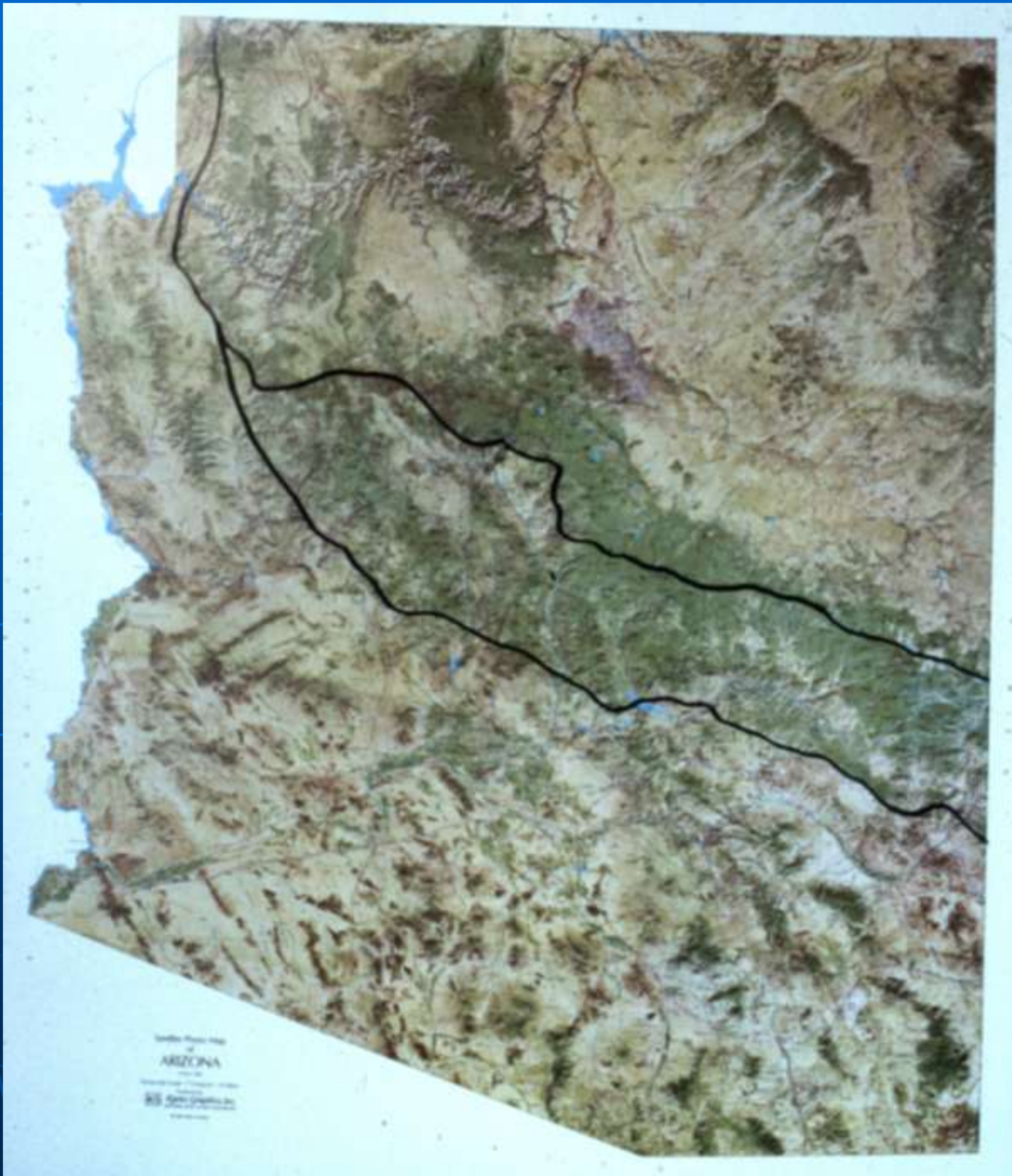
Grand Canyon Geologic History

Dr. Jan C. Rasmussen

Arizona physiography

- Depends on plate tectonics through geologic history
- Big environmental changes through geologic time
- Seas in, seas out
- Warm periods and ice ages



Arizona Physiographic Provinces

Colorado Plateau Province

- ❖ canyons
- ❖ horizontal sediments
- ❖ broad warping

Transition or Central Highlands Province

- ❖ lots of faulting
- ❖ mostly mountains
- ❖ rugged terrain (high relief)

Basin & Range Province

- ❖ fault block mountains
- ❖ broad alluvial valleys
- ❖ sand, clay, salt & gravel - fill up to 10,000 feet thick

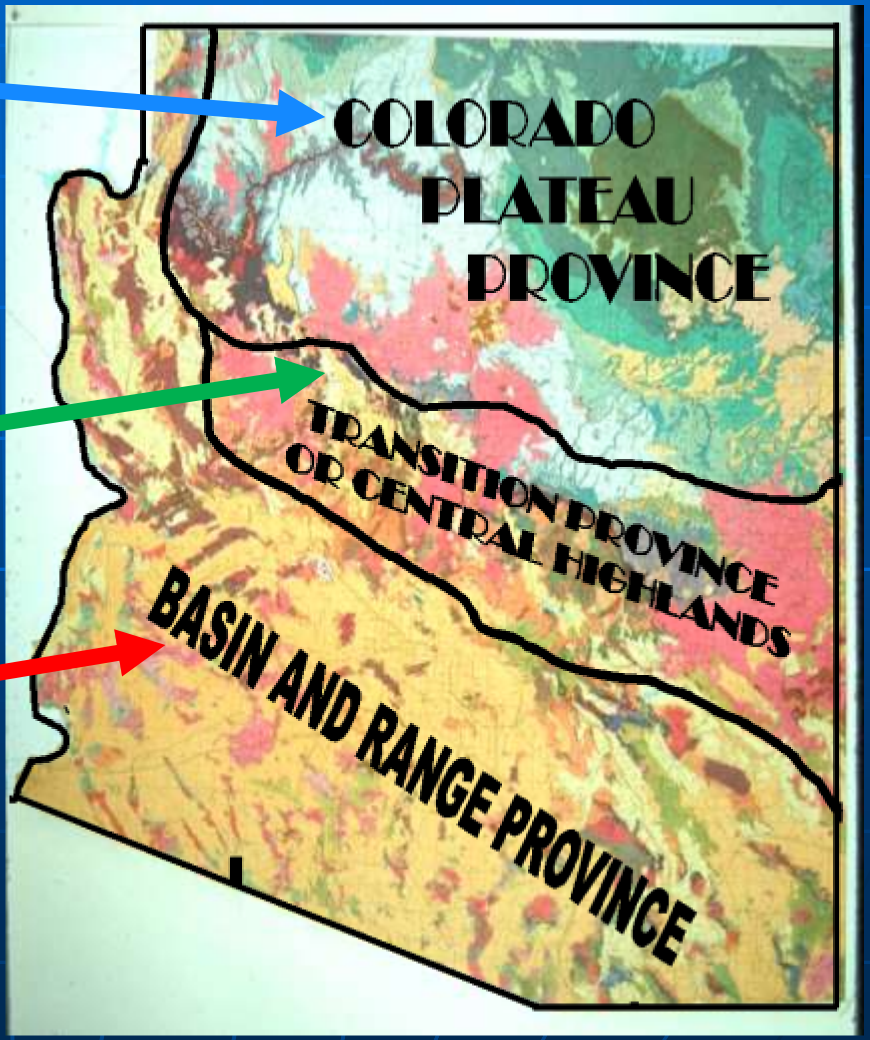
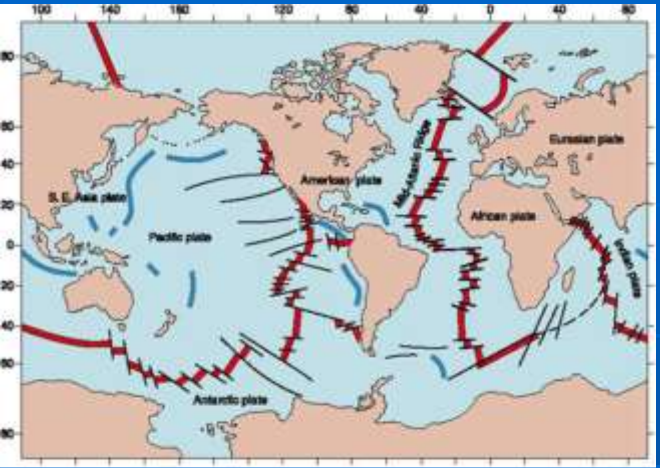
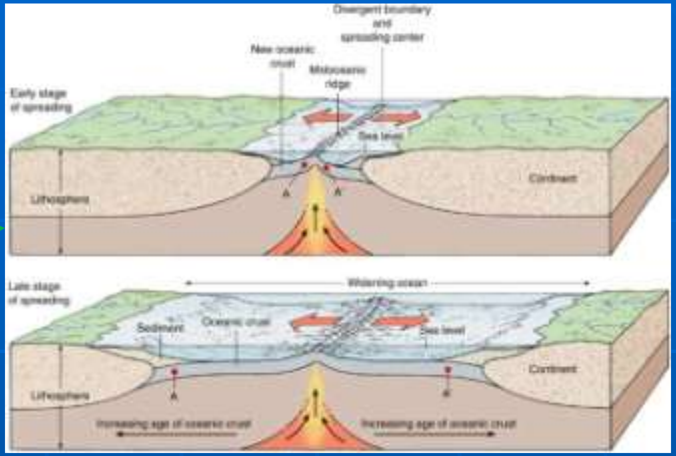
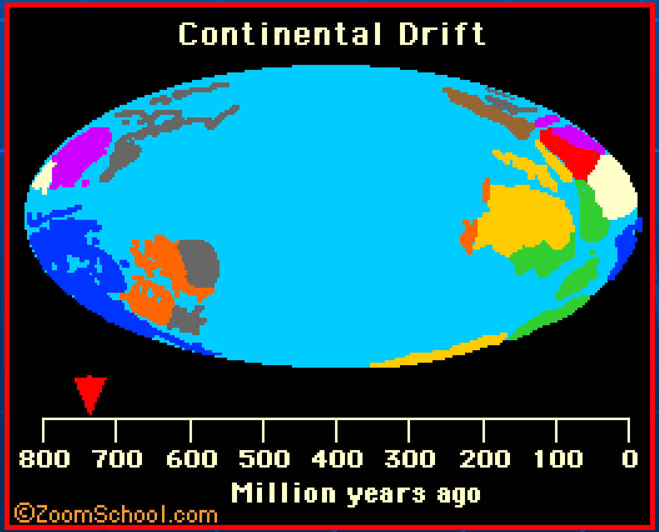


Plate Tectonics

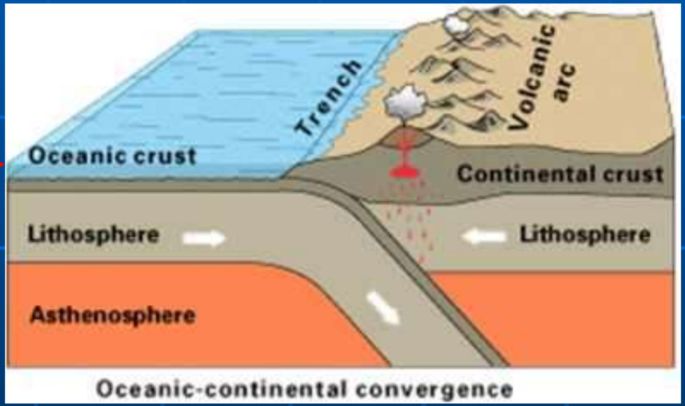


Sea floor spreading and mid-ocean ridge volcanism

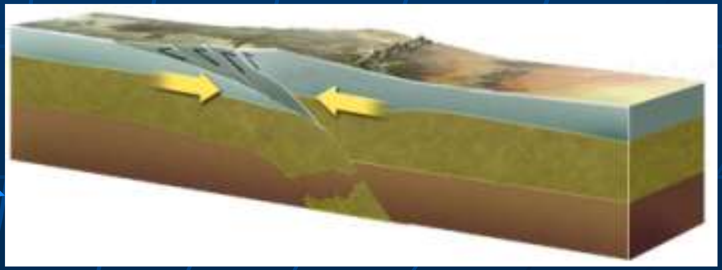




Subduction, Volcanoes, Mountains



Continent-continent collision and very tall mountains



Temp. & Geologic Time Scale

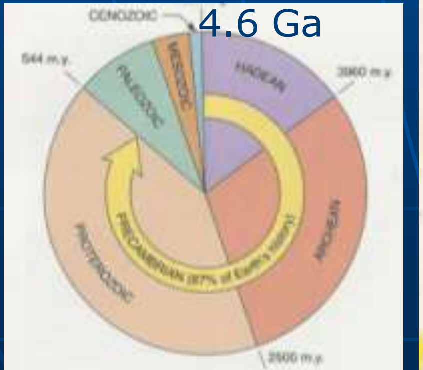
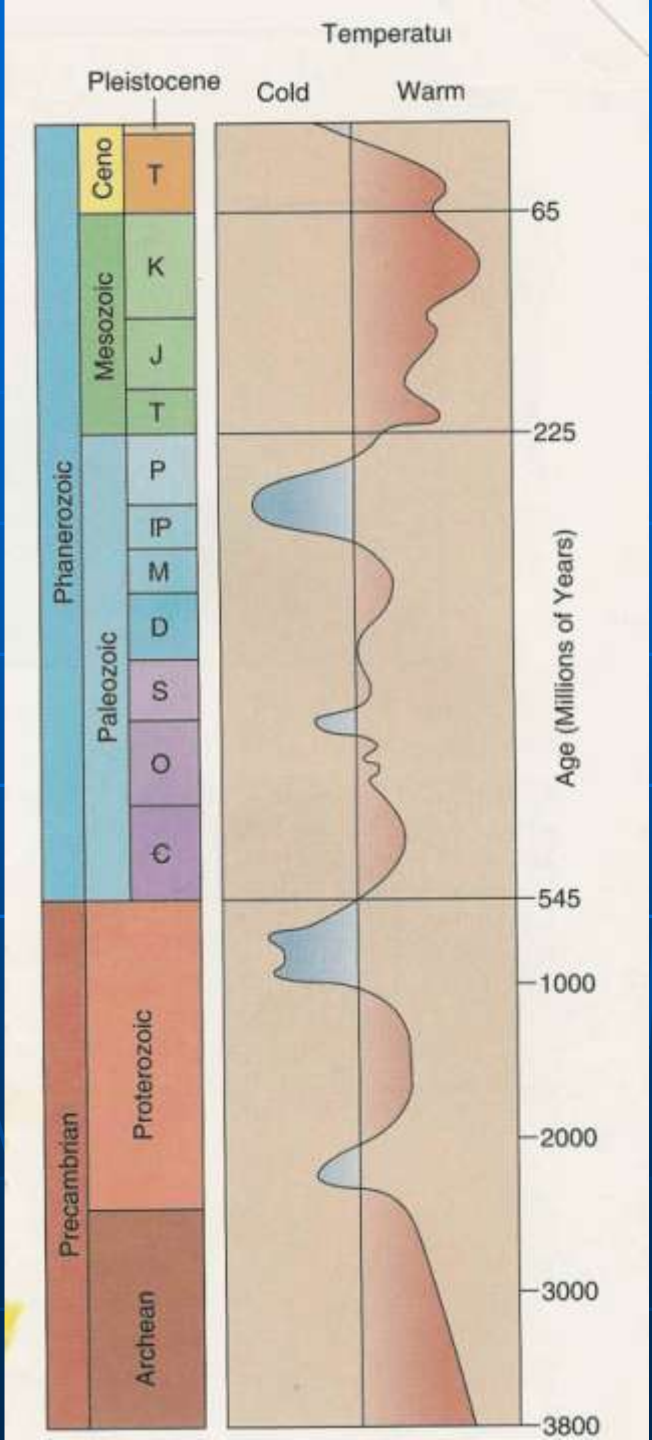
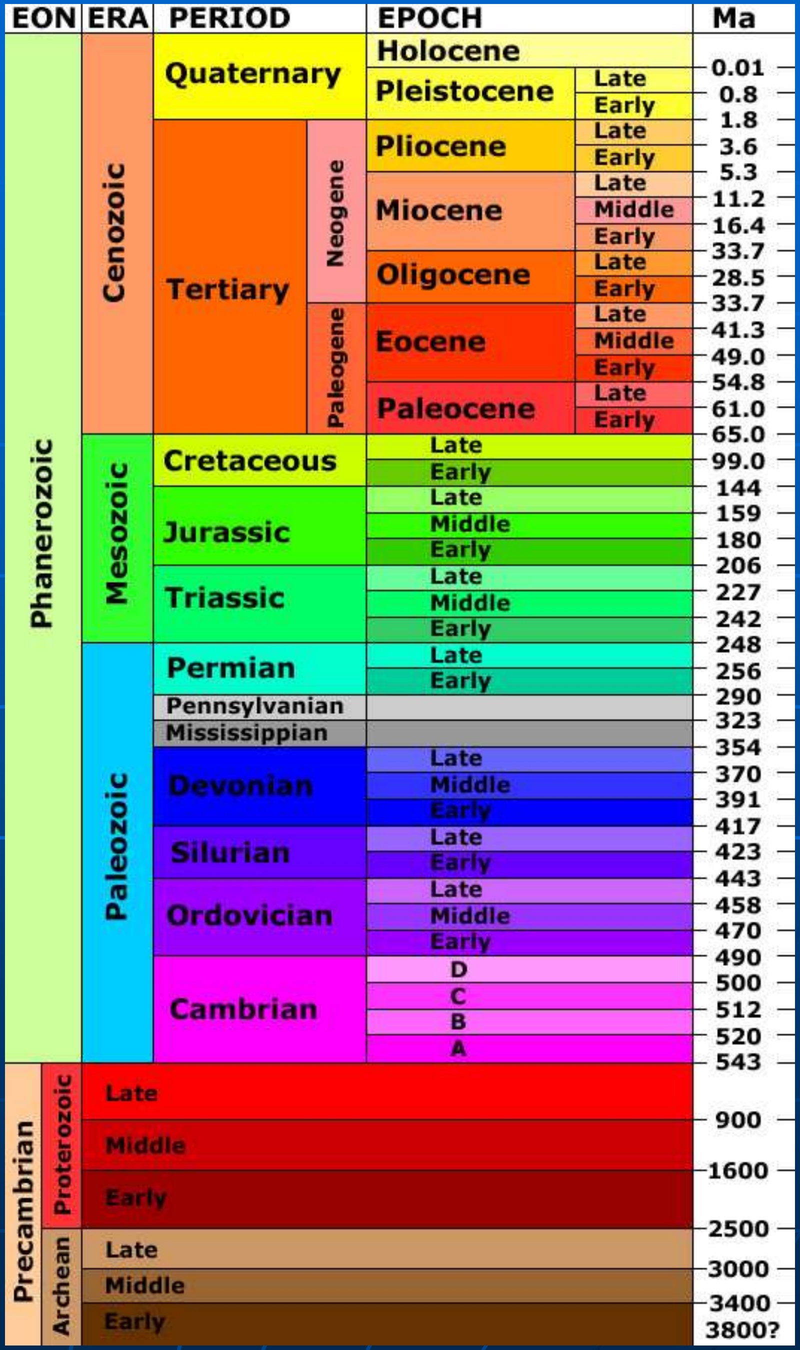
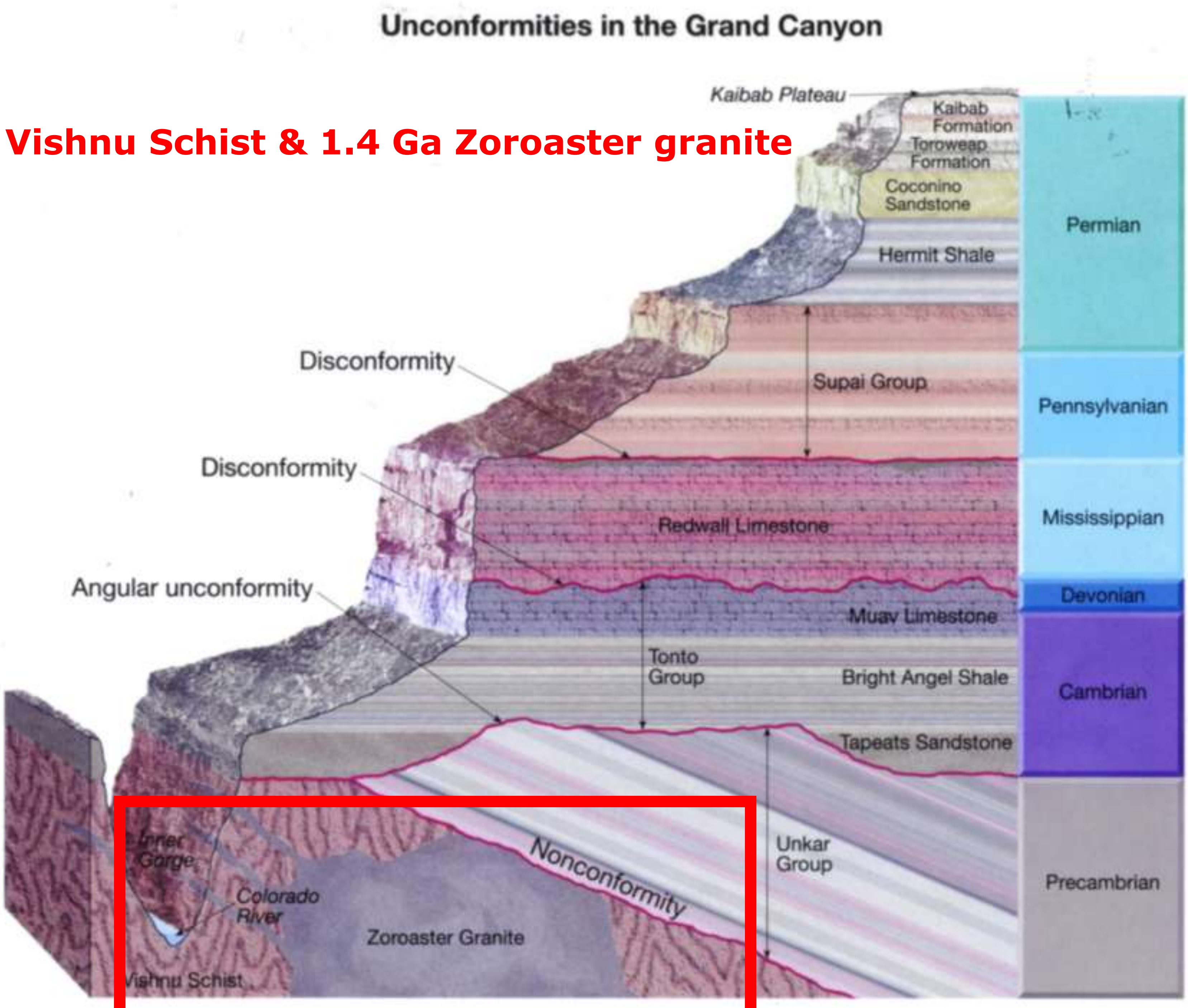


FIGURE 8-1 Proportions of geologic time encompassed by the Precambrian and its Hadean, Archean, and Proterozoic eons.





1.7 Ga Vishnu Schist & 1.4 Ga Zoroaster granite



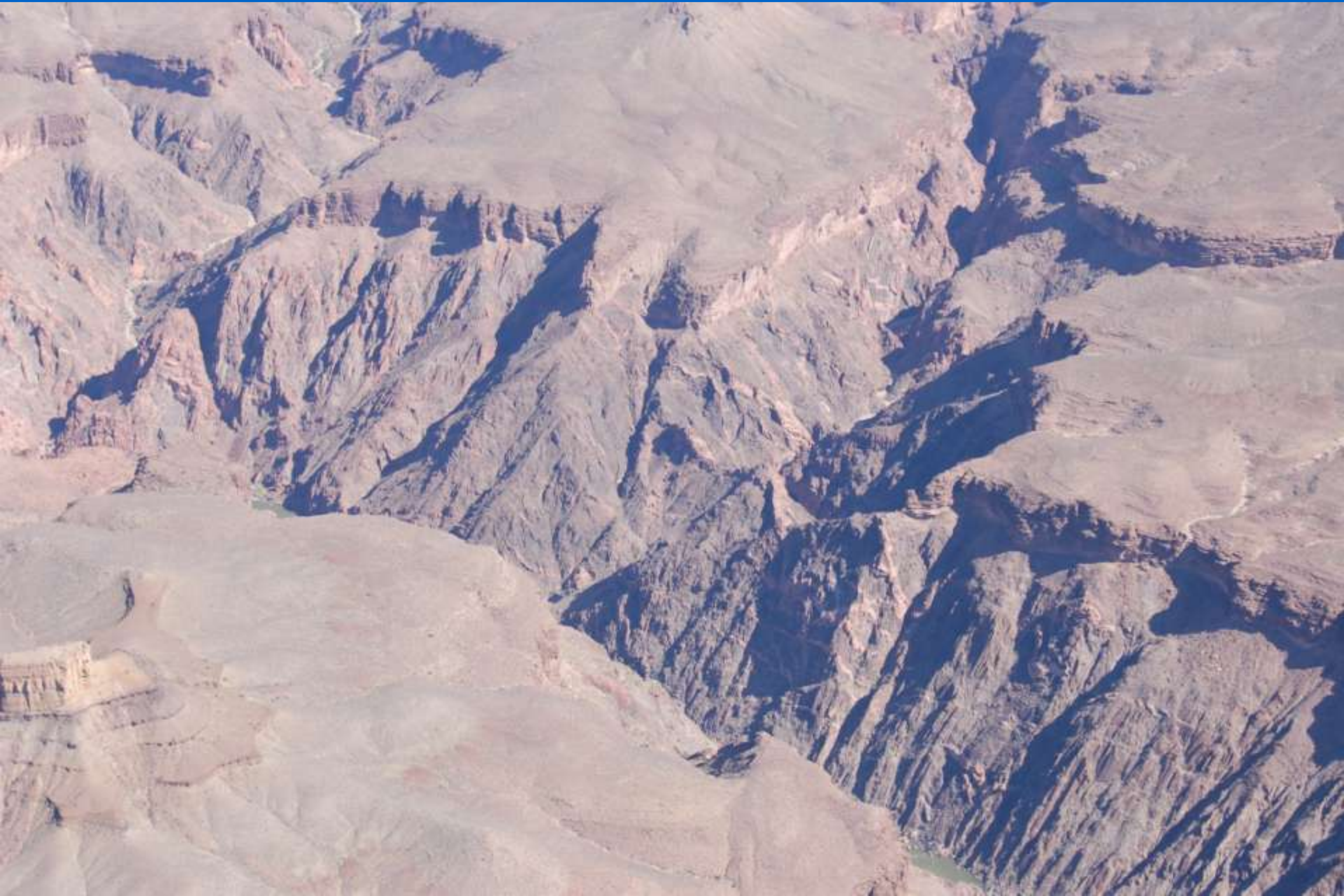
PreCambrian Arizona

Inner Gorge - metamorphic rocks

Mountain building episode in younger PreCambrian (older Proterozoic)

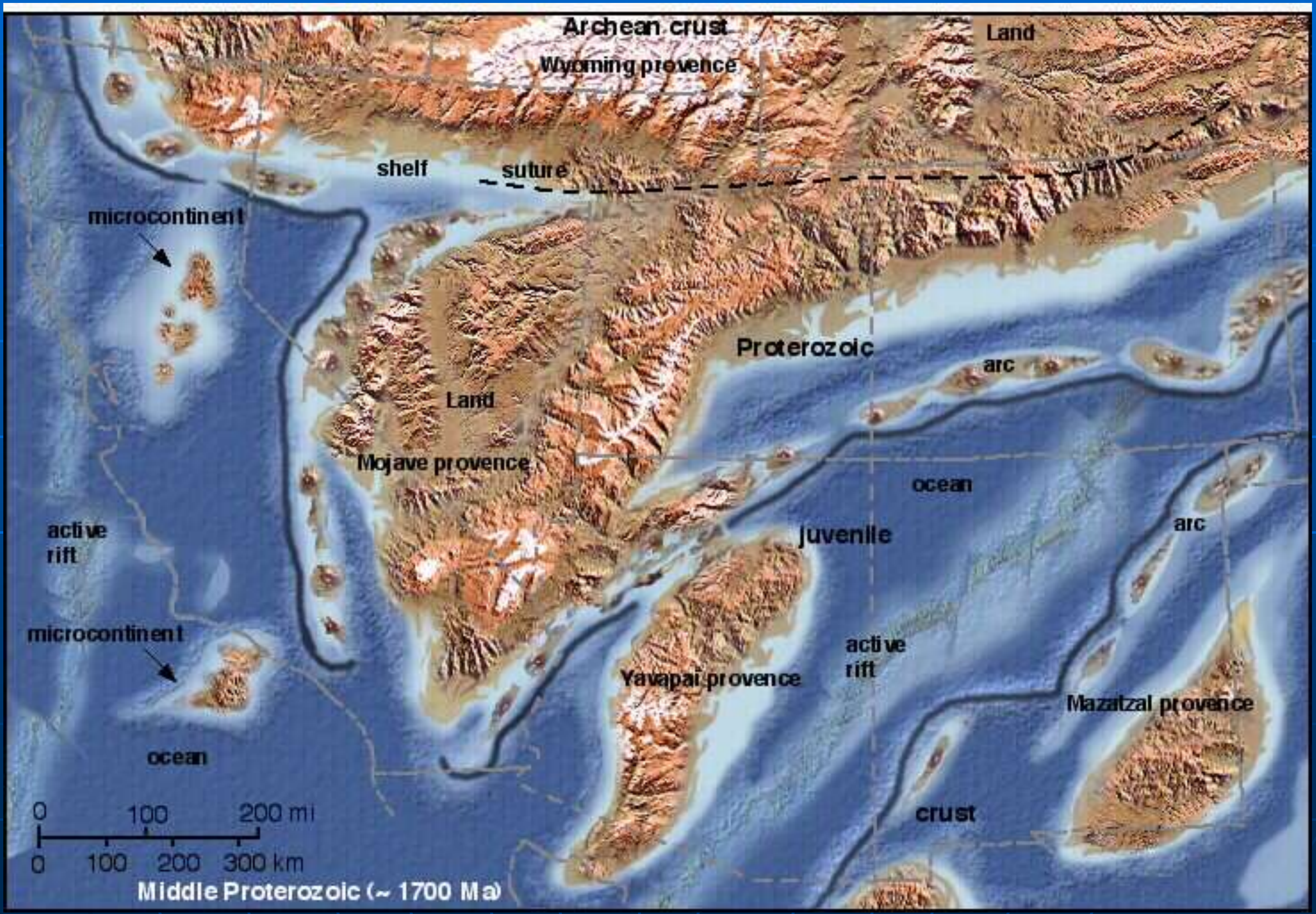
- 1.7 billion years – Mazatzal Orogeny produced Rocky Mt.-style mountains
- Metamorphism, folding, later intrusion of granitic rocks

