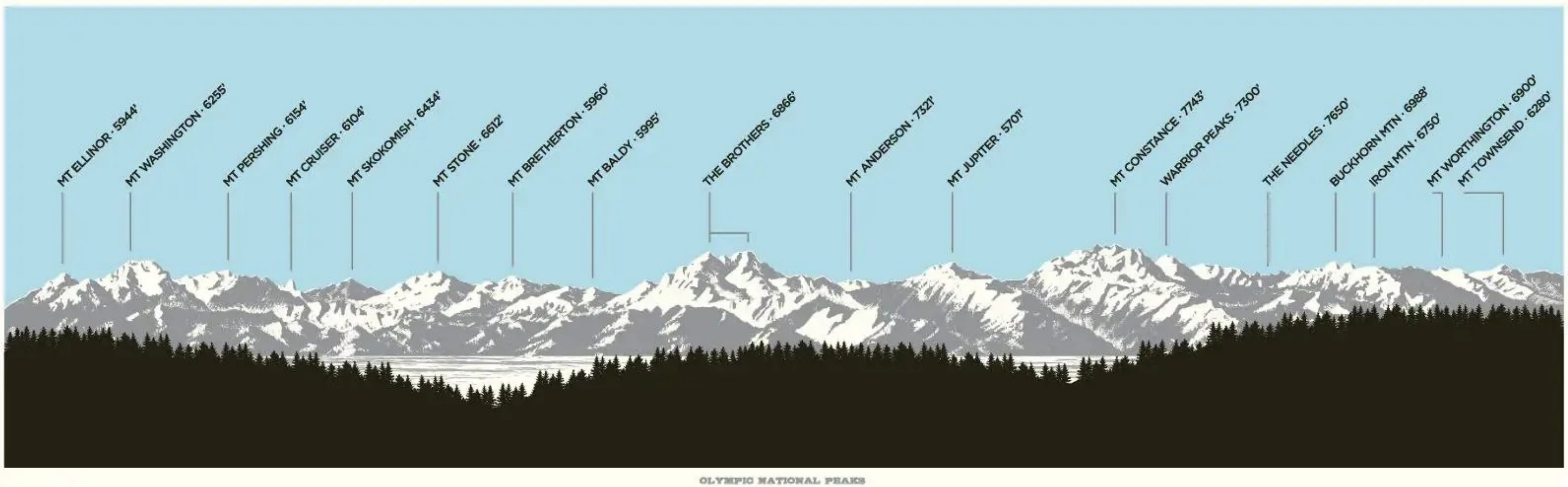
Subduction of the Juan de Fuca Plate results in the formation of the Coastal Ranges and Cascade Volcanoes, as well as a variety of earthquakes, in the
Northwest. Olympic and Mt. Rainier national parks showcase the contrasting landscapes of the two parallel mountain ranges..



Port Angeles
Olympic Mountains
Olympic NP
Puget Sound
North Cascades NP
Seattle
Tacoma
Mount Rainier NP
Coast Range
Pacific
5
Mt. St. Helens NVM
Astoria
Lewis & Clark NHP
Columbia
Washington
Oregon
Portland
Plateau
Ocean
Coast Range
Willamette Valley
Cascades
John Day Fossil Beds NM
Newport
Bend
Newberry NVM
Eugene
Coos Bay
Crater Lake NP
5
Basin
Oregon Caves NM
Klamath Mountains
Klamath Falls
and
California
Crescent City
Lava Beds NM
Range
Redwood N&SP
Province
Whiskeytown-Shasta-Trinity NRA
Coast Range
Great Valley
Lassen Volcanic NP



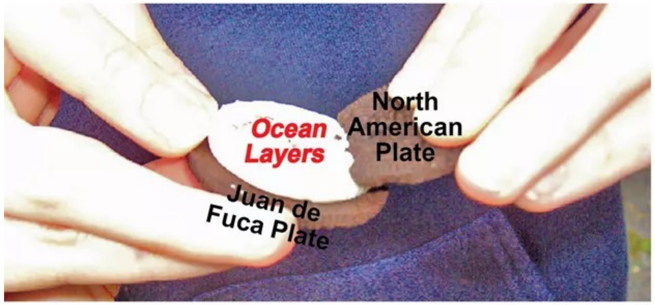
The Sierra Nevada are a remnant of volcanoes that extended southward when the ancient Farallon Plate dove beneath the edge of North America. The Coast Range (accretionary wedge), Great Valley (forearc basin), and Sierra Nevada (volcanic arc) still reflect the subduction zone topography. Rocks in Yosemite, Kings Canyon, Sequoia, and Joshua Tree national parks contain exumed magma chamber rock that formed beneath the ancient volcanoes. National Park Service sites are shown in red. Four-letter codes indicate the ancient volcanic arc parks listed near the top of this page.



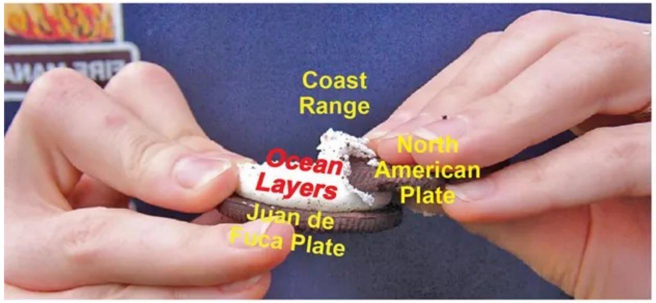
The mountains, part of the Pacific Coast Ranges, are not especially high – Mount Olympus is the highest summit at 7,980 ft (2,432 m)

Mount Waddington in Canada 4019m

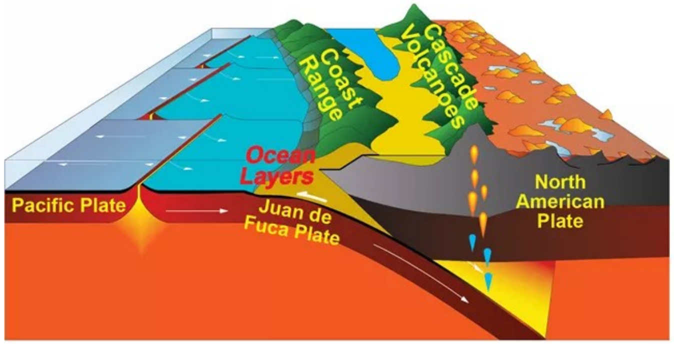
Jennifer Natoli



Jennifer Natoli



Jennifer Natoli



The Coast Range (including the Olympic Mountains) consists of sedimentary rock layers and hard crust scraped off the ocean floor where the Juan de Fuca Plate begins to dive downward. The grinding action also produces devastating earthquakes, including some that result in giant tsunami waves.

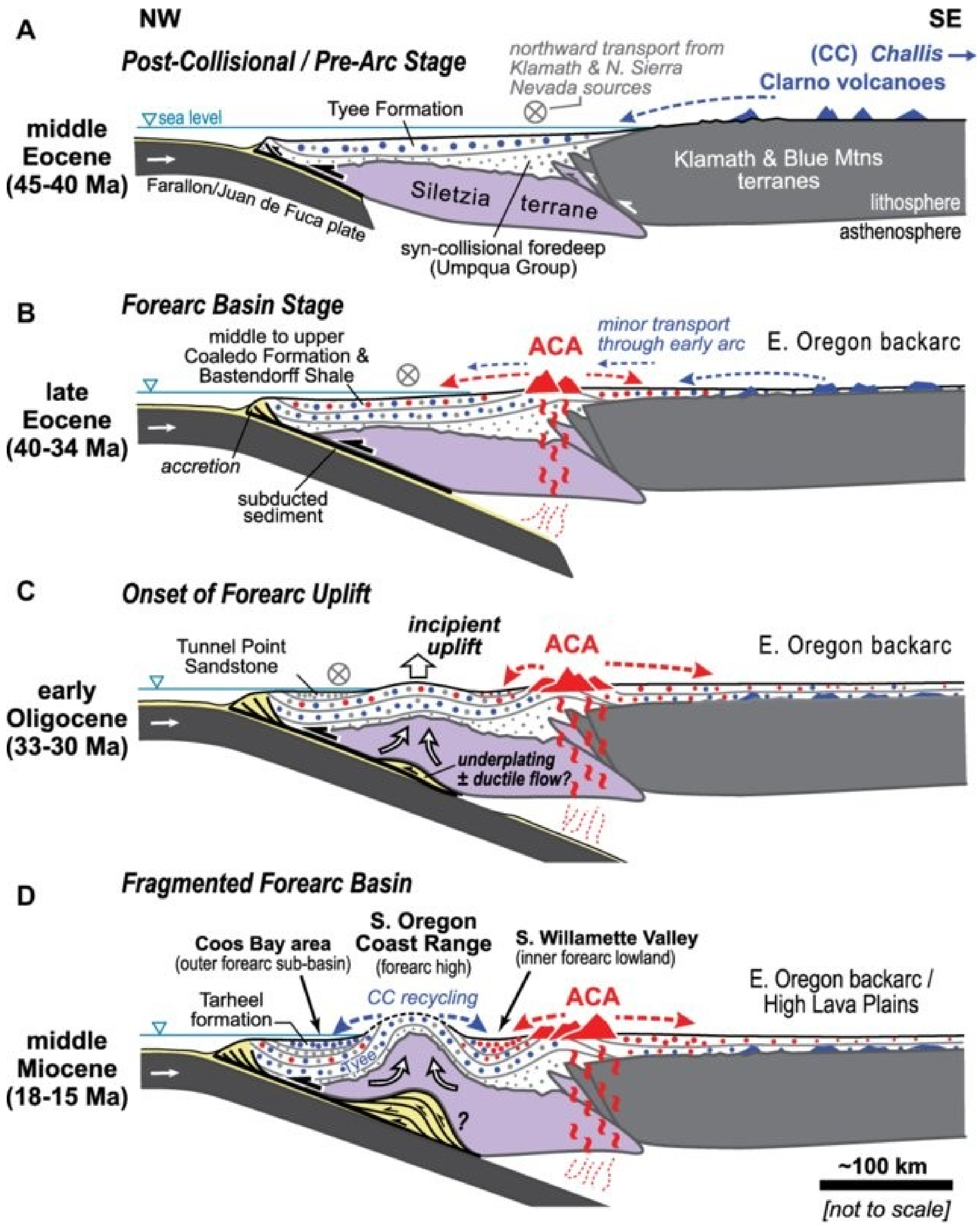
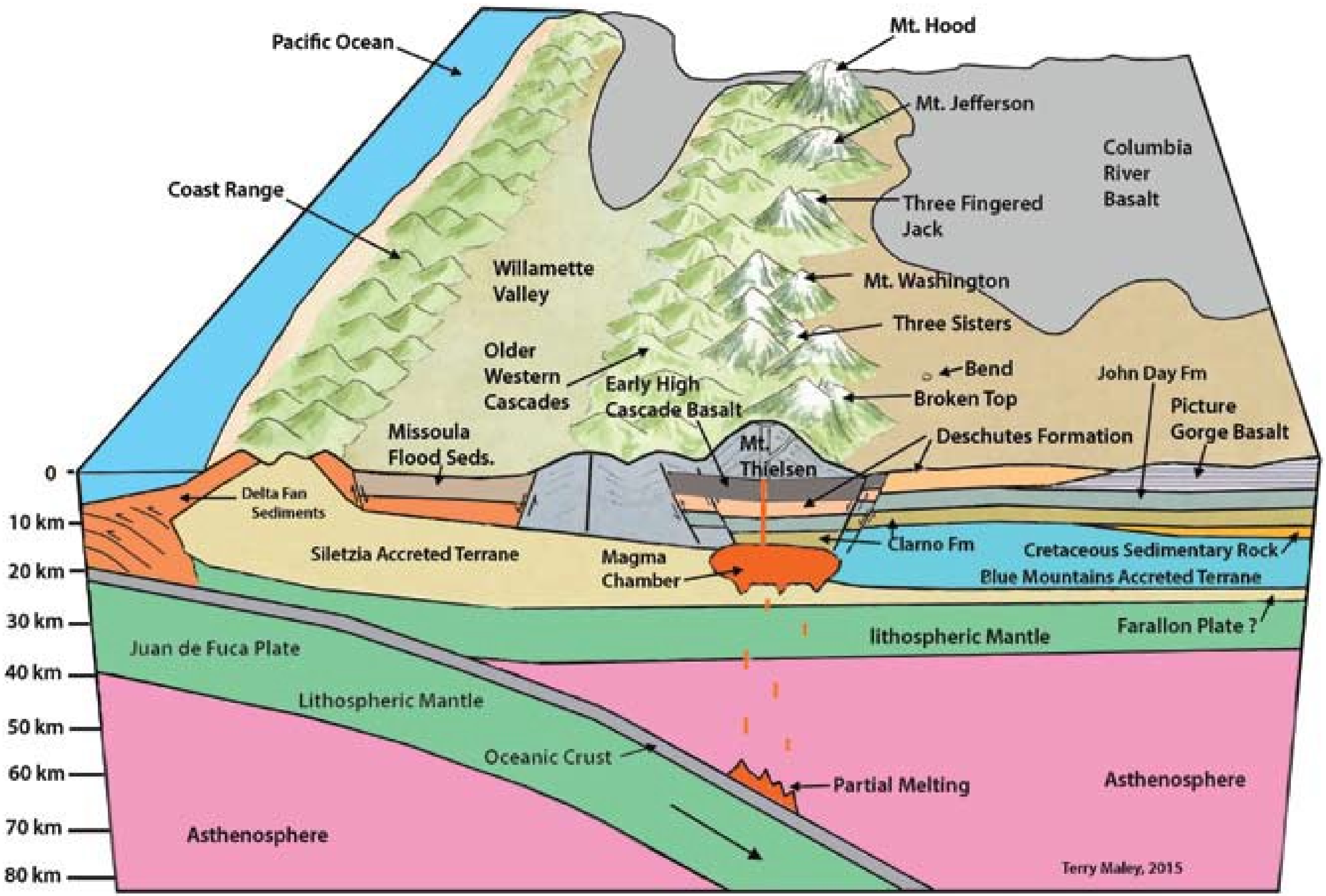
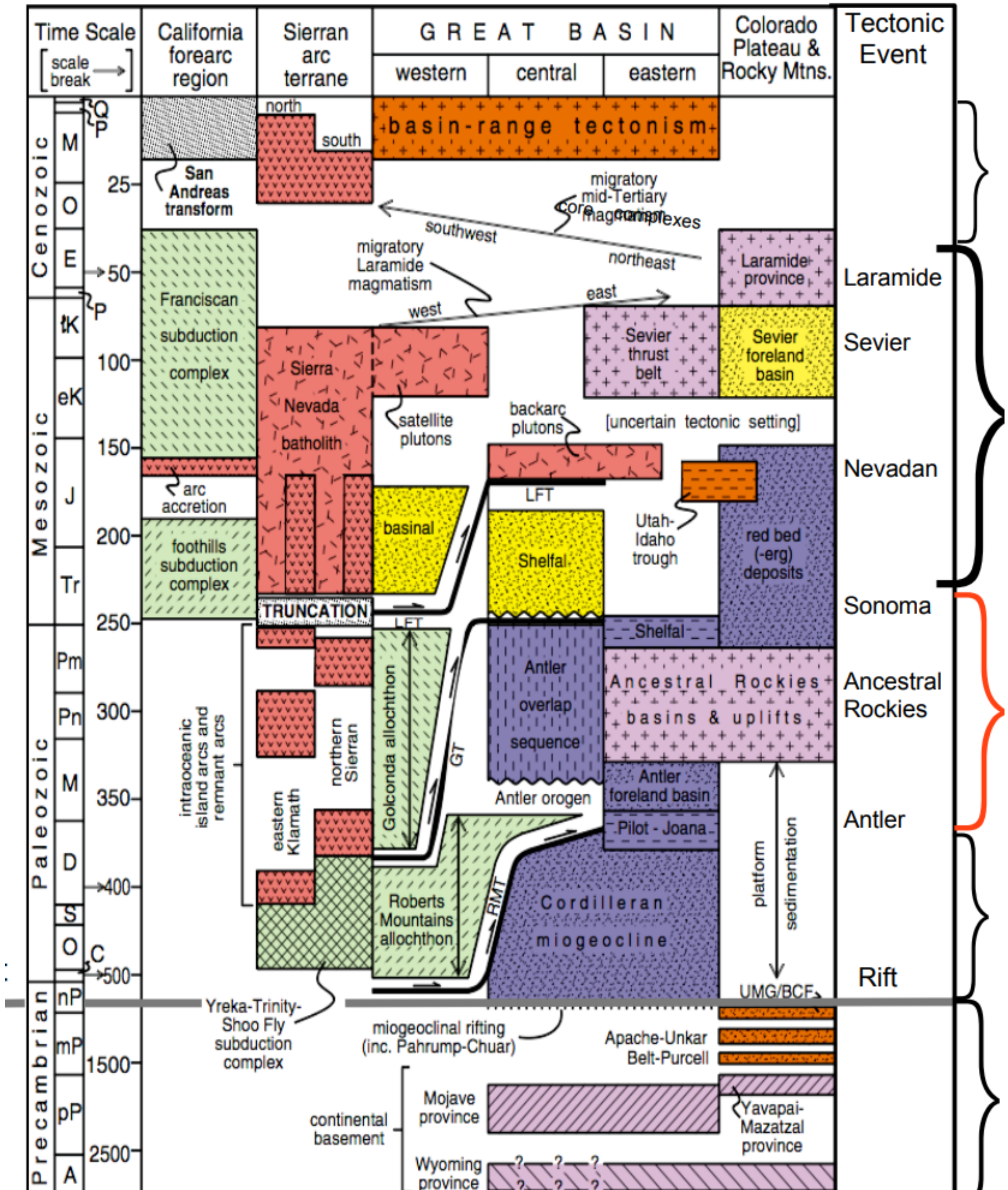


