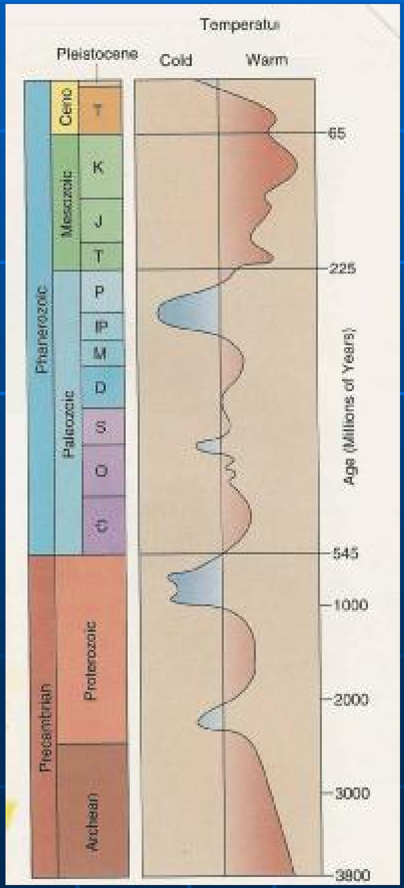
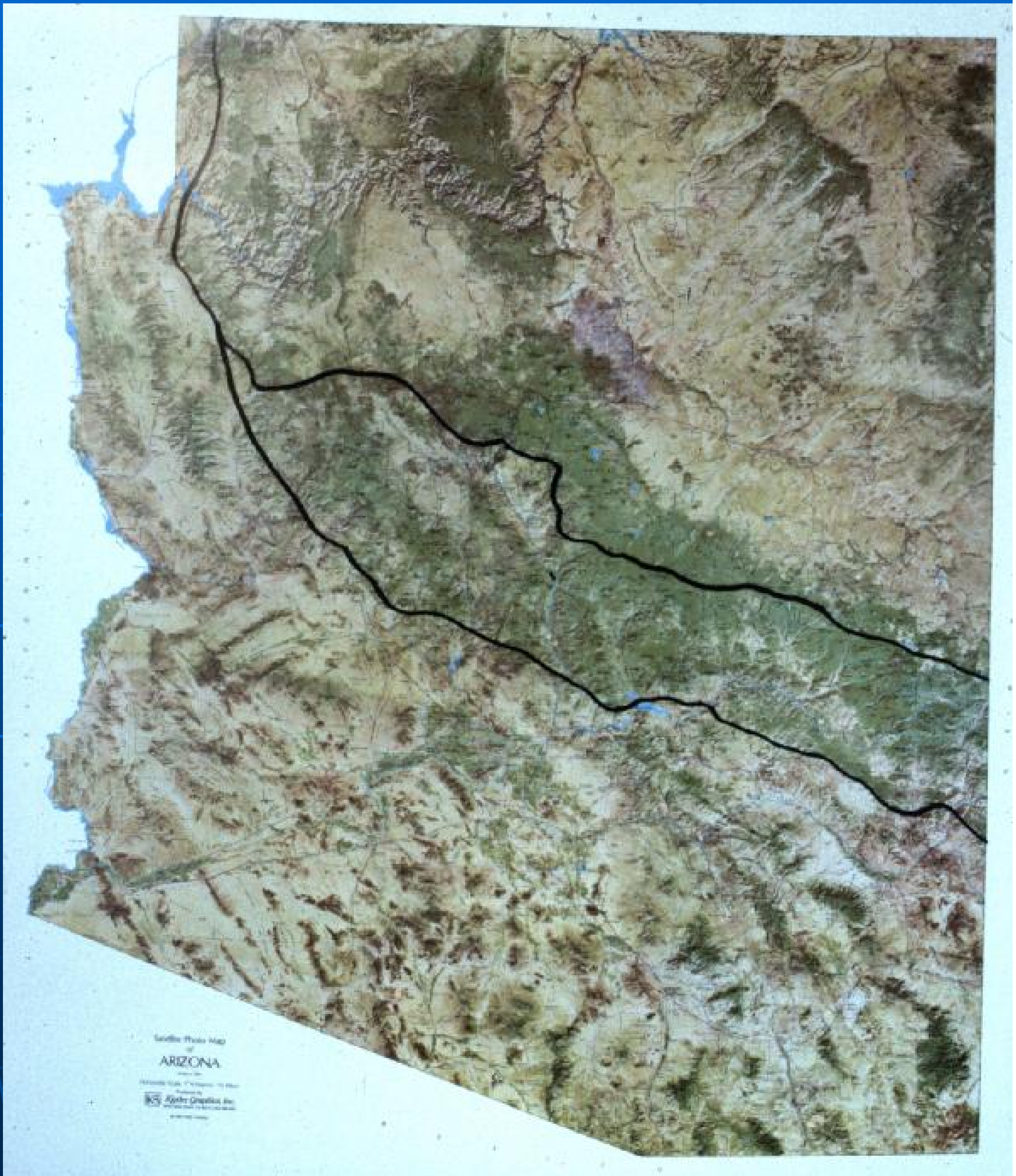
Climate Change in Arizona through Geologic History

Dr. Jan C. Rasmussen, Curator
Arizona Mining and Mineral Museum



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

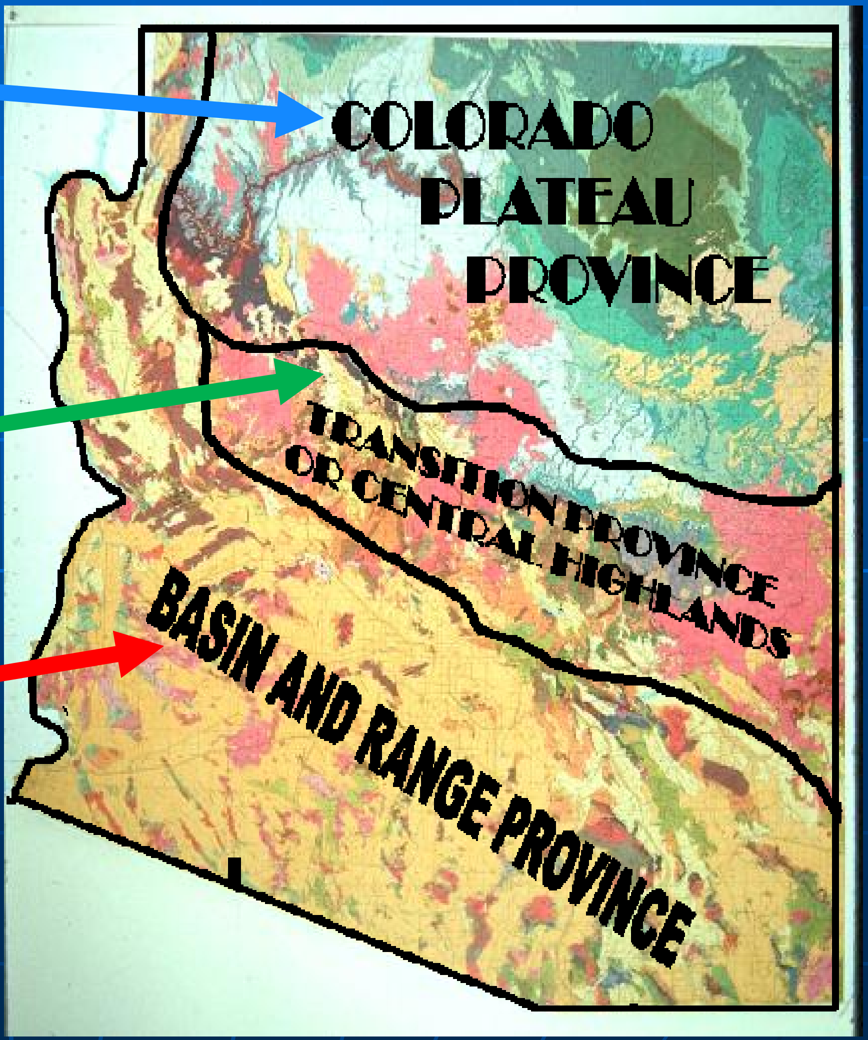
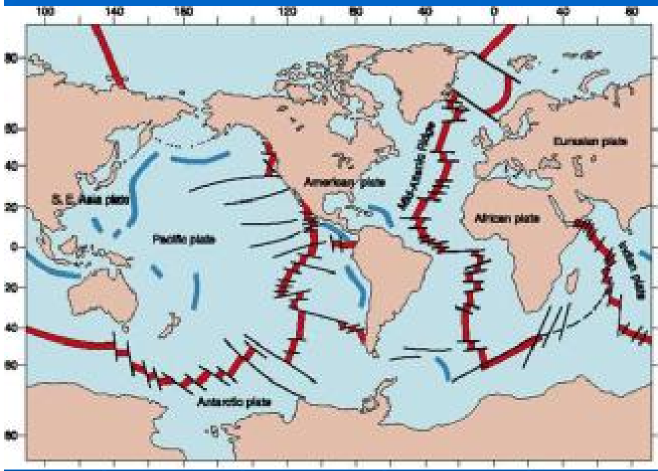
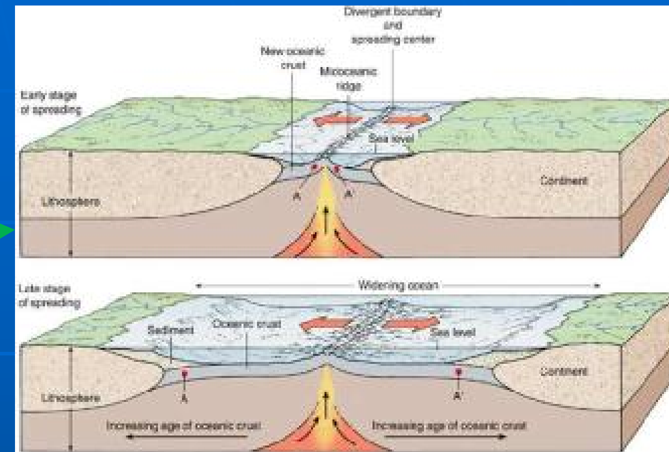
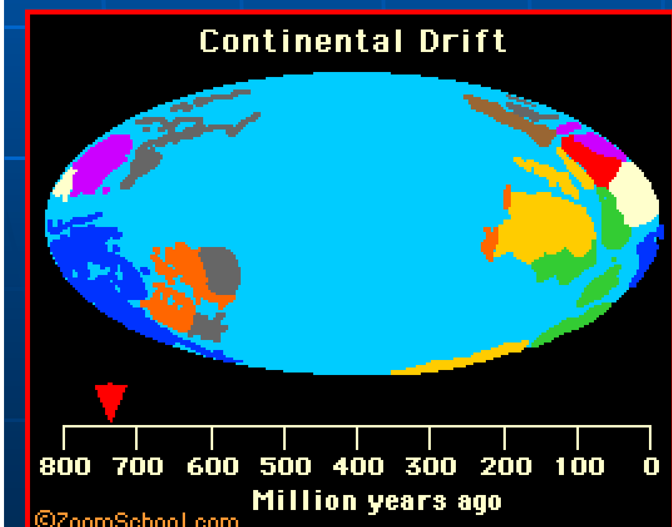