Tapeats Ss. Overlying Vishnu Schist (1.7 Ga and Zoroaster Granite (1.4 Ga)



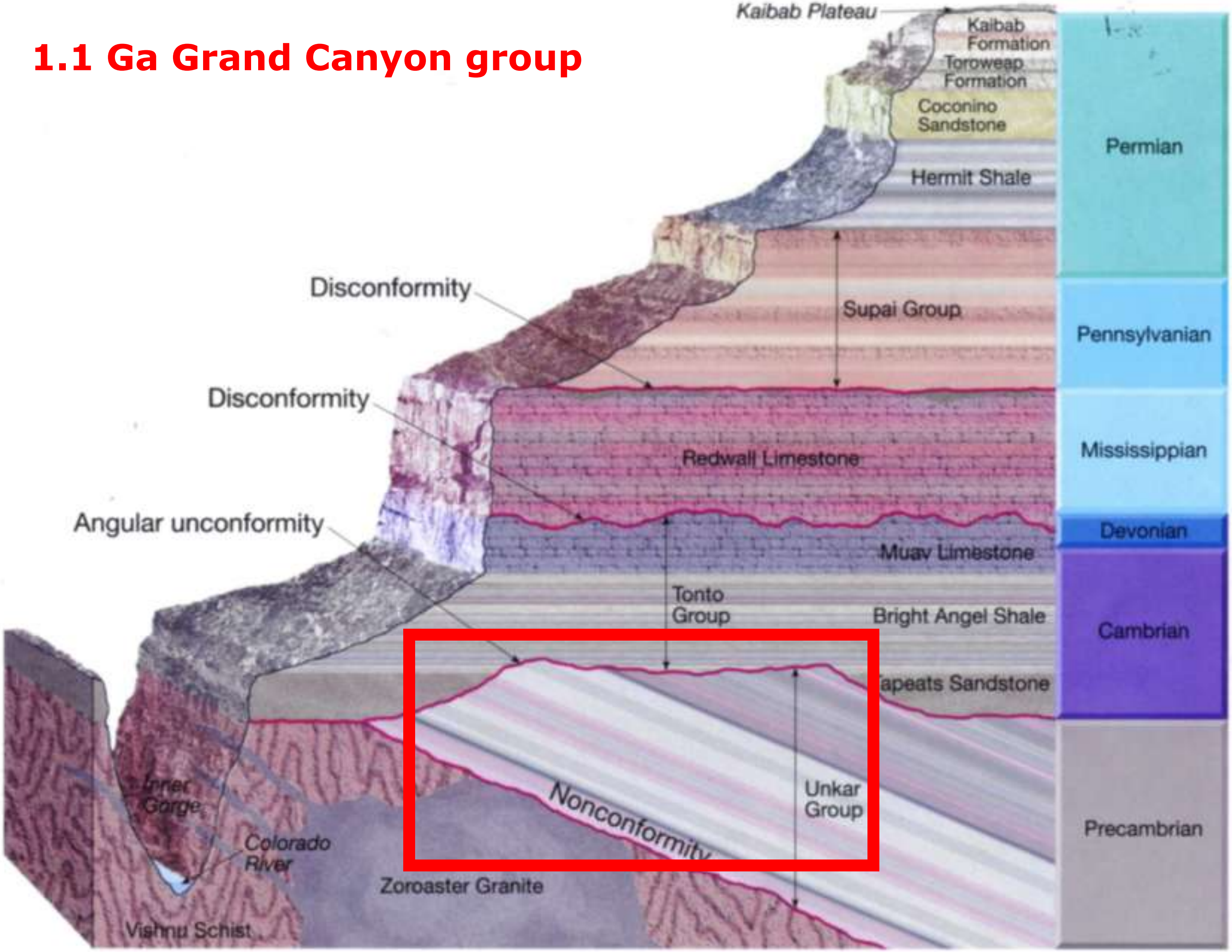
Dikes and Veins of Zoroaster Granite intruding Vishnu Schist

Meso-proterozoic (1.7 Ga)



Unconformities in the Grand Canyon

1.1 Ga Grand Canyon group

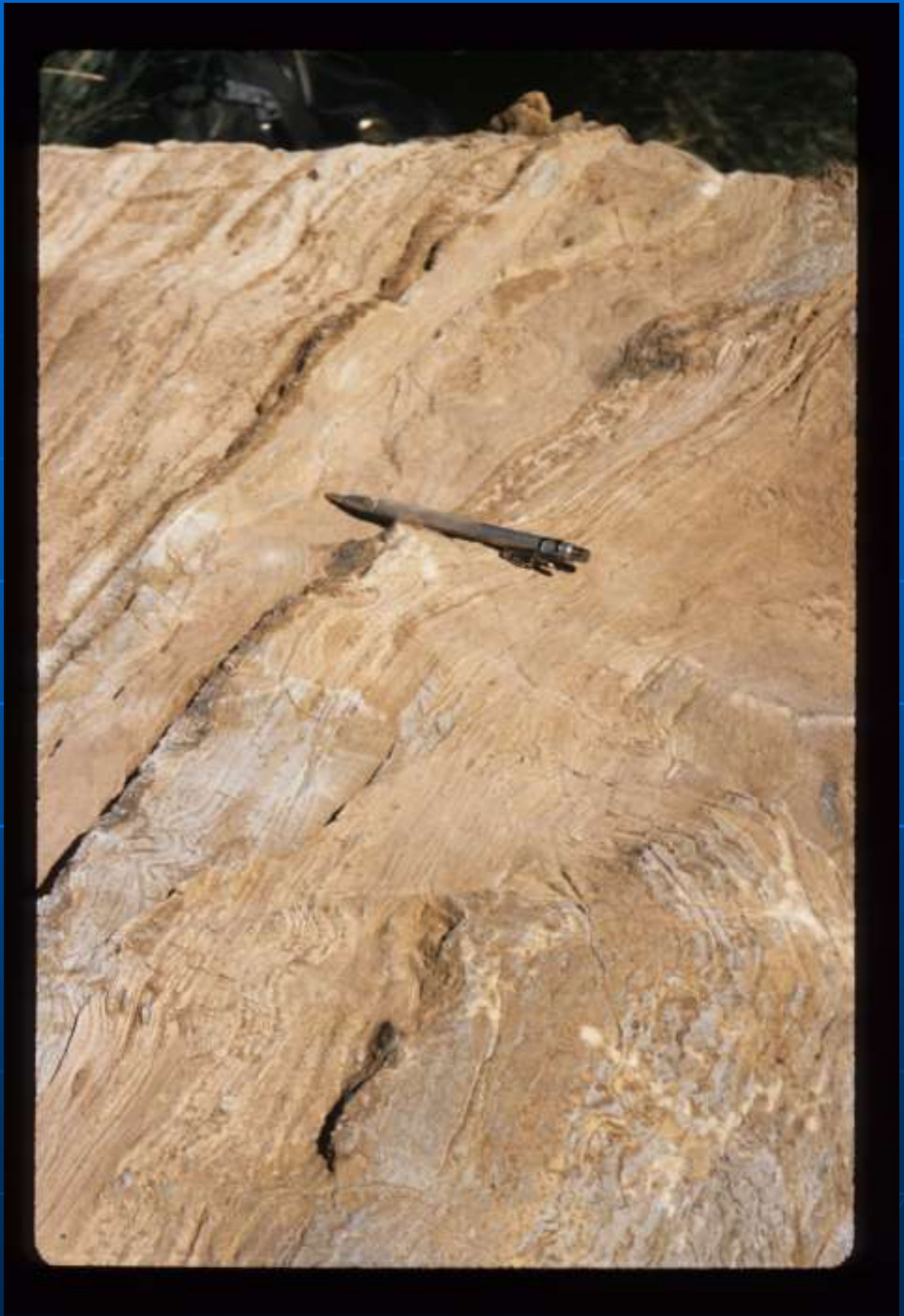


Grand Canyon Group

- 1.1 billion years ago - Fault block mountains (4,000′ offset)
- about 10,000 ft thick
- Eroded away to a nearly flat surface before the deposition of the Tapeats Sandstone 500 million years ago.

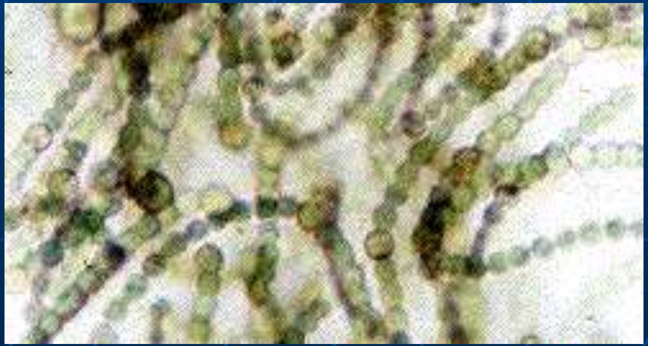
Meso-proterozoic (1.1 Giga-annum [Ga])

Stromatolites

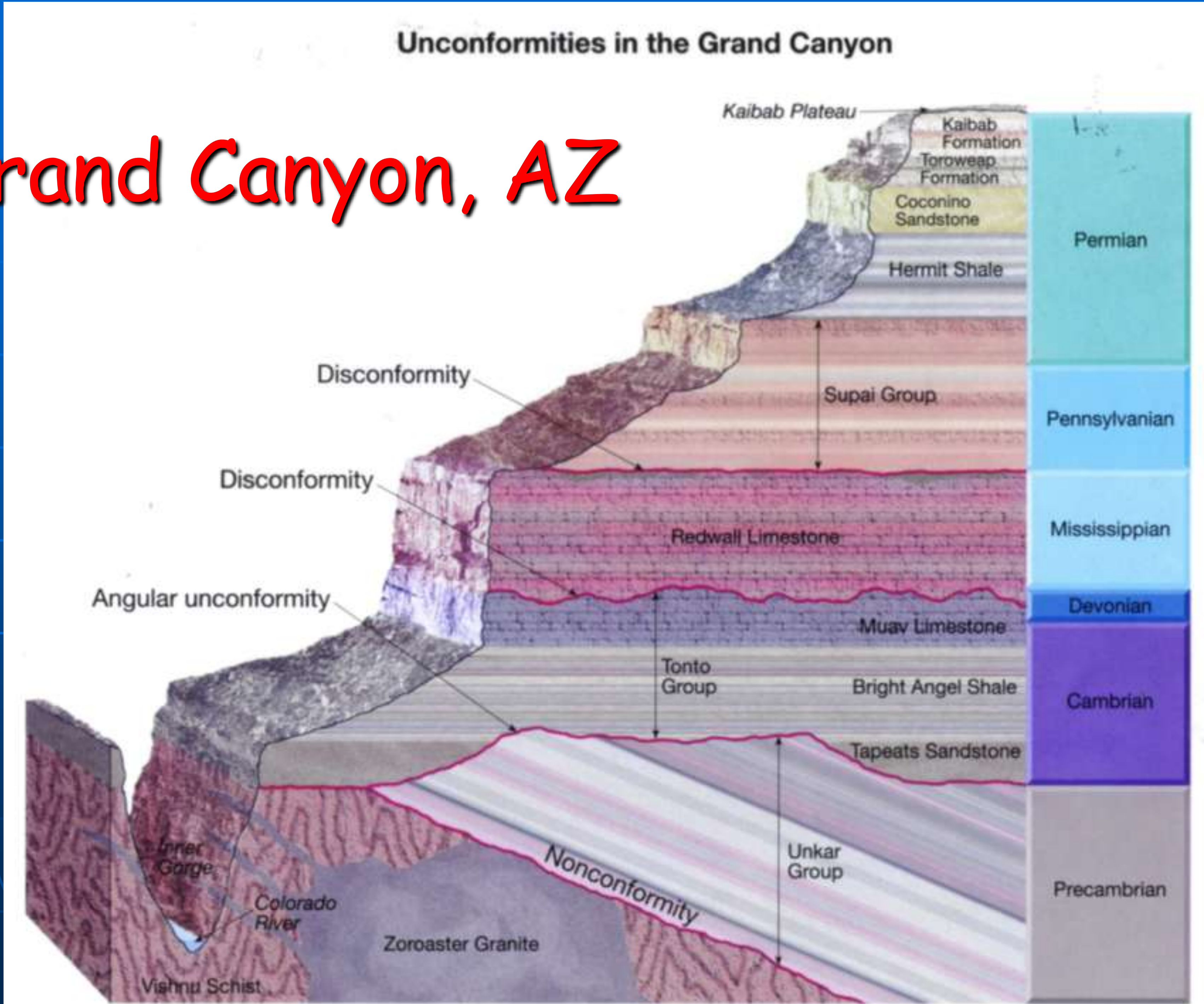


Blue-green algae gave O_2

- Photosynthesis by blue green algae (cyanobacteria) since 3.5 billion yrs ago
- When pigments developed in cells, they could absorb and process light.
- The products of this process were energy and oxygen.
- Between 2.4 – 2.2 billion years ago, the greater numbers of cyanobacteria increased production of oxygen.
- By 1.8-1.6 Ga, O_2 rose from 1% to 15%.
- Stromatolites deposited layers of calcium carbonate in layers.



Grand Canyon, AZ



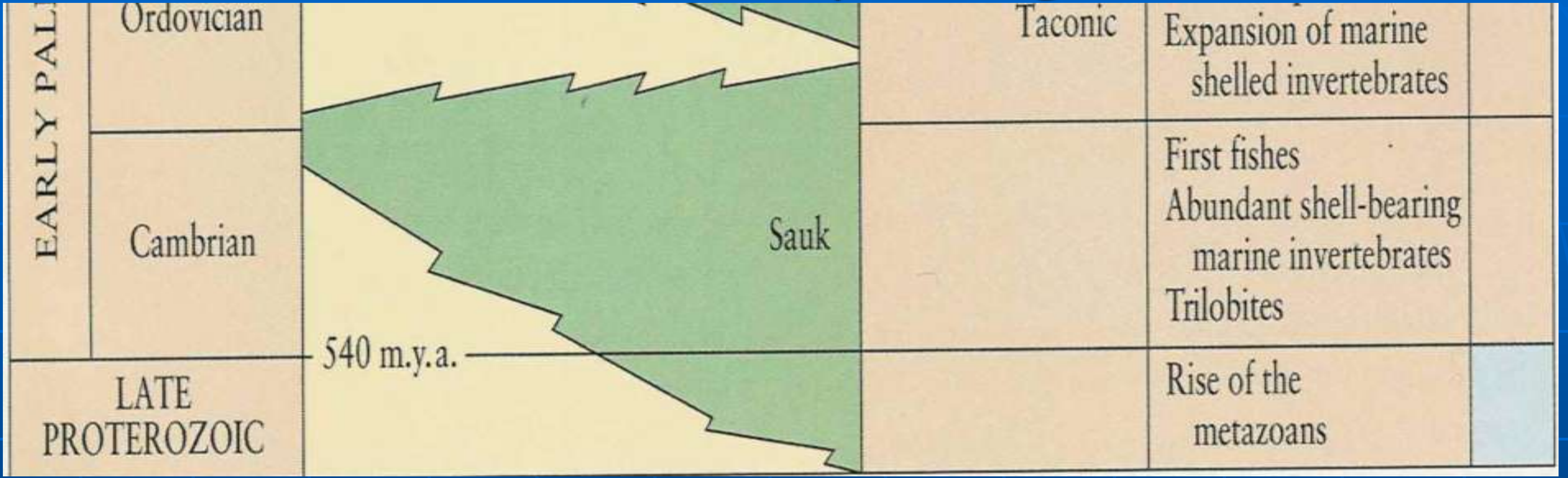
Inner Gorge Grand Canyon, black Vishnu Schist, intruded by white Zoroaster Granite, Tapeats Sandstone deposited on unconformity

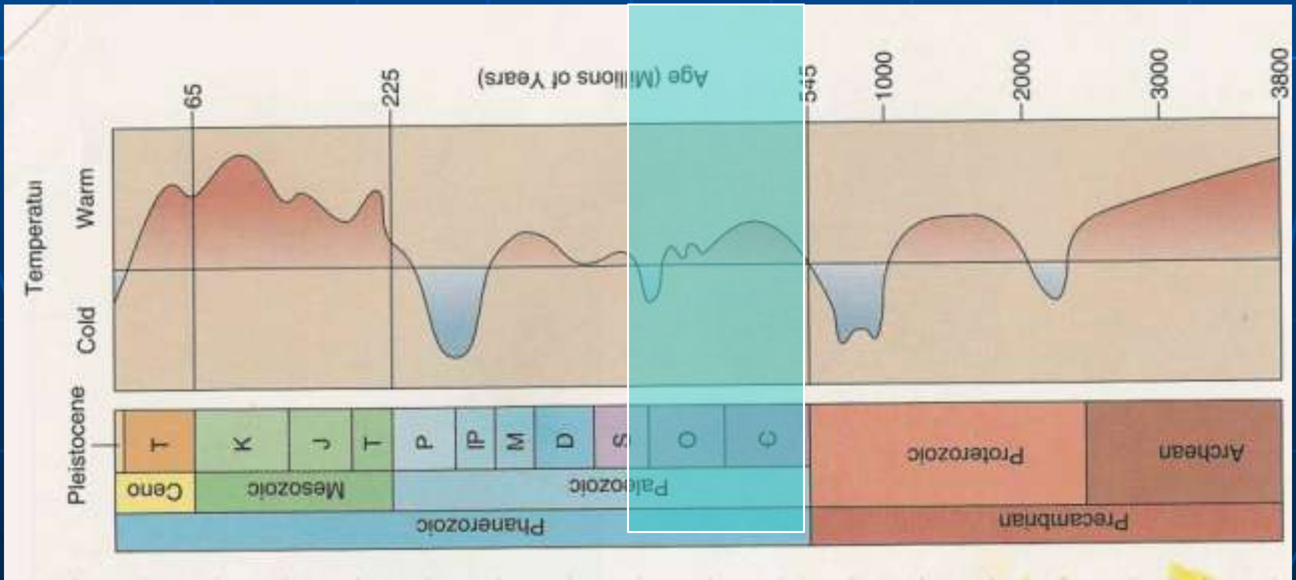

HATCH

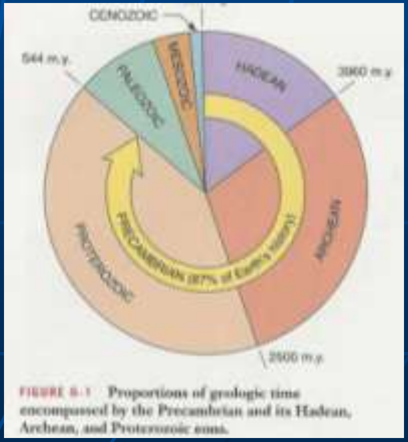
Grand Canyon formations

Cambrian – Early Ordovician

543 - 470 million years ago (Ma)

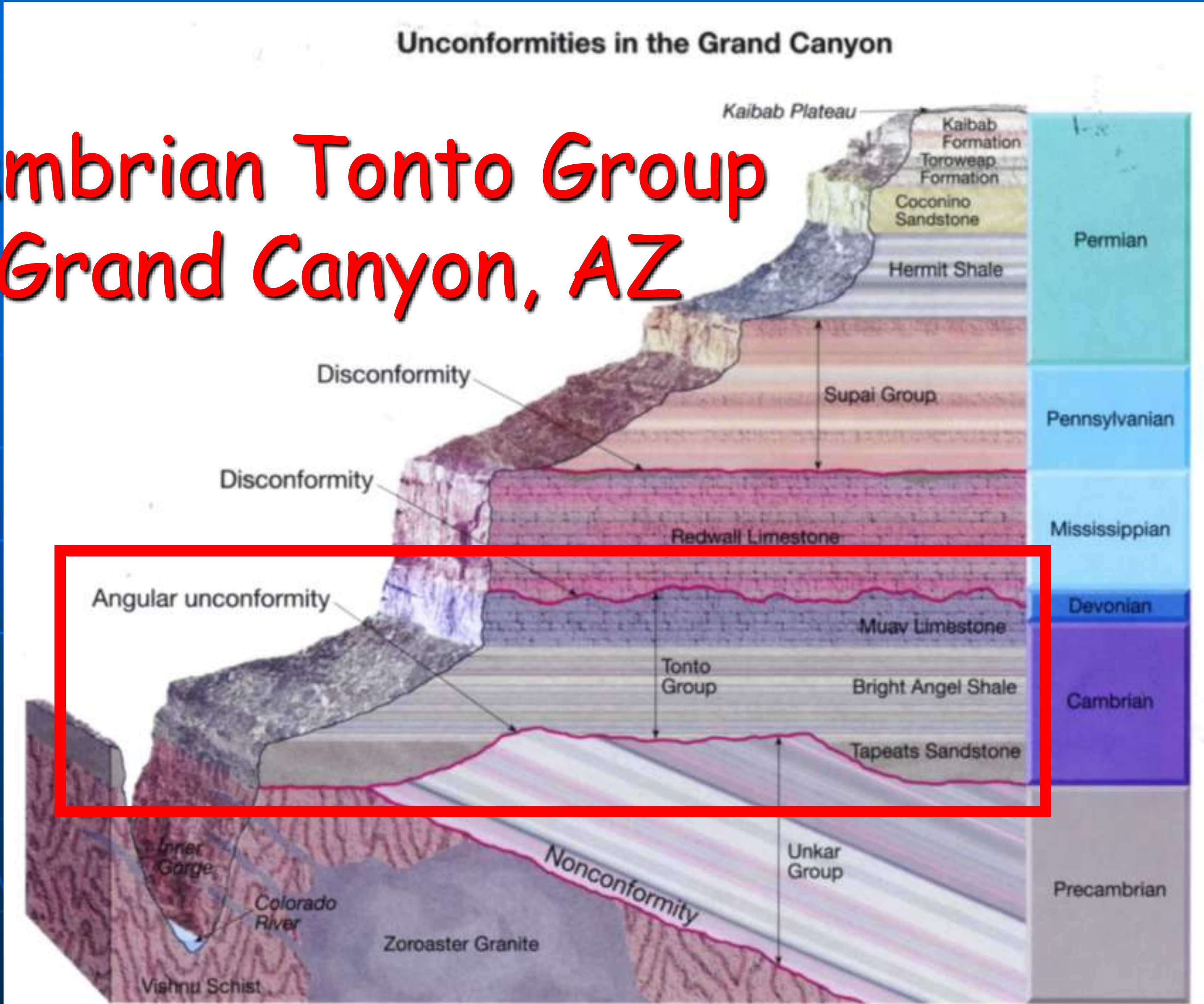




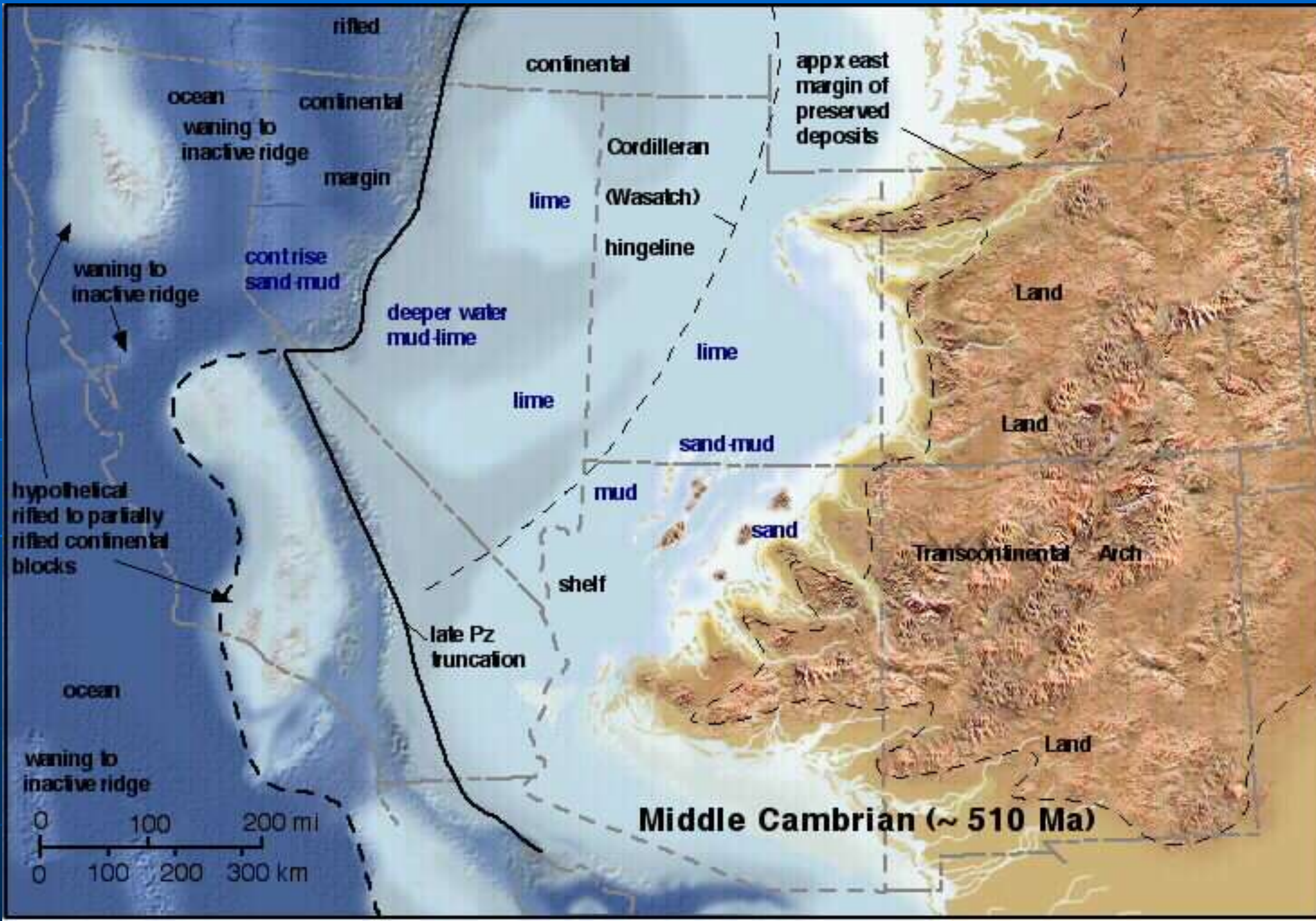


Tapeats Sandstone ledge at base, tan slope = Bright Angel Shale,
Thin ledges & cliffs below Redwall cliff = Muav Limestone

Cambrian Tonto Group Grand Canyon, AZ

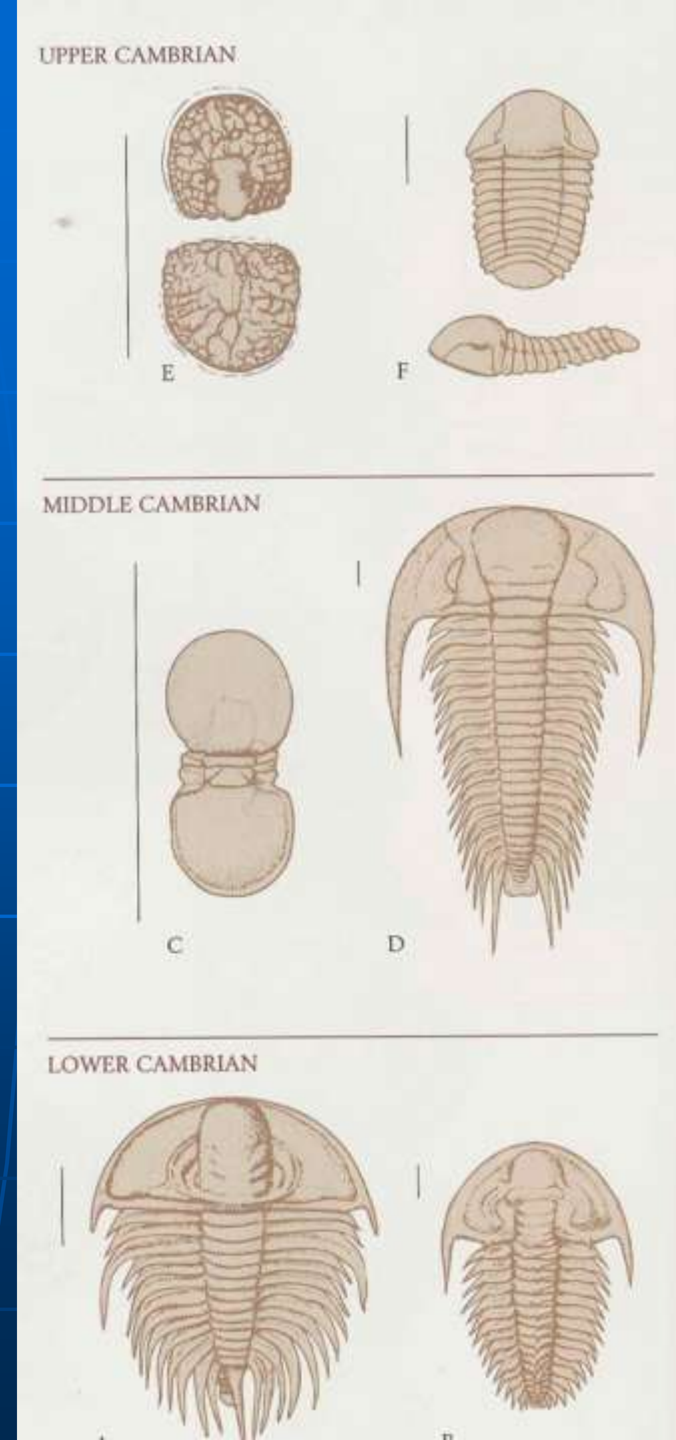


Cambrian (543-490 Ma)