Figure 3. Cross-section diagrams illustrating Cenozoic tectono-sedimentary evolution of the Cascadia forearc and the Oligocene emergence of the southern Oregon Coast Range; see text for details. ACA- Ancestral Cascades arc.



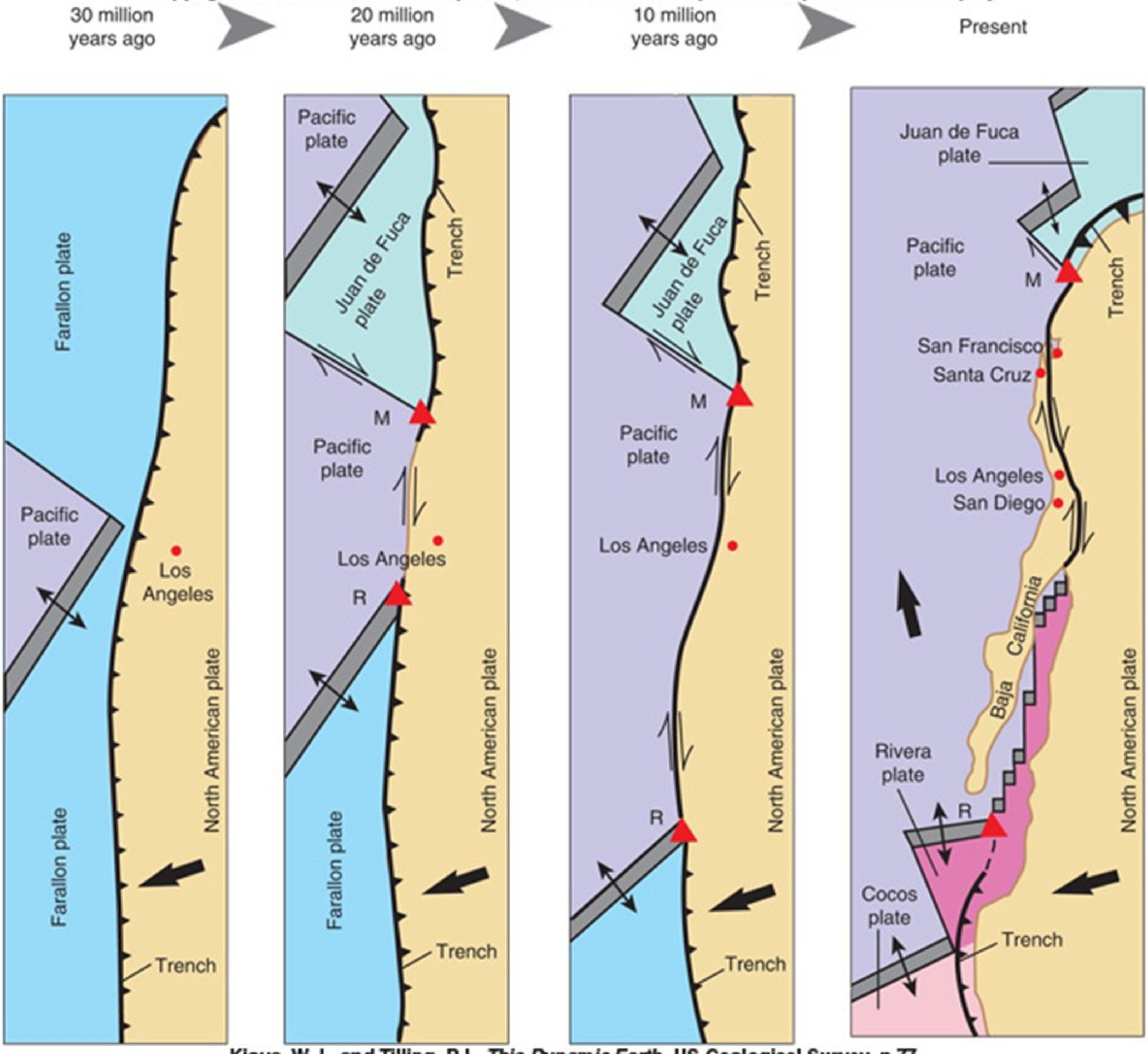
Block diagram showing a cross section across the **Coast Range**,Willamette Valley, older **Western Cascades**, **High Cascades** and the High Lava Plateau of northern Oregon.

East <--> West

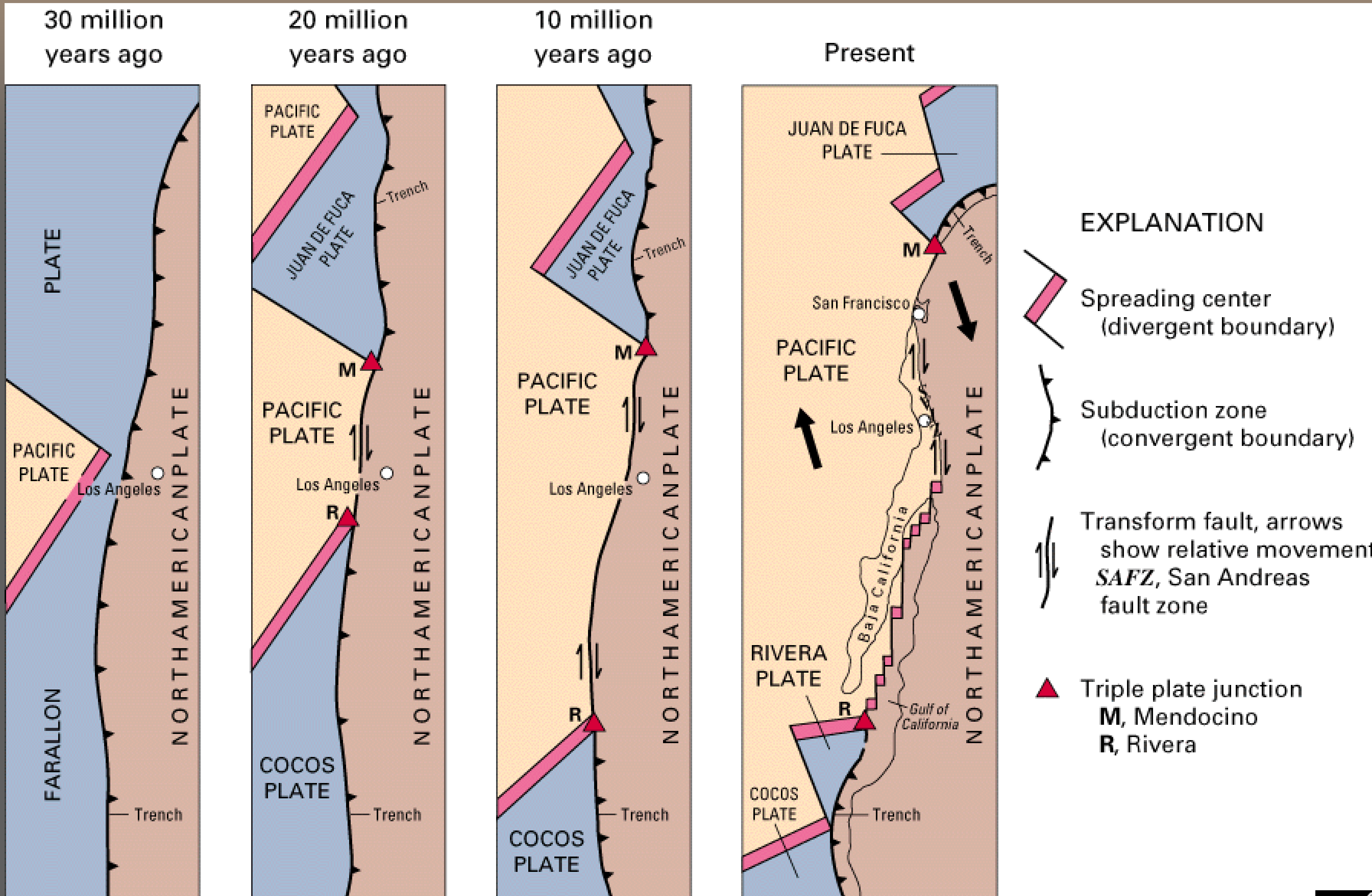


Time Scale
scale break
California forearc region
Sierran arc terrane
GREAT BASIN
western
central
eastern
Colorado Plateau & Rocky Mtns.
Tectonic Event
Cenozoic
Mesozoic
Paleozoic
Precambrian
Q
P
M
O
E
P
lK
eK
J
Tr
Pm
Pn
M
D
S
O
C
nP
mP
pP
A
25
50
100
150
200
250
300
350
400
500
1500
2500
north
south
basin-range tectonism
San Andreas transform
migratory mid-Tertiary magmatism
core complexes
southwest
northeast
Franciscan subduction complex
migratory Laramide magmatism
west
east
Laramide province
Sierra Nevada batholith
Sevier thrust belt
Sevier foreland basin
satellite plutons
backarc plutons
[uncertain tectonic setting]
arc accretion
LFT
Utah-Idaho trough
basinal
Shelfal
red bed (-erg) deposits
foothills subduction complex
TRUNCATION
LFT
Shelfal
intraoceanic island arcs and remnant arcs
northern Sierra
eastern Klamath
Golconda allochthon
GT
Antler overlap sequence
Ancestral Rockies basins & uplifts
Antler orogen
Antler foreland basin
Pilot - Joana
platform sedimentation
Roberts Mountains allochthon
RMT
Cordilleran miogeocline
UMG/BCF
Yreka-Trinity-Shoo Fly subduction complex
miogeoclinal rifting (inc. Pahrump-Chuar)
Apache-Unkar
Belt-Purcell
Mojave province
continental basement
Yavapai-Mazatzal province
Wyoming province
Laramide
Sevier
Nevadan
Sonoma
Ancestral Rockies
Antler
Rift