Plate Tectonics

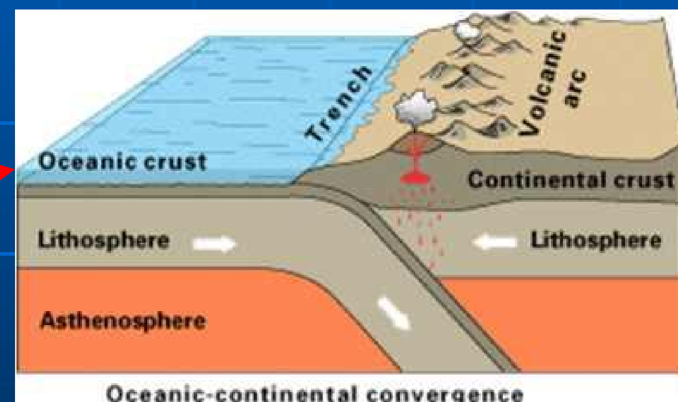


Sea floor spreading and mid-ocean ridge volcanism

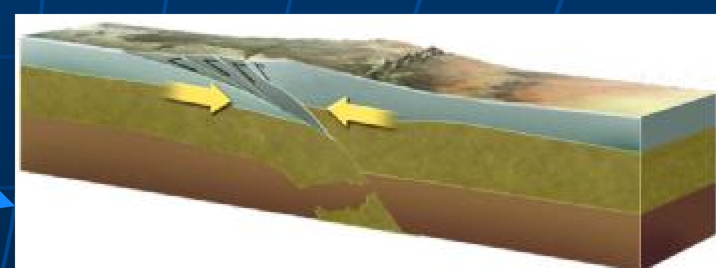




Subduction, Volcanoes, Mountains



Continent-continent collision and very tall mountains



Temp. & Geologic Time Scale

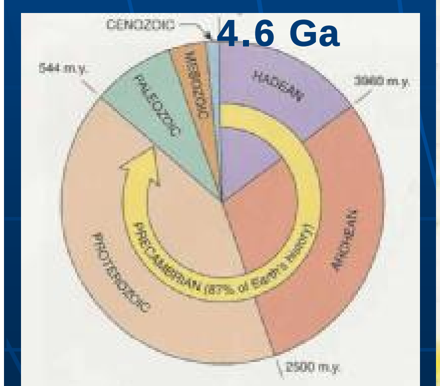
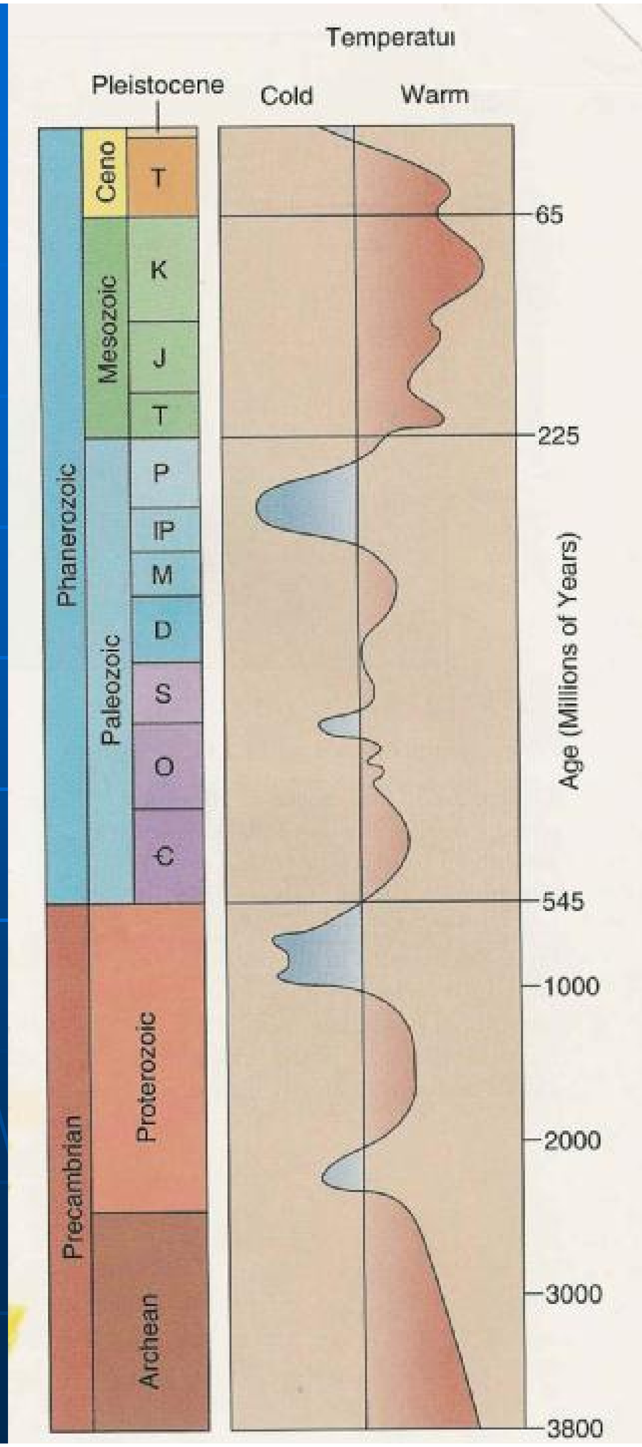
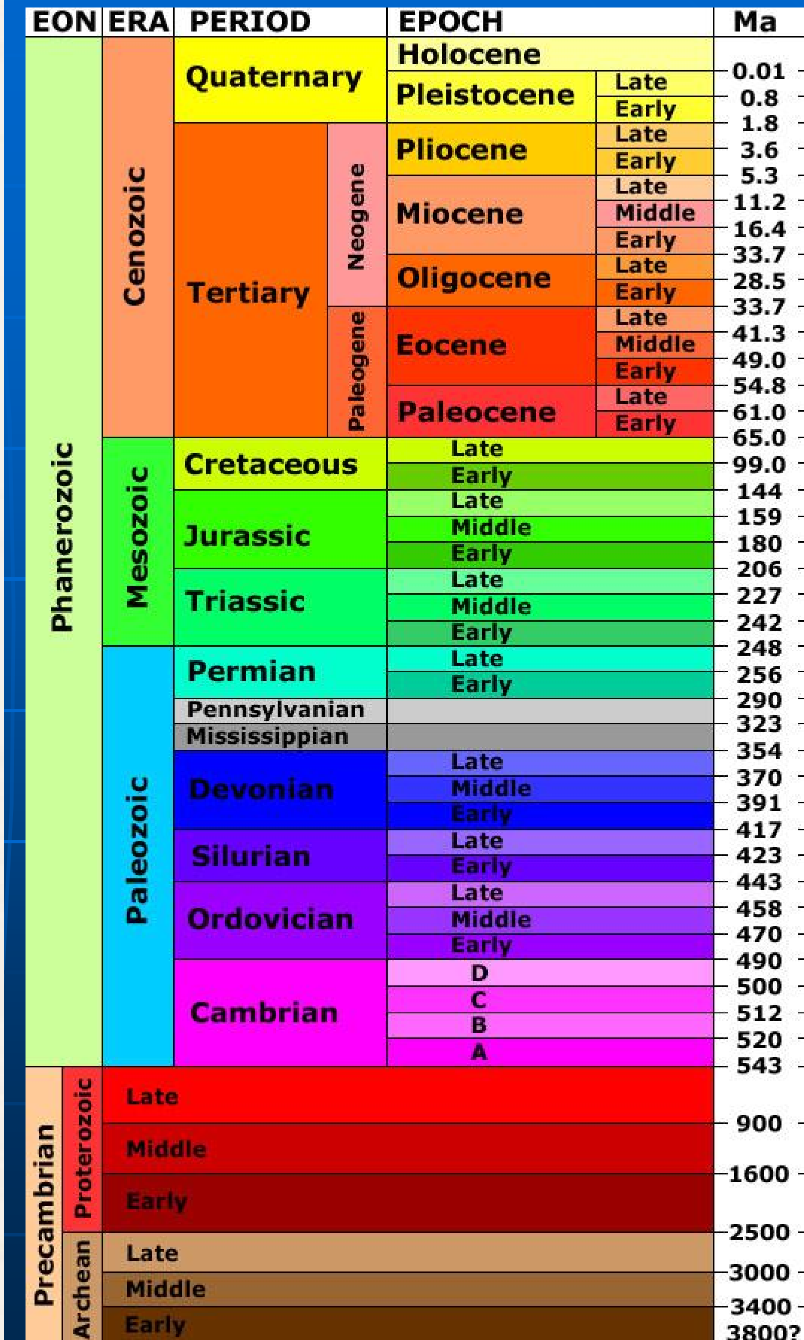