Worm burrows in Muav Ls

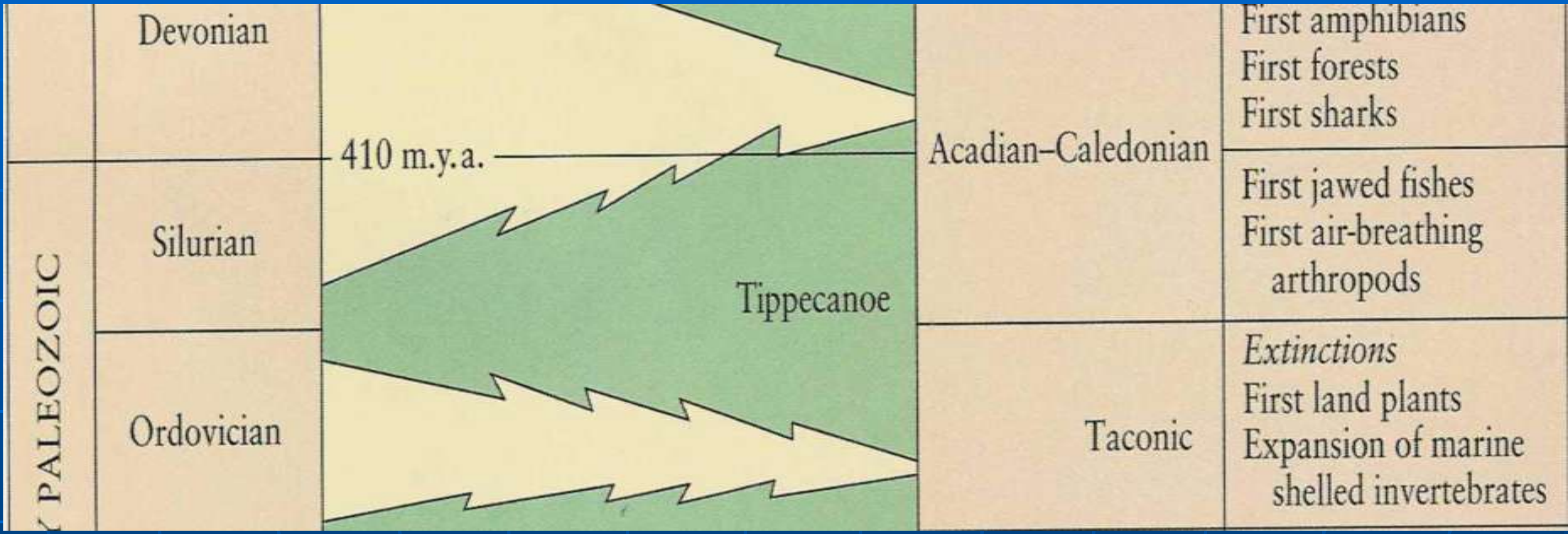
trilobites

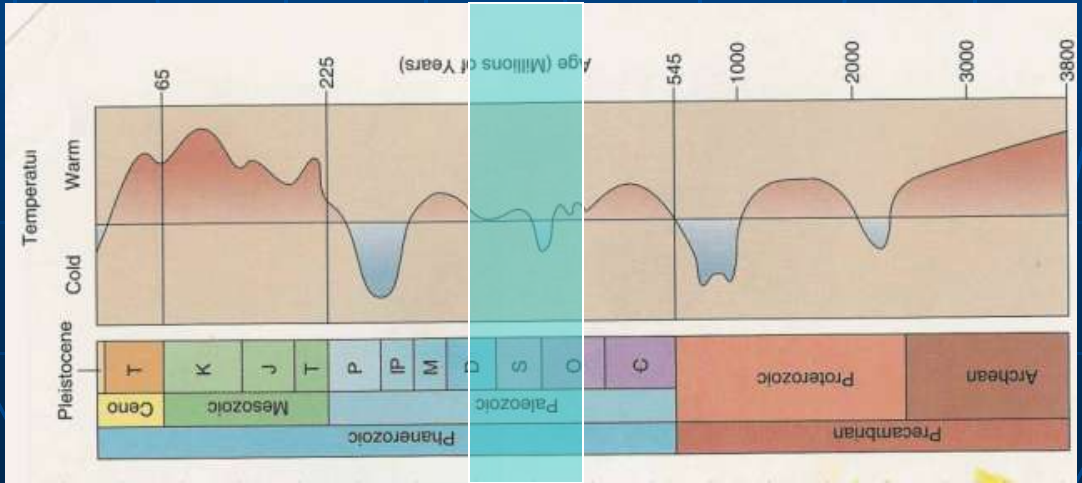


A B

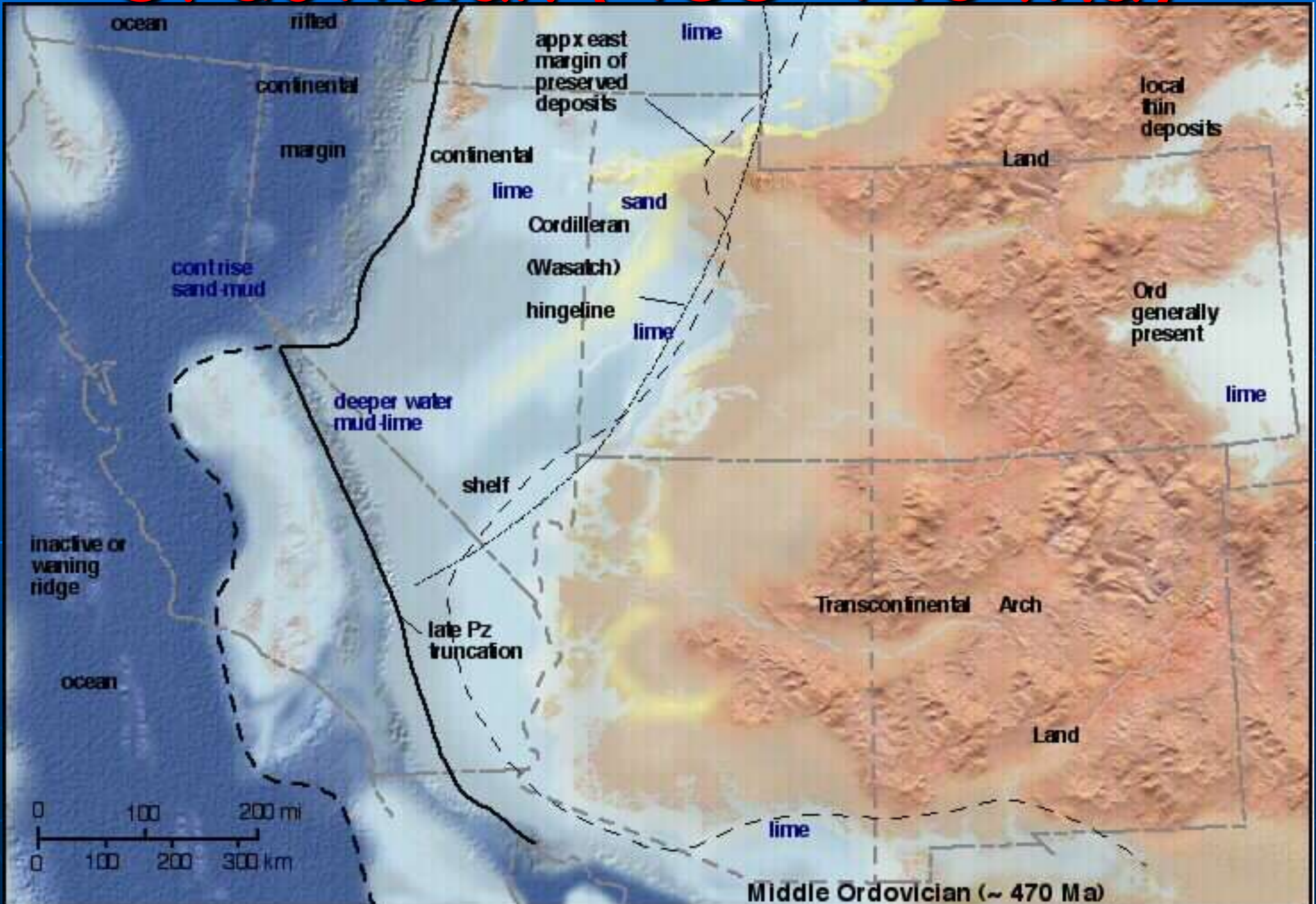
Figure 13-2 Typical Cambrian trilobites. A. *Olenellus.* B. *Holmia.* C. *Lejopyge.* D. *Paradoxides.* E. *Glyptagnostus.* F. *Illaenurus.* Trilobites were arthropods (invertebrate animals with segmented bodies and jointed legs). The soft body and the many legs were positioned beneath the flexible, jointed skeleton. Trilobites had mouthparts for chewing small pieces of food. Most species crawled over the seafloor, but some burrowed in sediment, and a few small species, including *Lejopyge and Glyptagnostus*, were planktonic. (Scale bars represent 1 centimeter [$\frac{3}{8}$ inch].) (After R. C. Moore, ed., *Treatise on Invertebrate Paleontology*, pt. O, Geological Society of America and University of Kansas Press, Lawrence, 1959.)

Middle Ordovician – Early Devonian (~470-400 Ma)





Ordovician (488-443 Ma)



Late Ordovician environments (430 Ma)

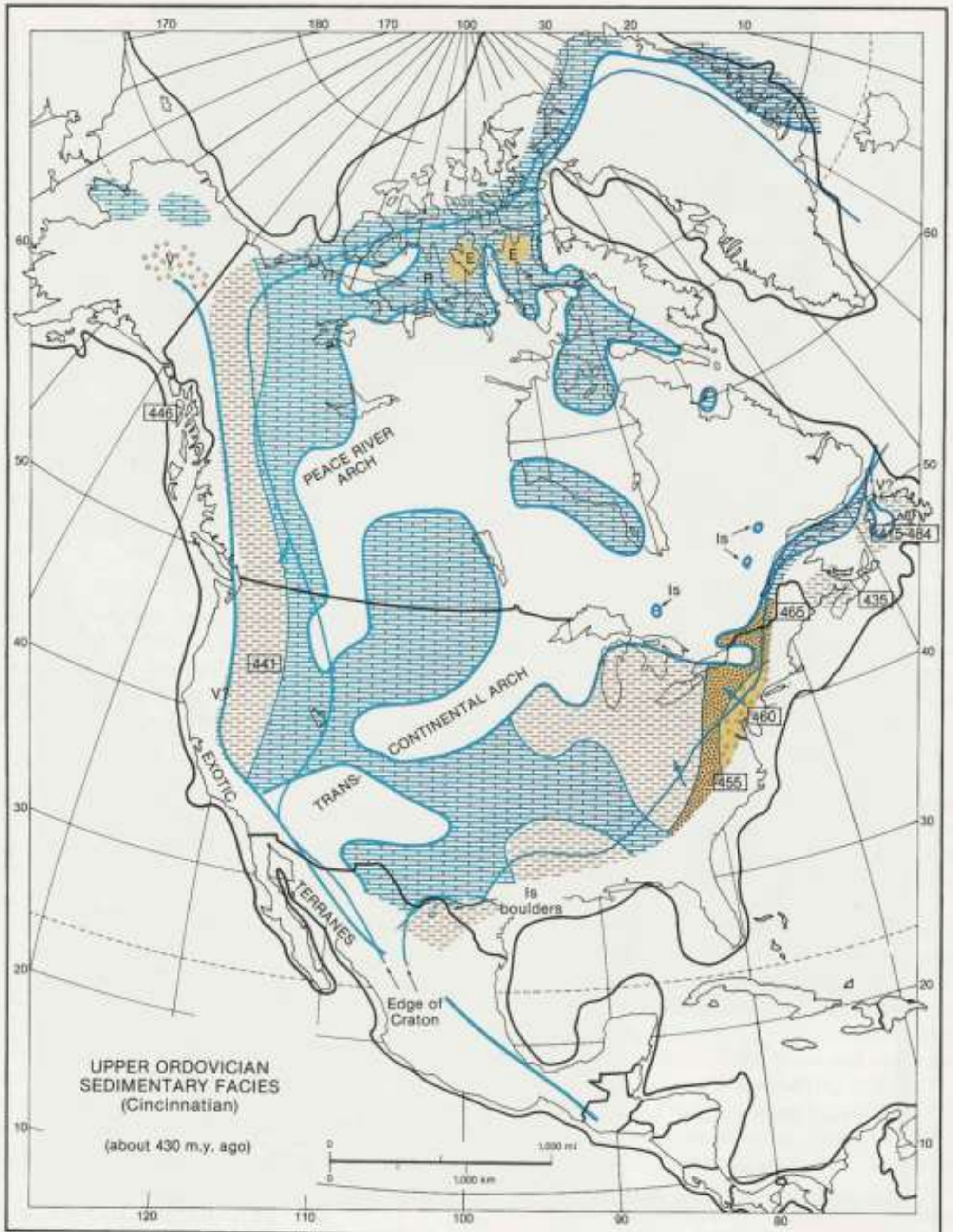


Figure 11.15 Upper Ordovician sediment patterns for North America. Widely scattered patches of sediments on the Canadian Shield prove the great extent of the Late Ordovician sea. Absence of Ordovician strata on several arches proves subsequent warping and erosion of these arches. Note the spread of red beds and marine shales westward from the Appalachian region, forming a clastic wedge. (See Box 10.2 for symbols and sources.)

Ordovician life

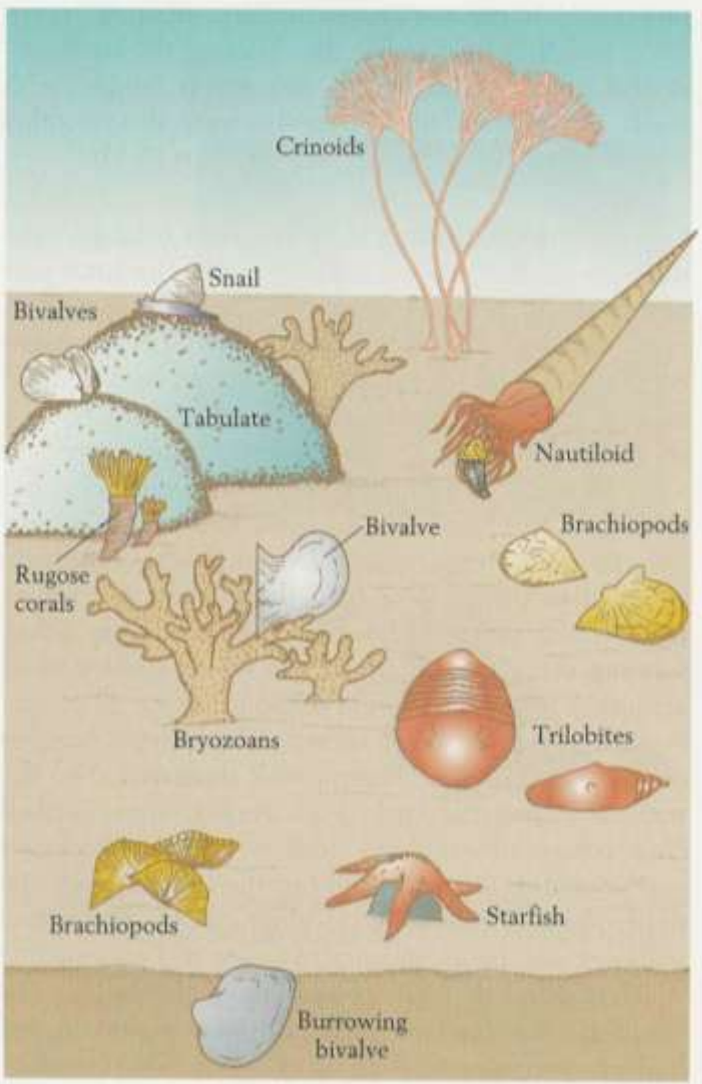
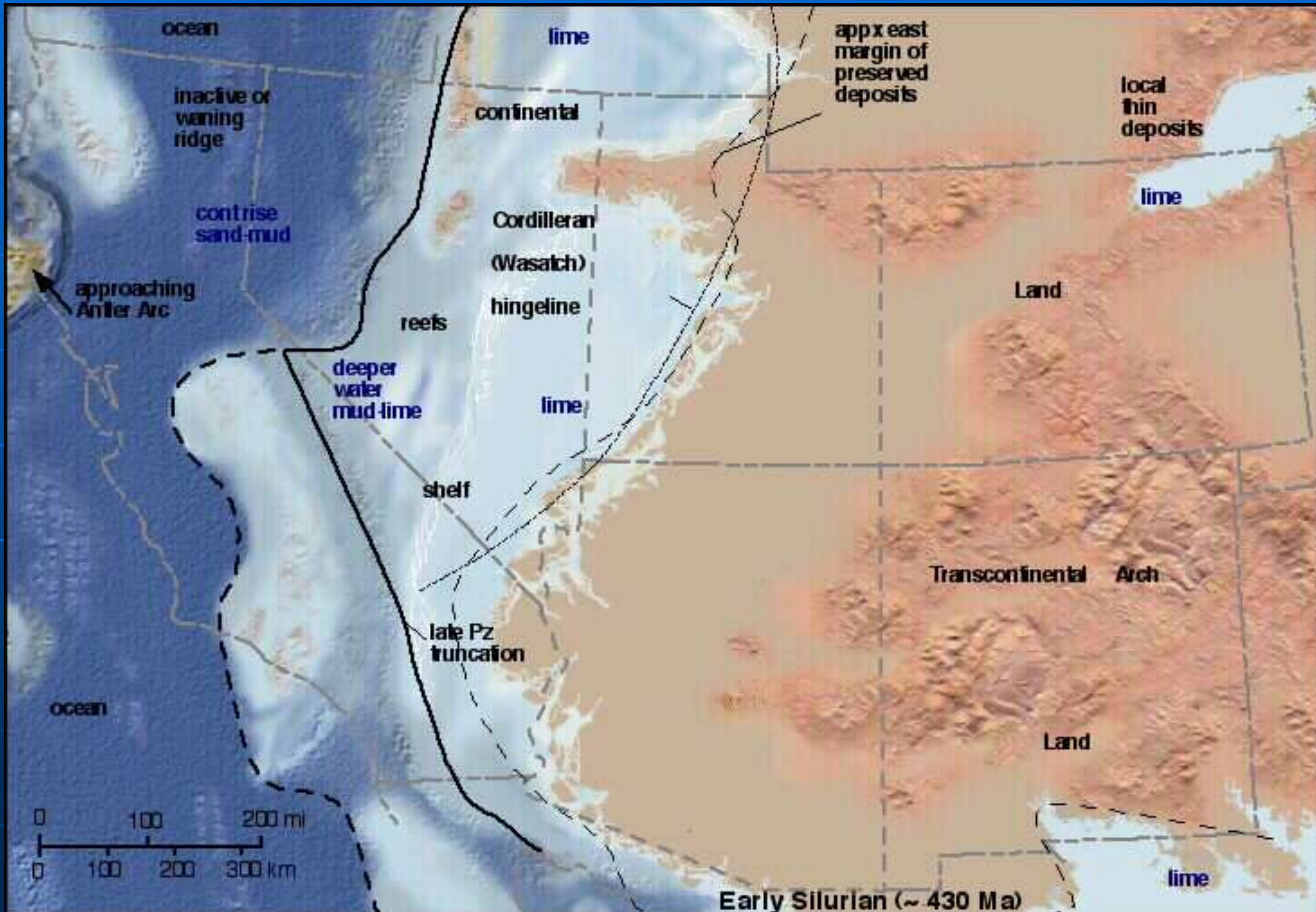


Figure 13-11 Ordovician invertebrate fossils. *A.* A straight-shelled nautiloid about 15 centimeters (6 inches) long. *B.* A spiny trilobite that lived on the sediment surface. *C.* A smooth-shelled burrowing trilobite. *D.* A snail (gastropod). *E* and *F.* Two kinds of articulate brachiopods. *G.* A bivalve mollusk that lived on the sediment surface. *H.* A branched bryozoan colony. *I.* A tabulate coral colony. *J.* A stromatoporoid colony. *K.* A rugose coral. (Courtesy Smithsonian Institution, photo by Chip Clark.)

Silurian (443-417 Ma)



Silurian - Devonian fossils

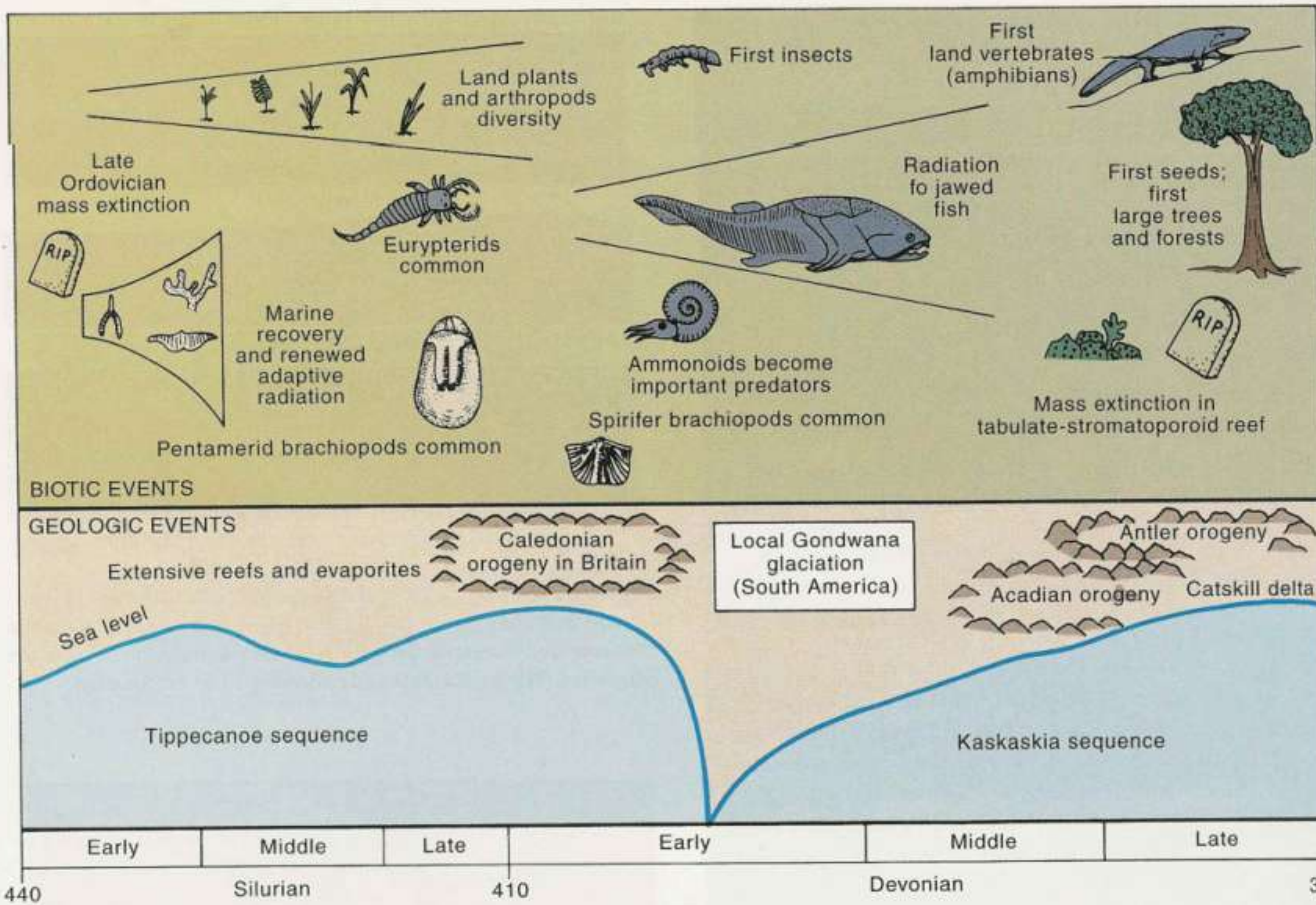
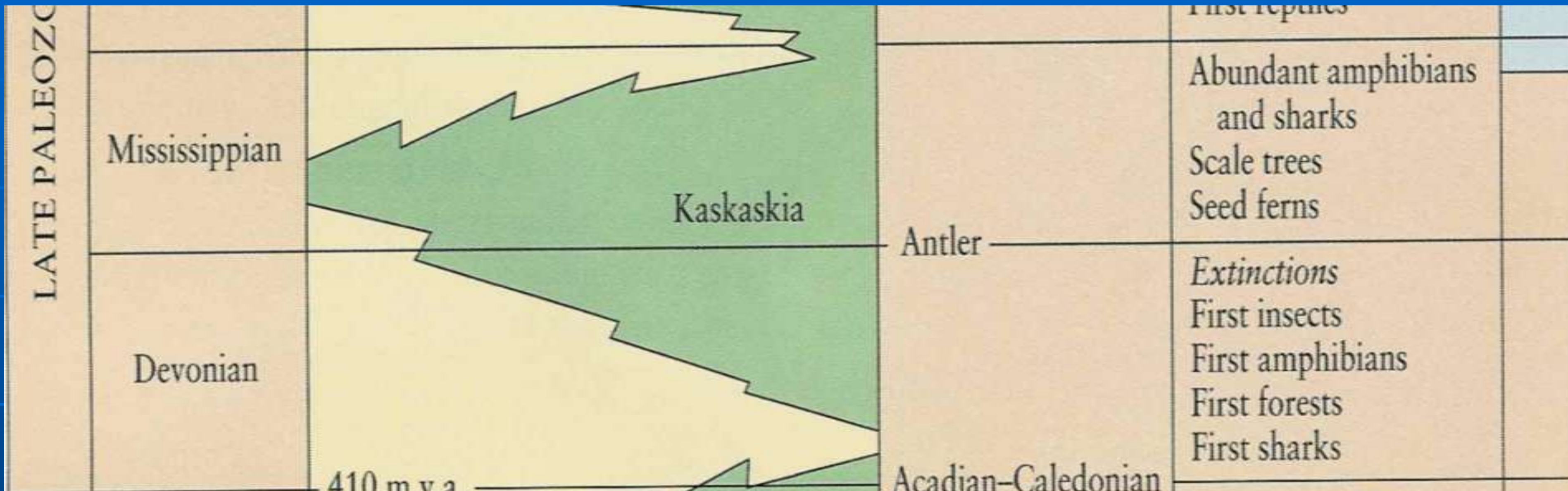
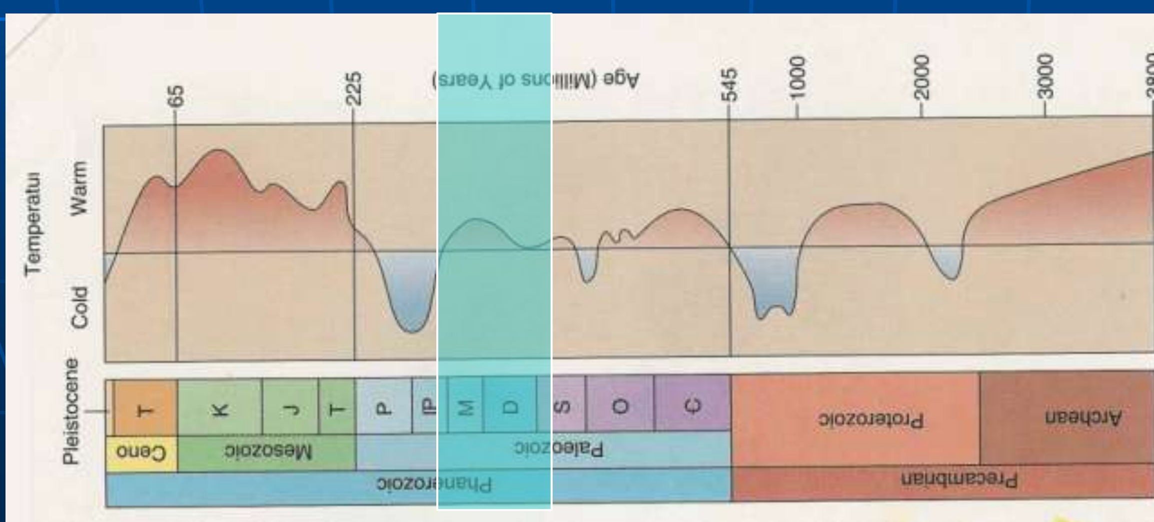


Figure 12.50 Summary time line of events of the Silurian and Devonian.