Growing influence of the Pacific plate



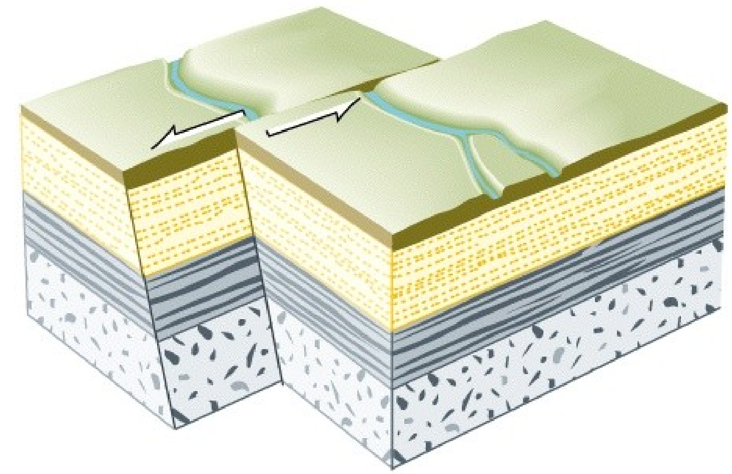
Kious, W.J., and Tilling, R.I., *This Dynamic Earth*. US Geological Survey, p.77



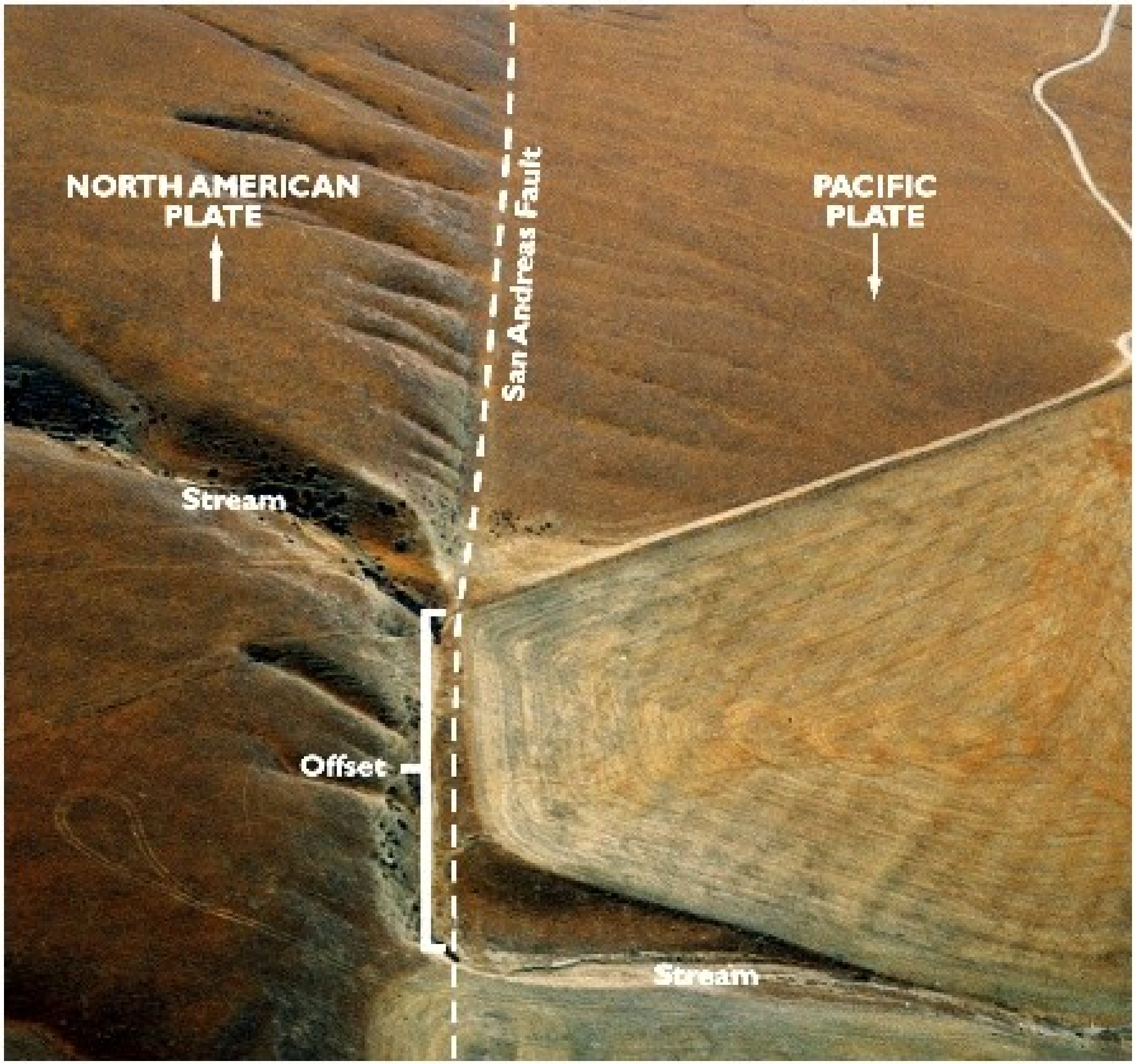
30 million years ago
20 million years ago
10 million years ago
Present
PLATE
FARALLON
PACIFIC PLATE
Los Angeles
NORTHAMERICANPLATE
Trench
PACIFIC PLATE
JUAN DE FUCA PLATE
Trench
M
PACIFIC PLATE
Los Angeles
R
COCOS PLATE
Trench
NORTHAMERICANPLATE
JUAN DE FUCA PLATE
Trench
M
PACIFIC PLATE
Los Angeles
R
COCOS PLATE
Trench
NORTHAMERICANPLATE
JUAN DE FUCA PLATE
Trench
M
San Francisco
PACIFIC PLATE
Los Angeles
Baja California
RIVERA PLATE
R
Gulf of California
COCOS PLATE
Trench
NORTHAMERICANPLATE
EXPLANATION
Spreading center (divergent boundary)
Subduction zone (convergent boundary)
Transform fault, arrows show relative movement
SAFZ, San Andreas fault zone
Triple plate junction
M, Mendocino
R, Rivera

Modern California: Strike-Slip tectonics

- On the other hand, California is also a transform plate boundary zone, which is accommodated be a series of strike-slip faults.



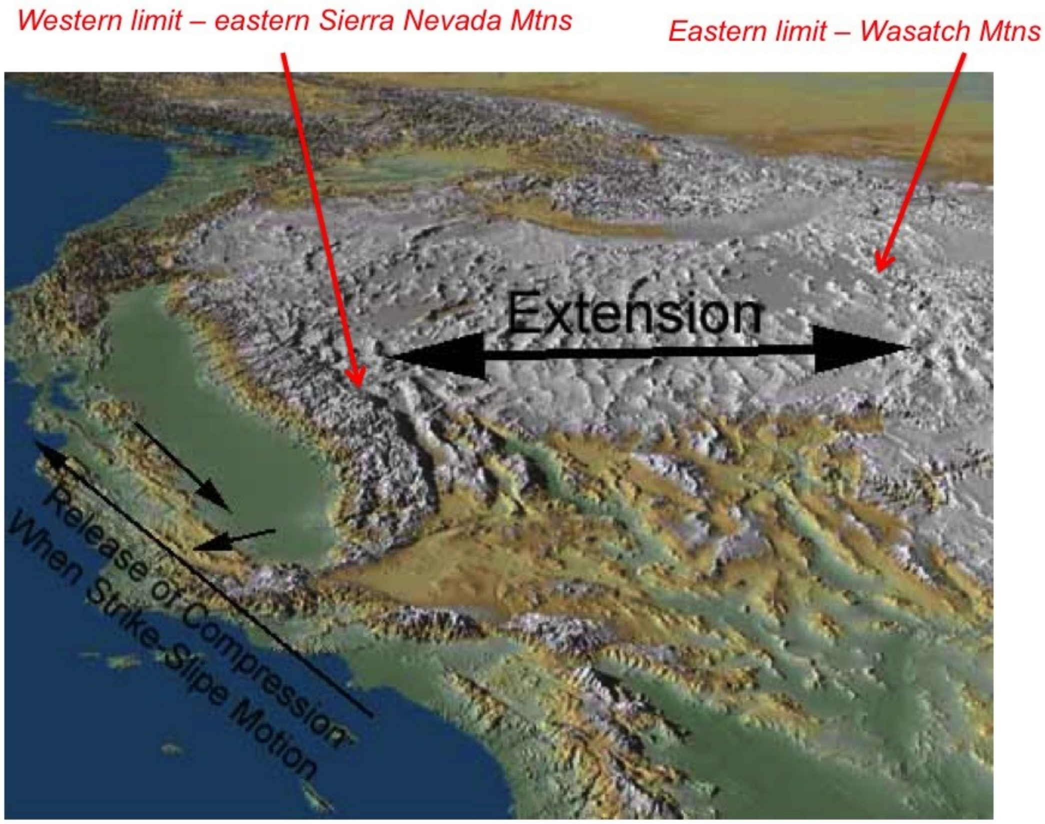
(c) STRIKE-SLIP FAULT
(left-lateral)



- There is evidence of strike-slip motion across the surface rupture of the 1872 Lone Pine earthquake. This air-photo of the San Andreas Fault shows a somewhat clearer offset drainage.

Basin and Range Province

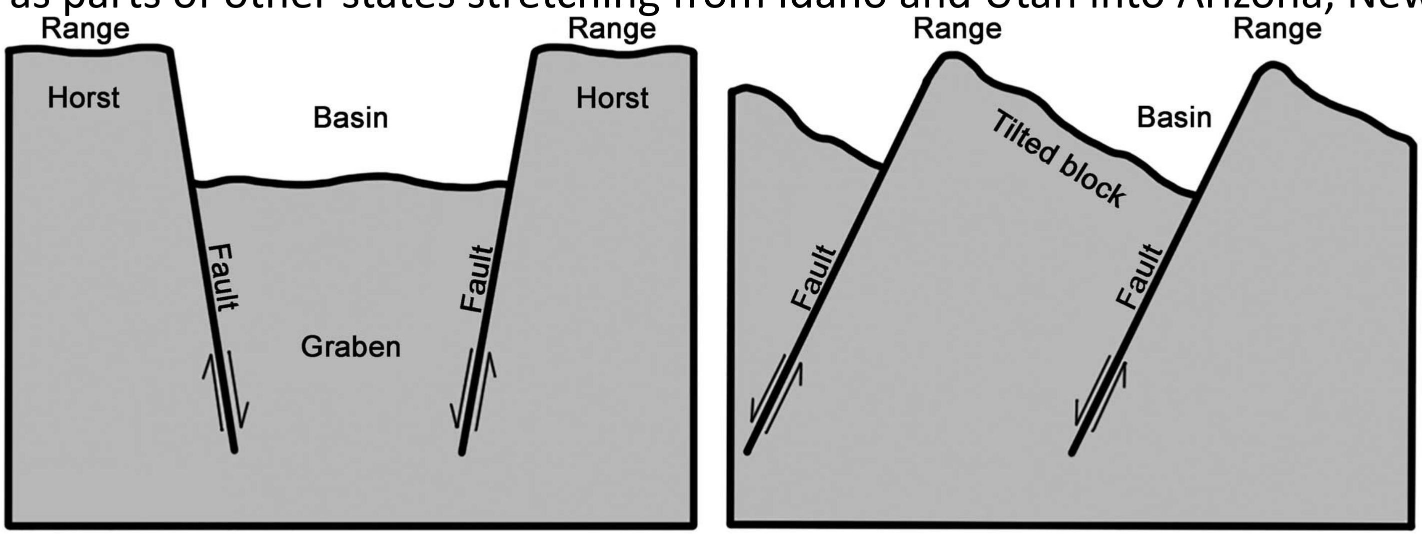
The Basin and Range Province began to develop about 20 million years ago. The cause of this disturbance is **highly controversial** amongst researchers. One possibility is that **tension in the earth's crust**, potentially developed as a result in a change in tectonic activity to the west, stretched and thinned, and in some places resulted in uplift as much as twice the crusts original width. This geologic **stretching** and **extension** split the region, resulting in down-dropped basins and narrow, elongated mountain ranges.