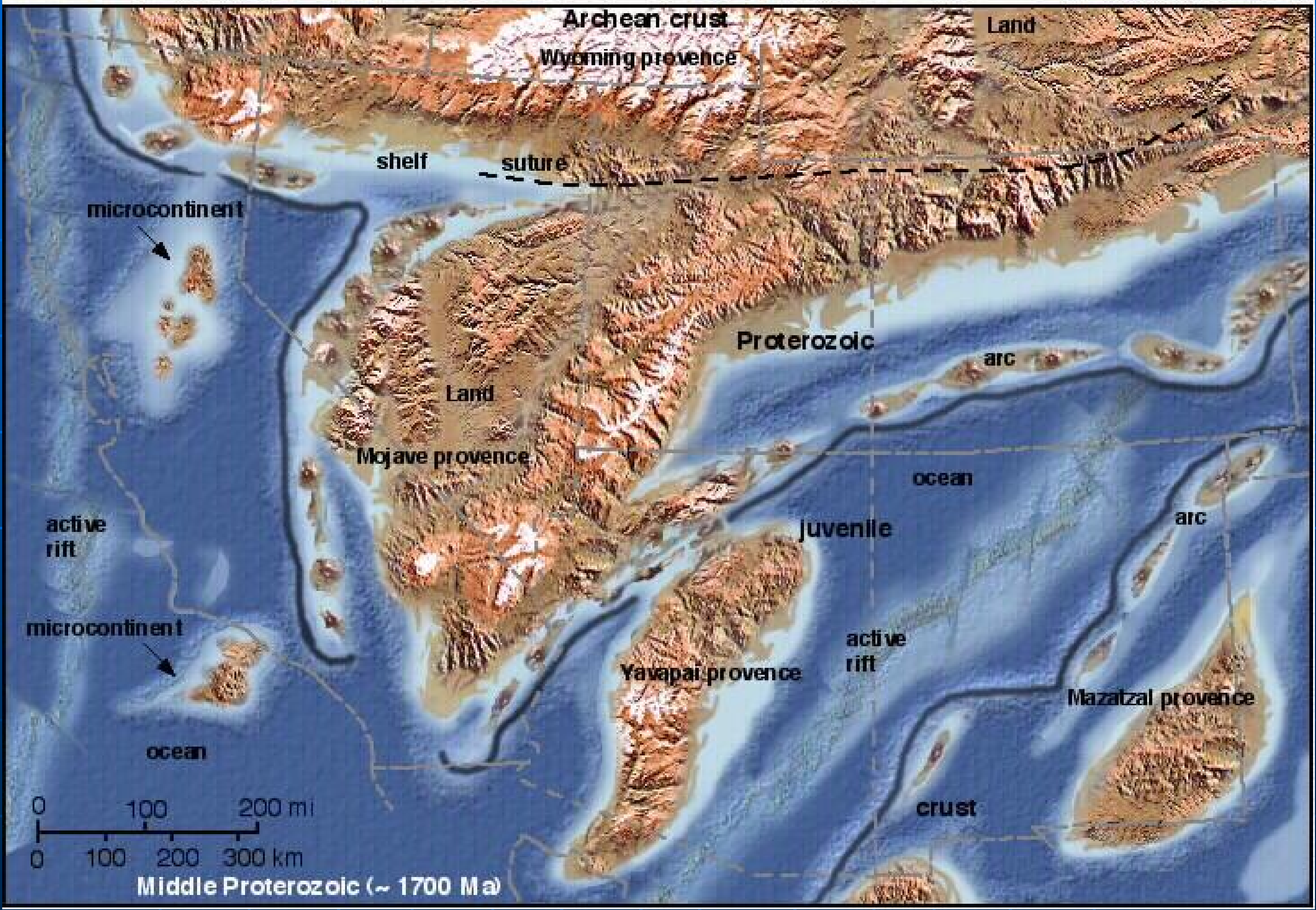
FIGURE 6-1 Proportions of geologic time encompassed by the Precambrian and its Hadean, Archean, and Proterozoic eons.





EON	ERA	PERIOD	EPOCH		Ma
Phanerozoic	Cenozoic	Quaternary	Holocene		0.01
			Pleistocene	Late	0.8
				Early	1.8
		Tertiary (Neogene)	Pliocene	Late	3.6
				Early	5.3
			Miocene	Late	11.2
				Middle	16.4
				Early	33.7
			Oligocene	Late	28.5
				Early	33.7
		Tertiary (Paleogene)	Eocene	Late	41.3
				Middle	49.0
				Early	54.8
			Paleocene	Late	61.0
				Early	65.0
	Mesozoic	Cretaceous	Late		99.0
			Early		144
		Jurassic	Late		159
			Middle		180
			Early		206
		Triassic	Late		227
			Middle		242
			Early		248
	Paleozoic	Permian	Late		256
			Early		290
		Pennsylvanian			323
		Mississippian			354
		Devonian	Late		370
			Middle		391
			Early		417
		Silurian	Late		423
			Early		443
		Ordovician	Late		458
			Middle		470
			Early		490
		Cambrian	D		500
			C		512
			B		520
			A		543
Precambrian	Proterozoic	Late			900
		Middle			1600
		Early			2500
	Archean	Late			3000
		Middle			3400
		Early			3800?

Meso-proterozoic (1.7 Ga)



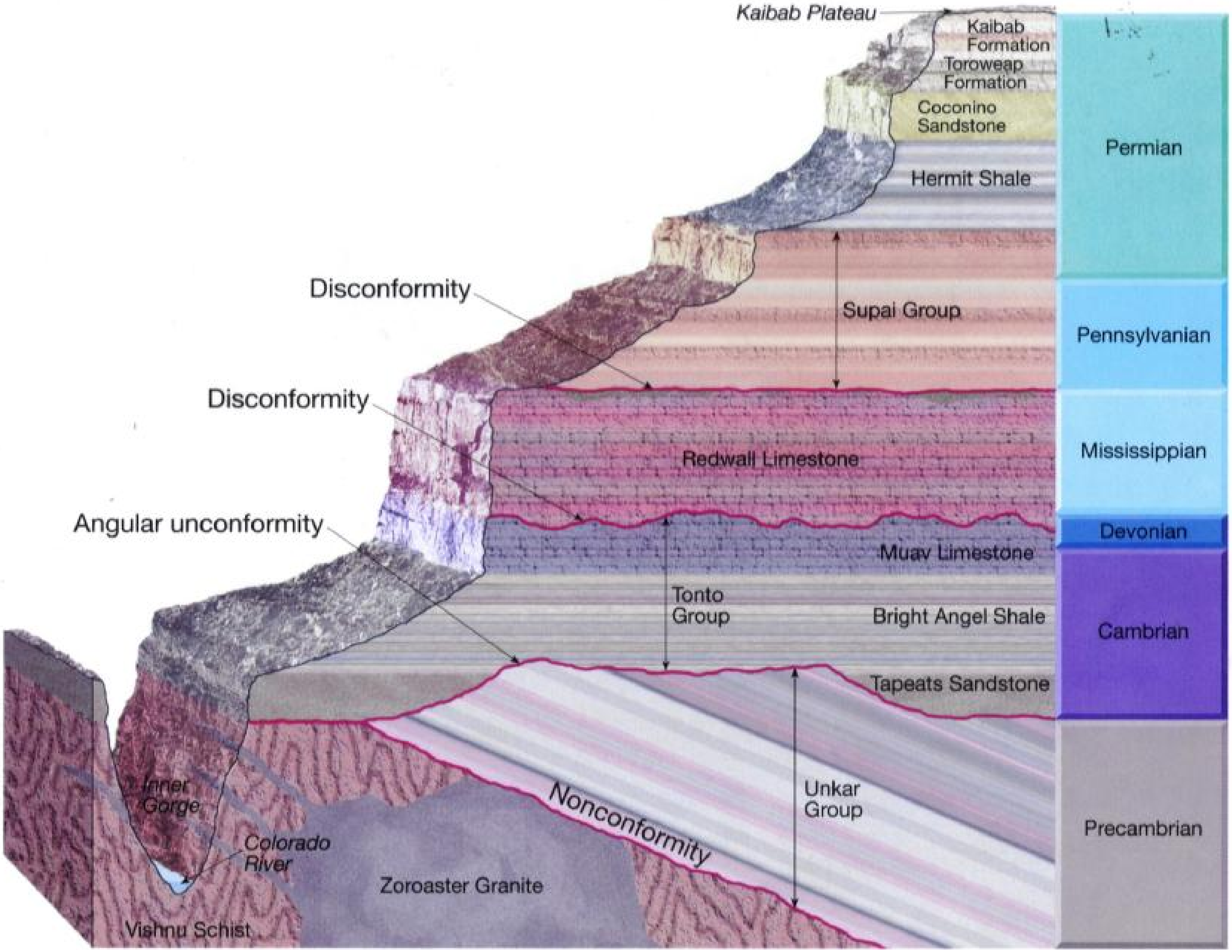
PreCambrian Arizona

Inner Gorge - metamorphic rocks

Mountain building episode in younger PreCambrian (older Proterozoic)