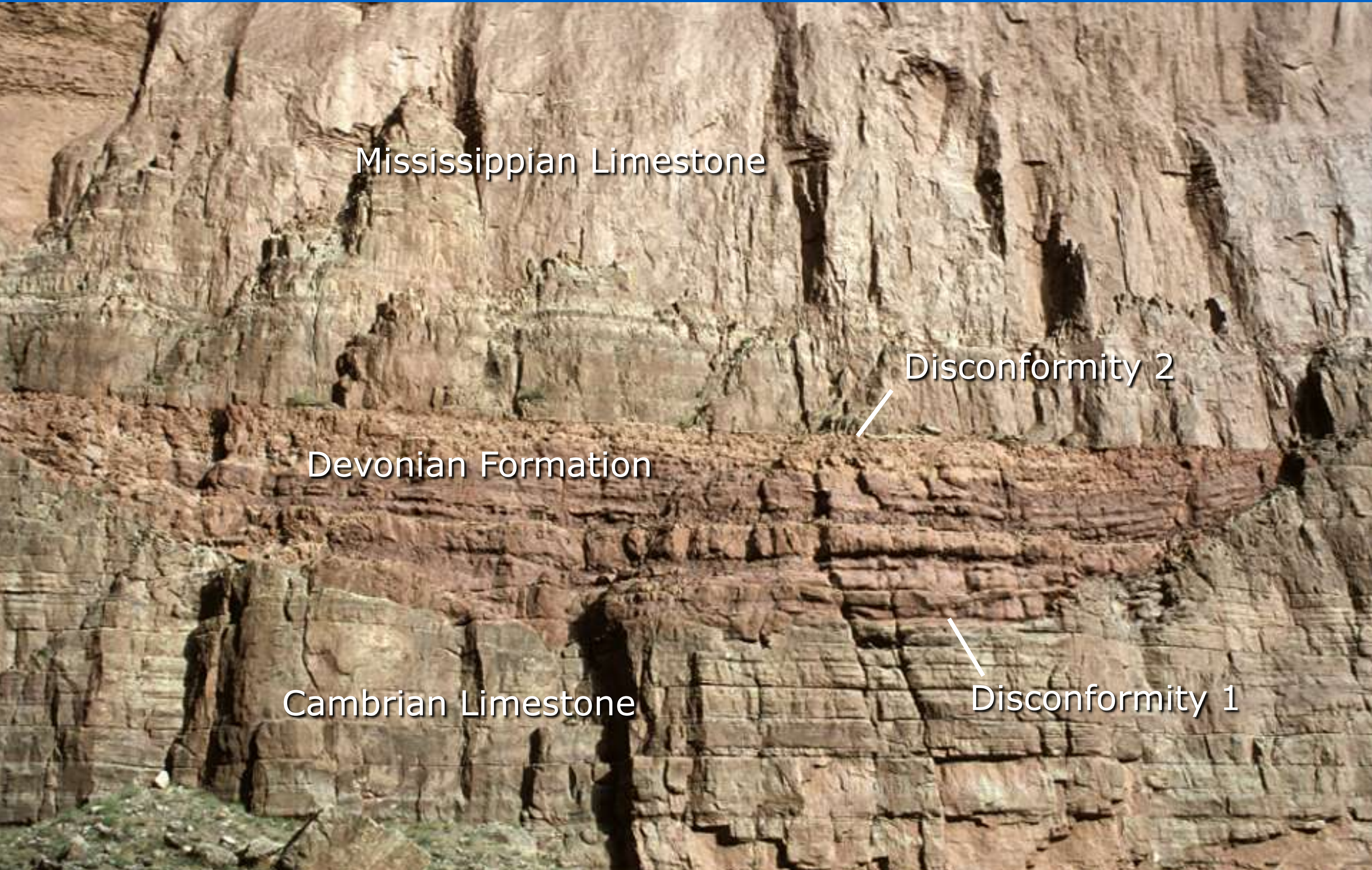
Devonian – Mississippian
416-359 – 318 Ma





Devonian age Temple Butte Limestone in an erosion channel at the top of the Cambrian Muav and below the Redwall Limestone

09.04.c



Devonian (416-359 Ma)

Devonian environments

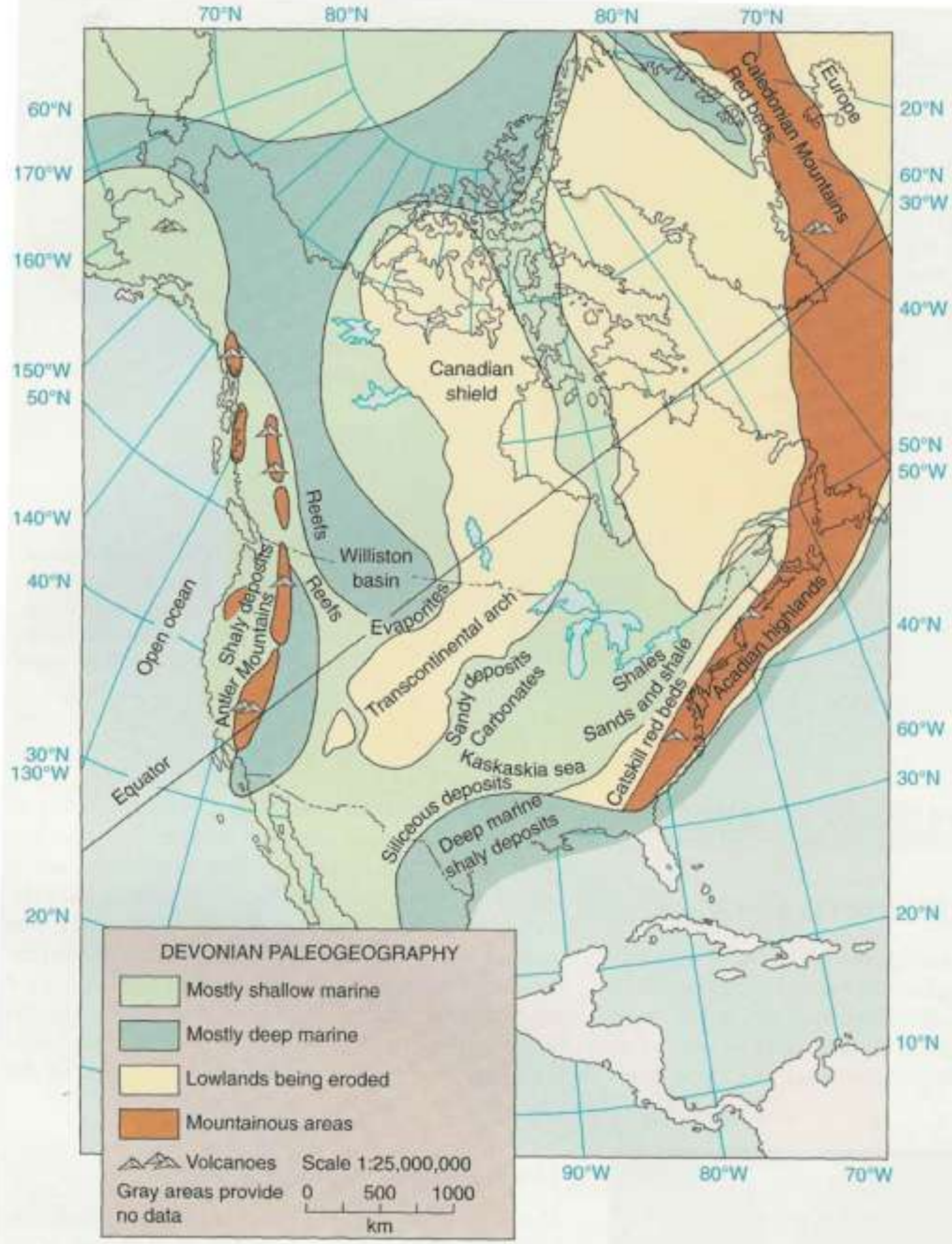


FIGURE 9-4 Paleography of North America during the Devonian Period.

Devonian fossils

solitary horn coral *Zaphrenthis*

Mucrospirifer

Lithostrotionella

Hexagonaria

Platyrachella

Devonian armored fish

FIGURE 10-62 **The gigantic armored skull and thoracic shield of the formidable late Devonian placoderm fish known as *Dunkleosteus*.** *Dunkleosteus* was over 10 meters (about 30 feet) long. The skull shown here is about 1 meter tall. It is equipped with large bony cutting plates that functioned as teeth. Each eye socket was protected by a ring of four plates, and a special joint at the rear of the skull permitted the head to be raised, thereby making an extra large bite possible. *Dunkleosteus* ruled the seas 350 million years ago. (*Courtesy of the U.S. National Museum of Natural History, Smithsonian Institution; photograph by Chip Clark.*)

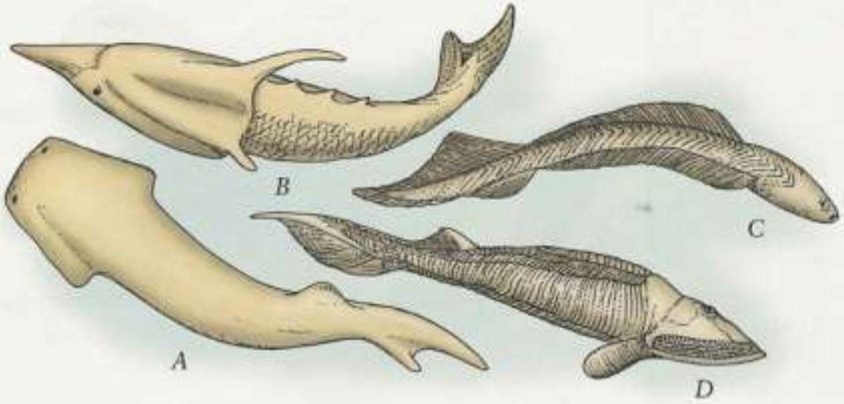


FIGURE 10-60 **Early Paleozoic ostracoderms.** (*A*) *Thelodus*, (*B*) *Pteraspis*, (*C*) *Jamoytius*, and (*D*) *Hemicyclaspis*, drawn to the same scale.

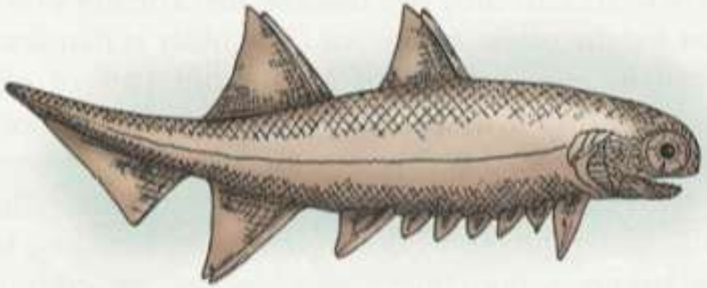


FIGURE 10-61 **The Early Devonian acanthodian fish *Climatius*.** (*After Romer, A. S. 1945.* Vertebrate Paleontology. *Chicago: University of Chicago Press.*)

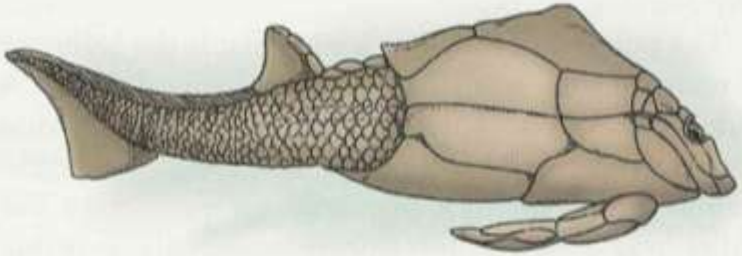


FIGURE 10-63 **The Devonian antiarch fish *Pterichthyodes*.** (*From Romer, A. S. 1945.* Vertebrate Paleontology. *Chicago: University of Chicago Press, p. 54, fig. 38.*)

Devonian plants

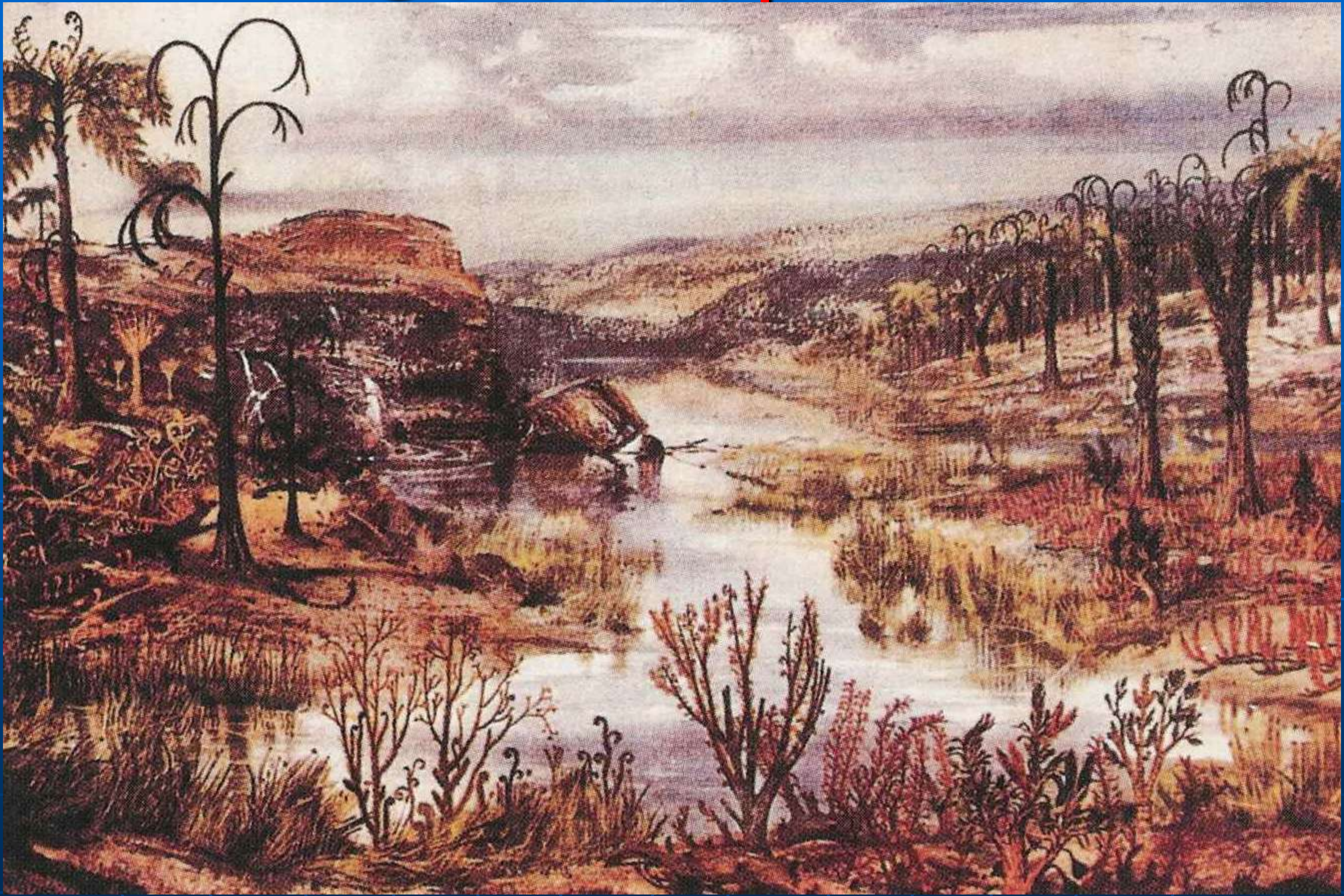
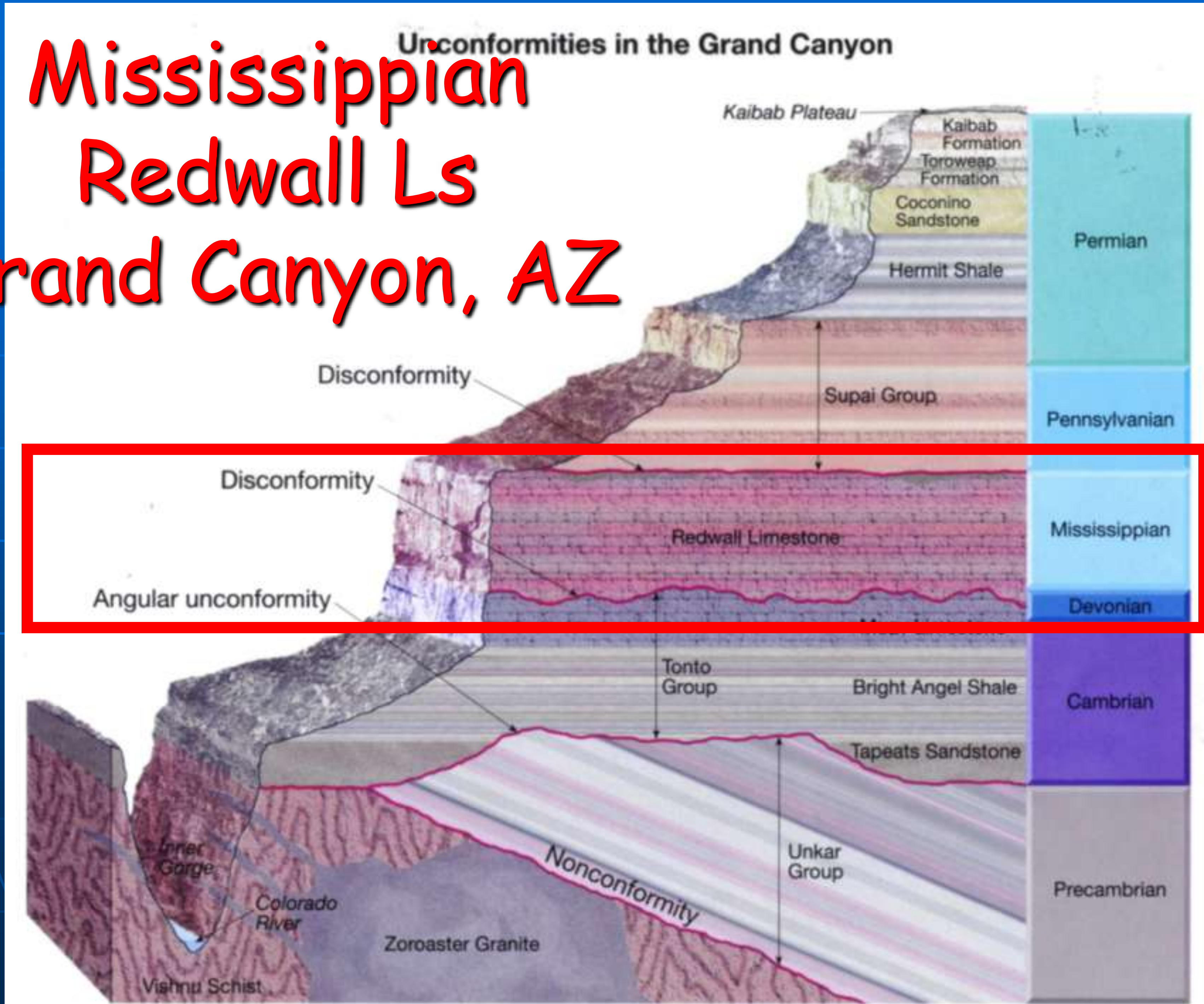
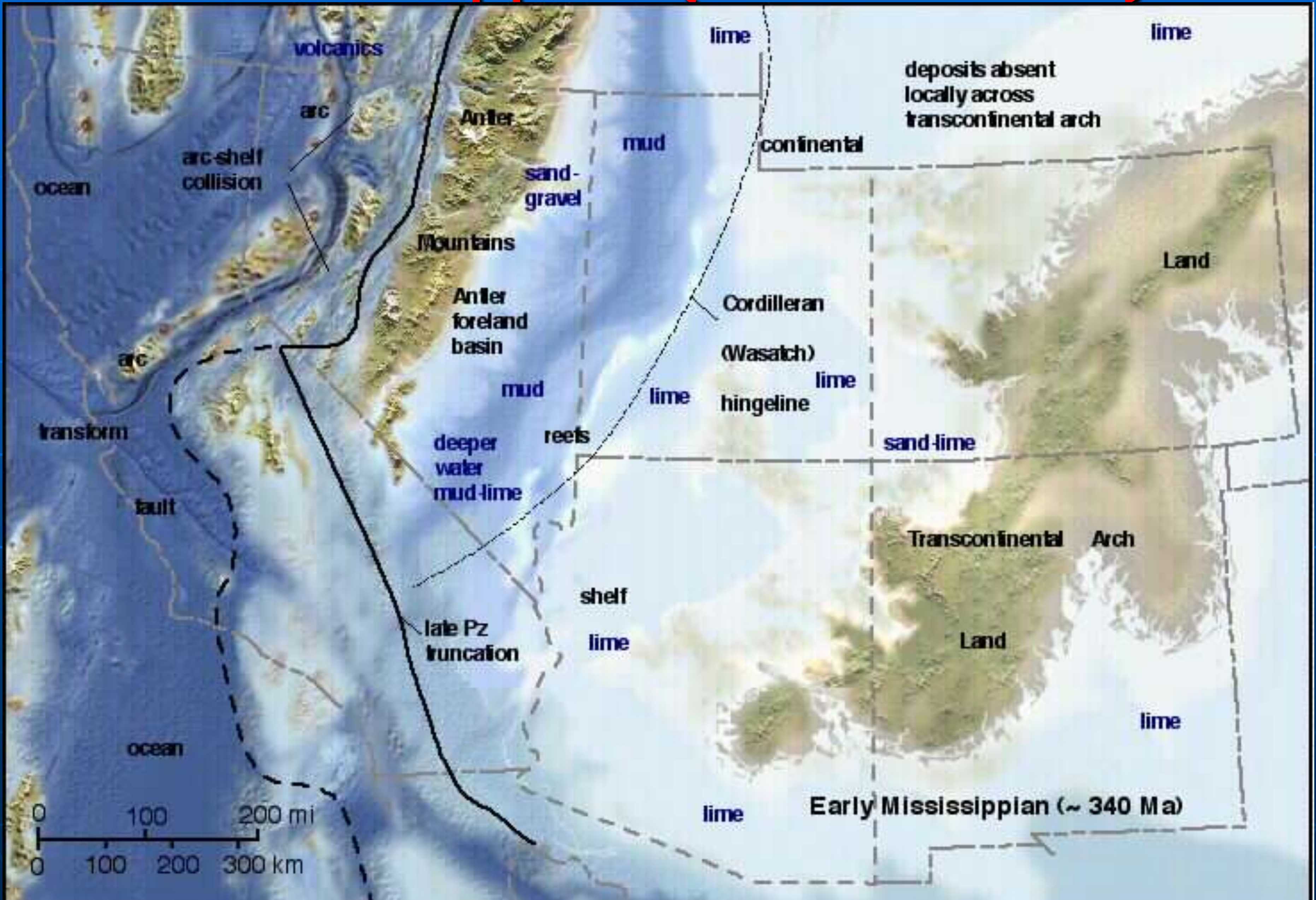


Figure 12.11 Artist's conception of the Late Devonian landscape. Tall seed fern and lycopsid trees are conspicuous, but most plants were low-growing psilophytes, lycopsids, sphenopsids, and ferns that clustered close to the water's edge. Against this backdrop, early land arthropods

Mississippian Redwall Ls Grand Canyon, AZ



Mississippian (359-318 Ma)



Mississippian environments

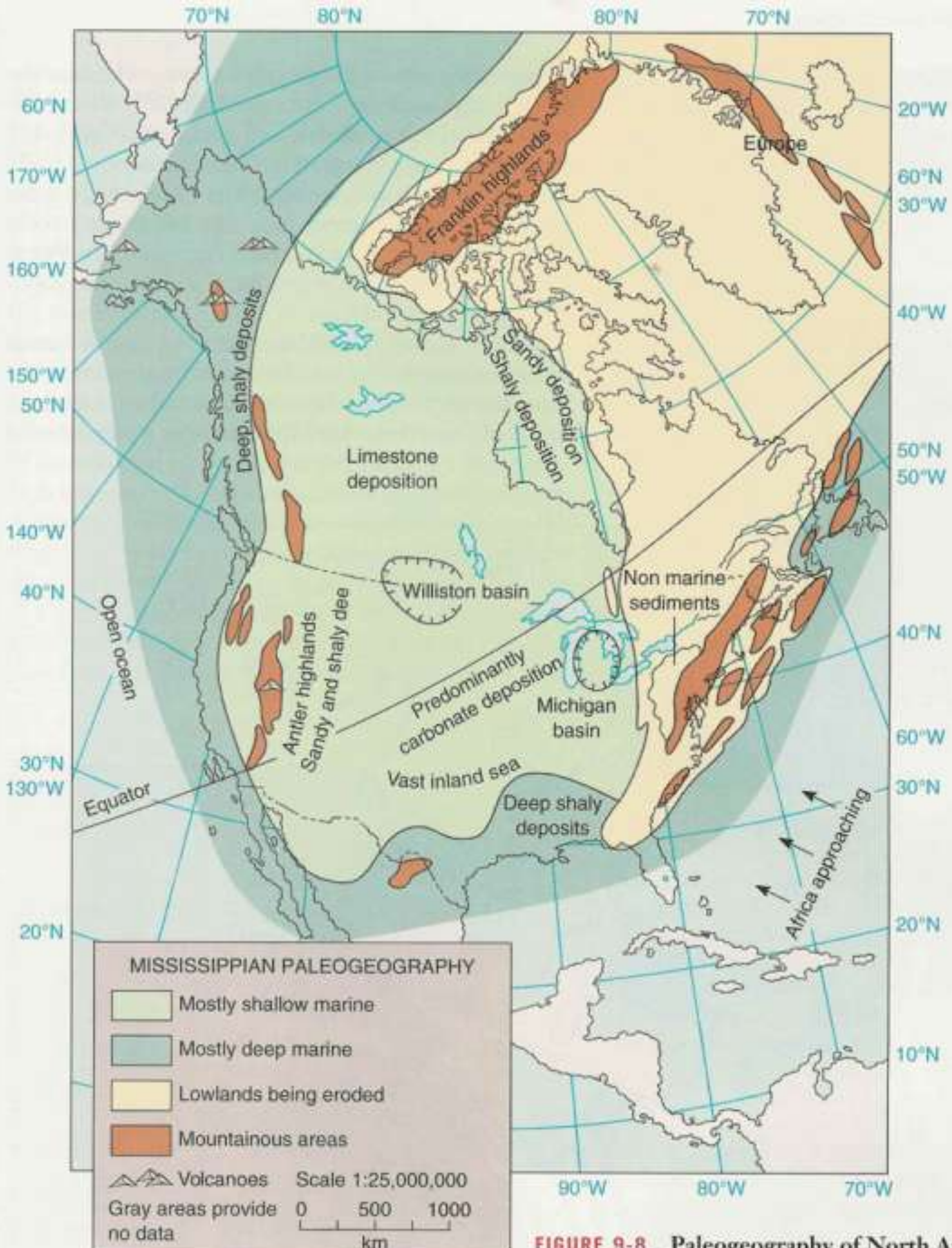
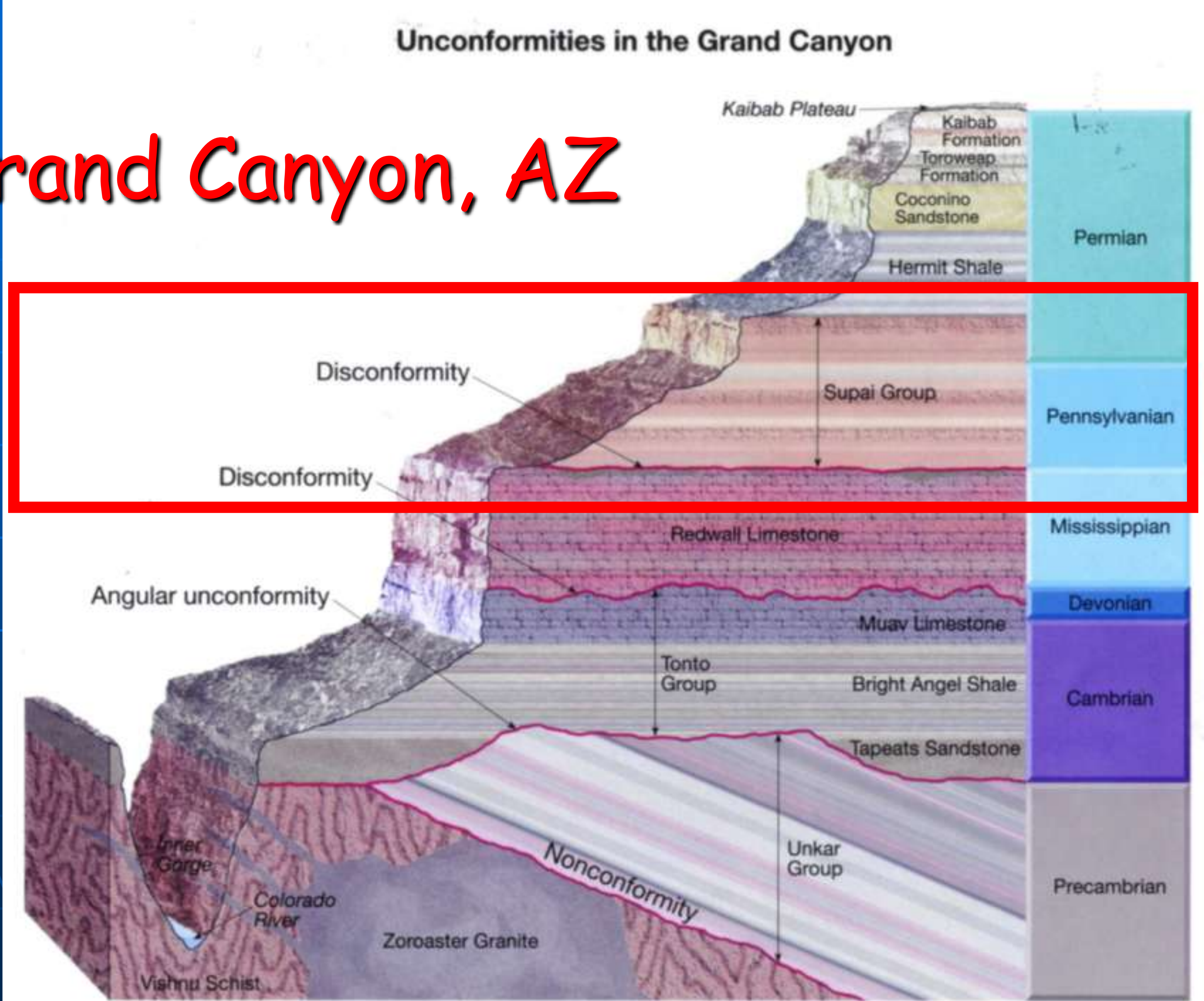


FIGURE 9-8 Paleogeography of North America during the Mississippian Period.