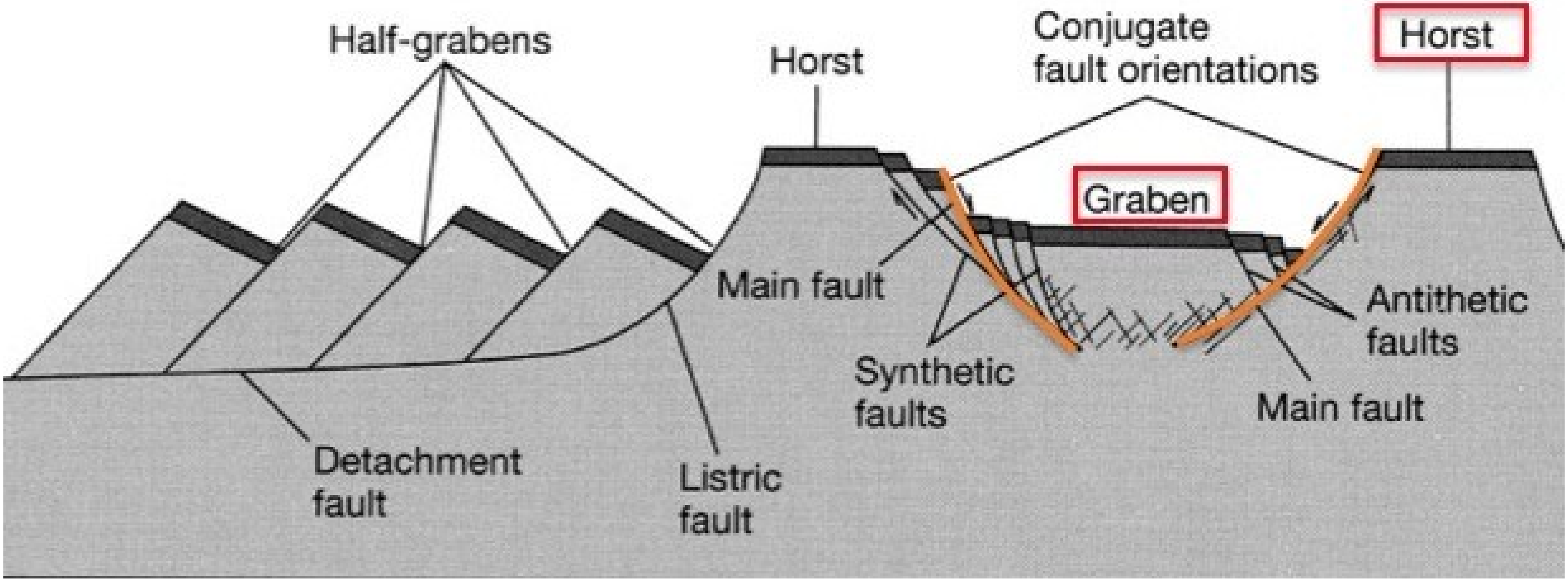
The Basin and Range Province is a vast physiographic region covering much of the inland Western United States and northwestern Mexico. It is defined by **unique basin and range topography**, characterized by **abrupt changes in elevation**, alternating between narrow faulted **mountain chains** and flat arid **valleys** or basins. The physiography of the province is the **result of tectonic extension that began around 17 million years ago** in the early Miocene epoch.

By the Neogene, the **Farallon plate lay shallowly** under the North American plate for **hundreds of kilometers eastward of the West Coast**. The Farallon plate was subjected to increasing temperatures as it subducted, causing it to expand. As heat dissipated to the overlying North American plate, that rock expanded as well. Finally, the **high temperatures in the upper mantle caused the Farallon plate to melt**, and the resulting **magma was injected into the North American plate**, destabilizing it.

These processes, along with the **complex crustal movements taking place along the San Andreas fault**, caused the surface of the North American plate to **pull apart** and fault into the north-south trending mountainous blocks and valleys of the huge **Basin and Range province**. This province covers part of eastern California, most of Nevada, and southern Oregon, as well as parts of other states stretching from Idaho and Utah into Arizona, New Mexico, and Texas.



Simple illustration of how basins and ranges are formed by faulting.
Formation of the Basin and Range. **Alternating basins and ranges were formed during the past 17 million years by gradual movement along faults**. Arrows indicate the relative movement of rocks on either side of a fault. Image modified from original by Wade Greenberg-Brand, in turn adapted from an image by the USGS (public domain).



Horsts, graben and half-grabens. Modified from University Idaho Structural Geology, online materials. Also in DeCourten 2003.

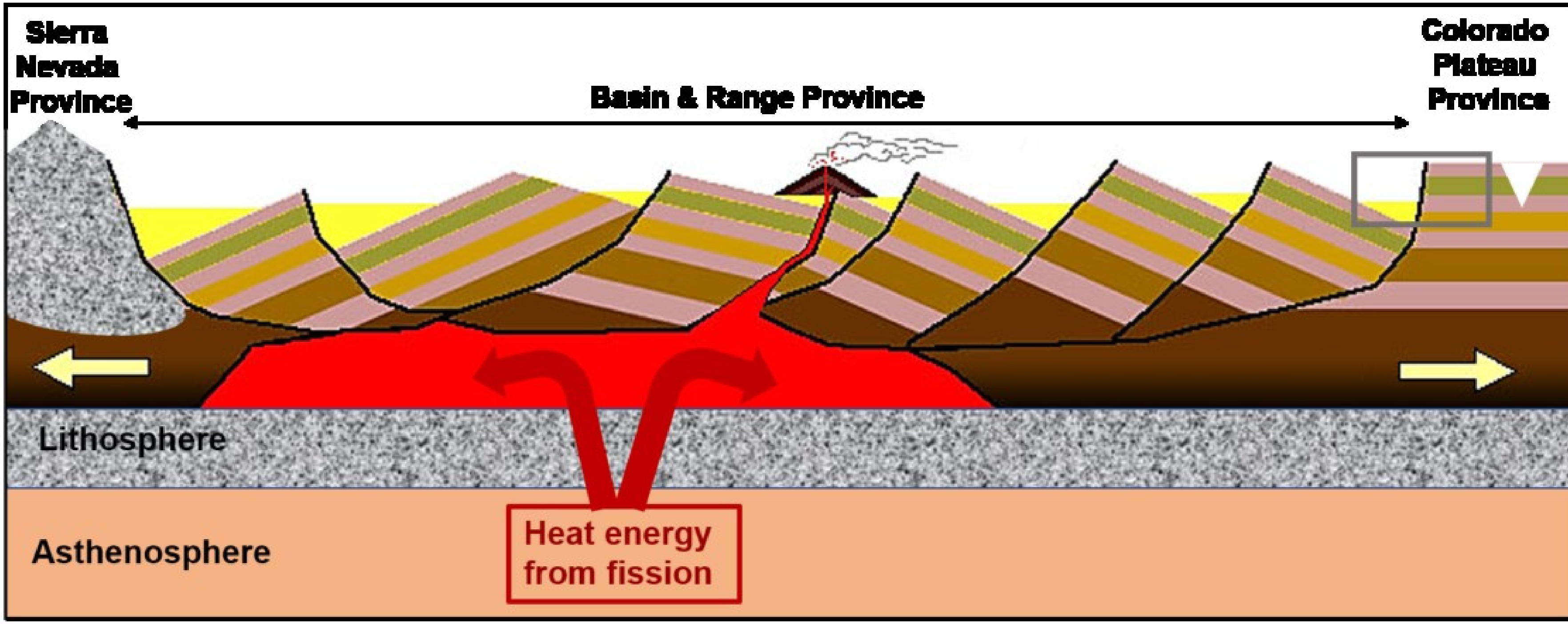


Figure 5. Cross section of the Basin and Range Province. The gray rectanglar outline represents the area traversed by the Virgin River Gorge. Thin curved black lines represent faults. Modified from USGS cross section.

This province is literally being split apart by tension resulting from a source of heat energy that exists below the region. Evidence for that **heat is provided by numerous volcanoes** and lava flows scattered throughout this province. The term "Basin and Range" comes from the generally parallel north-trending mountains (the ranges) separated by valleys (the basins). Rocks in each of these mountain ranges are tilted and bounded by faults and are thus described as fault block mountains.

The tectonic activity responsible for the **extension** in the Basin and Range is a complex and **controversial** The most accepted hypothesis suggests that **crustal shearing** associated with the San Andreas Fault caused spontaneous **extensional faulting.** However, plate movement alone does not account for the **high elevation** of the Basin and Range region. The western United States is a region **of high heat flow** which lowers the density of the lithosphere and stimulates **isostatic uplift** as a consequence. Geologic processes that elevate heat flow are varied, some researchers suggest that **matle plume** heat generated at a subduction zone is transferred to the overriding plate as subduction proceeds other prefer subduction of **Faralon plate**

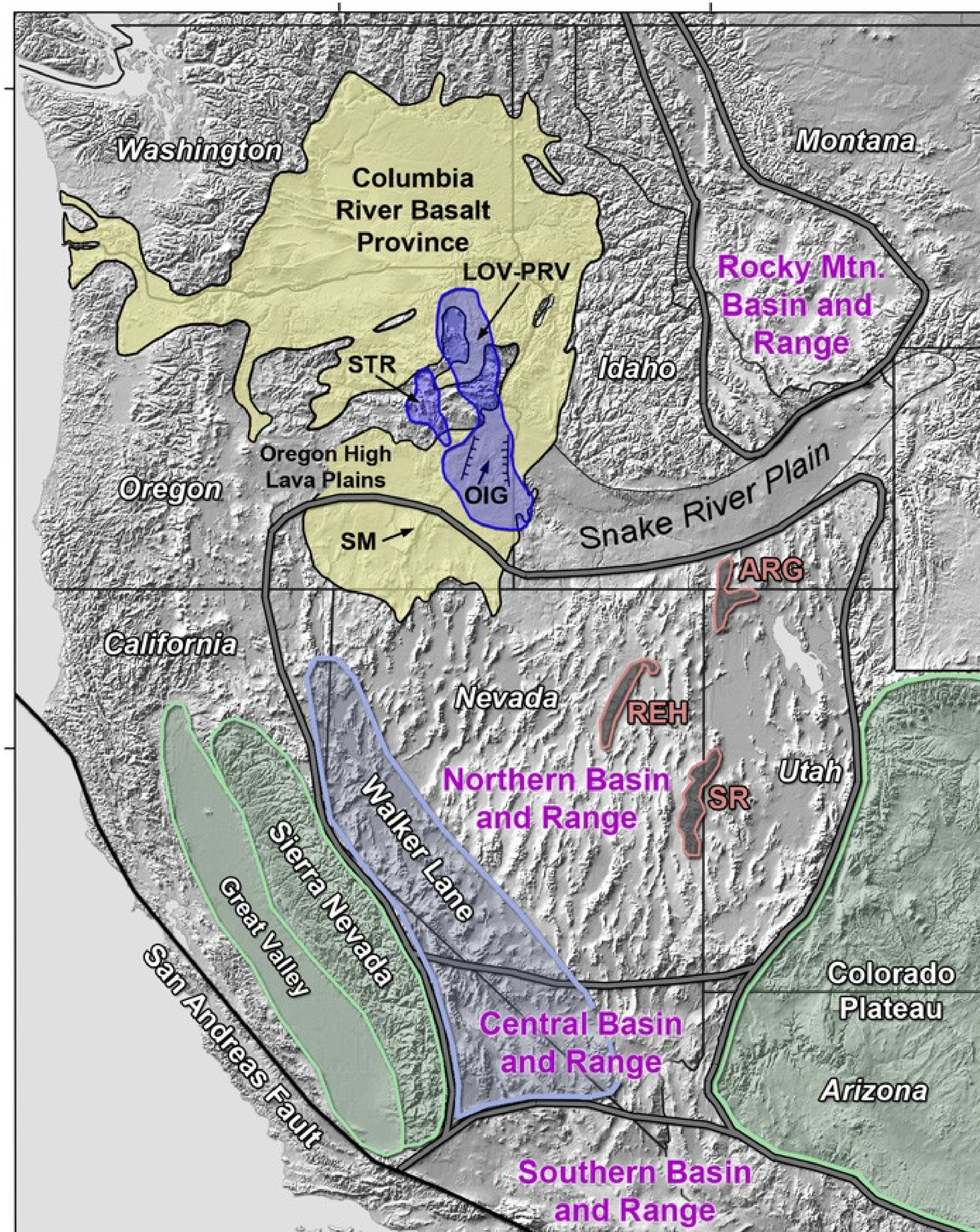
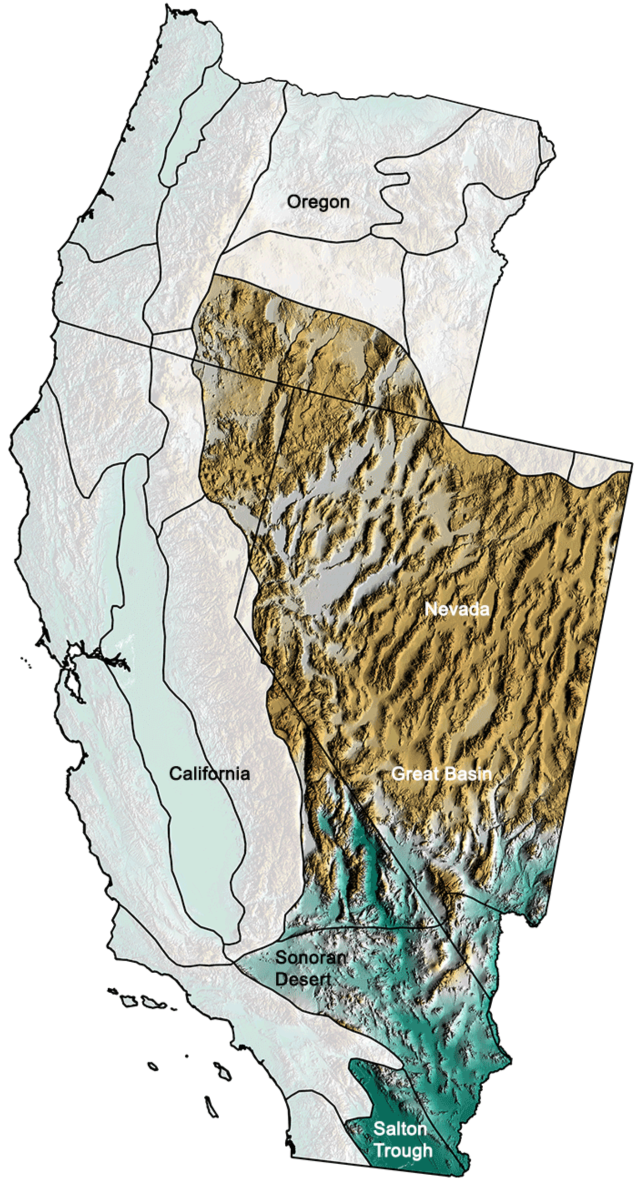


Figure 1. The **Basin and Range Province**, with northern, central, and southern segments modified from Jones et al. (1992) and Wernicke (1992). The **northern and central** Basin and Range are bounded to the west by the **Sierra Nevada** batholith and to the east by the **Colorado Plateau**. The **northern** Basin and Range incorporates most of Nevada and western Utah. Its northern boundary is transitional with the Oregon High Lava Plains and the southern extension of the **Columbia River Basalt Province**, which containsthe initial eruptions of flood basalt in the vicinity of Steens Mountain (SM). It also extends to the northeast, south of the Snake River Plain.