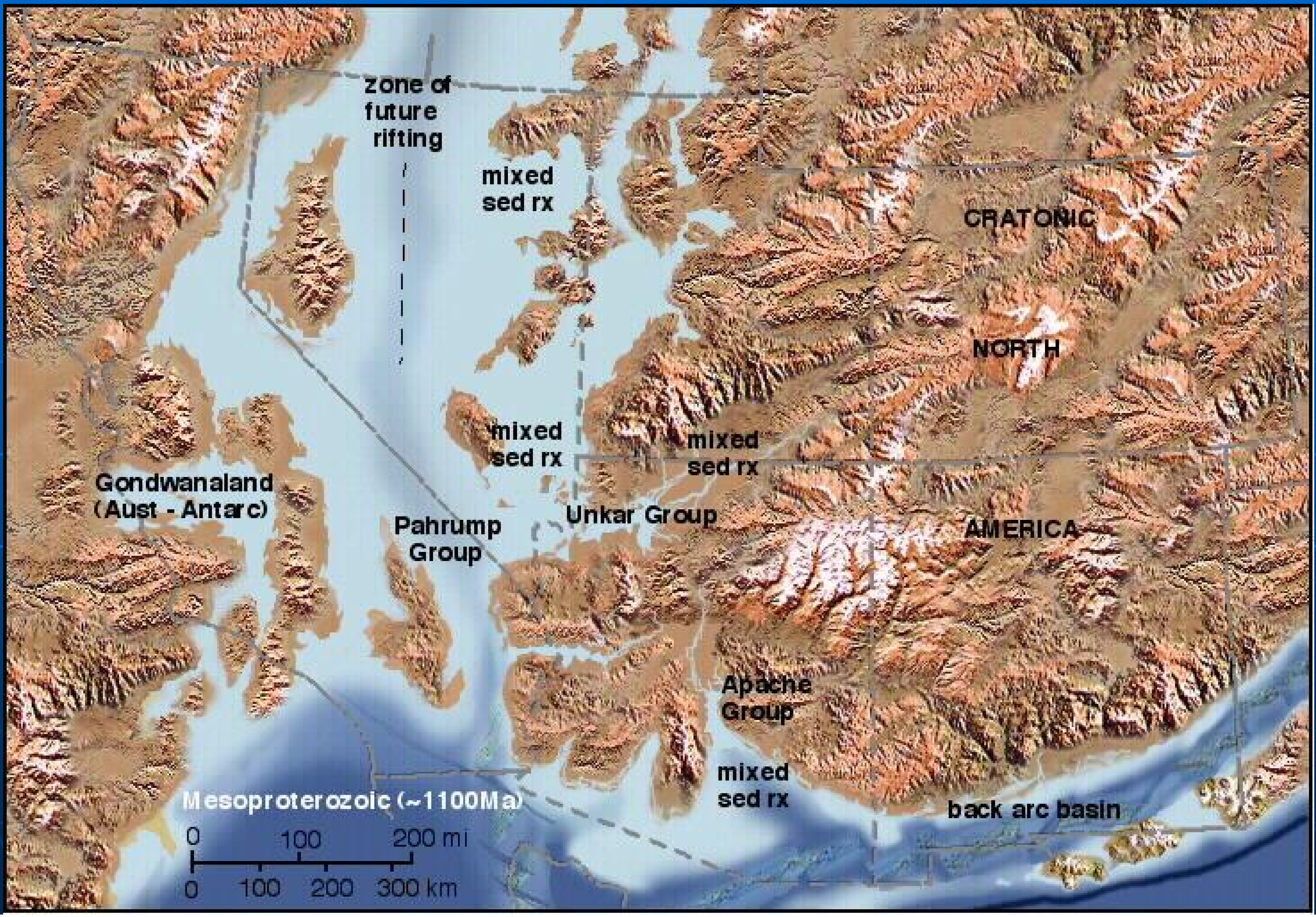
- 1.7 billion years – Mazatzal Orogeny produced Rocky Mt.-style mountains
- Metamorphism, folding, later intrusion of granitic rocks

Unconformities in the Grand Canyon



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

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

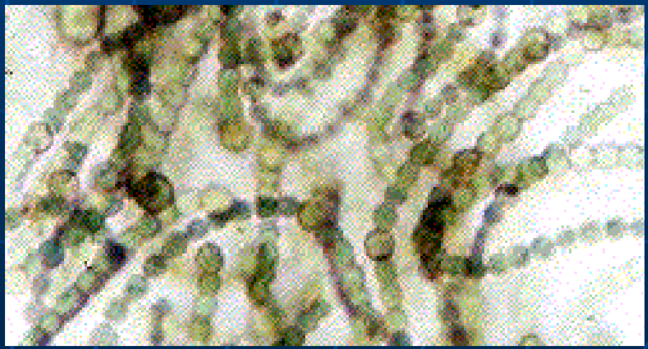


Grand Canyon Group

- 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.

Blue-green algae gave O_2

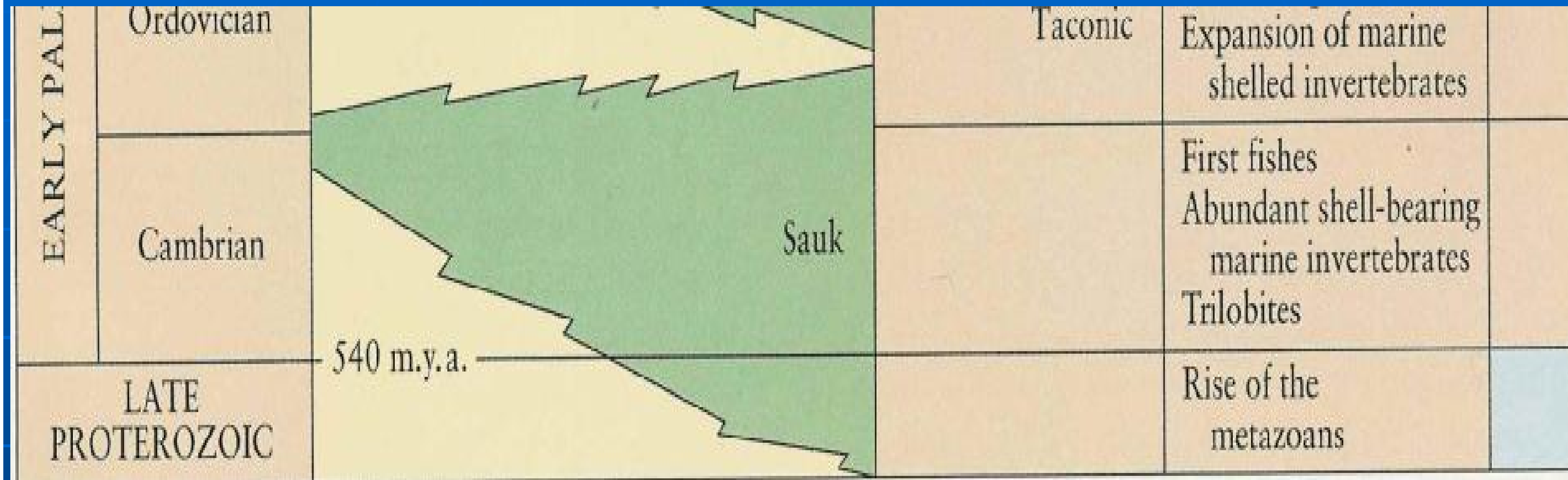
- **Photosynthesis by blue green algae (cyanobacteria) since 3.5 billion yrs ago**
- **When pigments developed in cells, they could absorb and process light.**
- **The products of this process were energy and oxygen.**
- **Between 2.4 – 2.2 billion years ago, the greater numbers of cyanobacteria increased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