Red cliff at top = Redwall Limestone;

Vertical cliff of the Redwall Limestone – red from the overlying Supai

Grand Canyon, AZ




HATCH


2010/08/08

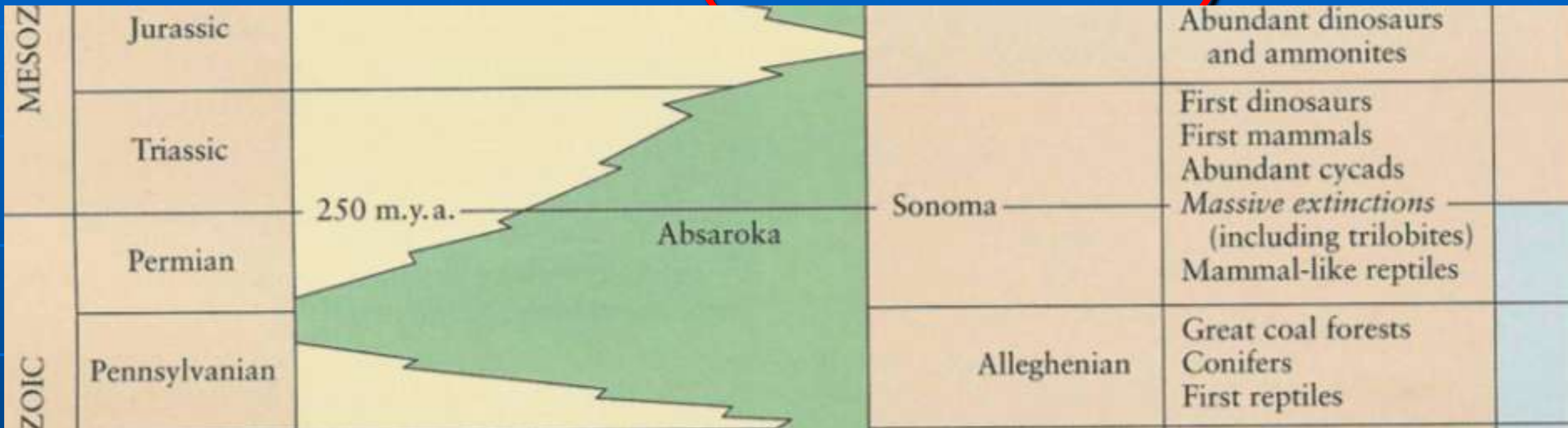

2010/08/08

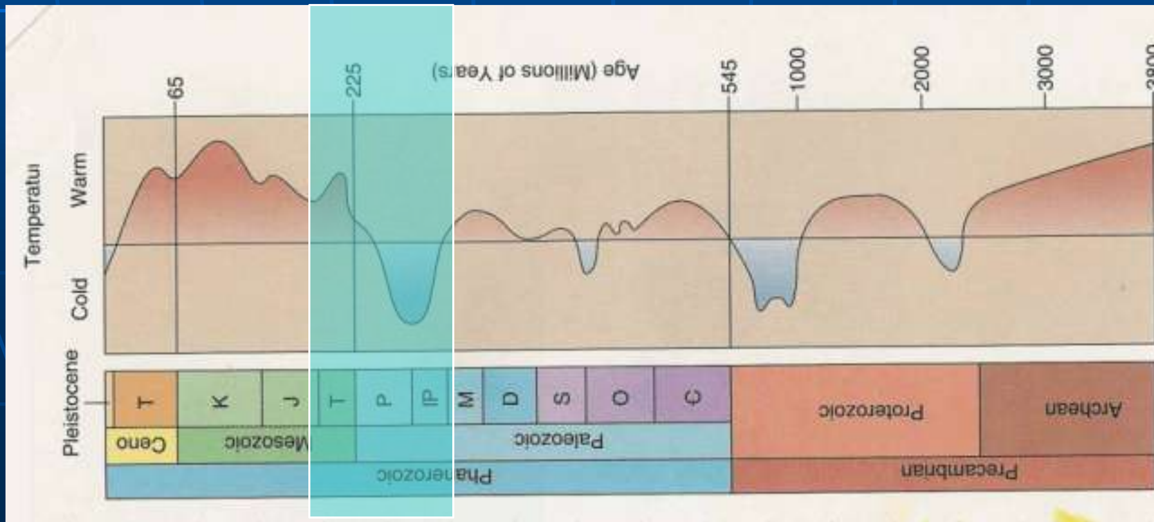
Crinoids

Syringopora - coral

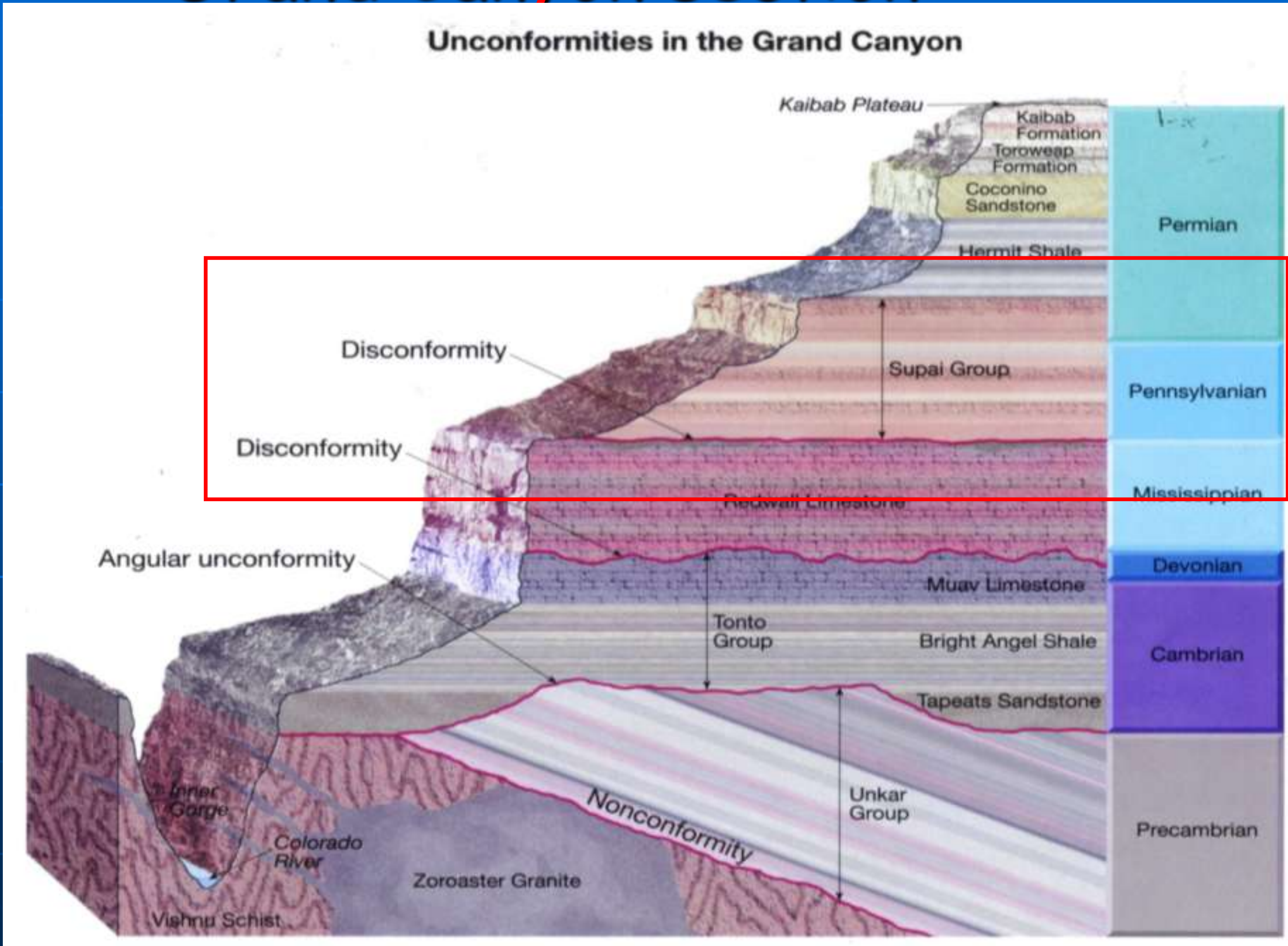
Crinoids
(echinoids related to starfish,
but called sea lilies)

Pennsylvanian (318-299 Ma) – Permian (299-251 Ma) – Triassic (251-200 Ma)

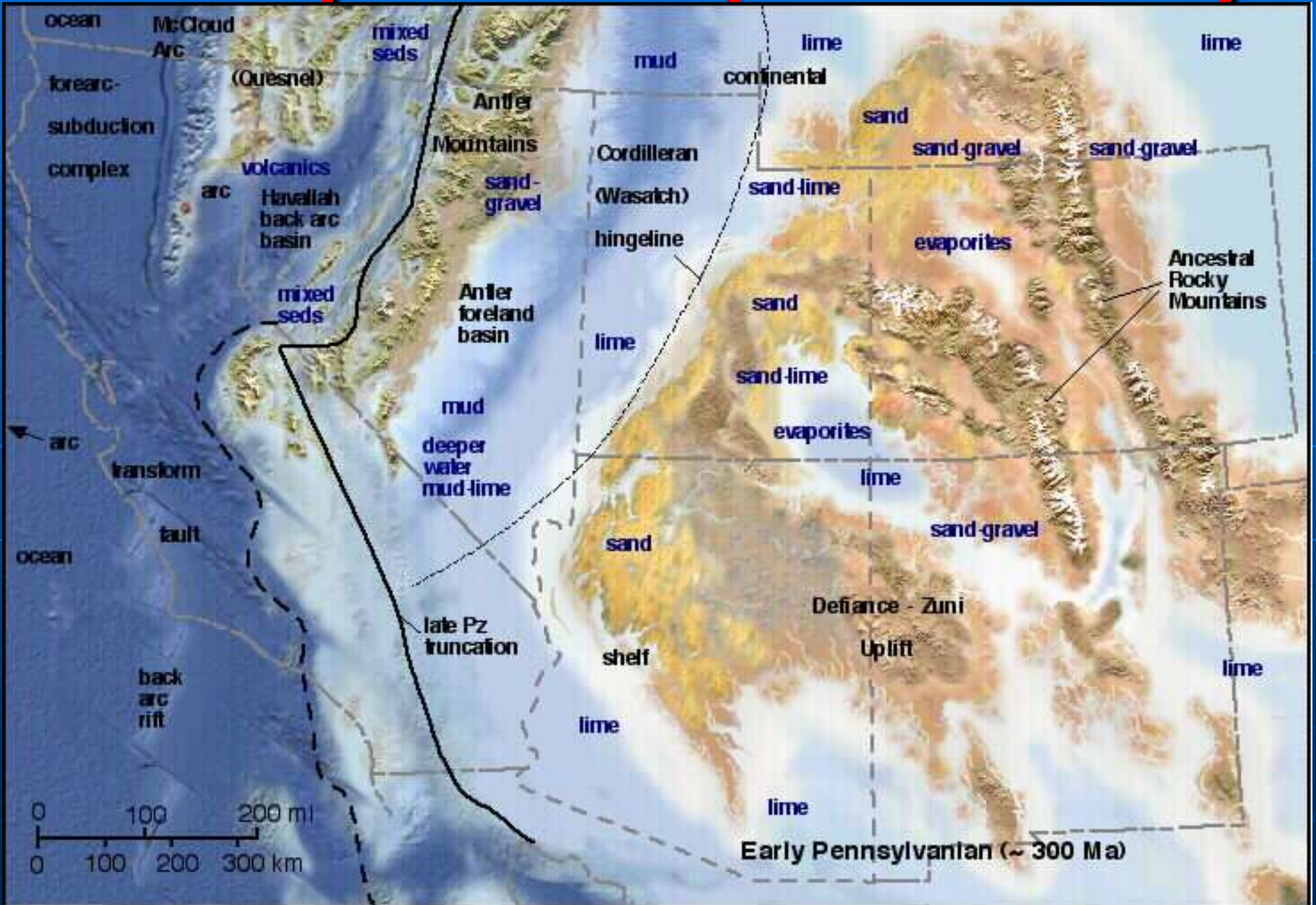




Grand Canyon section



Pennsylvanian (318-299 Ma)



Pennsylvanian environments

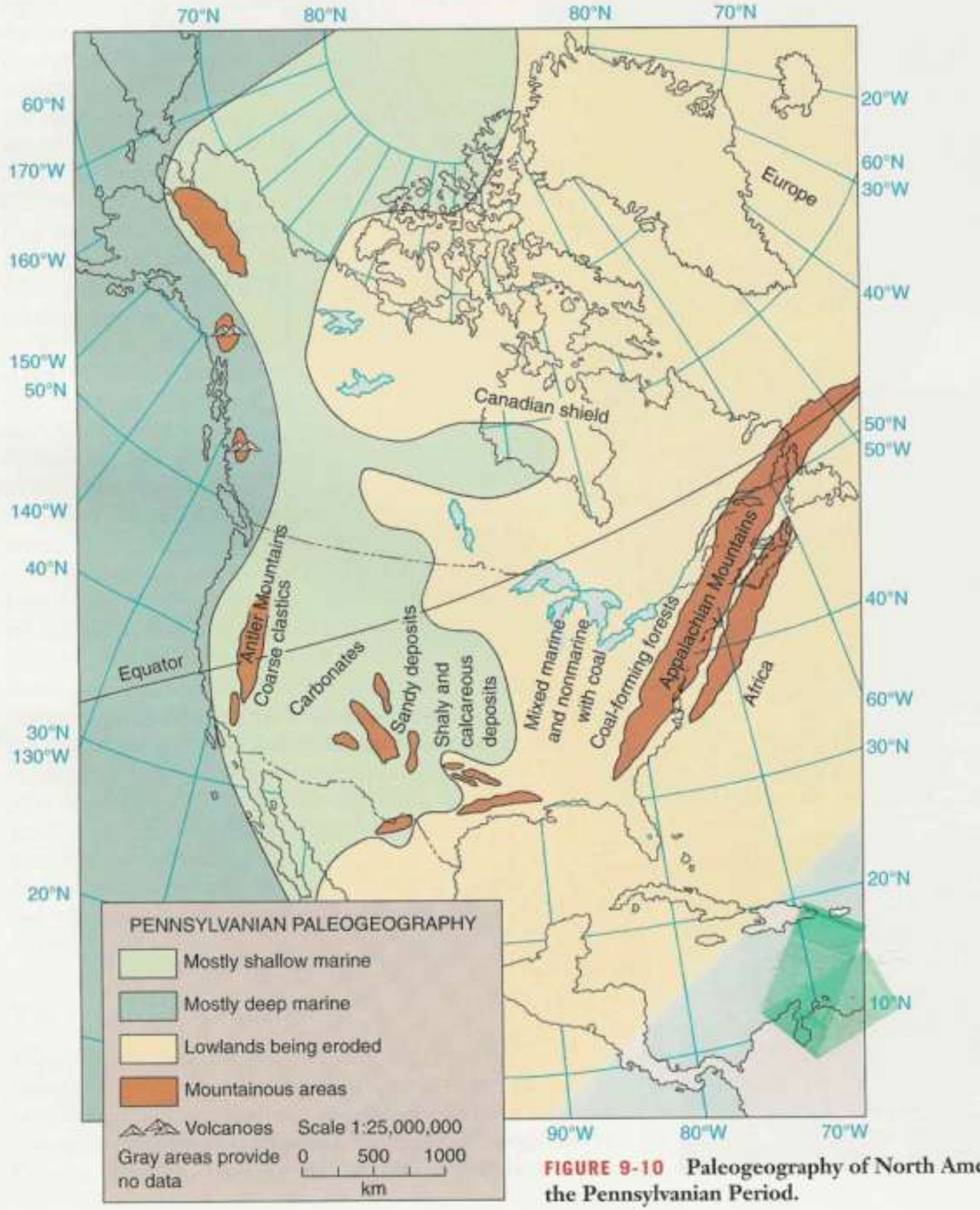


FIGURE 9-10 Paleogeography of North Am… the Pennsylvanian Period.

Amphibian fossils

FIGURE 10-77 ***Cacops*, a small labyrinthodontic amphibian from the Lower Permian.** *(Photograph of a specimen on exhibit at the Field Museum in Chicago.)*

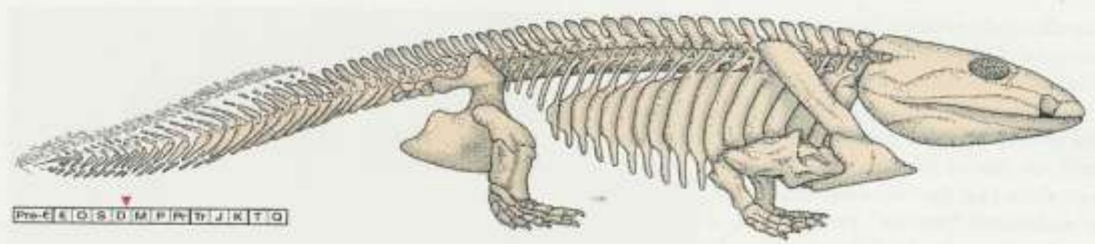


FIGURE 10-76 **The skeleton of *Ichthyostega* still retains the fishlike form of its crossopterygian ancestors.** (*From Levin, H. L. 1975.* Life Through Time. *Dubuque, Iowa: William C. Brown Co.*)

Supai Group – Pennsylvanian age

Pennsylvanian Coal Forest

Pennsylvanian plants

FIGURE 10-88 ***Calamites*, a sphenopsid.** Plants shown are about 3 to 5 meters tall.

Extinction overtook many plant groups near the end of the Permian Period. Many species of lycopsids, seed ferns, and conifers disappeared. Small ferns that grow in damp areas, however, were not profoundly affected by the crisis.

FIGURE 10-89 ***Annularia*, an abundant sphenopsid of Pennsylvania age.**

FIGURE 10-90 ***Pecopteris*, a true fern from the Pennsylvanian of Illinois** (the penny is for scale).

FIGURE 10-91 **End of a branch of *Cordaites*, showing the straplike leaves of these trees.** Not uncommonly, the leaves attained lengths of 1 meter. The clustered bodies produced the plant's male gametes. (*Adapted from Grand'Eury, C. 1877. Flore Carbonifère de Département de la Loire et du centre de la France.* Mem. Acad. Sci. Institut France. 24:624 pp.)

MASS EXTINCTIONS

For most of the Paleozoic, the Earth was populated by a rich diversity of life. There were, however, times when the planet was less hospitable, and large groups of organisms suffered extinction (Fig. 10-92). Early geologists saw evidence of these mass extinctions in the fossil record and used the abrupt termination of fossil ranges to define the boundaries between geologic

Cyclic coal beds (Cyclothems)

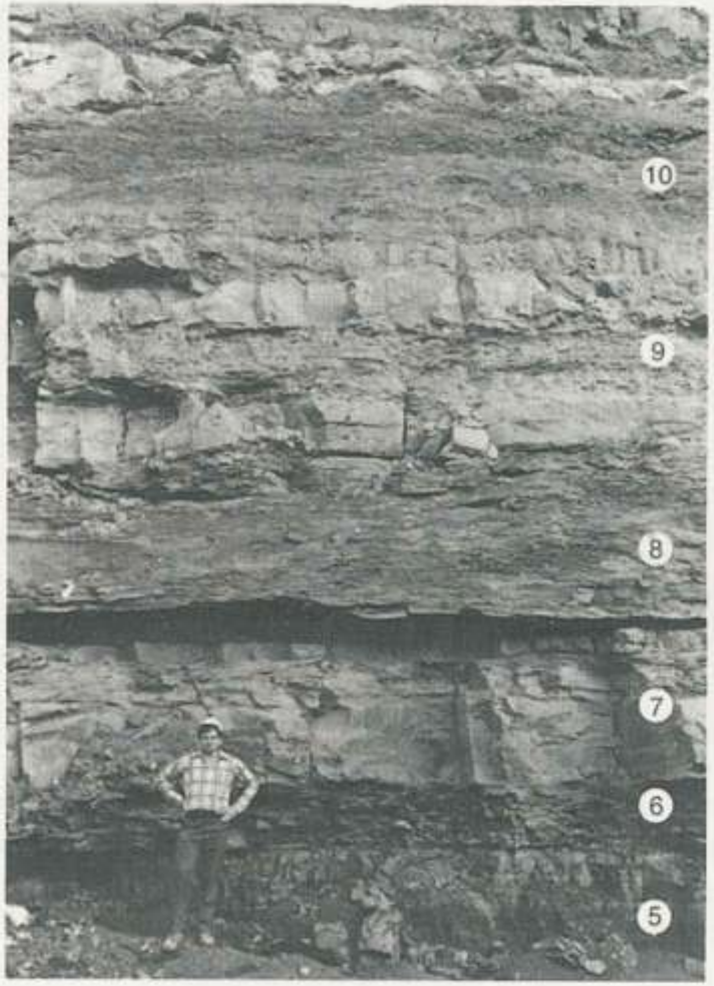


FIGURE 9-12 Part of an Illinois cyclothem. The lowermost layer is the coal seam (cyclothem bed 5), followed upward by shale (bed 6) near the geologist's hand, limestone (bed 7), shale (bed 8), another limestone (bed 9), and the upper shale (bed 10). Part of another sequence caps the exposure. This cyclothem is part of the Carbondale Formation. *(Photograph courtesy of D. L. Reinertsen and the*

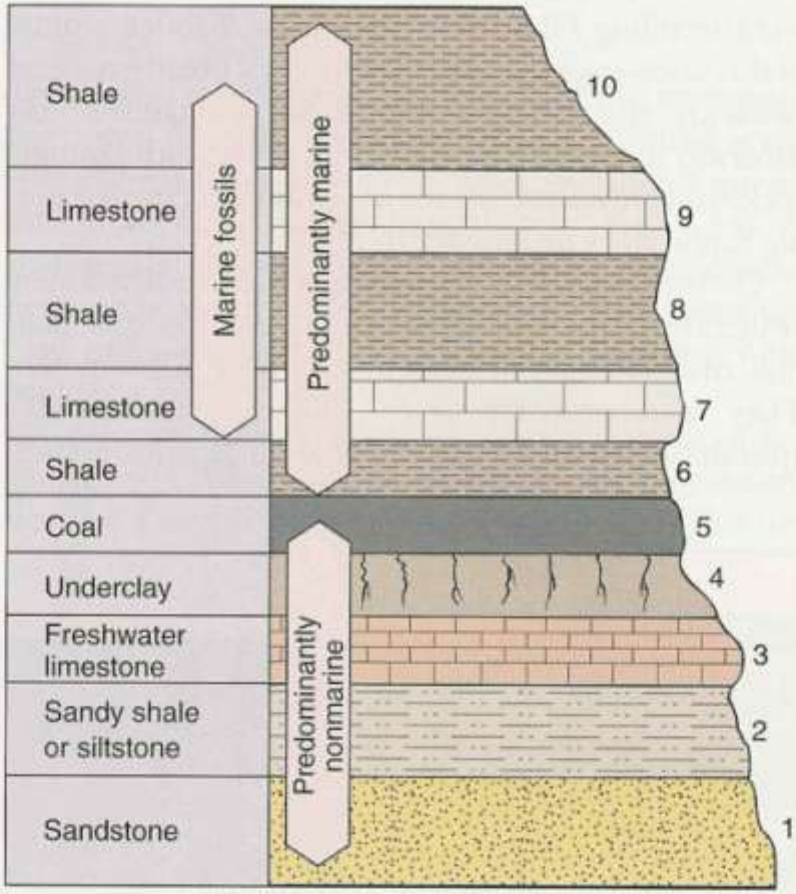
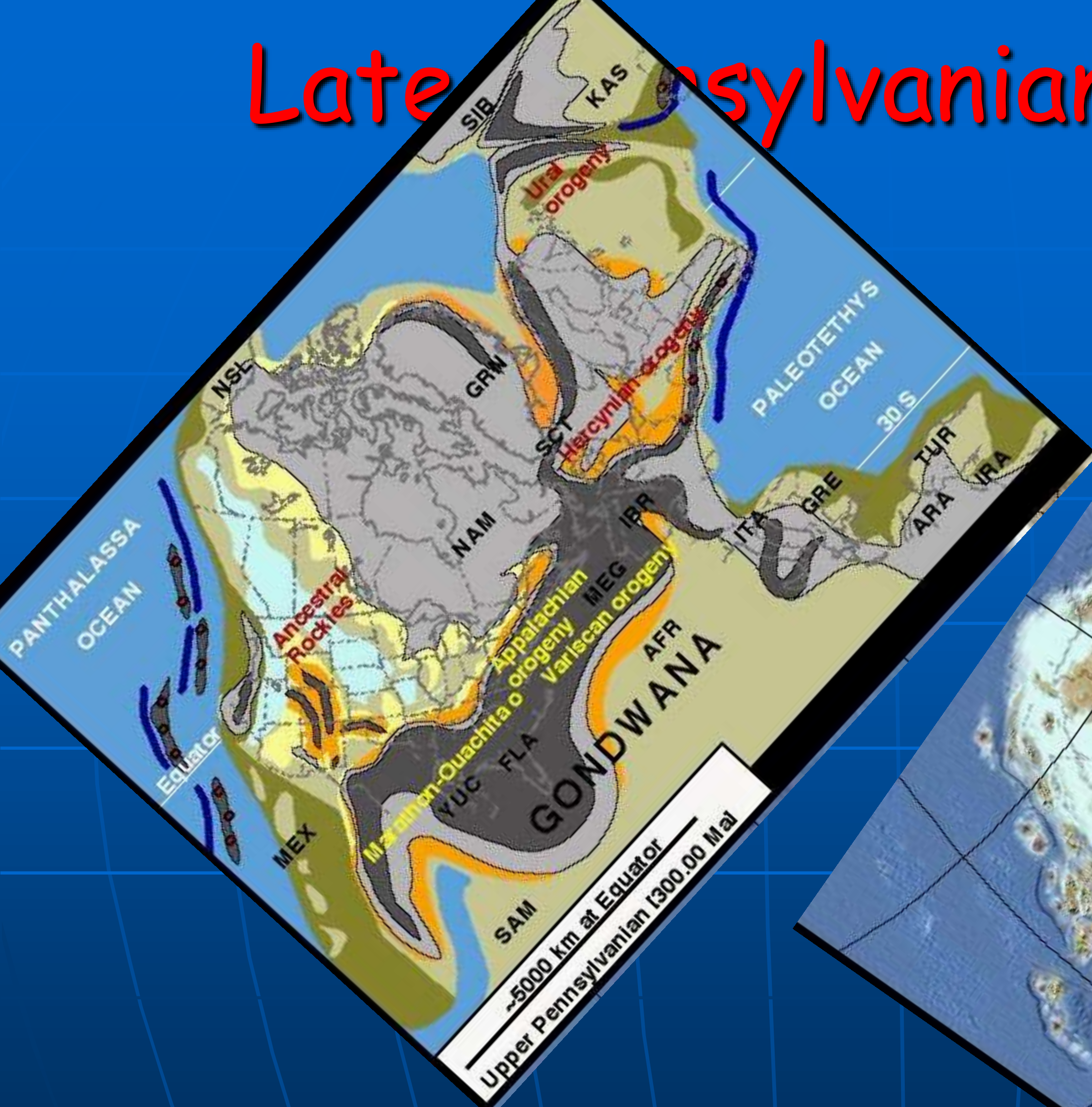


FIGURE 9-11 An ideal coal-bearing cyclothem, showing the typical sequence of layers. Many cyclothems do not contain all 10 units, as in this illustration of an idealized sequence. Some units may not have been deposited because changes from marine to nonmarine conditions may have been abrupt and/or units may have been removed by erosion following marine regressions. The number 8 bed usually represents maximum inundation and, correlated with the same bed elsewhere, provides an important correlative stratigraphic horizon. *If you came*

Goosenecks of the San Juan

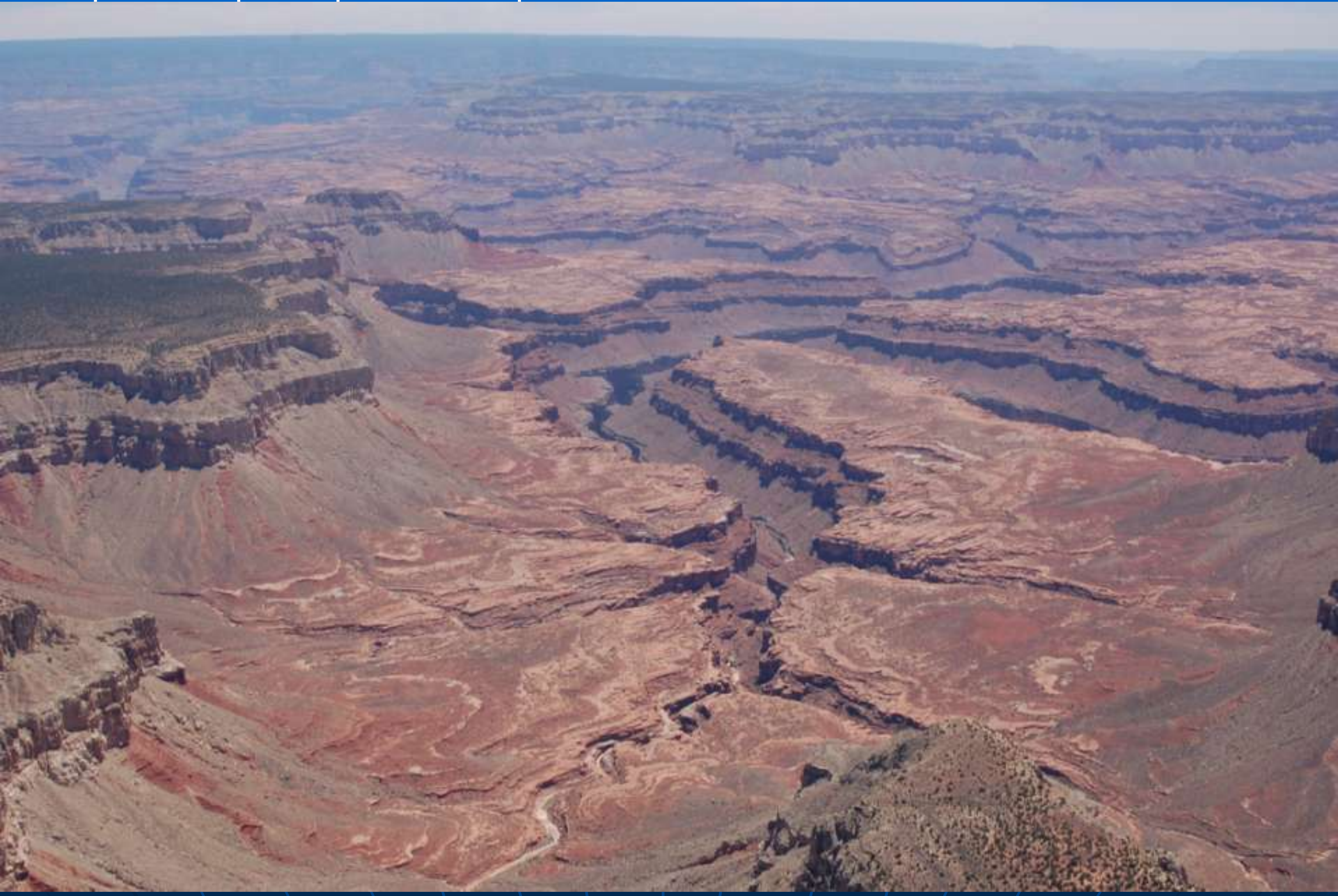
Pennsylvanian Hermosa Formation

Late … sylvanian (300 Ma)