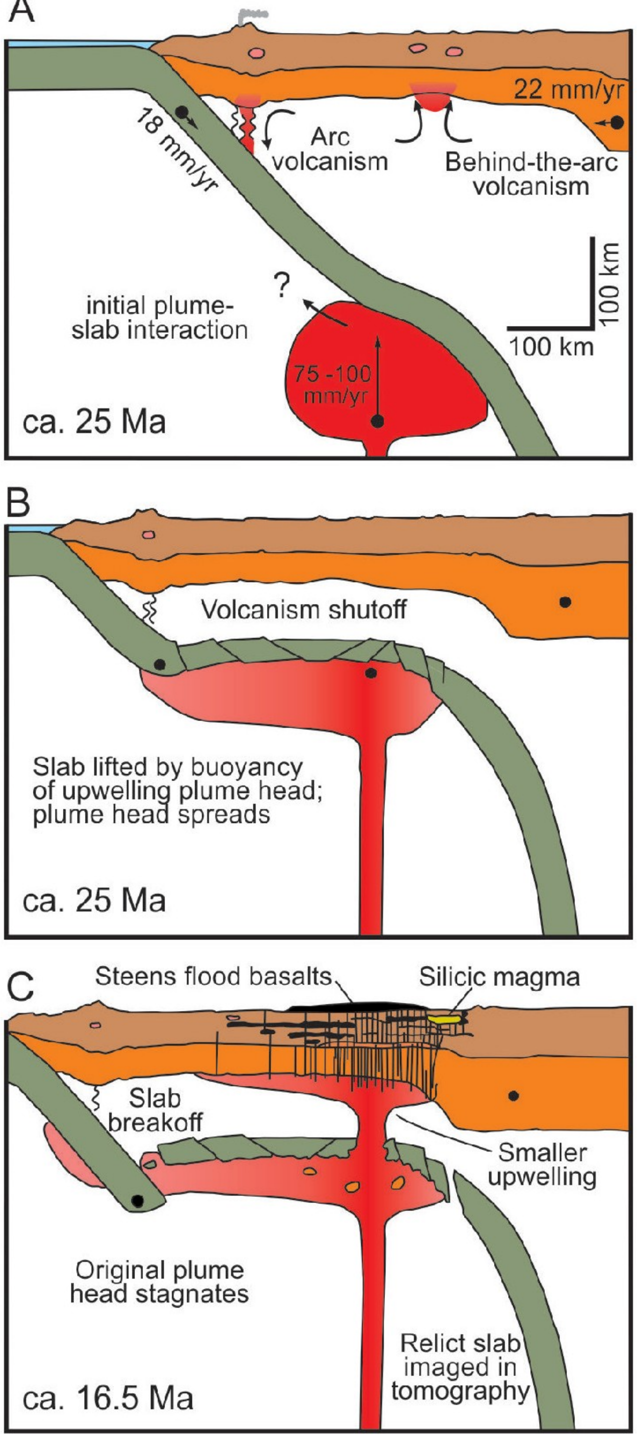


Physiographic subdivisions of the Basin and Range region of the western United States. Greens indicate lower elevation, browns higher elevation

Columbia Plateau

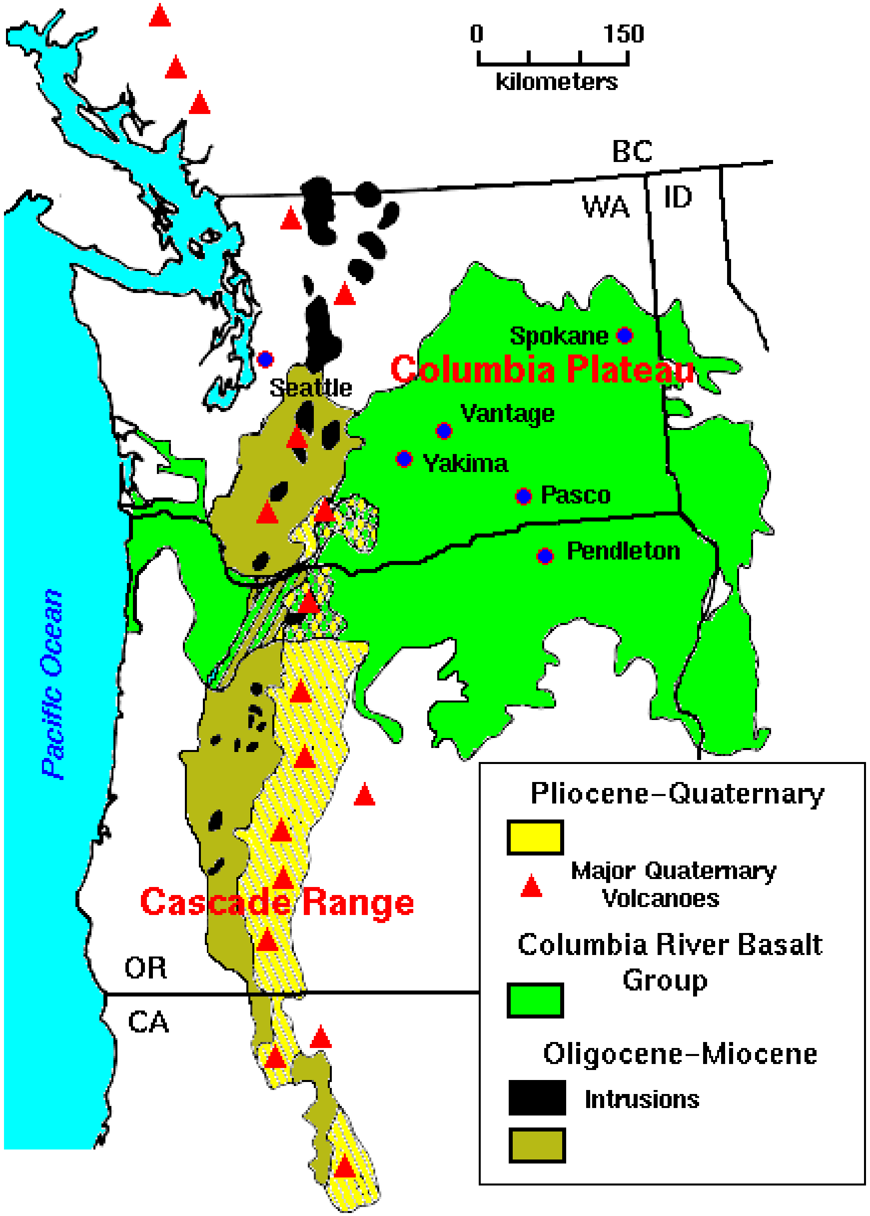
Nestled **between the Cascade and Rocky Mountain ranges**, the Columbia Plateau was an **inland sea** for tens of millions of years, until about 15 million years ago when volcanic activity deposited layer upon layer of lava. The plateau formed between **6 million and 16 million** years ago as the result of successive flows of basalt. The **subsidence of the crust** produced a large, slightly depressed lava plain now known as the Columbia Basin (Plateau). As the molten rock came to the surface, the earths **crust gradually sank** into the space left by the rising lava.

A probable explanation is that a **hot spot**, an extremely hot plume of deep mantle material, is rising to the surface beneath the Columbia Plateau Province. **The track of this hot spot starts in the west and sweeps up to Yellowstone National Park**. Another theory explains migrating hotspot volcanism as the result of the **fragmentation** and dynamics of the subducted **Farallon Plate**



Siletzia terrane has chemical and physical characteristics that suggest it formed due to a **mantle plume**, and it has a composition similar to the **Columbia River Basalts**, indicating that the two large lava flow provinces are related. Might the Siletzia terrane have formed due to an early version of the Yellowstone hotspot?

Figure 6. Model for the evolution of Yellowstone plume (after Coble and Mahood 2012) that considers the lifting of the Juan de Fuca slab at 25 Ma (A) to have resulted in volcanic quiescence (B) between ca. 23 and 17 Ma, and the distribution of voluminous bimodal basalts and coeval rhyolites (C) to represent breakthrough of plume material at ca. 17 Ma into the upper plate to form a secondary plume head.

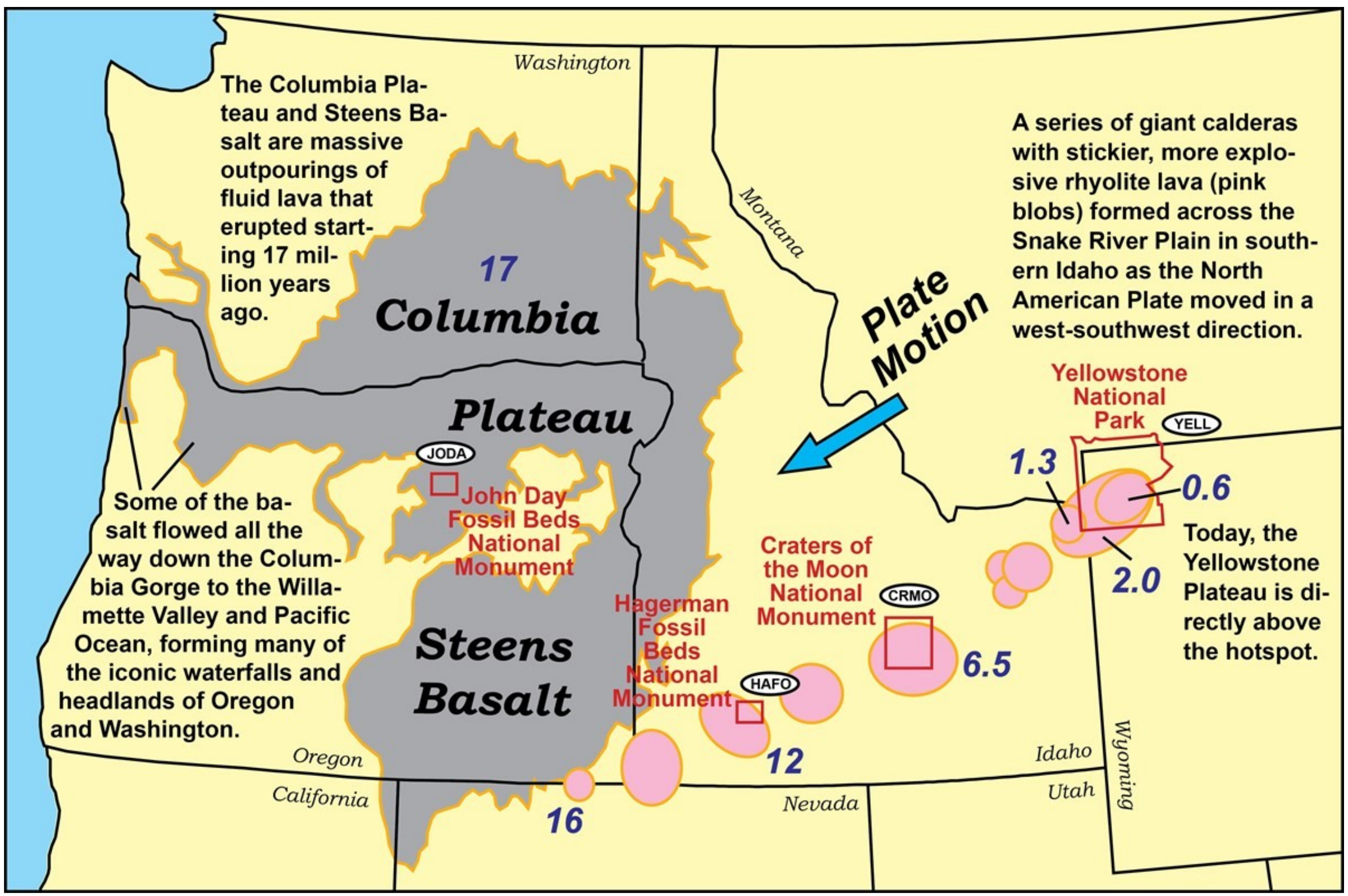


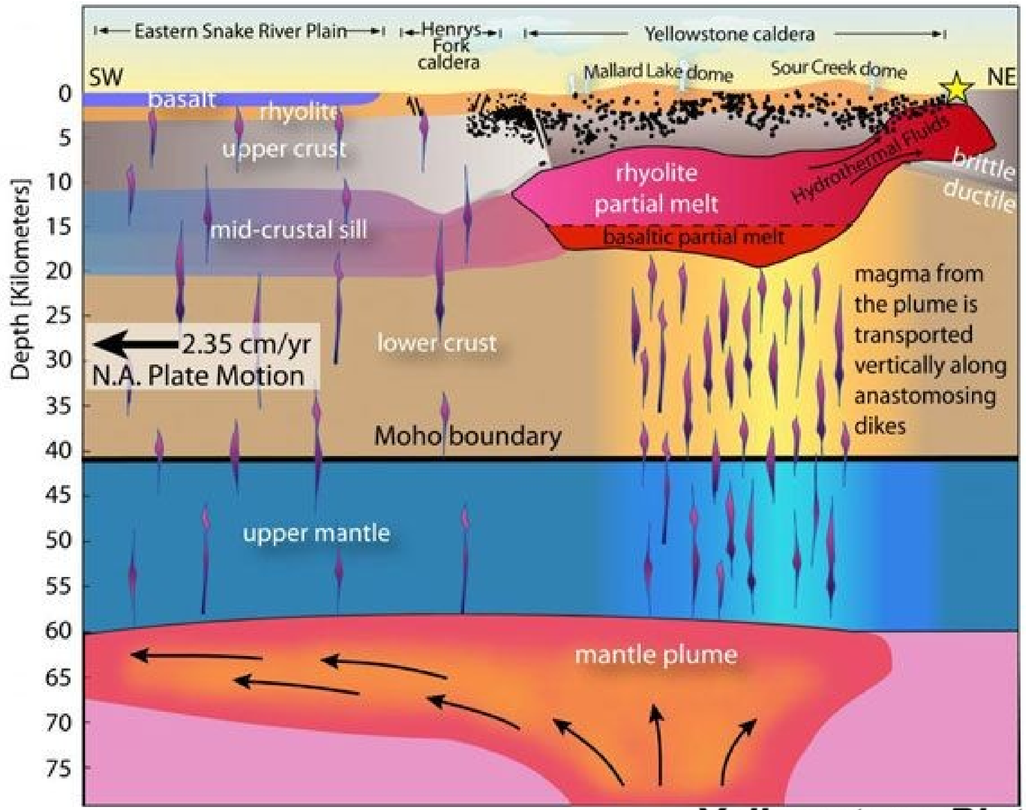
The Columbia Plateau covers much of the Columbia River Basalt Group, shown in green on this map. The Washington cities of Spokane, Yakima and Pasco, and the Oregon city of Pendleton, lie on the Columbia Plateau.