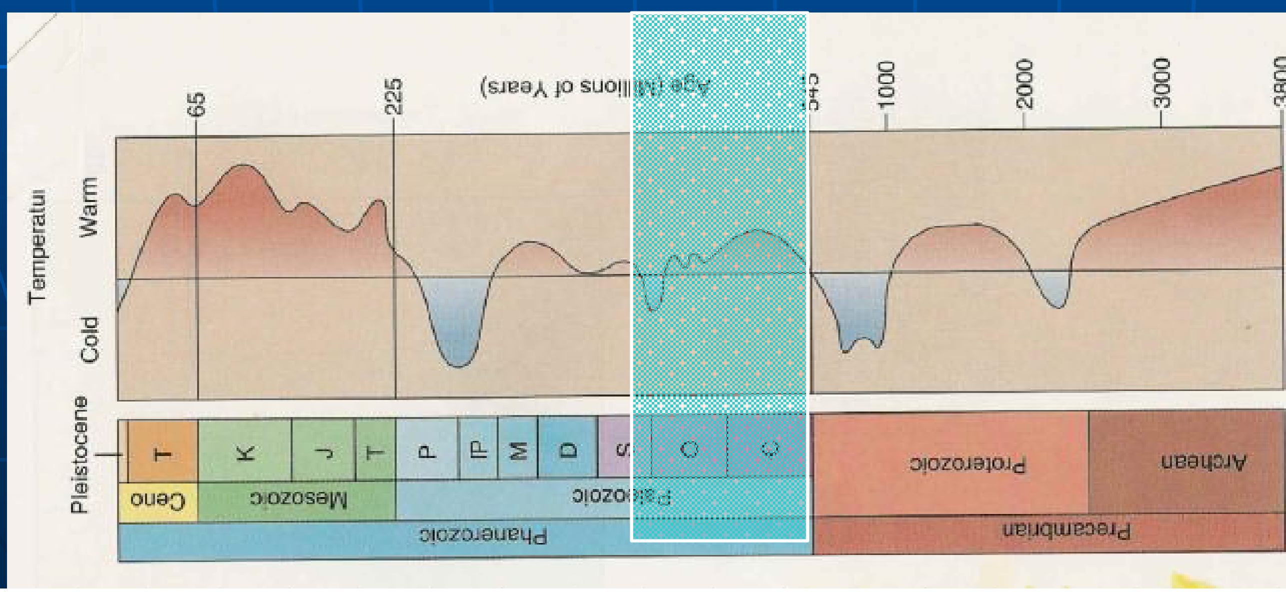


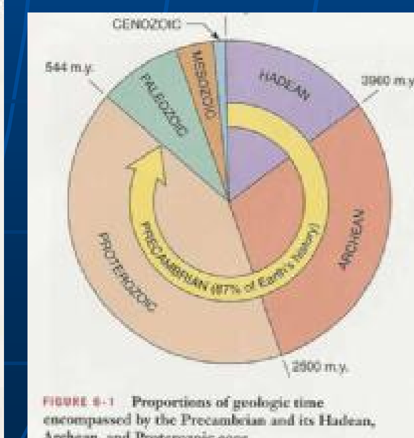
Stromatolites

Cambrian – Early Ordovician

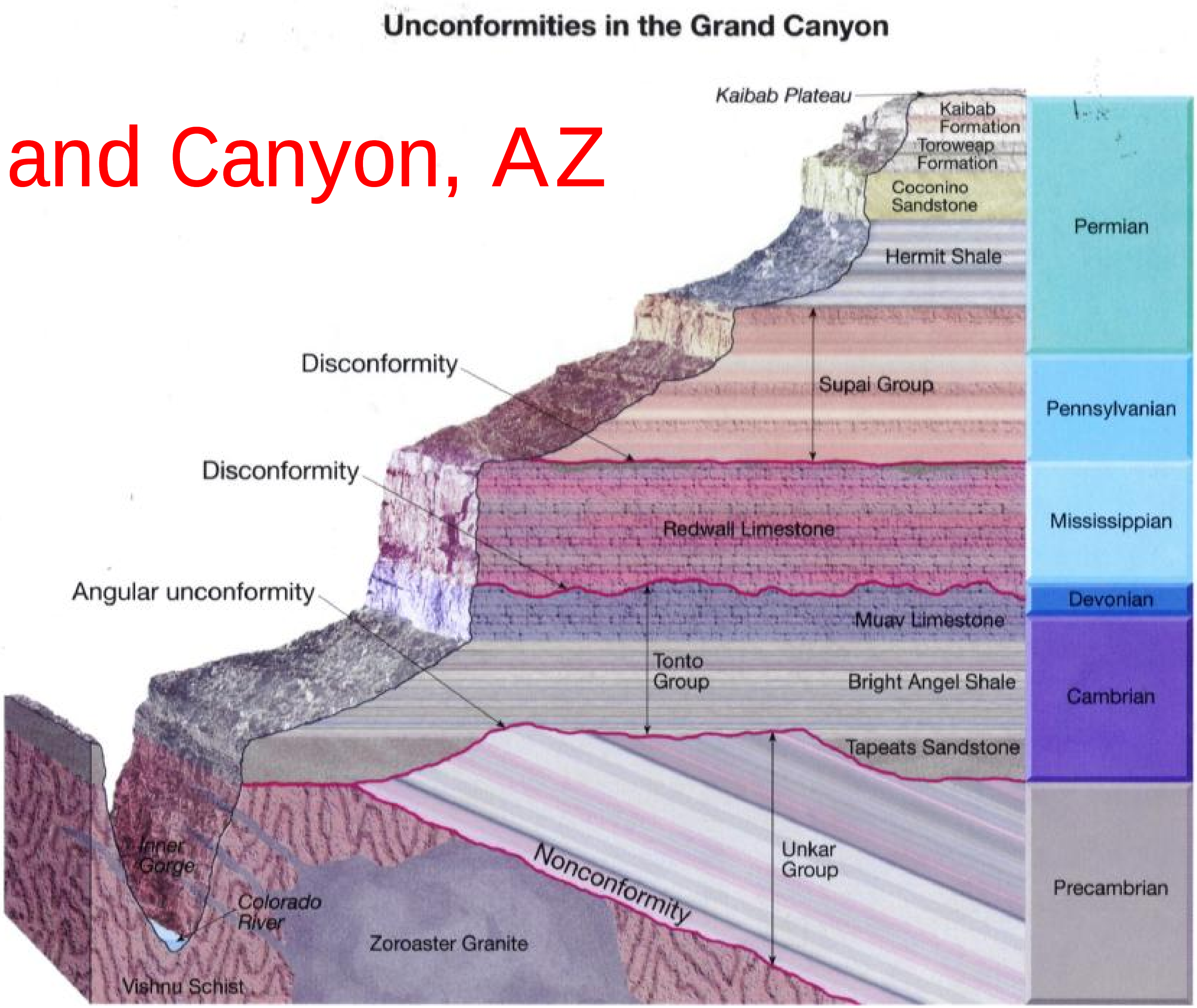
543 - 470 million years ago (Ma)