Permian Supai Group, Sedona

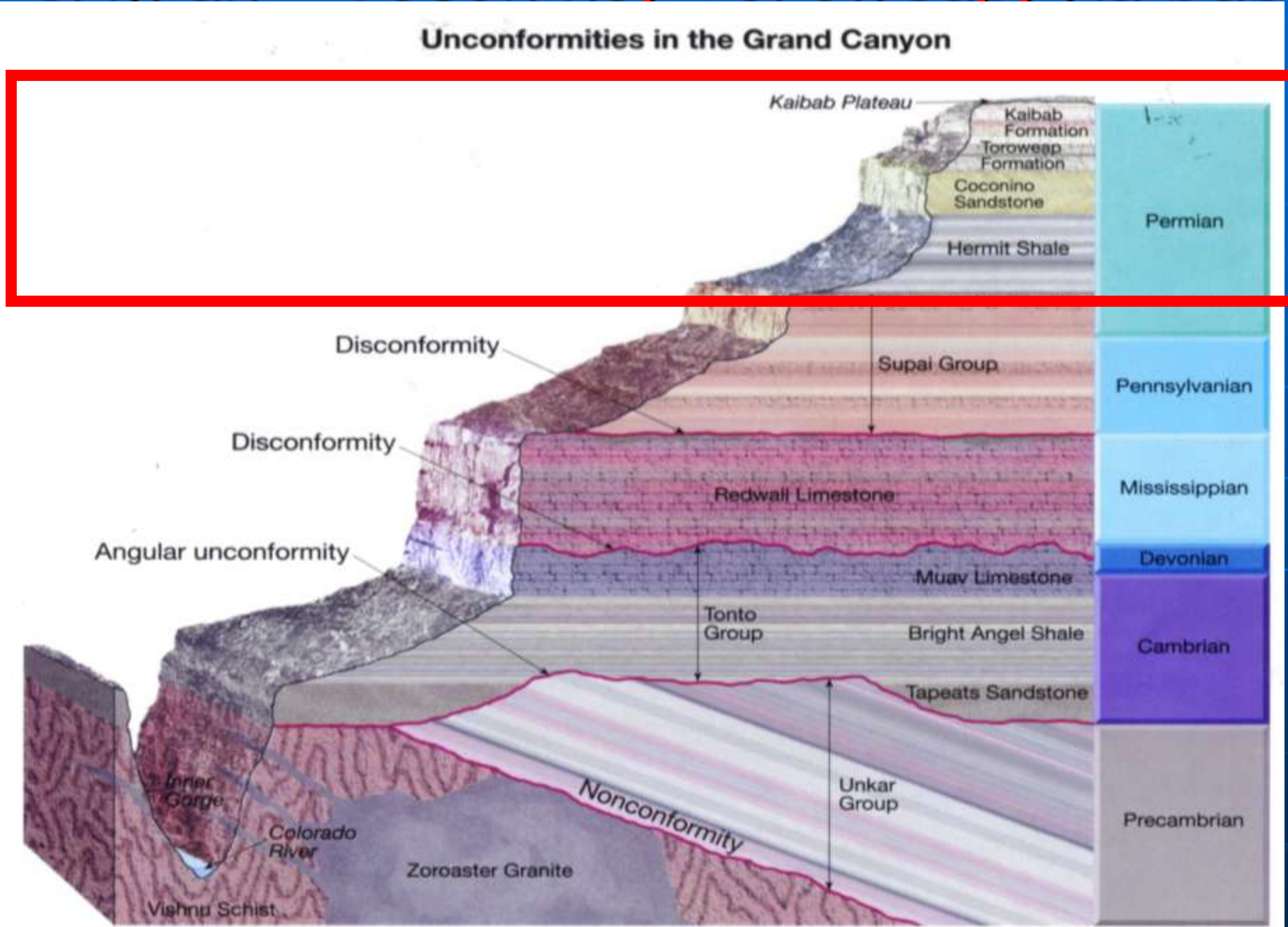
Supai Group – top of the Esplanade Sandstone



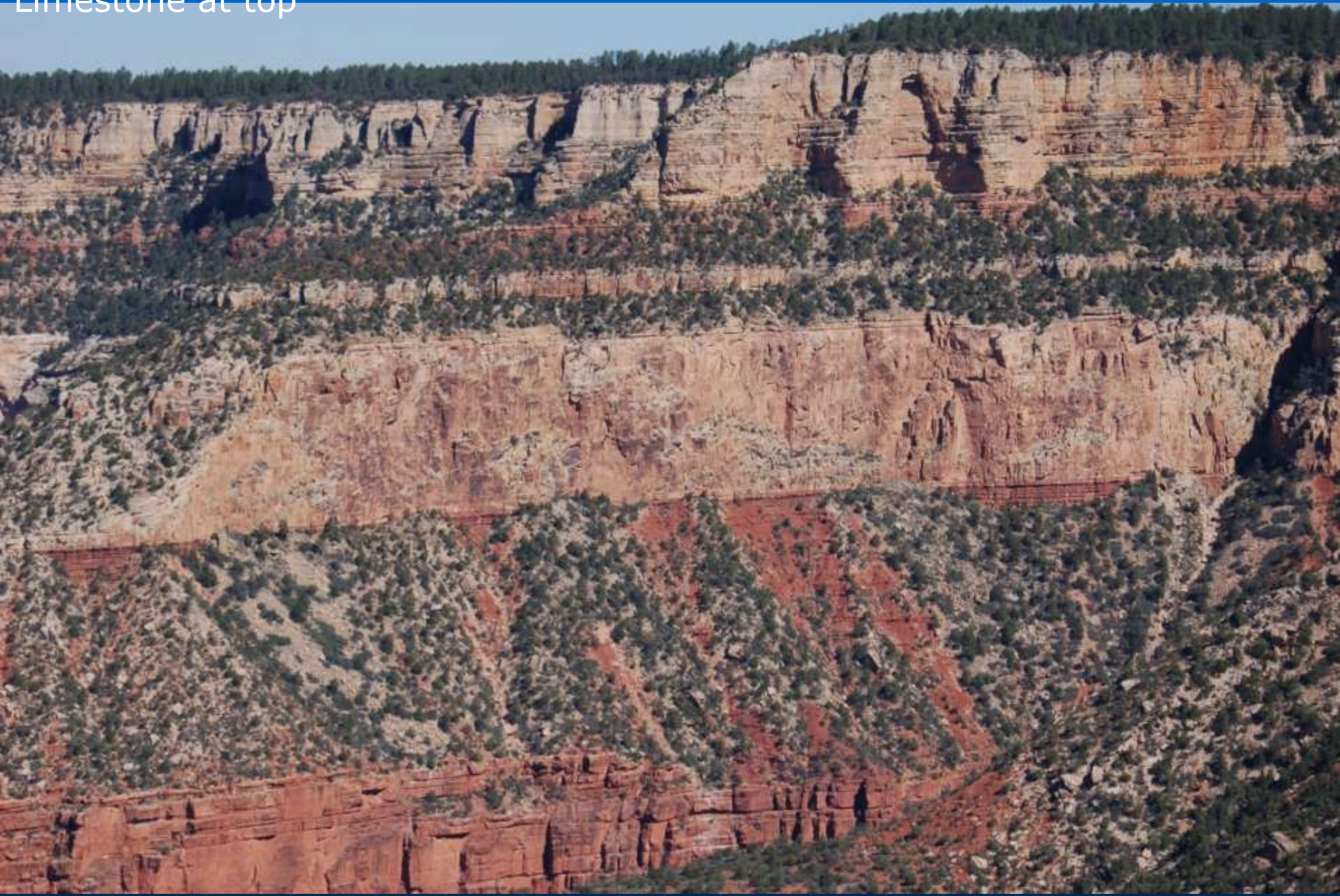

Supai mud
HATCH
HATCH
2010/08/08

Ripple marks

Permian – Coconino, Toroweap, Kaibab



Supai cliff, overlain by Hermit Shale slope, then by white Coconino Sandstone cliff, then by Toroweap Formation , then white cliff of Kaibab Limestone at top

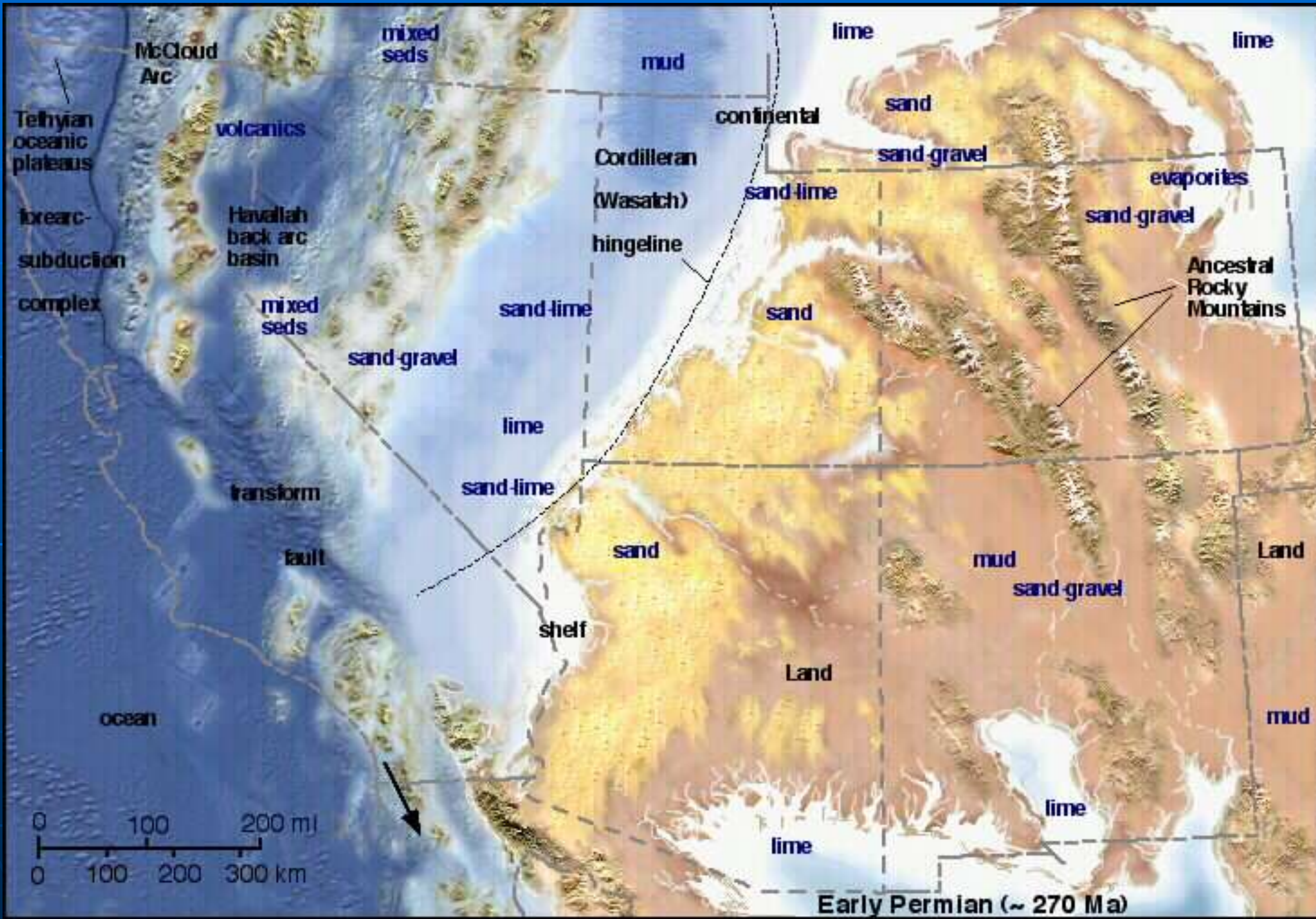


Cross bedded Coconino Sandstone


Amphibian tracks (Laoporus) in Coconino Ss


HATCH
9

Permian (290-248 Ma)



Permian environments

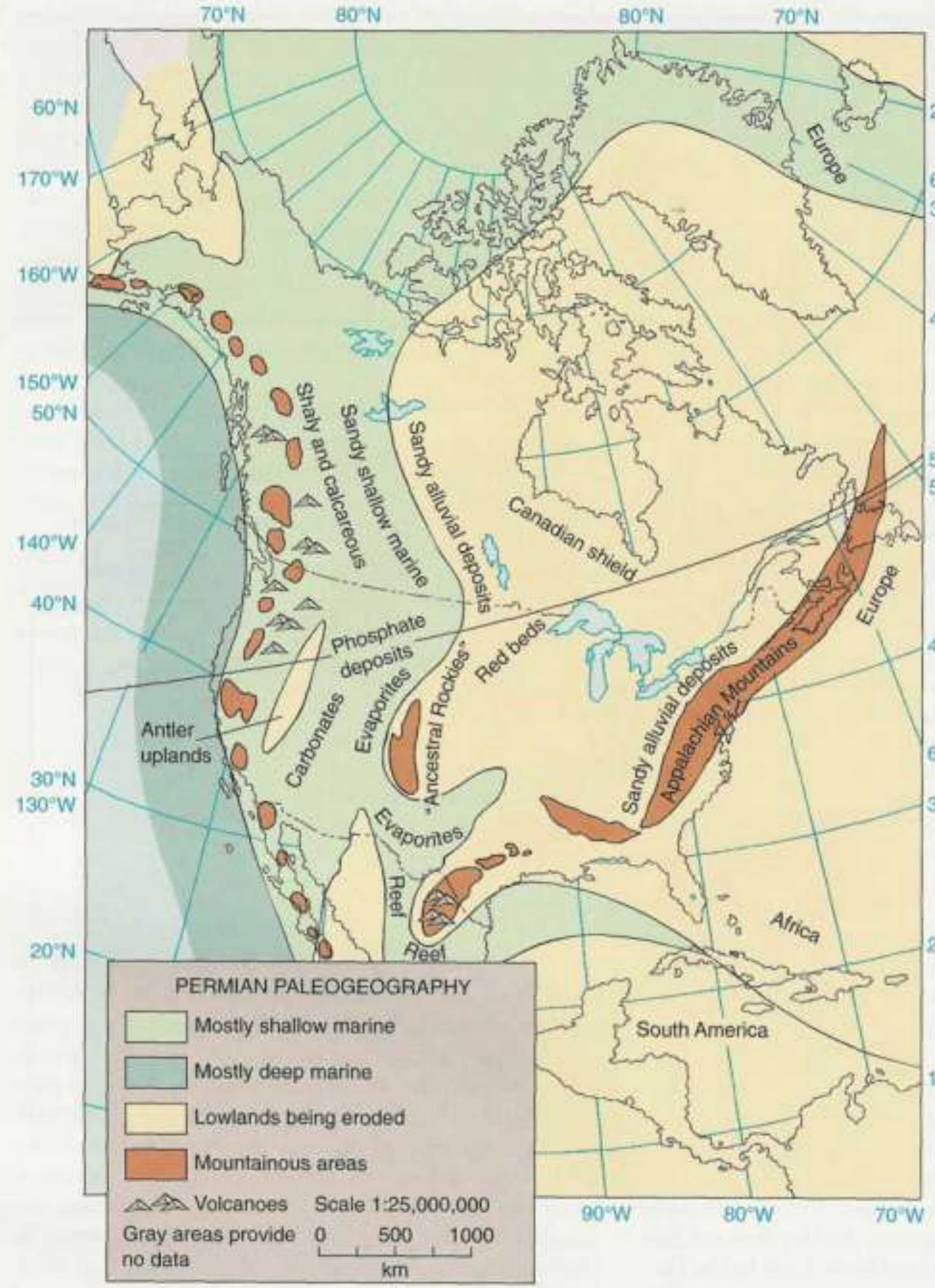
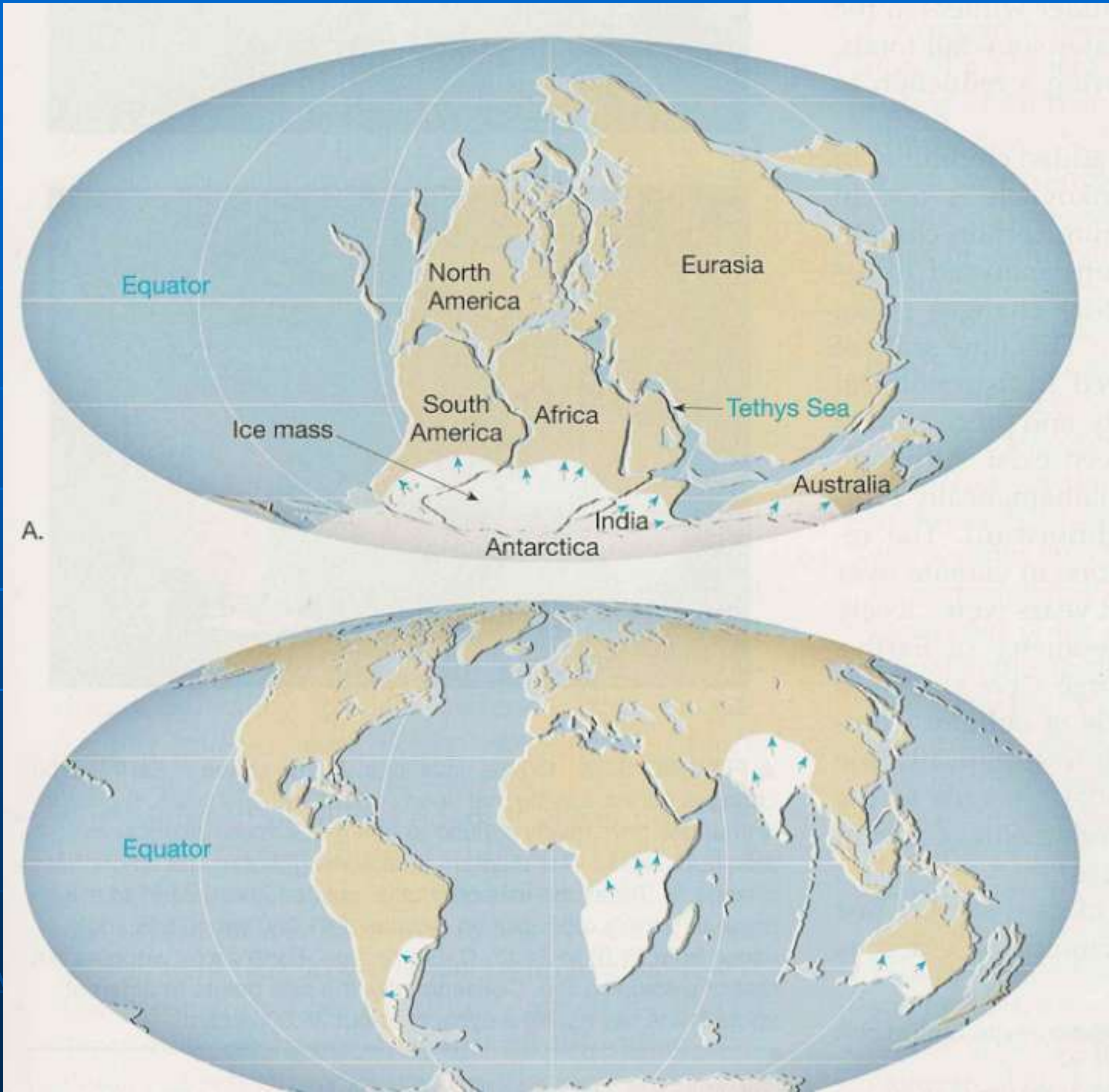


FIGURE 9-18 Generalized paleogeographic map for the Permian Period.

Permian Ice Age




Chert beds in Kaibab Limestone

Permian formations: Red Hermit Shale, overlain by white Coconino Sandstone cliff, overlain by Toroweap Formation, with Kaibab Limestone cliff at the top

White cliffs of Kaibab Limestone near the top of the Grand Canyon

Productid brachiopods in the Kaibab Limestone

Mammal-like Reptiles

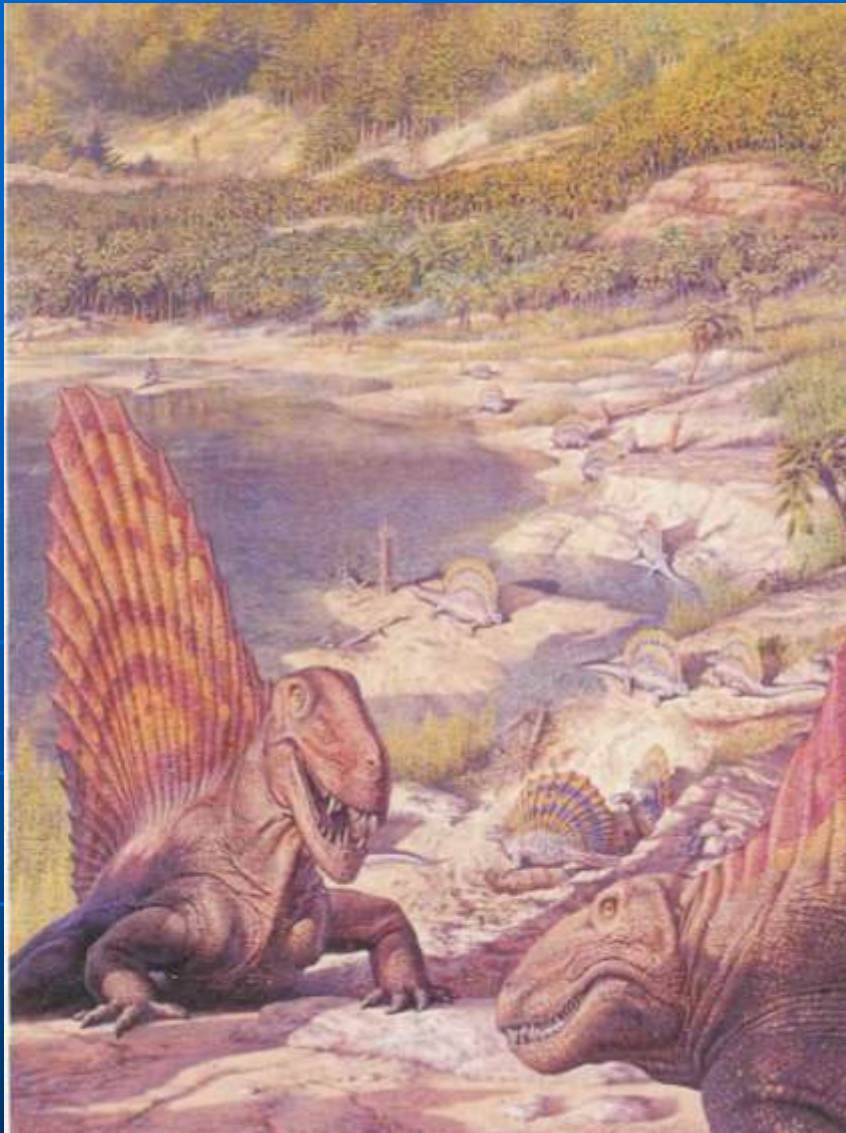
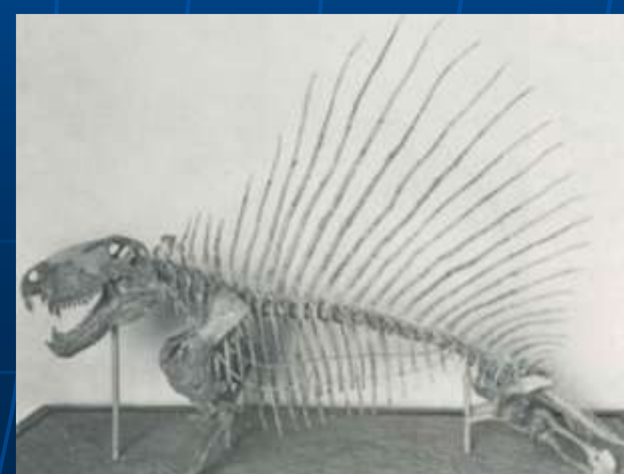


FIGURE 10-78 **Permian reptiles.** The prominent sailback reptile in the left foreground, with a larger skull and daggerlike teeth, is the carnivore *Dimetrodon*. The sailbacks with smaller heads and blunt cheek teeth, in the foreground at right and in the distance, are plant-eaters of the genus *Edaphosaurus*. (*Copyright J. Sibbick.*) ? *Is it likely*

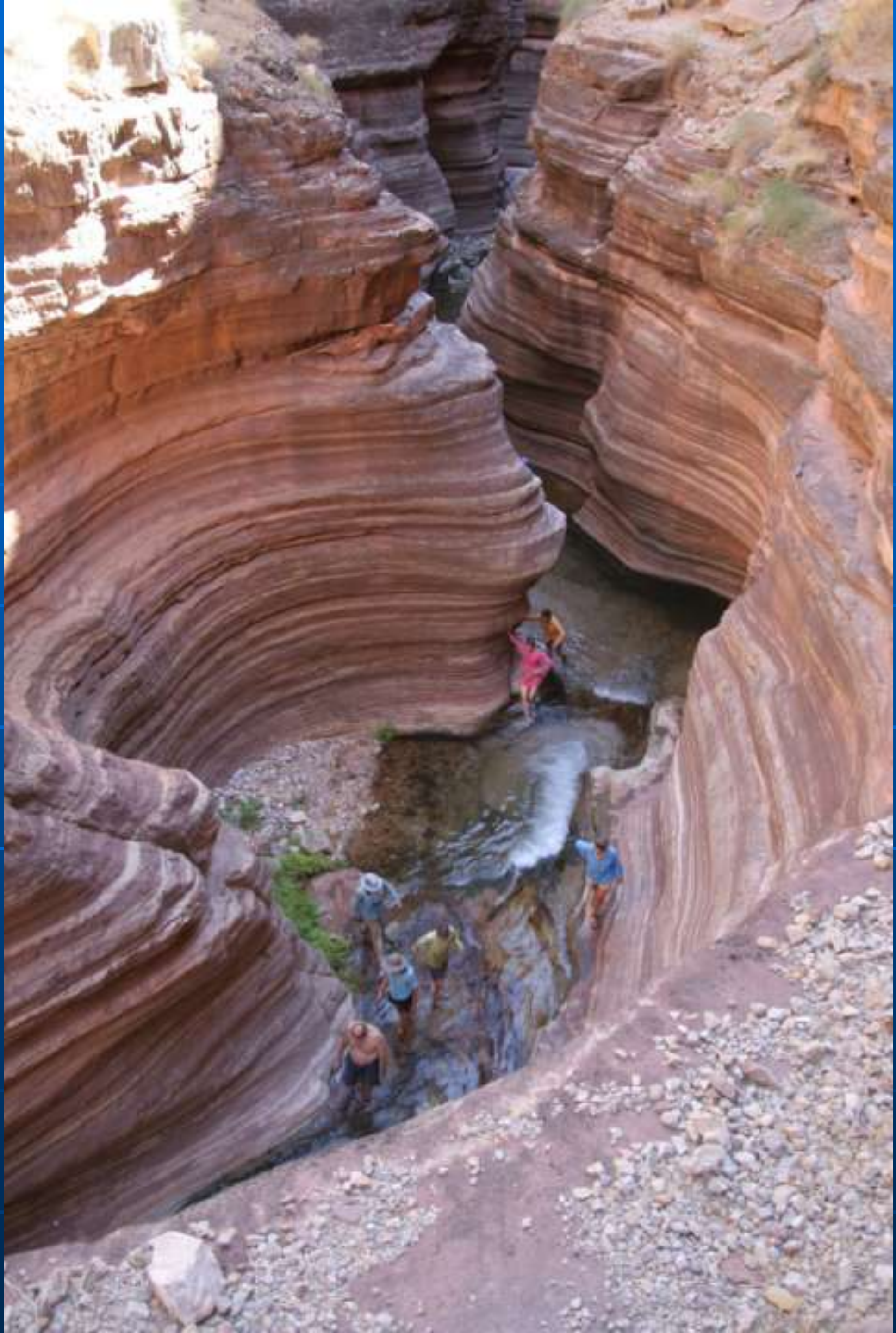
FIGURE 10-80 **Mammal-like reptiles.** The scene depicts three carnivorous forms (*Cynognathus*) about to attack a plant-eating therapsid reptile (*Kannemeyeria*). (*Courtesy of*