Columbia Plateau —Yellowstone Hotspot Track

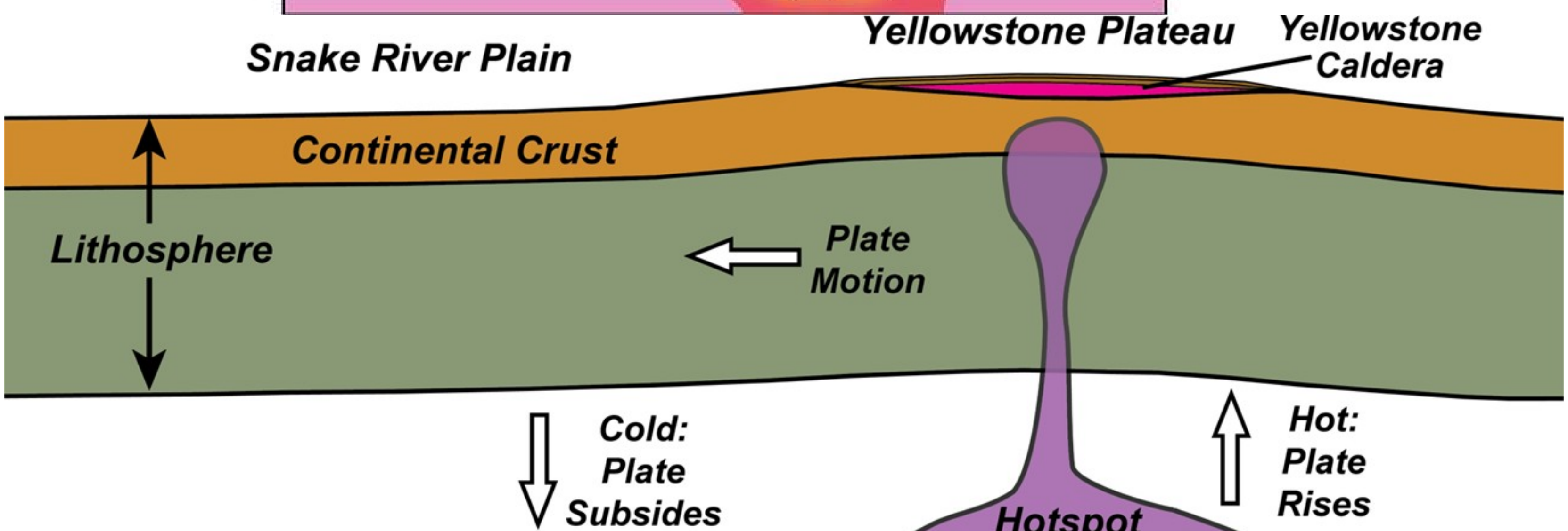
Volcanic rocks in the Pacific Northwest show the effects of a tectonic plate riding over a deep-mantle hotspot.

The Pacific Northwest of the United States has a variety of active tectonic settings, including plate convergence at the Cascadia Subduction Zone and divergence in the **Basin and Range** Continental Rift Zone. But **superimposed** on these active tectonic features **is a line of volcanic activity stretching from the Columbia Plateau of eastern Oregon and Washington all the way to the Yellowstone Plateau** at the intersection of Wyoming, Idaho and Montana.

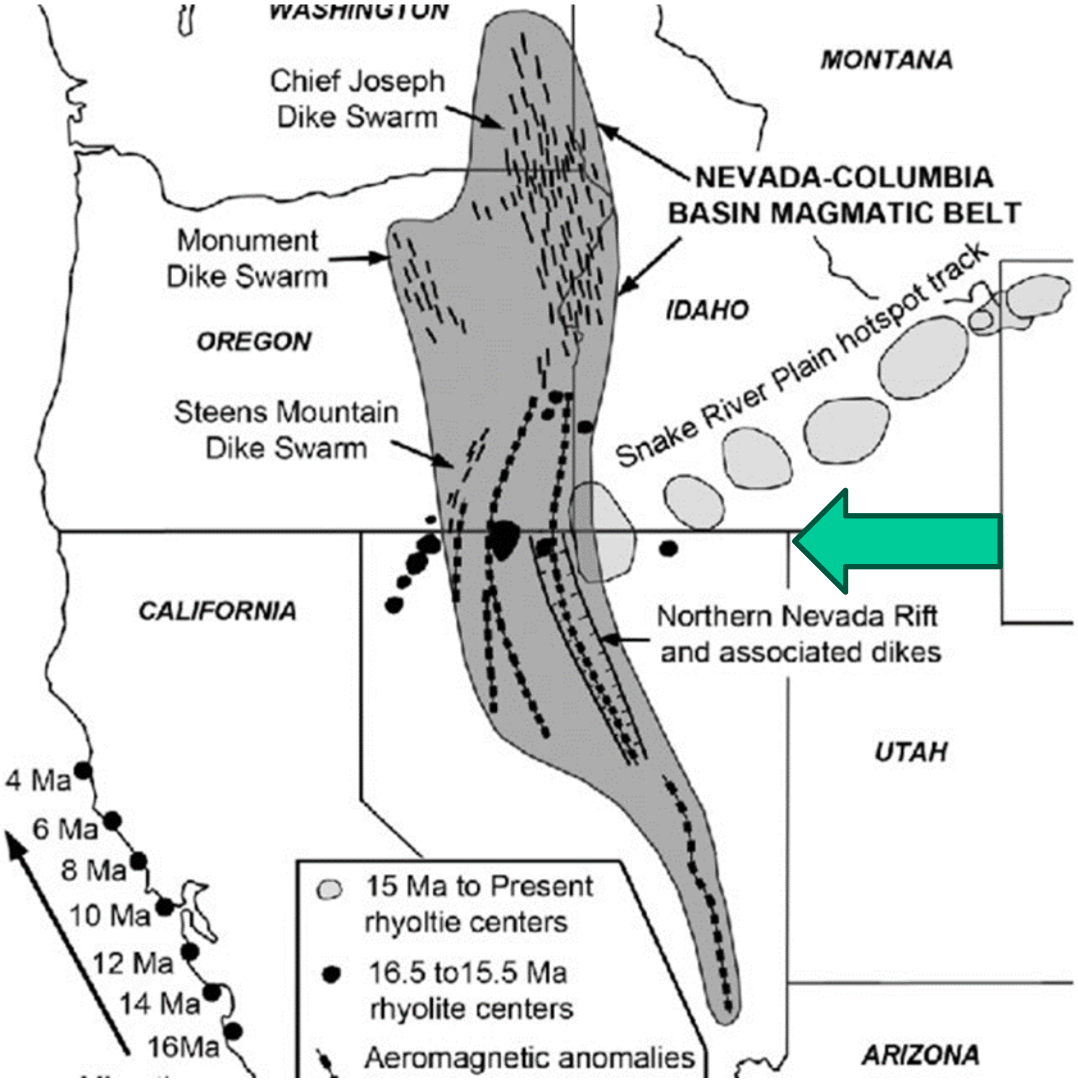




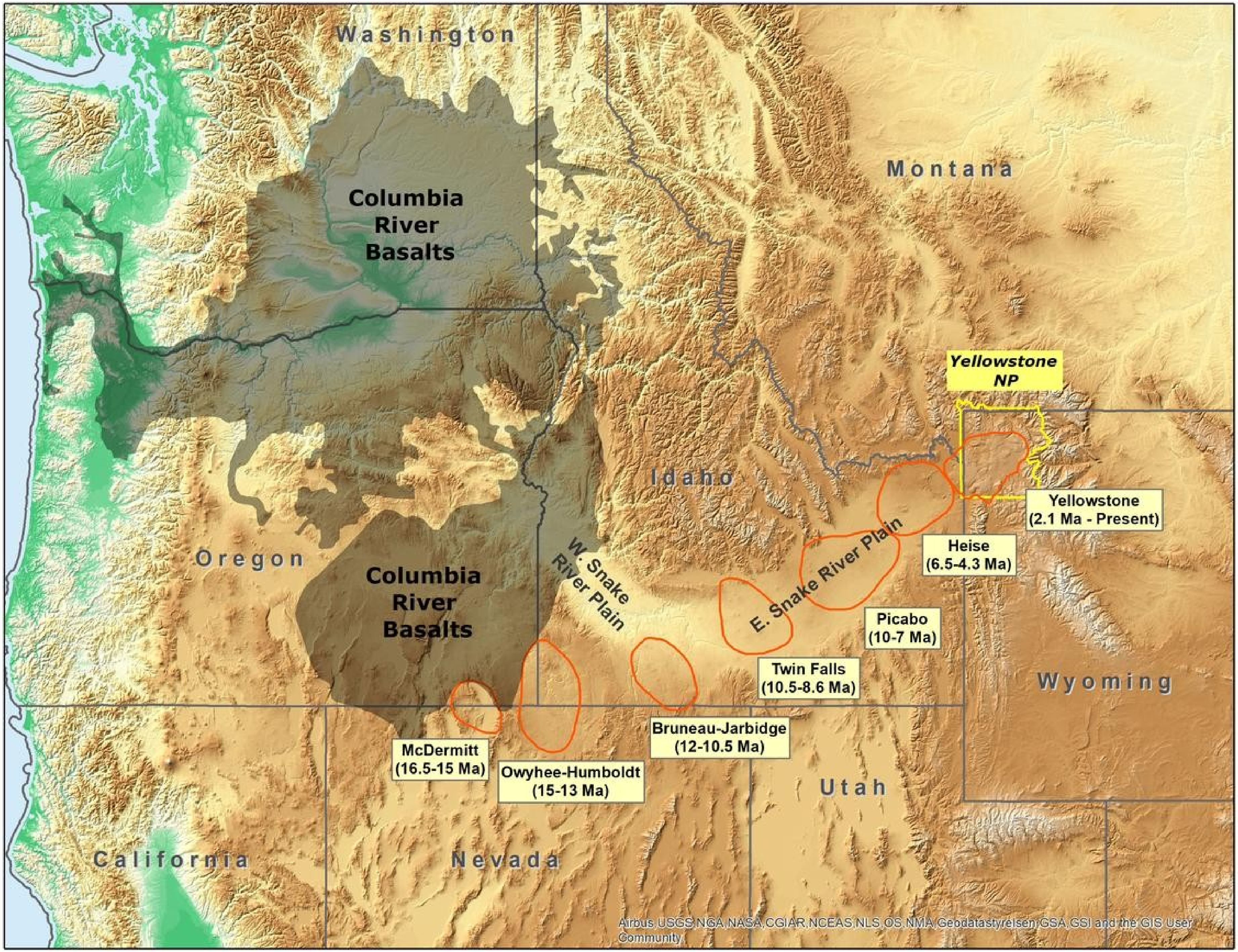
Eastern Snake River Plain
Henrys Fork caldera
Yellowstone caldera
Mallard Lake dome
Sour Creek dome
SW
NE
basalt
rhyolite
upper crust
rhyolite partial melt
Hydrothermal Fluids
brittle
ductile
mid-crustal sill
basaltic partial melt
magma from the plume is transported vertically along anastomosing dikes
Depth [Kilometers]
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
2.35 cm/yr
N.A. Plate Motion
lower crust
Moho boundary
upper mantle
mantle plume



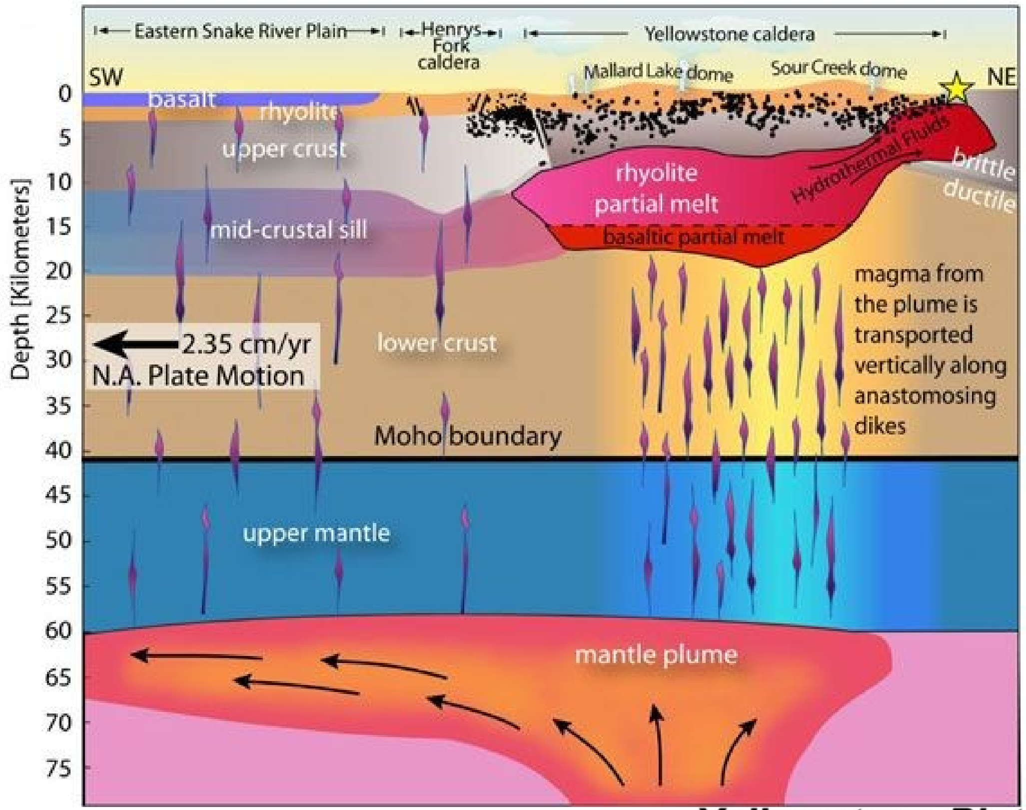
Snake River Plain
Yellowstone Plateau
Yellowstone Caldera
Continental Crust
Lithosphere
Plate Motion
Cold: Plate Subsides
Hot: Plate Rises
Hotspot