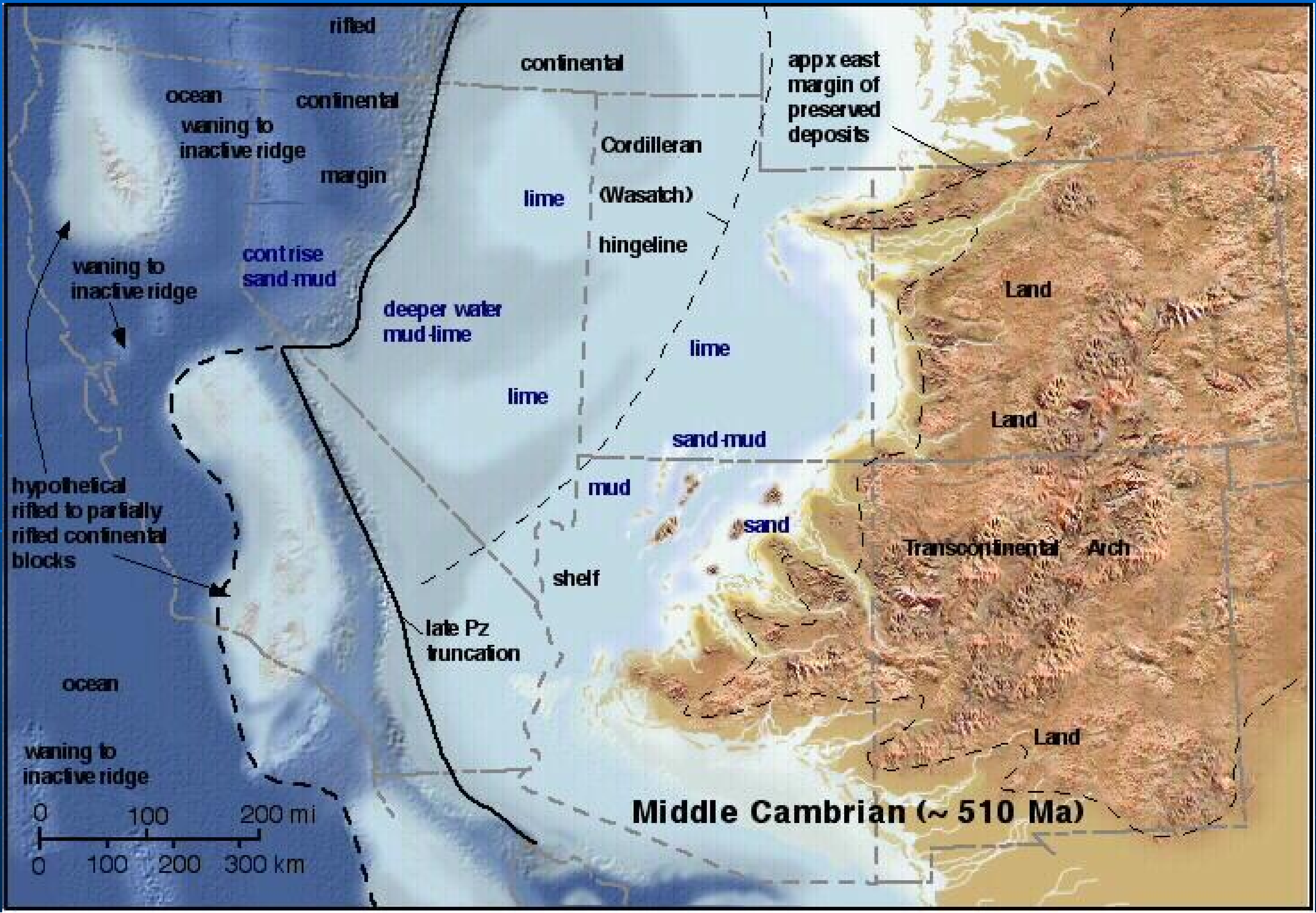


Grand Canyon, AZ

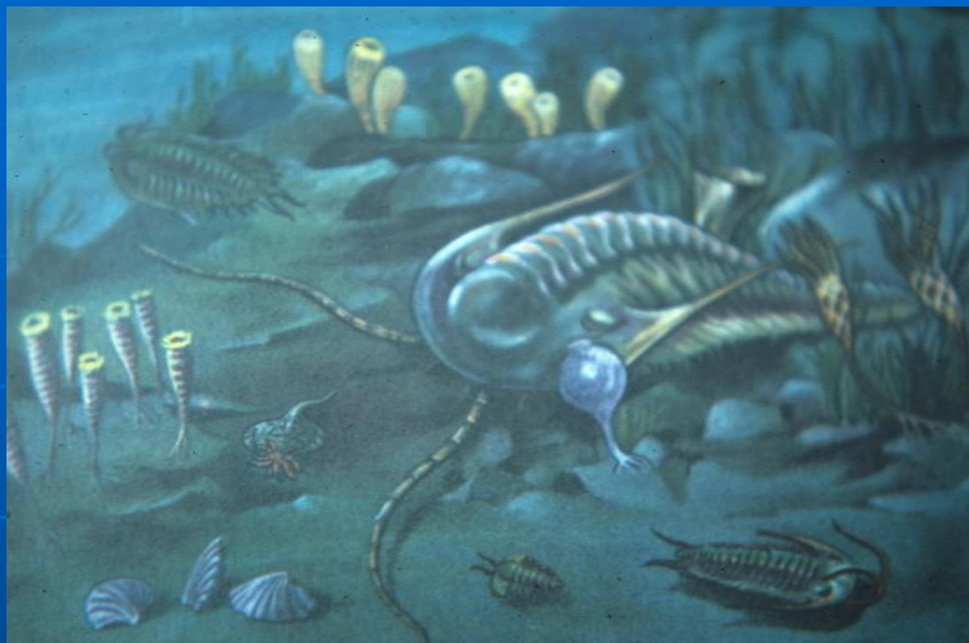


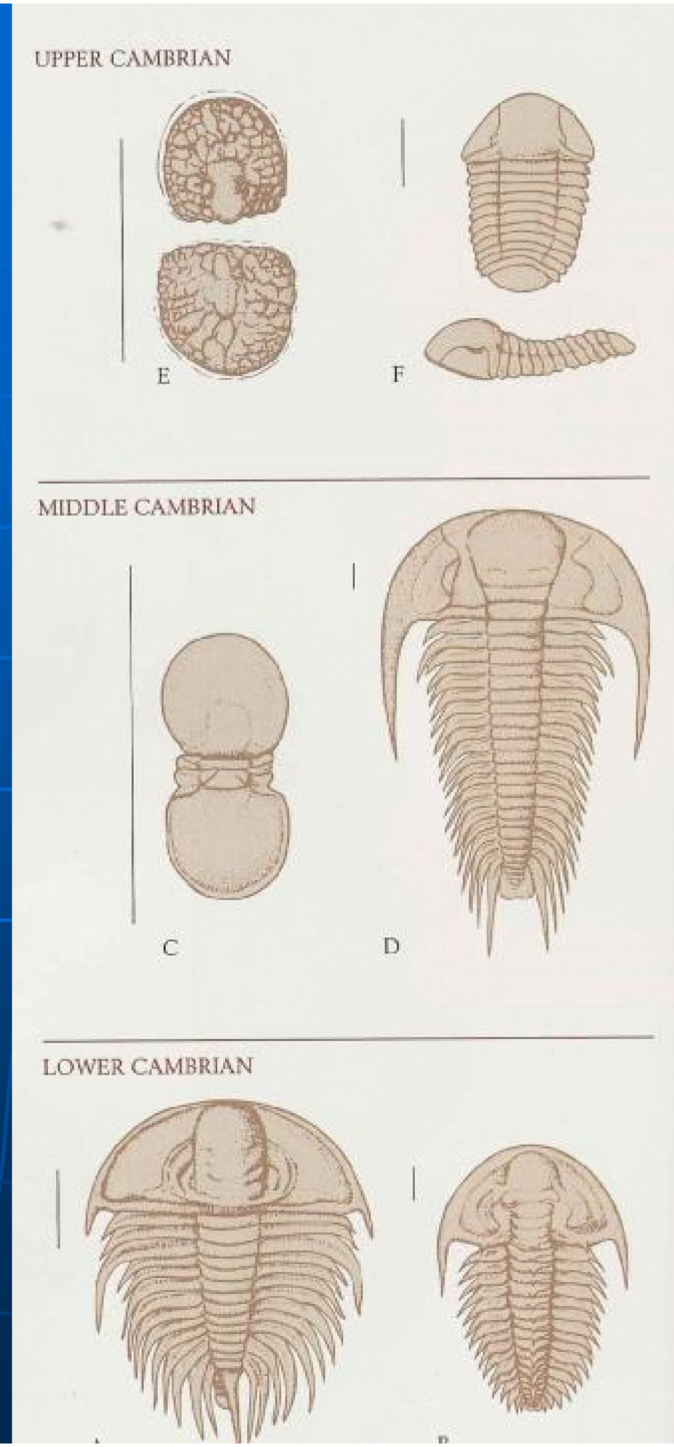
Grand Canyon formations

Cambrian (543-490 Ma)



trilobites

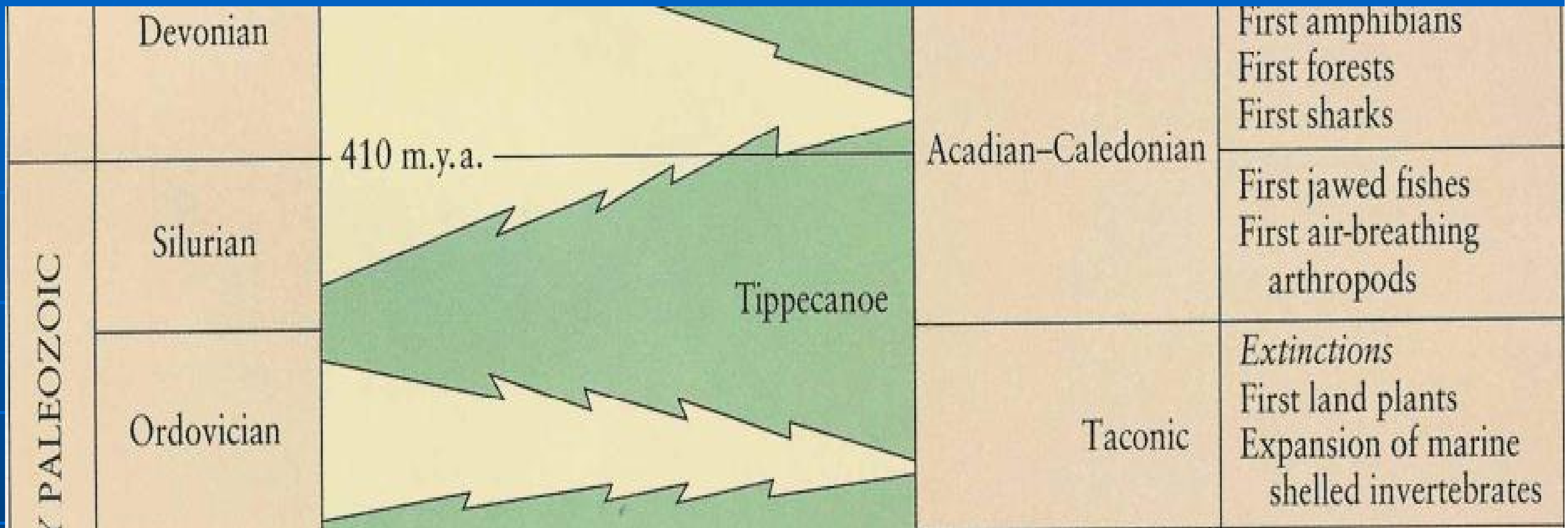


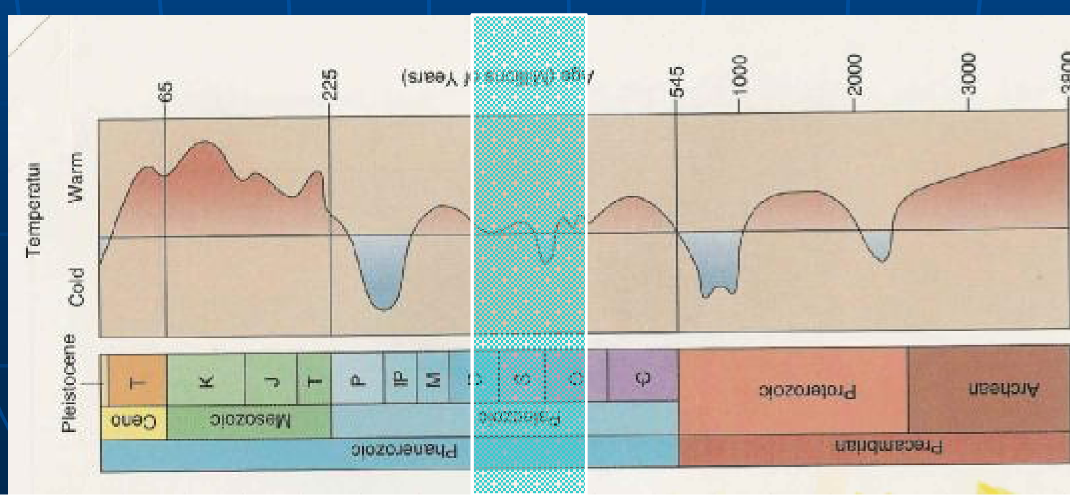


A B

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)