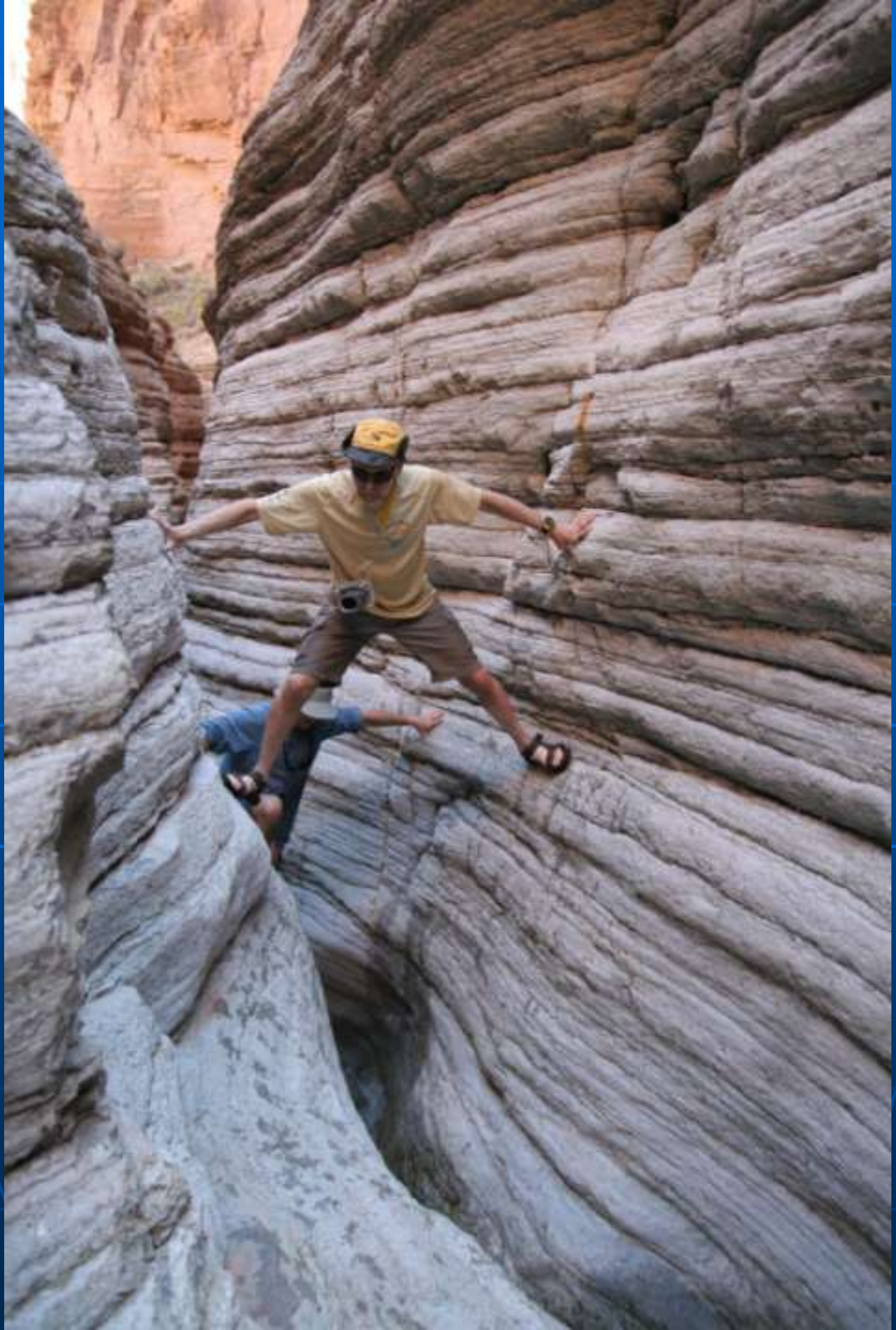


Kaibab Limestone and Toroweap Formation under Navajo Bridge

Kaibab Limestone over Toroweap Formation

Navajo Bridge on the Permian Kaibab Limestone, overlain by Mesozoic formations

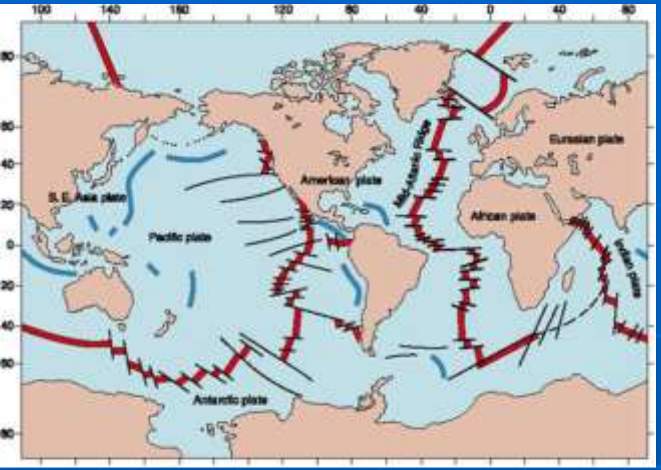




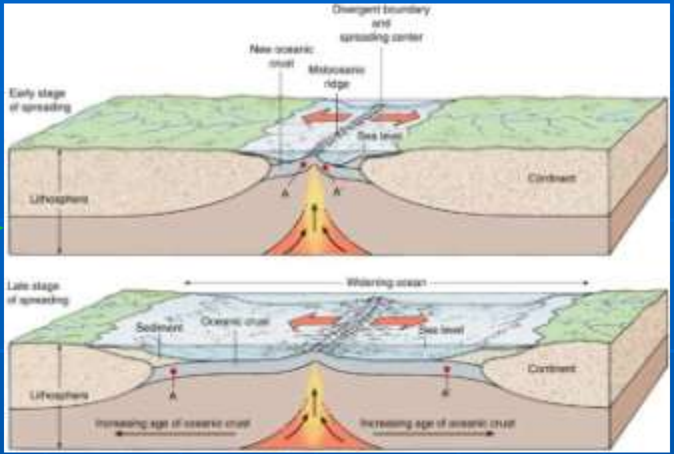
Grand Canyon

Triassic formations at Lee’s Ferry

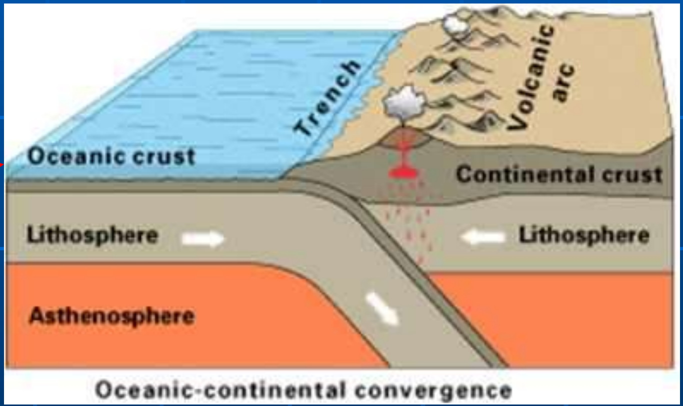
Plate Tectonics

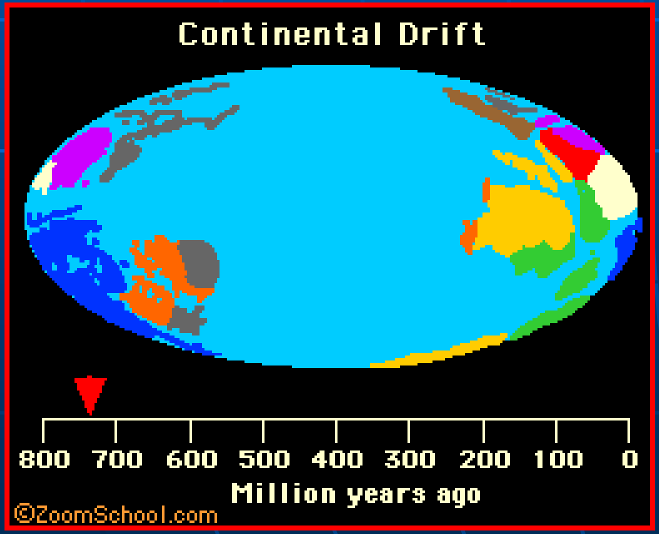


Sea floor spreading and mid-ocean ridge volcanism

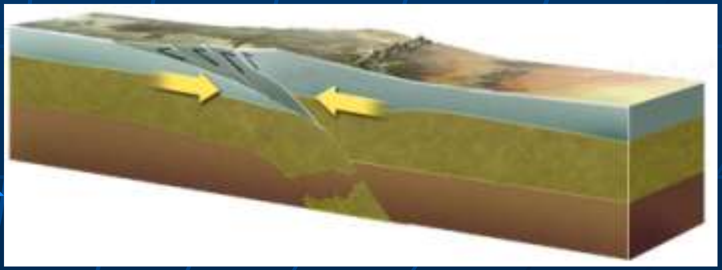


Subduction, Volcanoes, Mountains

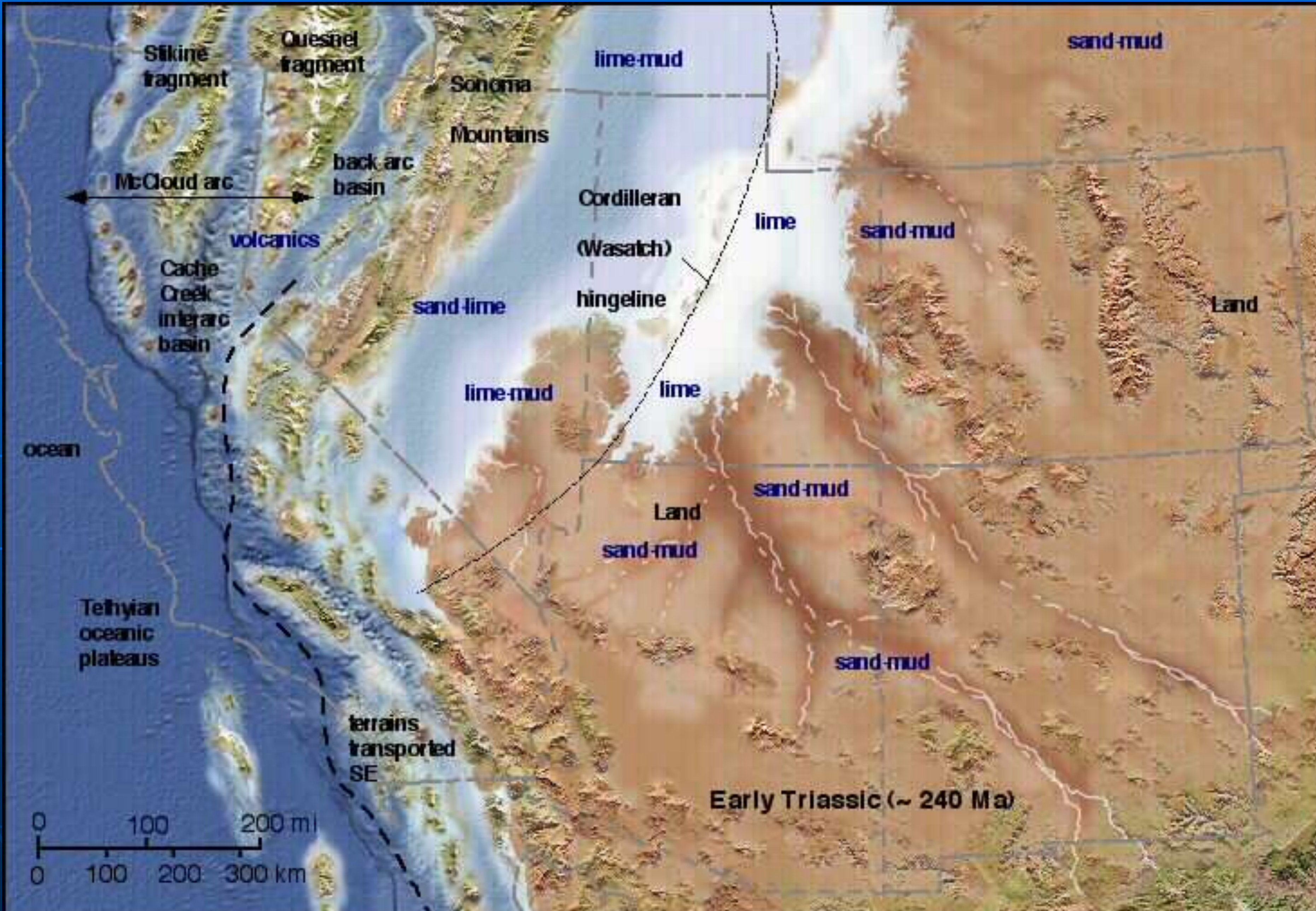




Continent-continent collision and very tall mountains



Triassic (248-206 Ma)



Triassic paleogeography

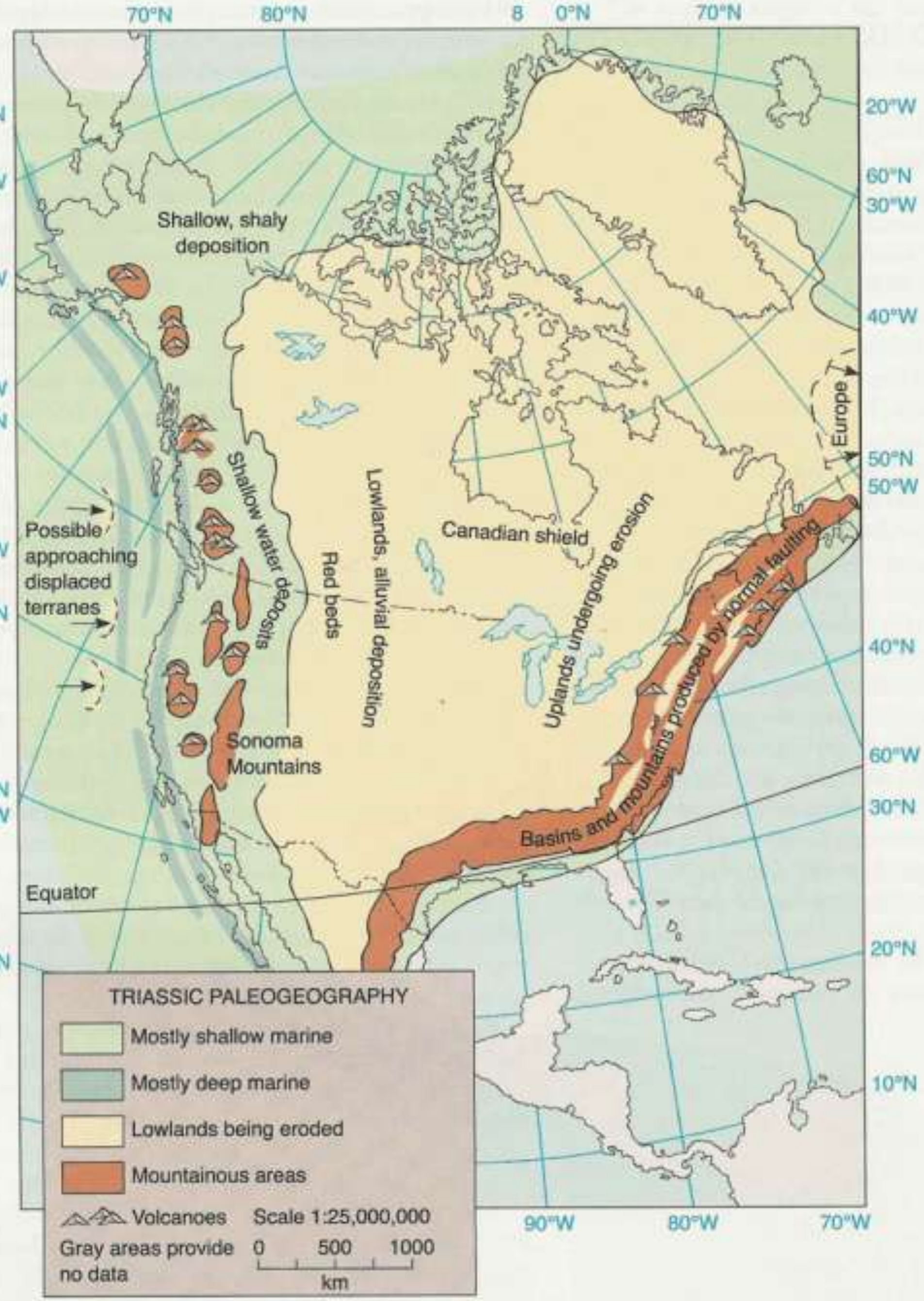


FIGURE 11-3 Generalized paleogeographic map for the Triassic of North America.

What was the cause of the faulting along the eastern margin of the continent?

Triassic plate tectonics

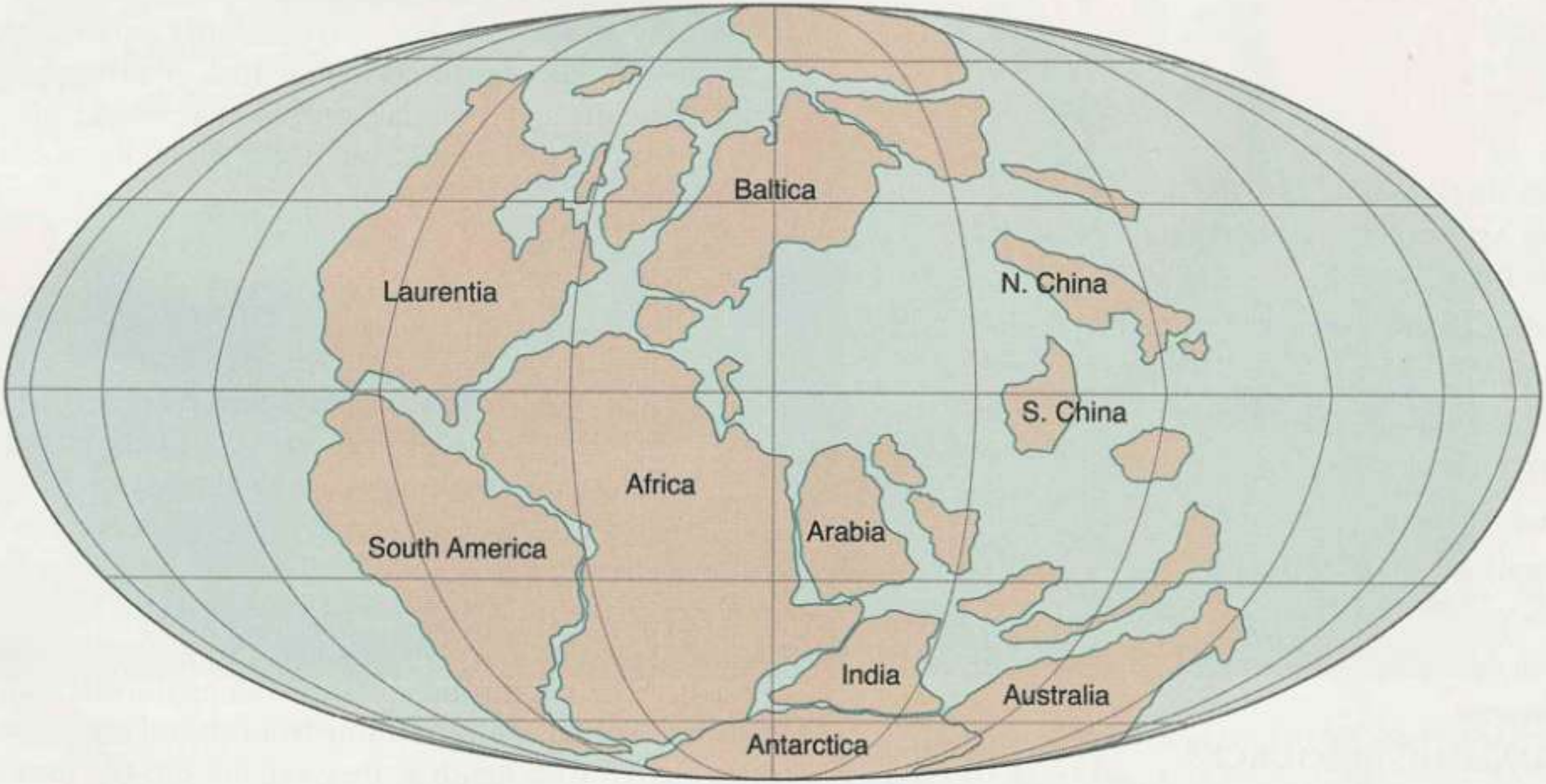
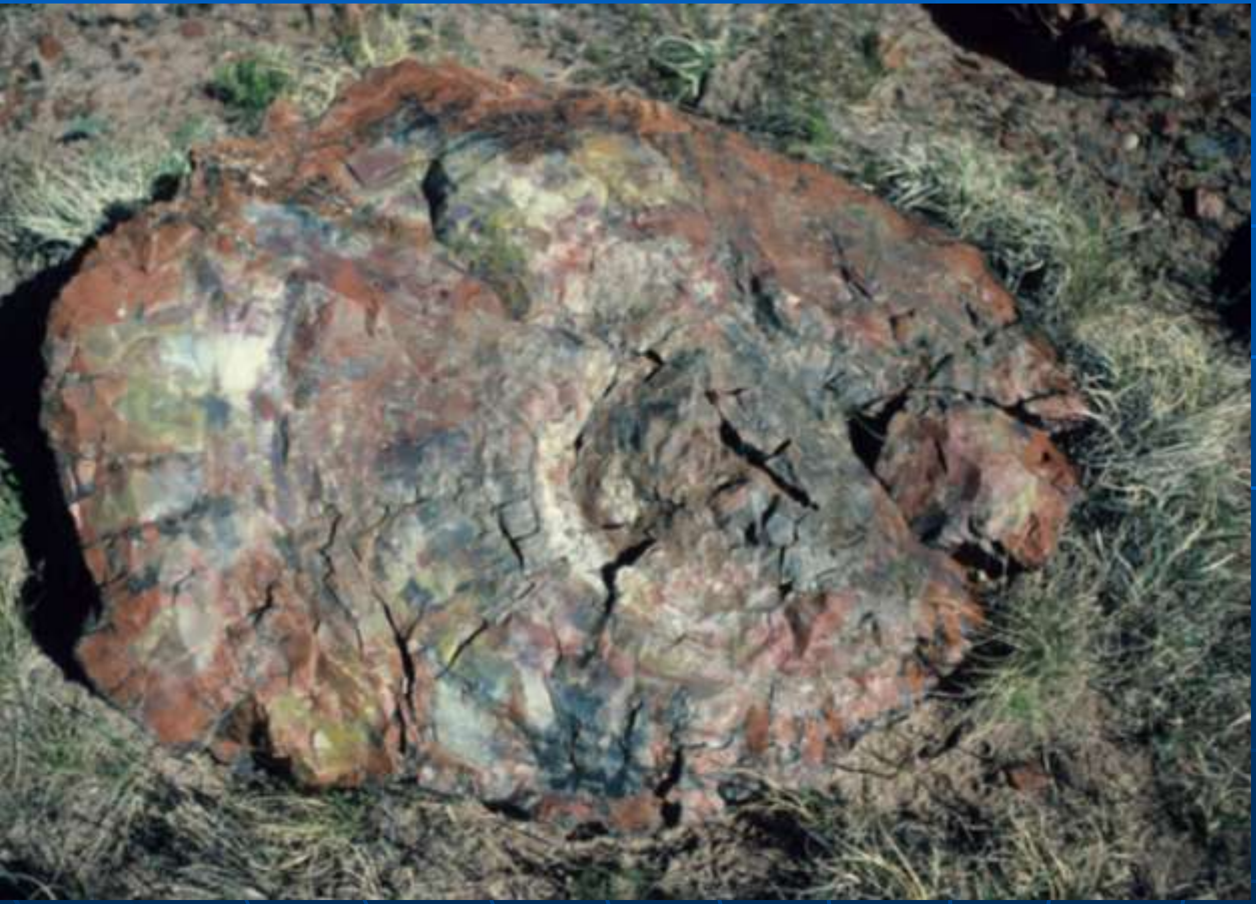


FIGURE 11–1 **Paleogeographic reconstruction of the world about 180 million years ago, when the break-up of Pangea was beginning.** (After Scotese, C. R. and McKerrow, W. S. 1990. Paleogeography and Biogeography, *Geol. Soc. London Mem. 12:1–21.*)

Petrified Forest Fm. - late Triassic

Petrified log, Pet. Forest



Triassic Reptiles

FIGURE 12-21 **The small, agile theopod *Coelophysis* lived about 220 million years ago, during the Late Triassic.** *Coelophysis* was about 3 meters in length. These fast, agile, bipedal predators may have pursued their prey in packs, and there is evidence that they occasionally even ate juveniles of their own species. (*Copyright*

FIGURE 12-17 ***Rutiodon*, a Triassic phytosaur.** Like many other phytosaurs, *Rutiodon* grew to lengths of 10 or more feet. (*Illustration by Carlyn Iverson.*) *What living reptile is an example of convergent evolution with Rutiodon?*

Hesperosuchus from the Triassic of the southwestern United States.

Pet. For. Labyrinthodont teeth

Jurassic Vermilion Cliffs between Lee’s Ferry and Flagstaff

Middle Jurassic

Jurassic paleogeography

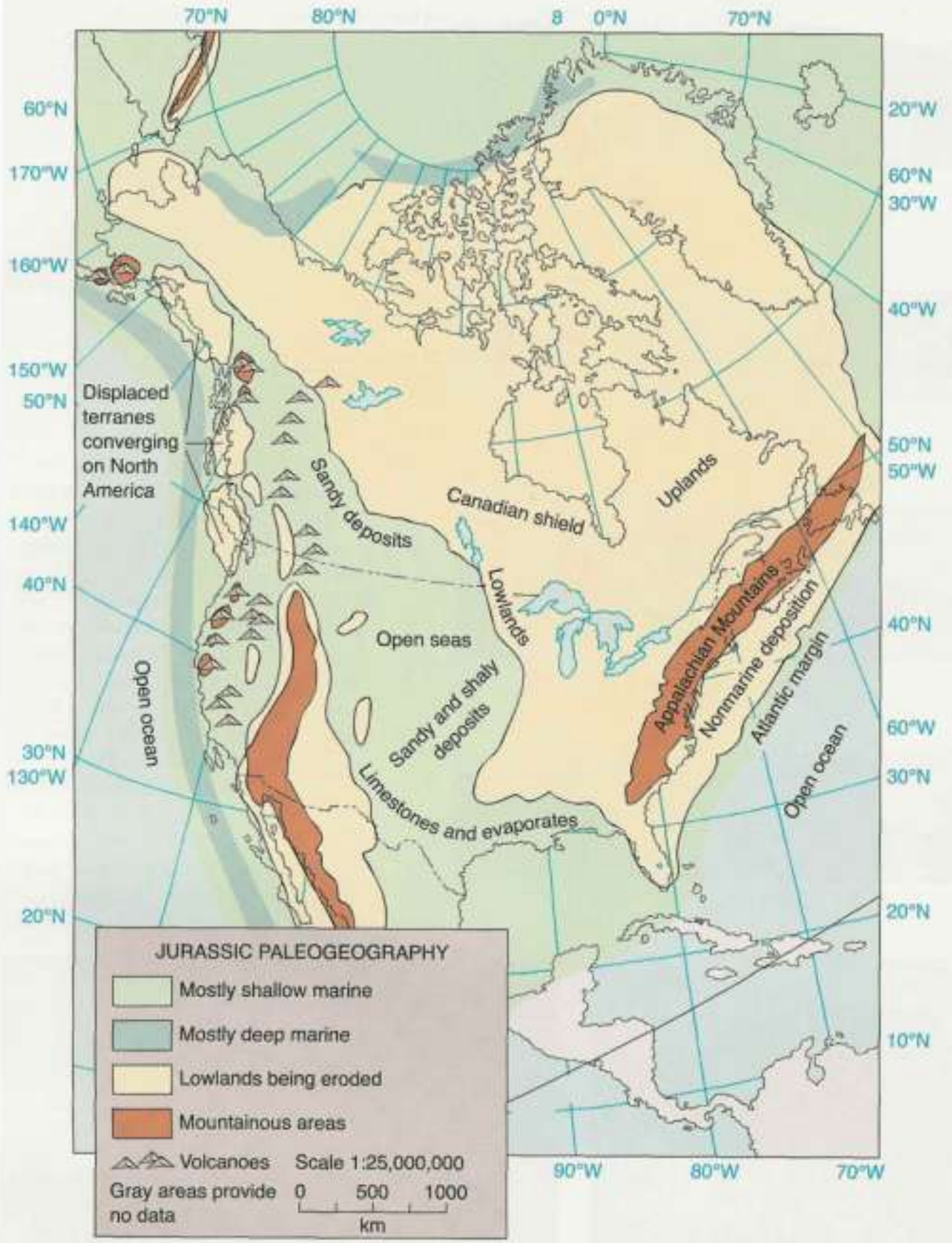
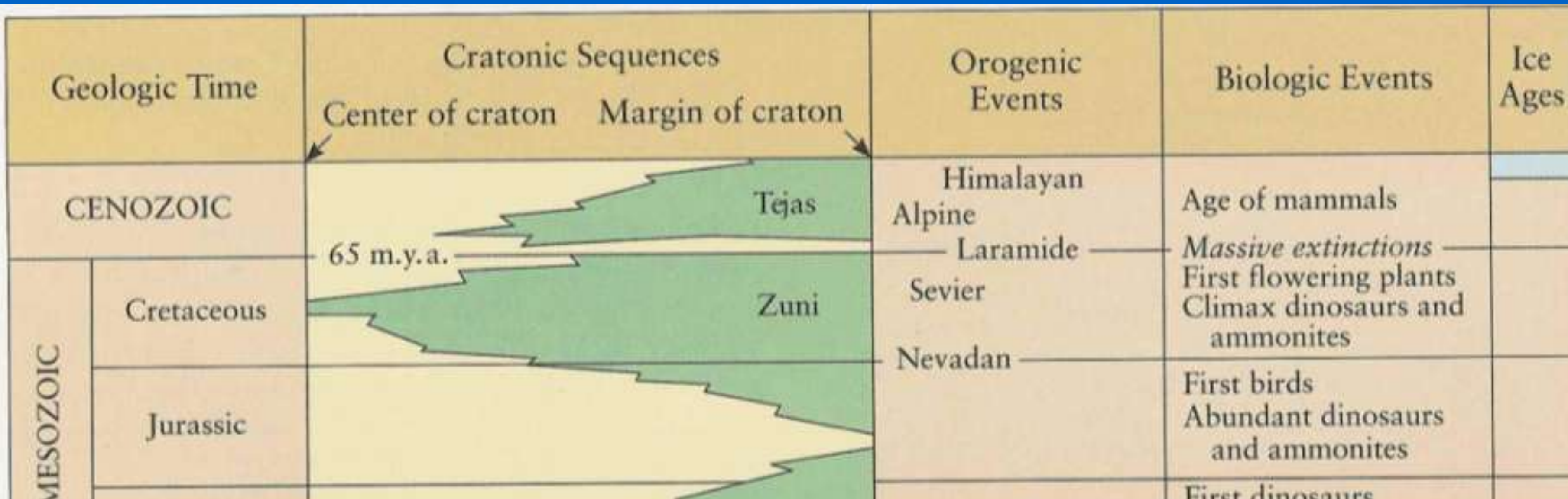
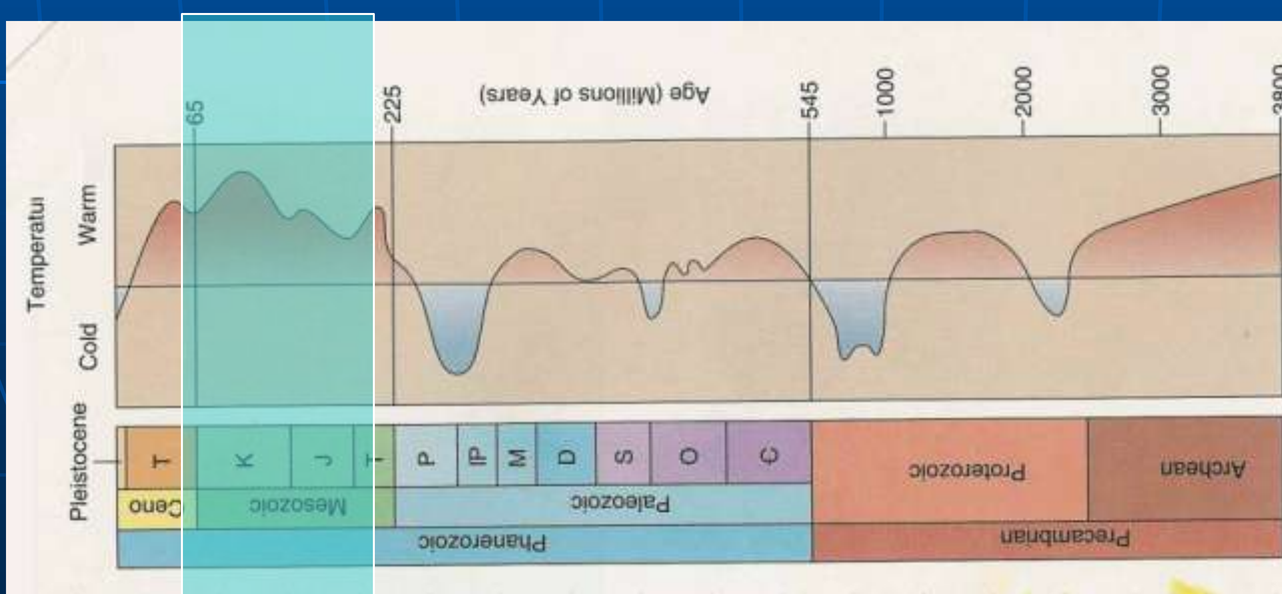