The volcanism of **Yellowstone** is believed to be linked to the somewhat **older volcanism of Snake River plain**. Yellowstone is thus the active part of a hotspot that has moved northeast over time.The origin of this **hotspot volcanism** is **disputed**. One theory holds that a **mantle plume** has caused the Yellowstone hotspot to migrate northeast, while another theory explains migrating hotspot volcanism as the result of the **fragmentation** and dynamics of the subducted **Farallon Plate** in Earth's interior



Washington
Montana
Columbia River Basalts
Columbia River Basalts
Yellowstone NP
Idaho
Oregon
W. Snake River Plain
E. Snake River Plain
Yellowstone (2.1 Ma - Present)
Heise (6.5-4.3 Ma)
Picabo (10-7 Ma)
Twin Falls (10.5-8.6 Ma)
Bruneau-Jarbidge (12-10.5 Ma)
McDermitt (16.5-15 Ma)
Owyhee-Humboldt (15-13 Ma)
Wyoming
Utah
California
Nevada
Airbus, USGS, NGA, NASA, CGIAR, NCEAS, NLS, OS, NMA, Geodatastyrelsen, GSA, GSI and the GIS User Community


Eastern Snake River Plain
Henrys Fork caldera
Yellowstone caldera
Mallard Lake dome
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N.A. Plate Motion
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Moho boundary
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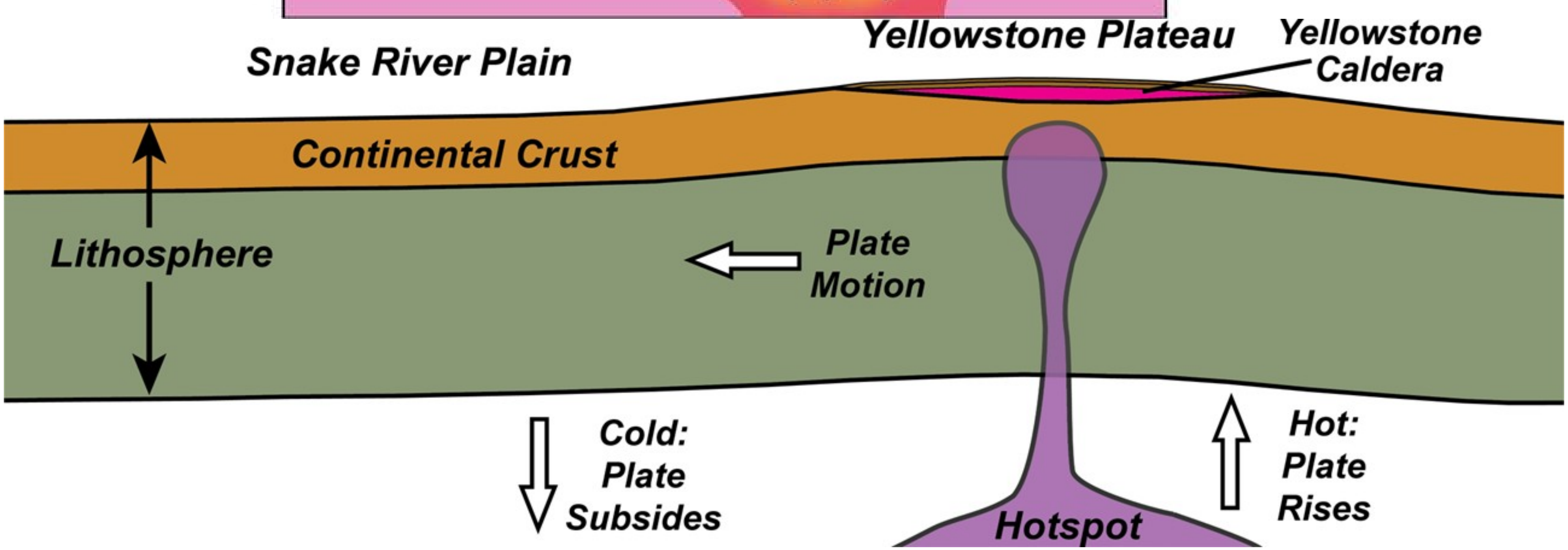
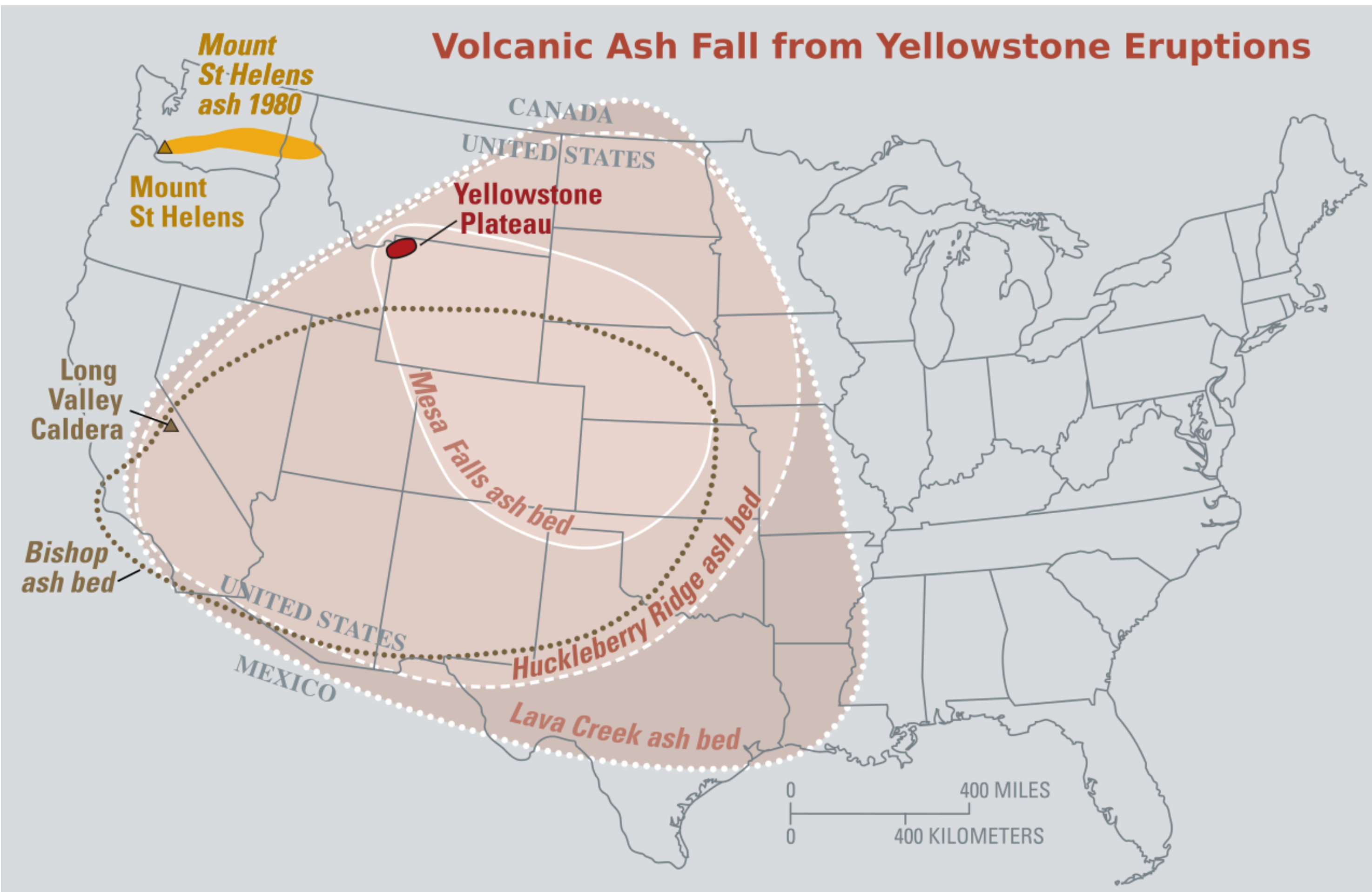
mantle plume


Snake River Plain
Yellowstone Plateau
Yellowstone Caldera
Continental Crust
Lithosphere
Plate Motion
Cold: Plate Subsides
Hot: Plate Rises
Hotspot

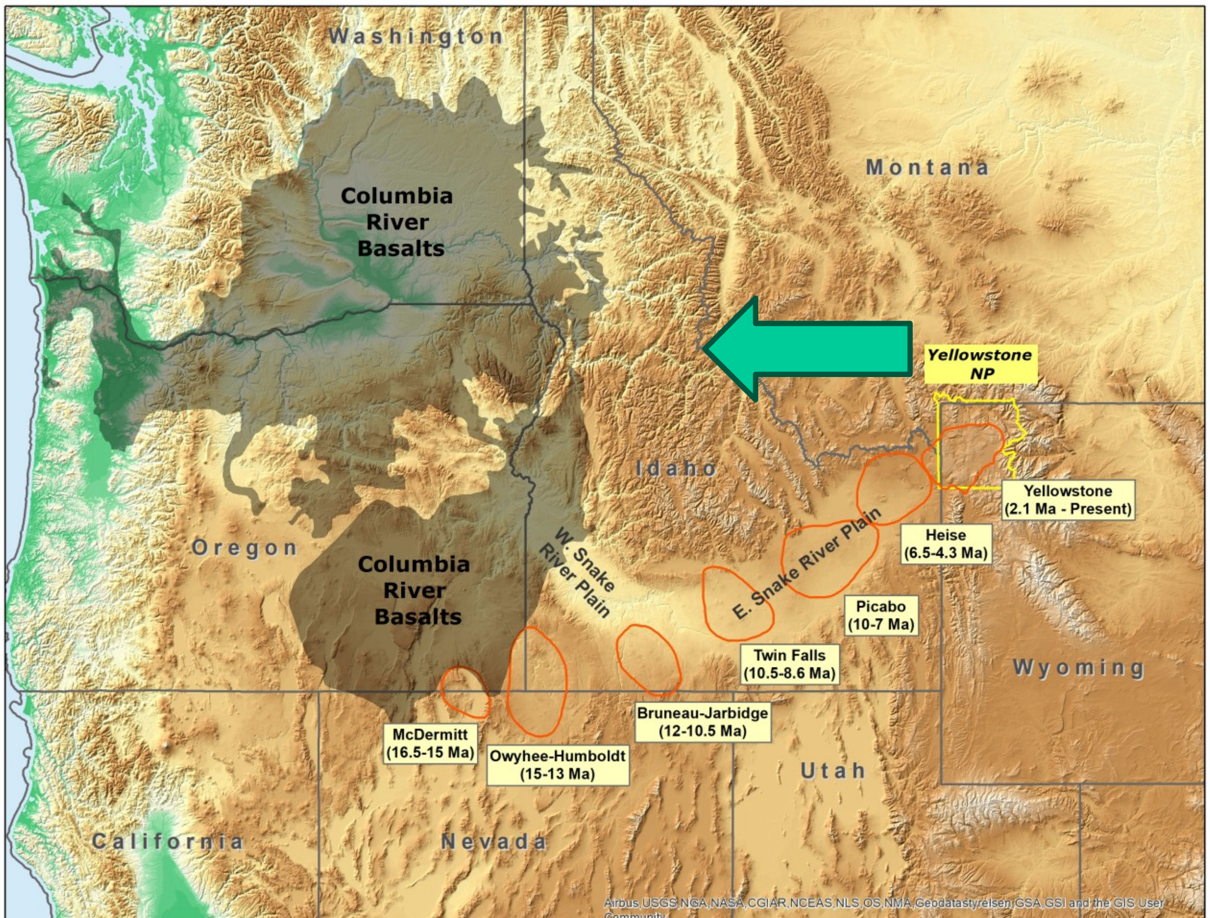
Yellowstone Plateau Volcanic Field

The **Yellowstone Plateau** Volcanic Field, also known as the Yellowstone Supervolcano or the Yellowstone Volcano, is a complex volcano, volcanic plateau and volcanic field located mostly in the western U.S. state of Wyoming, but it also stretches into Idaho and Montana



The volcanism of Yellowstone is believed to be linked to the somewhat older volcanism of the **Snake River Plain**. Yellowstone is thus the active part of a **hotspot** that has moved northeast over time. The **origin of this hotspot volcanism is disputed**. One theory holds that a **mantle plume** has caused the Yellowstone hotspot to migrate northeast, while another theory explains migrating hotspot volcanism as the result of the **fragmentation and dynamics of the subducted Farallon Plate** in Earth's interior.

Yellowstone is at the **northeastern end of the Snake River Plain**, a great bow-shaped arc through the mountains that extends roughly 400 miles (640 km) from the park to the Idaho-Oregon border.