Late Ordovician environments (430 Ma)

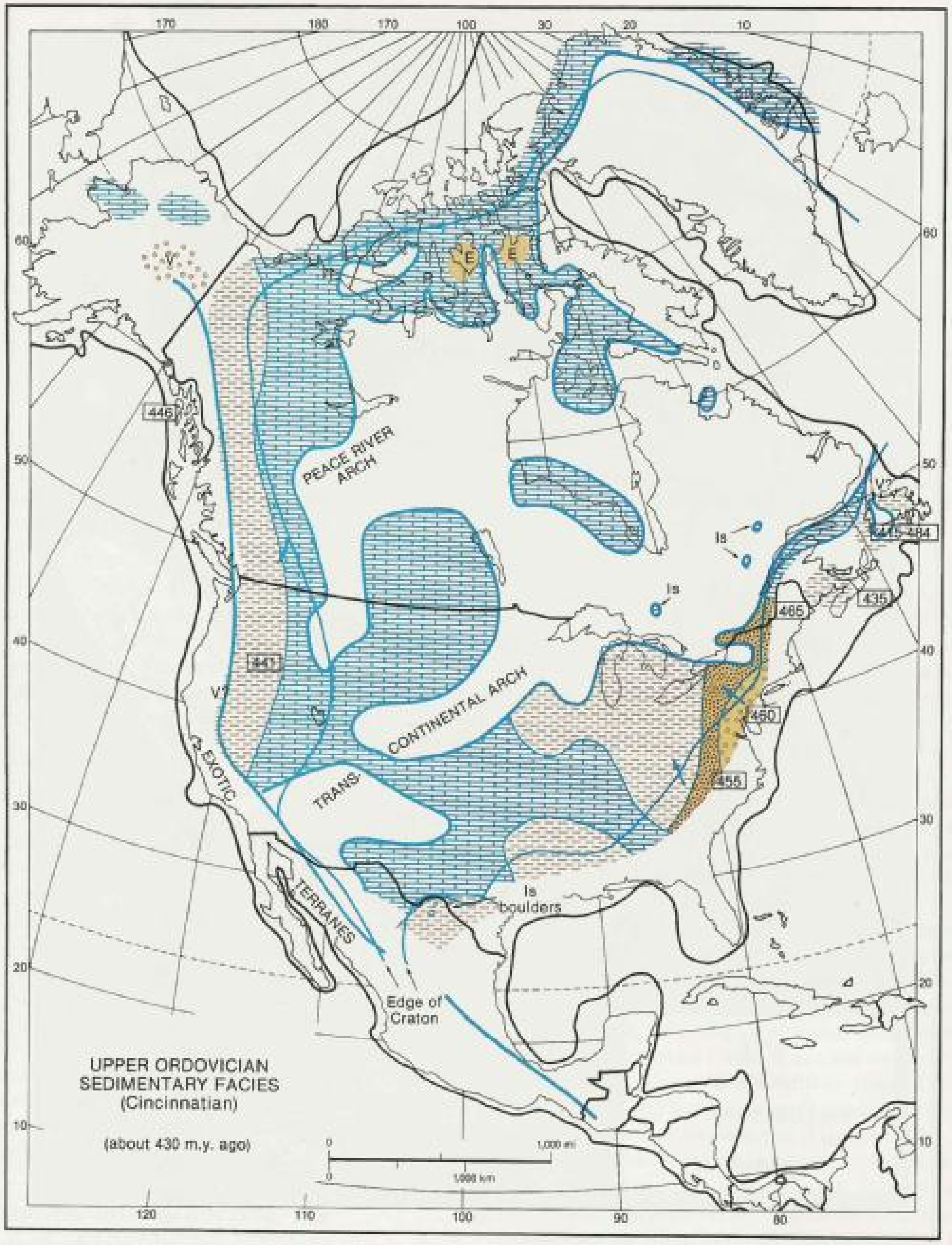
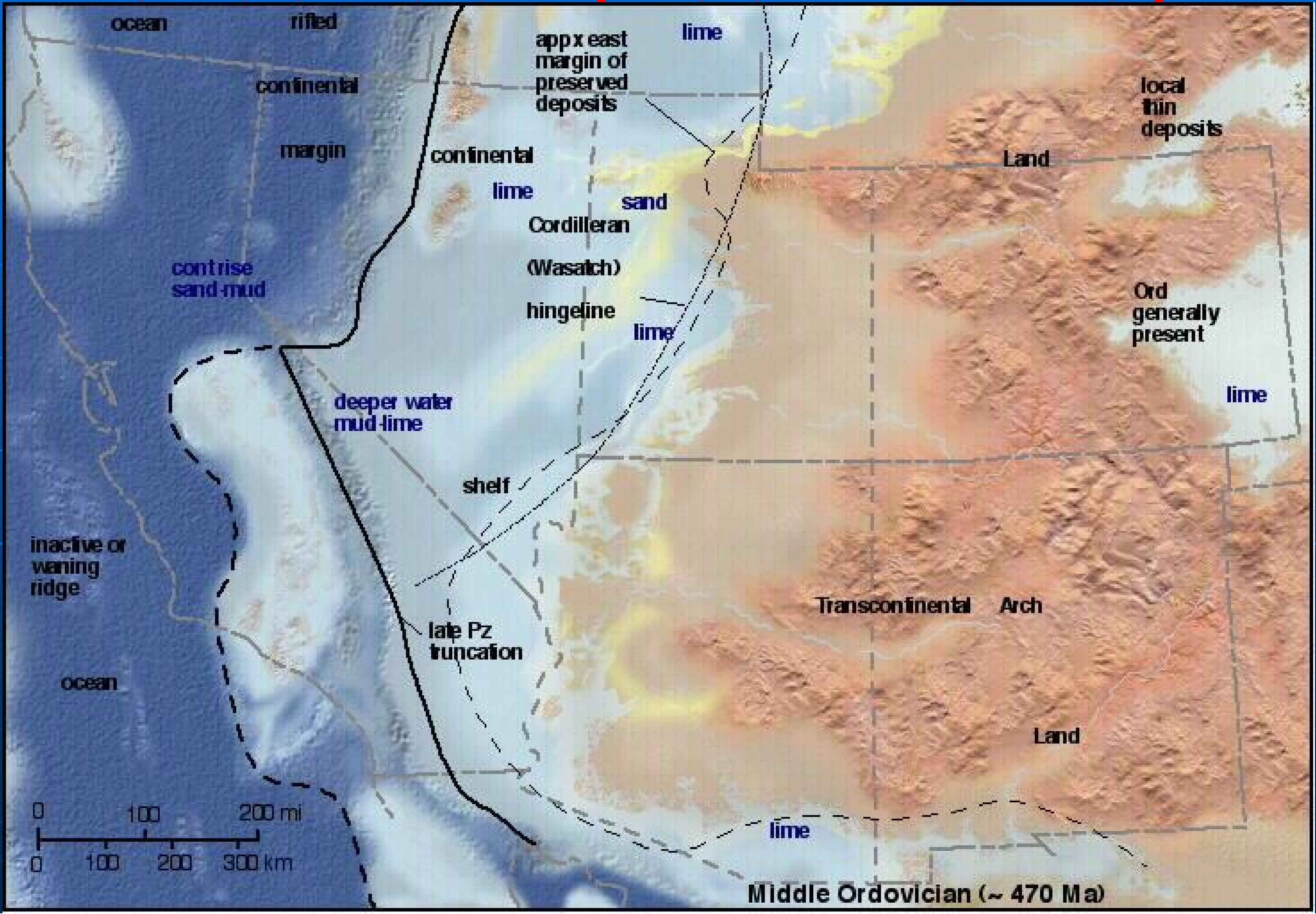


Figure 11.15 Upper Ordovician sediment patterns for North America. Widely scattered patches of sediments on the Canadian Shield prove the great extent of the Late Ordovician sea. Absence of Ordovician strata on several arches proves subsequent warping and erosion of these arches. Note the spread of red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

Ordovician (488-443 Ma)