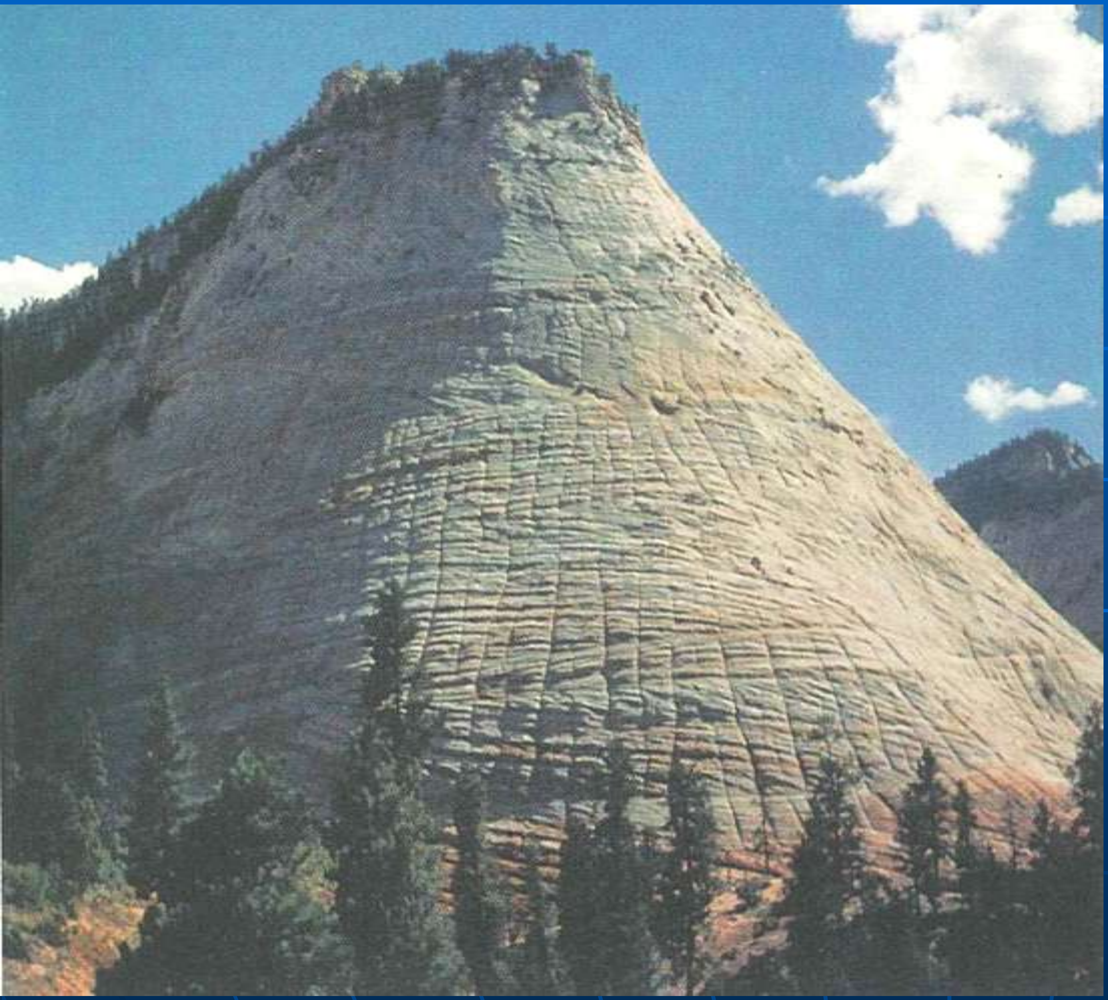
FIGURE 11-7 Generalized paleogeographic map for the Jurassic of North America.
Describe the conditions at the site of your school during the Jurassic Period.

Late Jurassic & Cretaceous 200-65 Ma





Navajo Sandstone – Jurassic age



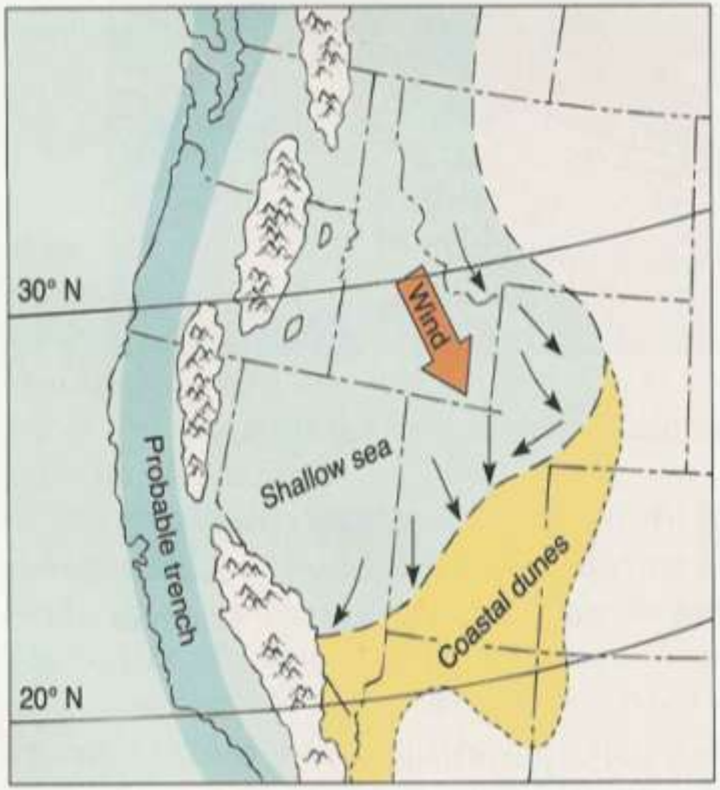


FIGURE 11-26 Paleogeographic map for the early Jurassic of the western United States, showing general extent of sea and land as well as paleolatitudes. (*From Stanley, K. O., Jordan, W. M., and Dott, R. H. 1971.* Bull. Am. Assoc. Petrol. Geol. 55(1):13.)

Jurassic tracks N.AZ

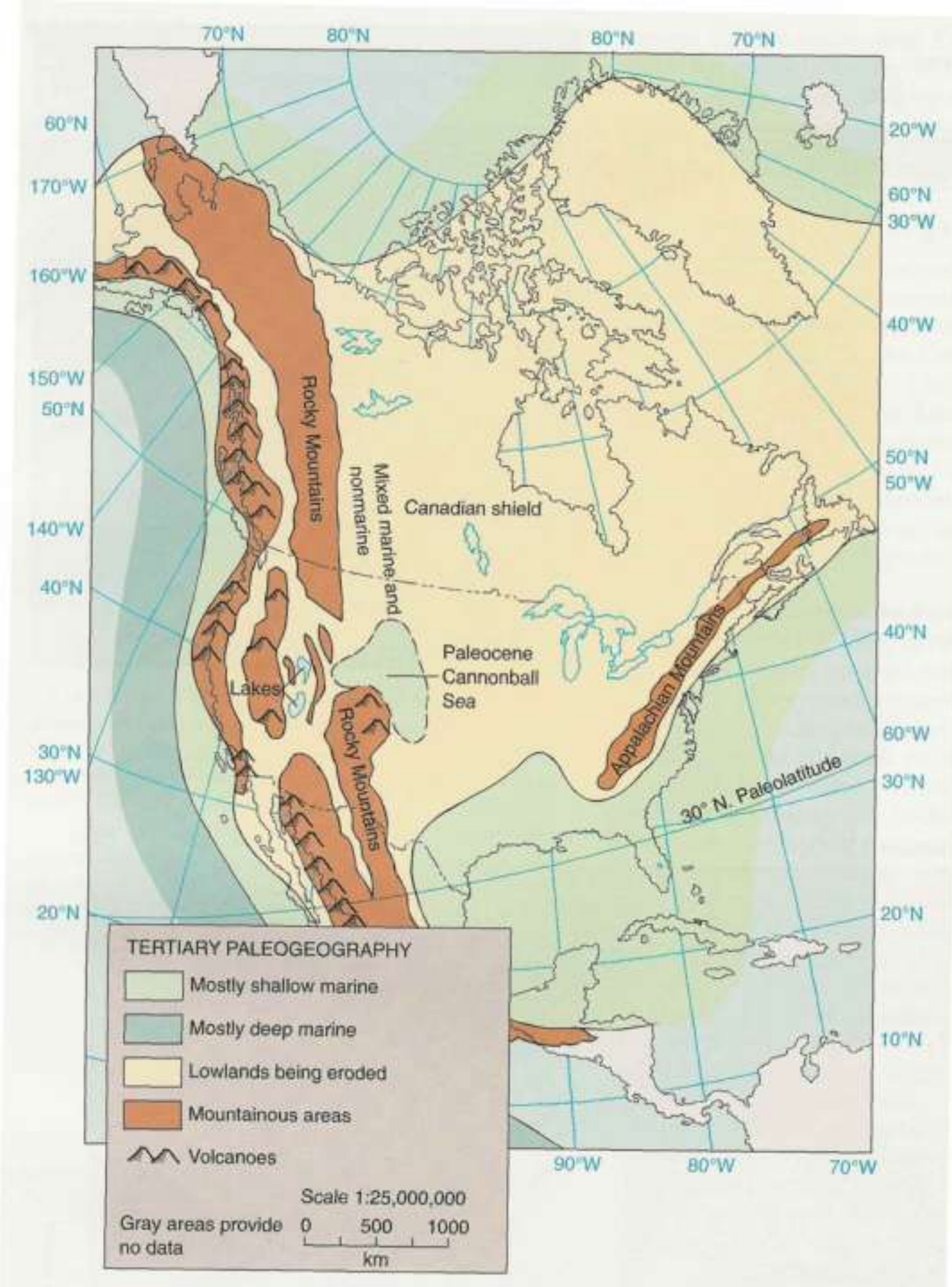
Jurassic - Stegosaurus

Echo Cliffs, Jurassic Ss

Middle Cretaceous (~90 Ma)

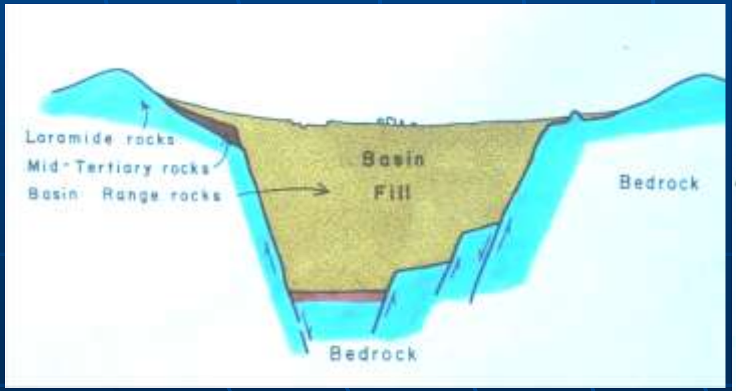
Late Cretaceous – volcanics, Mts.

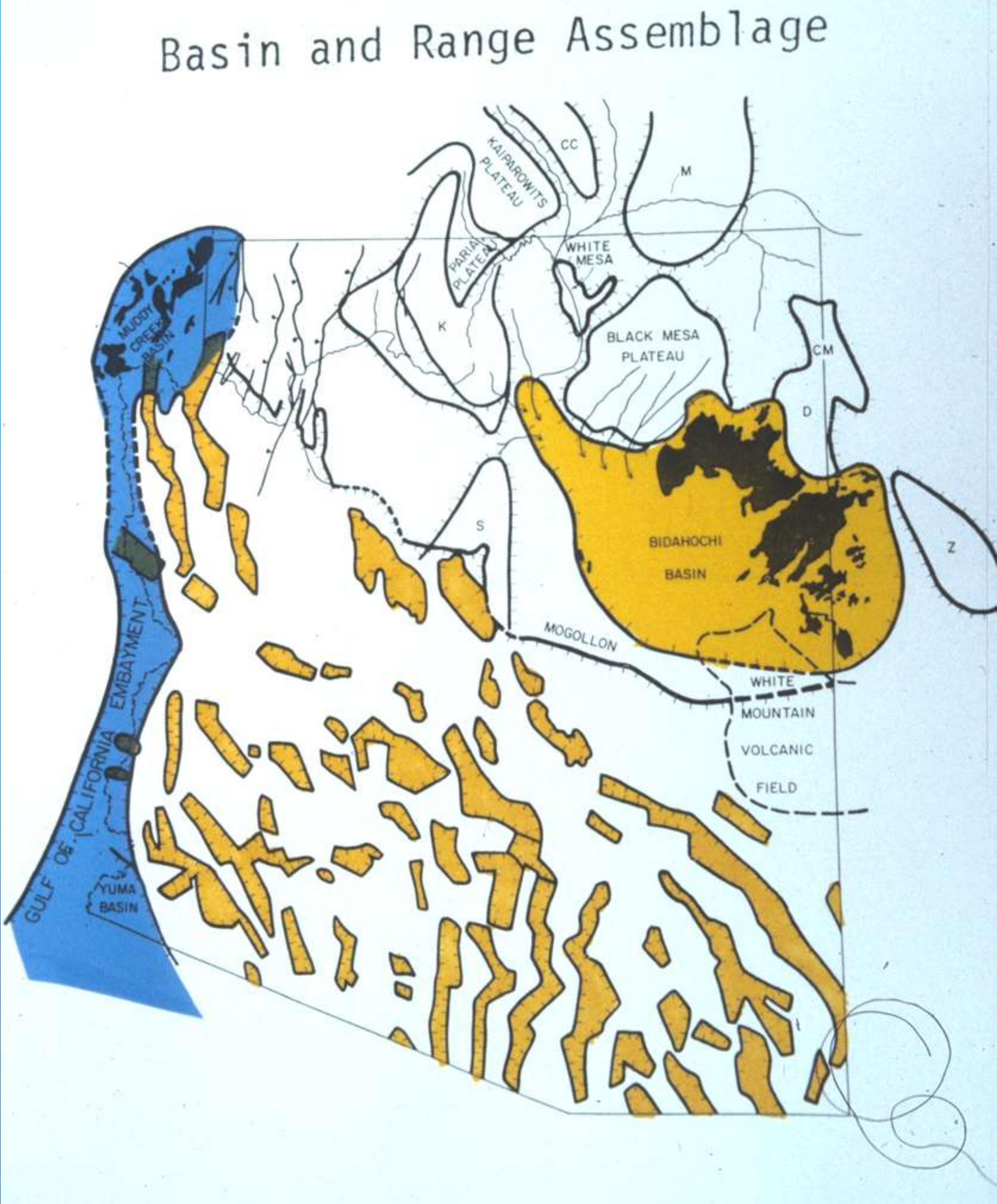
Early Tertiary paleogeography



Tertiary (65-1.8 Ma)

Basin and Range Valleys filled with sand, gravel, clay, gypsum, & salt





Late Cenozoic volcanics

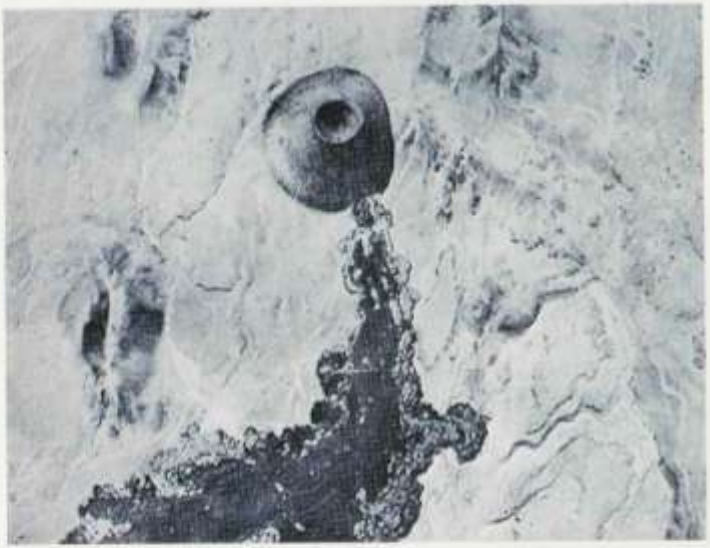
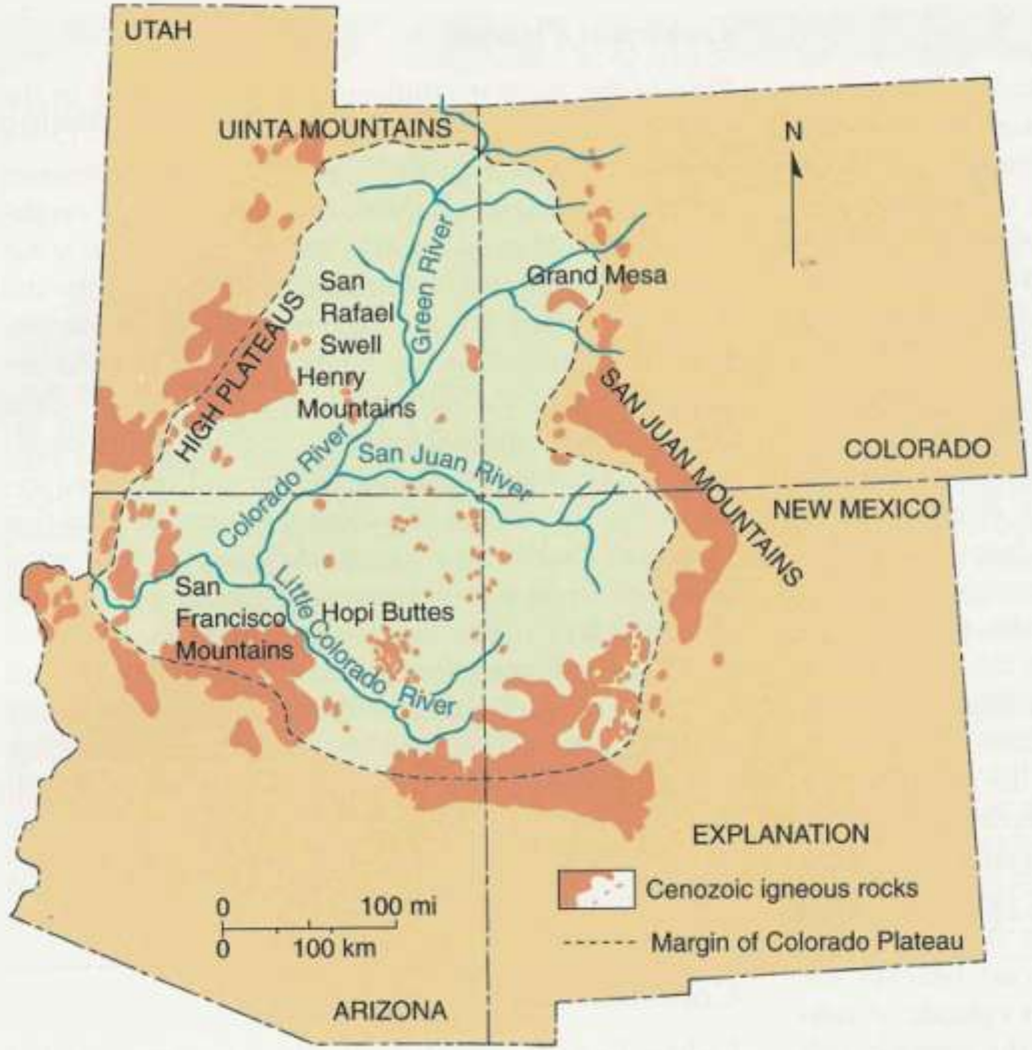


FIGURE 13-20 Vertical aerial photograph of a large cinder cone in the San Francisco volcanic field of northern Arizona. The solidified flow issuing from the cone is 7 kilometers long and more than 30 meters thick.



La Brea tarpits, Los Angeles – Pleistocene 1 Ma

San Francisco Peaks volcanism 5-0 Ma


Lava flow into the Grand Canyon

Columnar jointing in basalt flow into the Grand Canyon – Lava Falls

Grand Canyon at Toroweap Valley, West of Visitor Center; Lava flow at Vulcan's Throne into canyon

Basalt lava flow created Lava Falls in the Grand Canyon

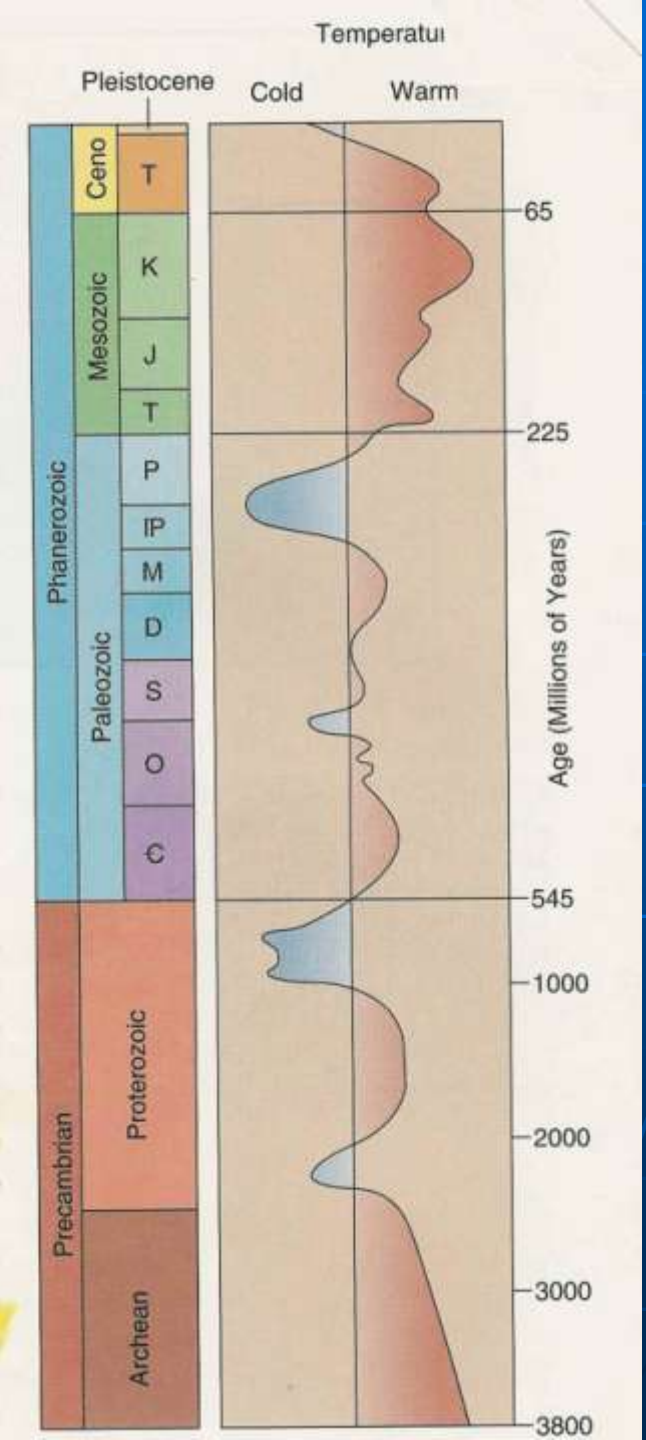
Lava Falls

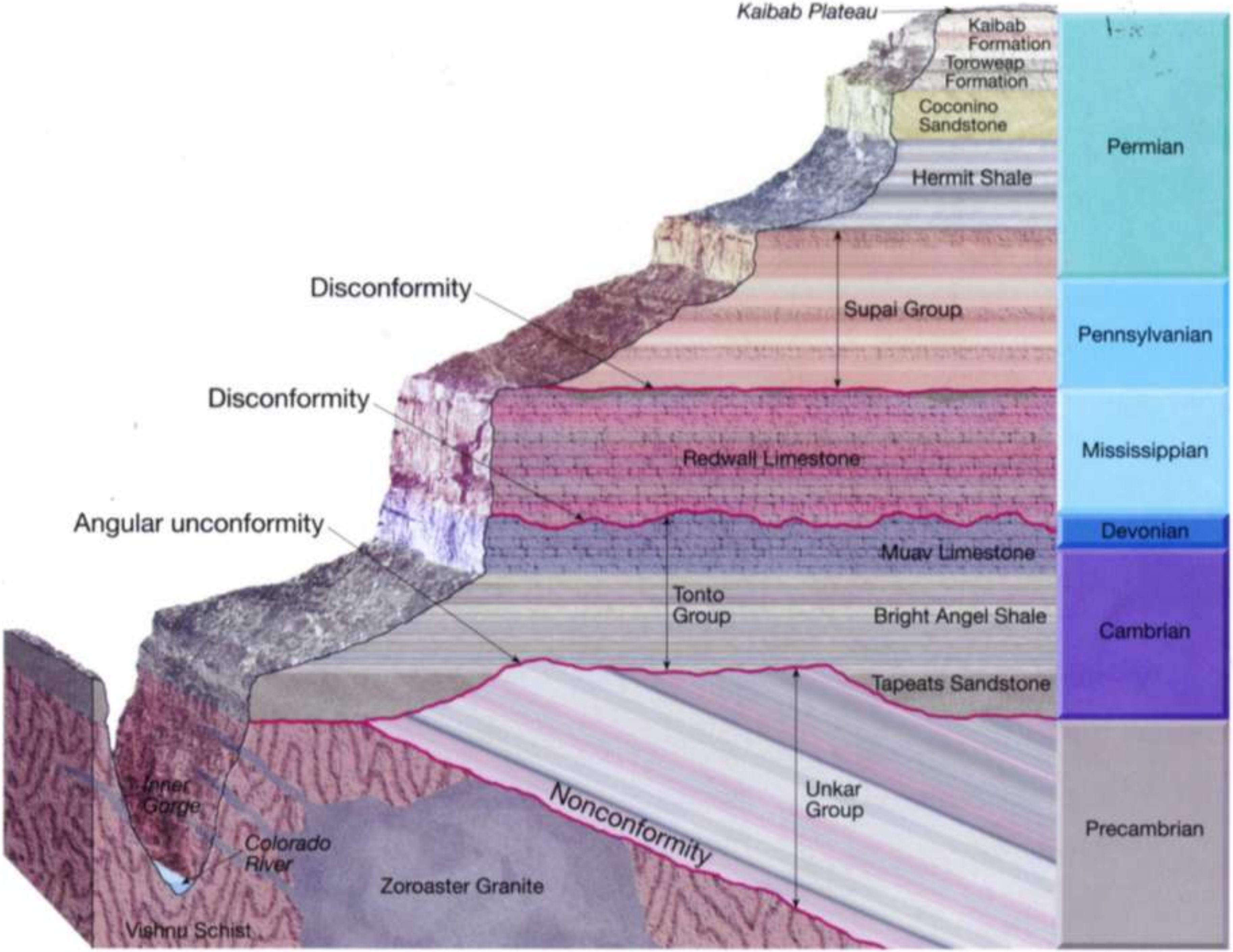

Cinder cones and basalt lava flows at top of Grand Canyon

Sunset Crater
1066 AD eruption

Glaciation through Geologic time

- Depends on plate tectonics through geologic history
- Continental collisions = ice ages
- Big environmental changes through geologic time
- Warm periods vs. ice ages ~ every 250 million years





Kaibab Plateau
Kaibab Formation
Toroweap Formation
Coconino Sandstone
Hermit Shale
Supai Group
Disconformity
Disconformity
Redwall Limestone
Angular unconformity
Muav Limestone
Tonto Group
Bright Angel Shale
Tapeats Sandstone
Inner Gorge
Colorado River
Nonconformity
Unkar Group
Zoroaster Granite
Vishnu Schist
Permian
Pennsylvanian
Mississippian
Devonian
Cambrian
Precambrian