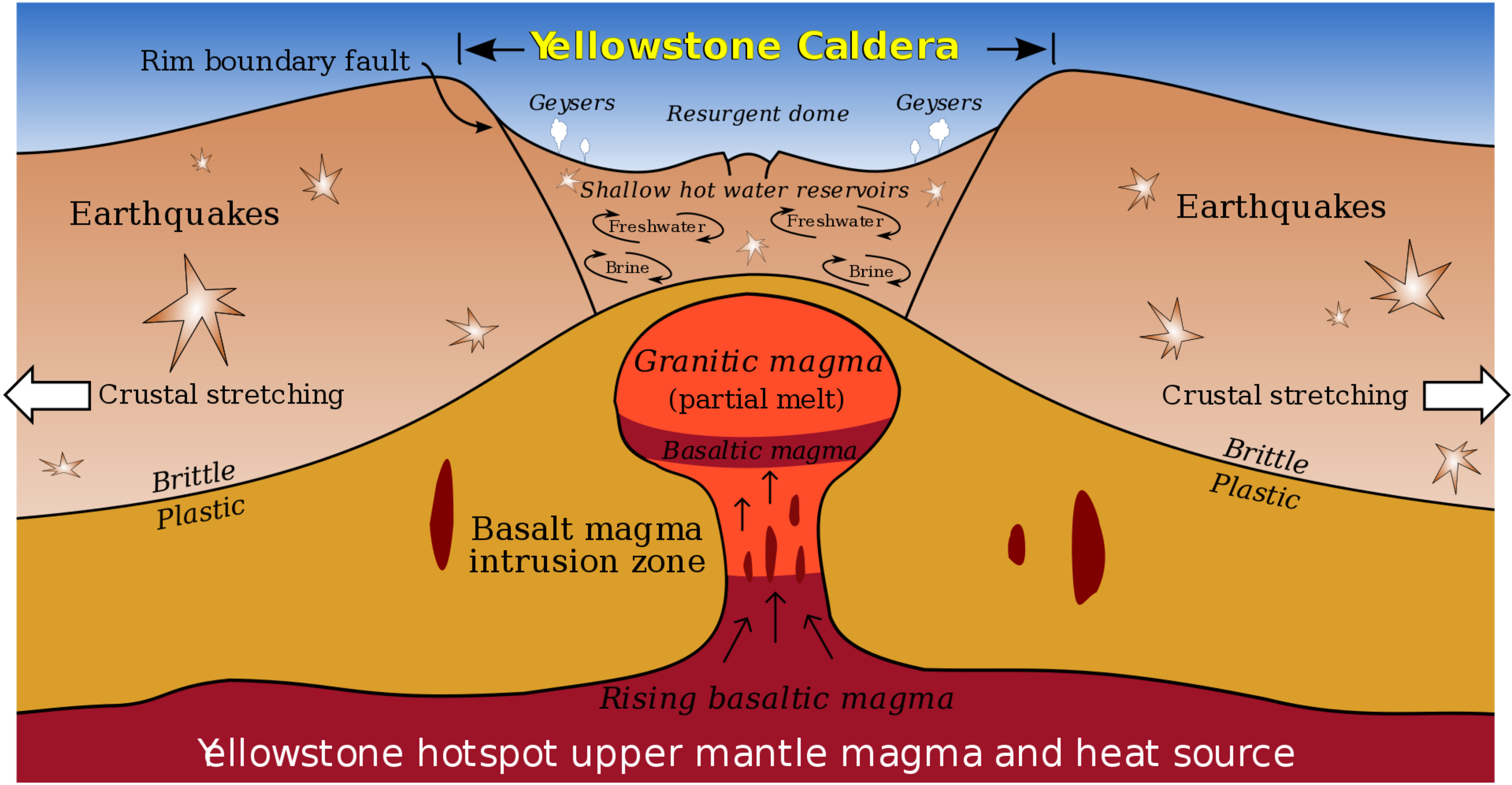


Yellowstone National Park

Grand Prismatic Spring

Old Faithful

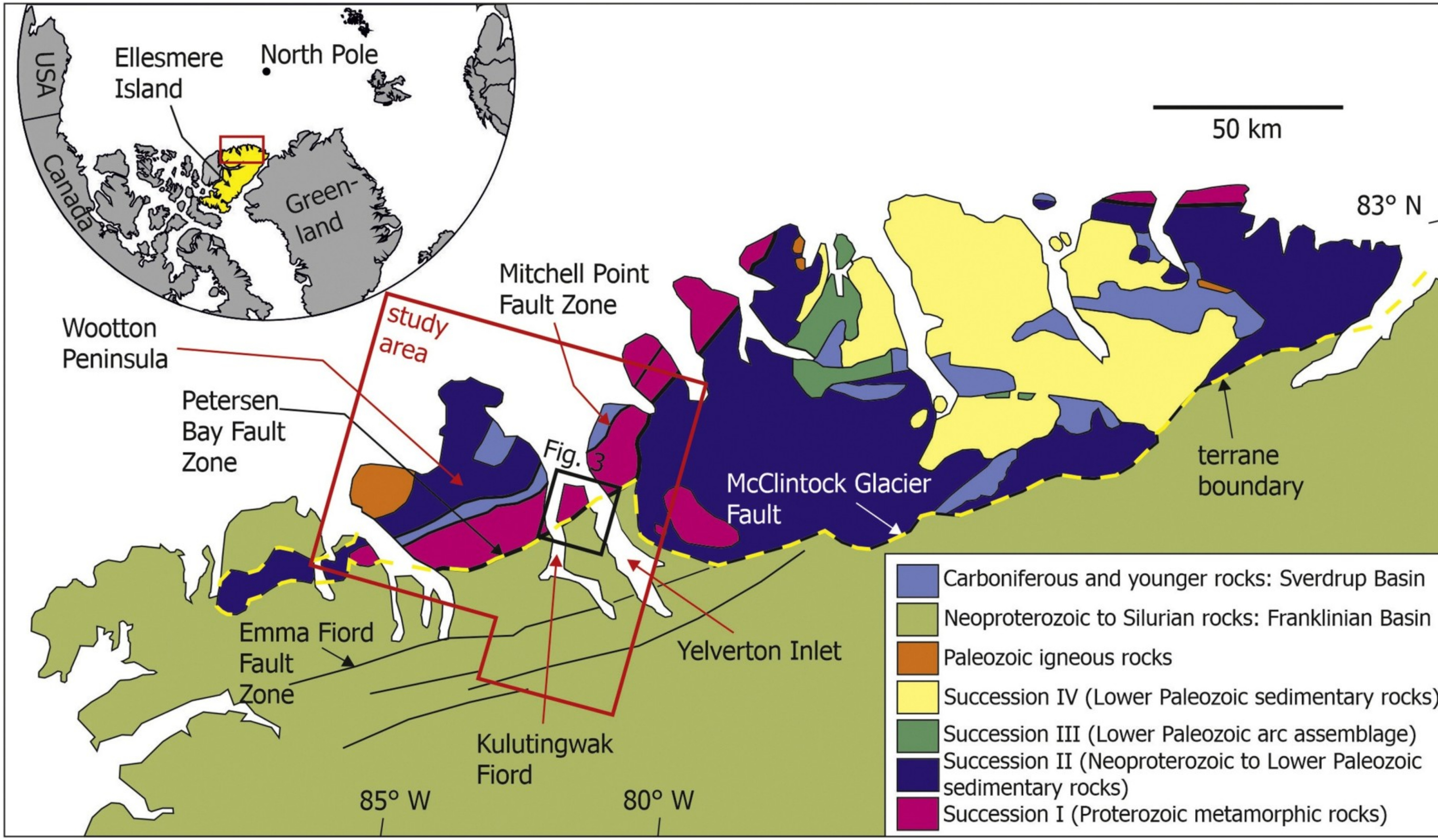
Nachází se zde velké množství horkých pramenů, bublajících bahnitých jam, horských jezer, kaňonů, erodovaných lávových proudů a gejzírů. Nejznámějším gejzírem je Old Faithful, jenž tryská průměrně po 64,5 minutách do výšky 40 m, maximálně pak až do výšky 56 m. Takto vytryskuje asi 120 let.



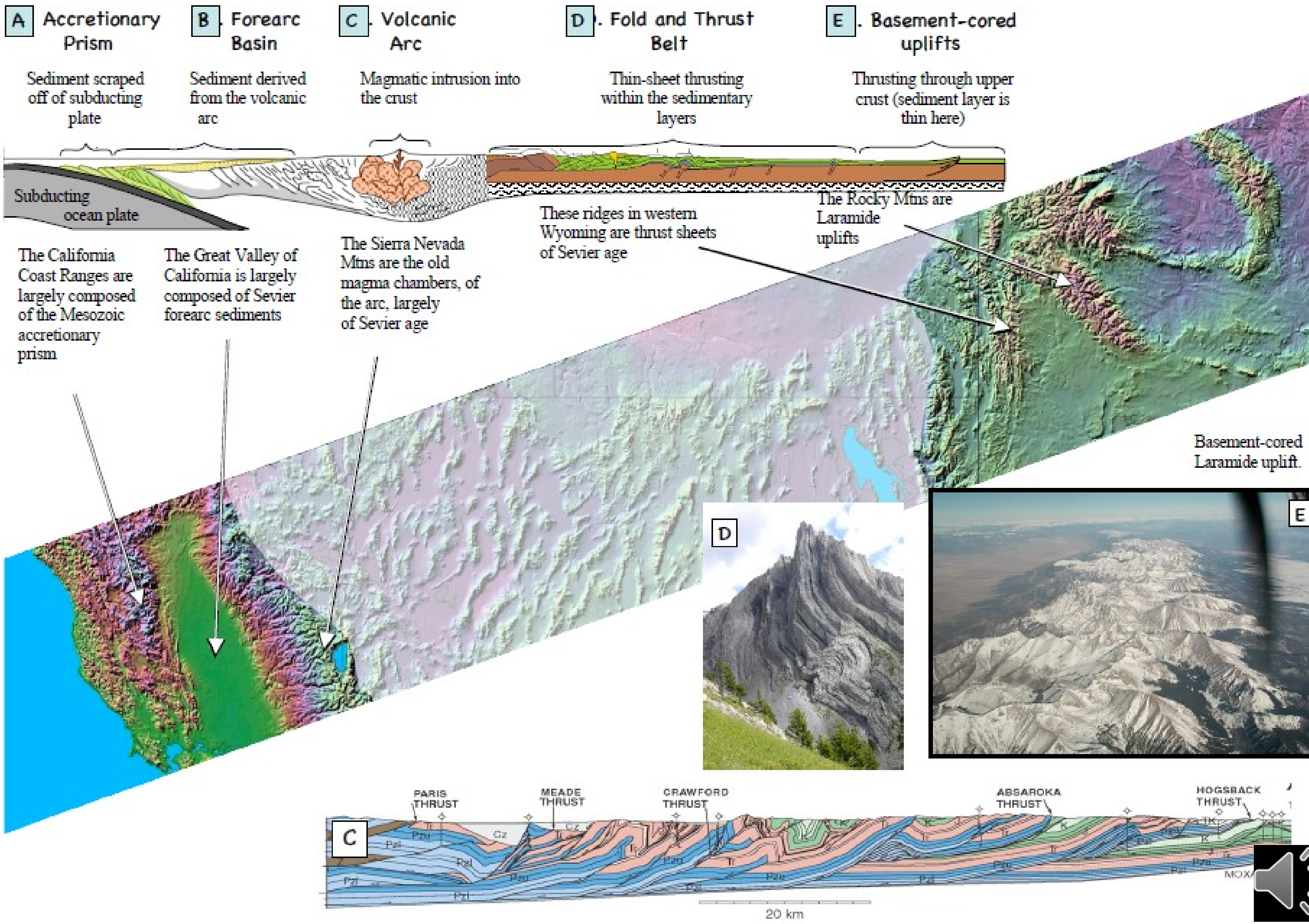
The Yellowstone Plateau Volcanic Field forms the high continental divide between the northern and middle Rocky Mountains. The average elevation of the plateau is about 2,400 m (7,900 ft) and is surrounded on all sides but the southwest by mountainous terrain with peaks that reach 3,000-4,000 m (10,000 - 13,000 ft). The eastern Snake River Plain extends to the southeast as a structural depression that is about 350 km (220 mi) long. Yellowstone National Park, encompassing parts of Wyoming, Montana, and Idaho, is the location for the most recent volcanic activity.

Ellesmersko– inuitská orogeneze

Při severním okraji severoamerického kratonu probíhala ve spodním paleozoiku ellesmersko-inuitská orogeneze.
Dostupné údaje zatím neumožňují jejich jednoznačnou interpretaci.


USA
Canada
Ellesmere Island
North Pole
Green-land
50 km
83° N
Mitchell Point Fault Zone
Wootton Peninsula
study area
Petersen Bay Fault Zone
Fig. 3
McClintock Glacier Fault
terrane boundary
Emma Fiord Fault Zone
Yelverton Inlet
Kulutingwak Fiord
85° W
80° W
Carboniferous and younger rocks: Sverdrup Basin
Neoproterozoic to Silurian rocks: Franklinian Basin
Paleozoic igneous rocks
Succession IV (Lower Paleozoic sedimentary rocks)
Succession III (Lower Paleozoic arc assemblage)
Succession II (Neoproterozoic to Lower Paleozoic sedimentary rocks)
Succession I (Proterozoic metamorphic rocks)

Parts of the Sevier/Laramide Orogeny



The Coast Range Arc formed as a result of subduction of the Juan de Fuca, Kula and pre-existing Farallon Plates. It is most famous for being the **largest granitic outcropping in North America**, which then it is usually referred to as the **Coast Plutonic Complex** or the Coast Mountains Batholith. Although taking its name from the Coast Mountains, this term is a geologic grouping rather than a geographic one, and the Coast Range Arc extended south into the **High Cascades of the Cascade Range**, past the Fraser River which is the northward limit of the Cascade Range proper.