Ordovician life

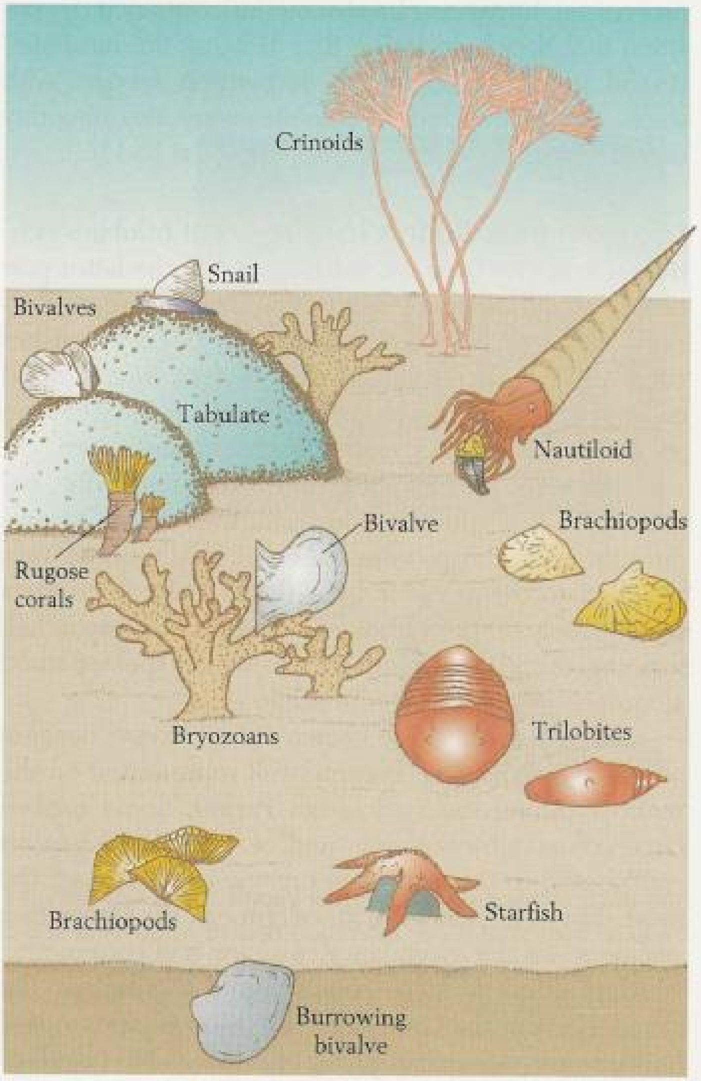
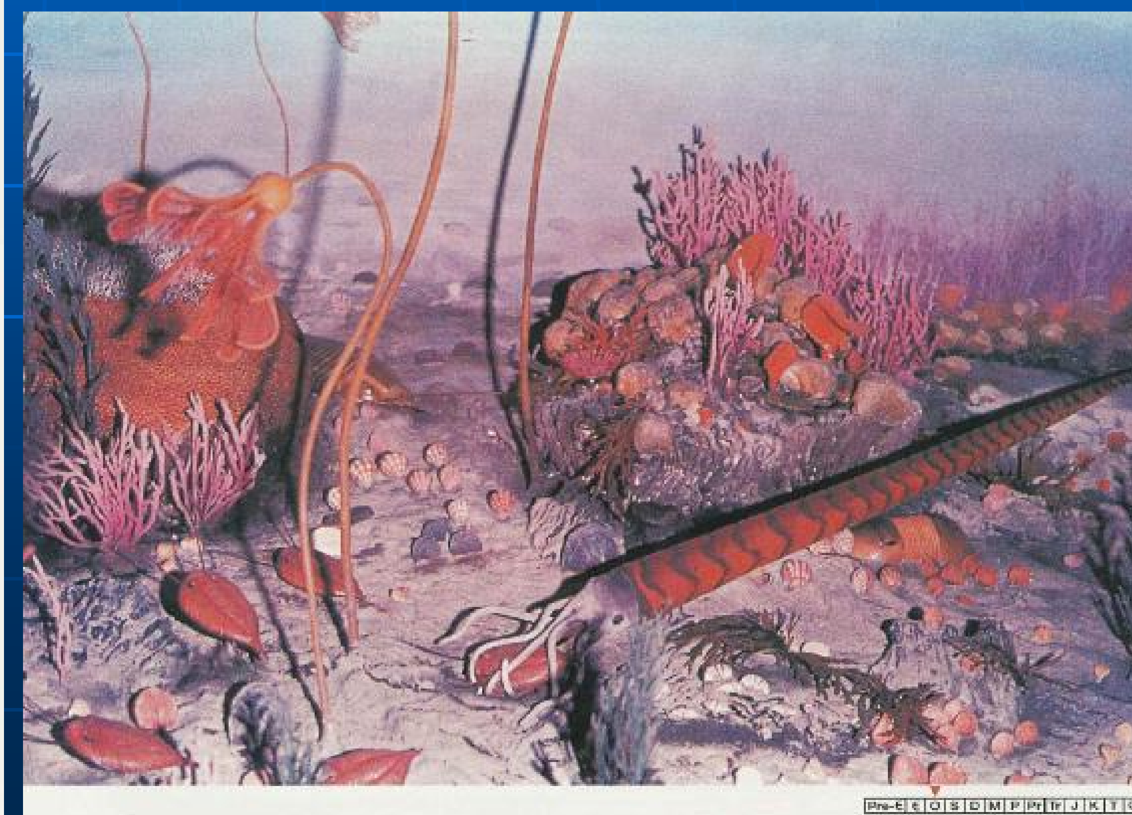
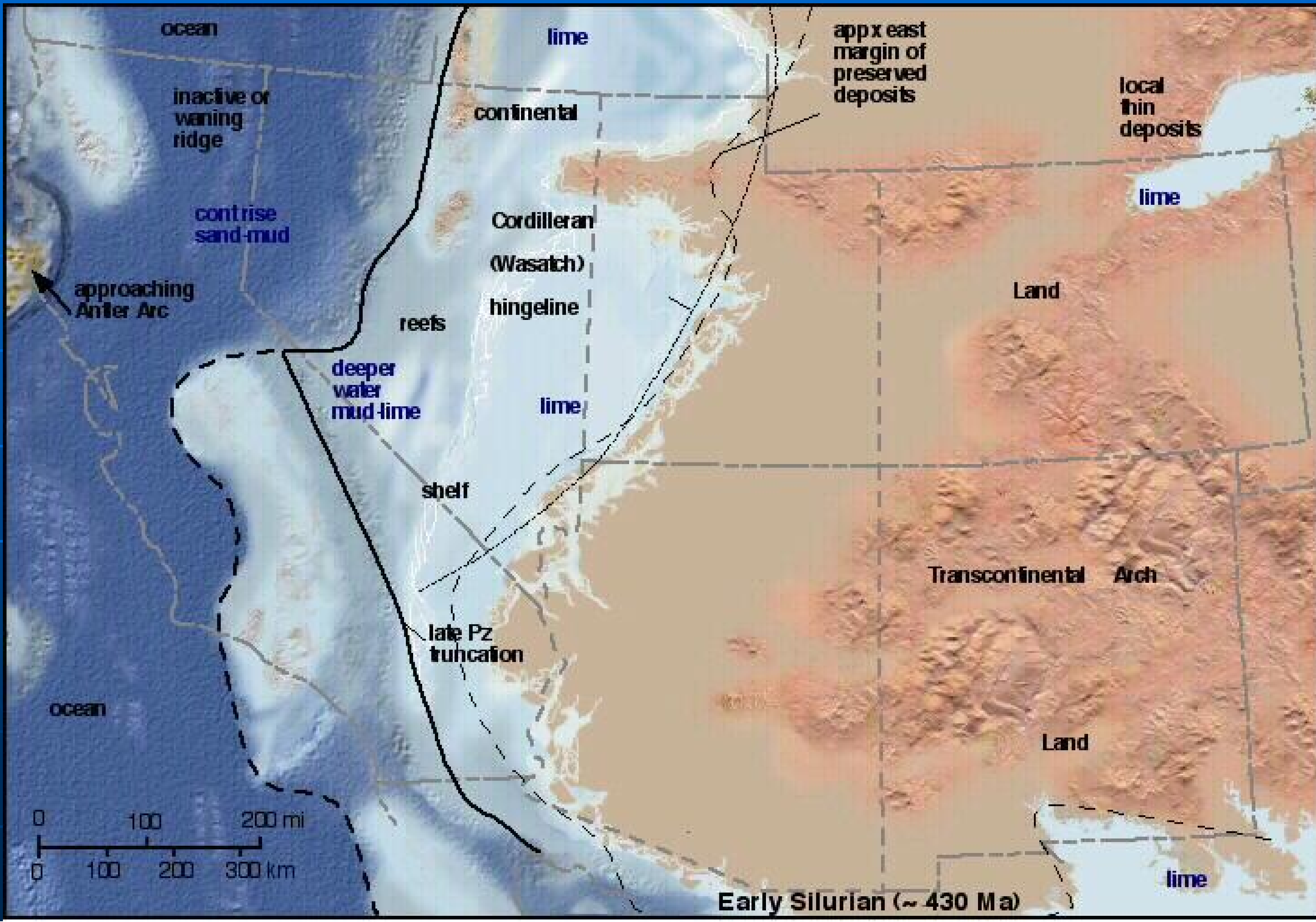


Figure 13-11
Ordovician invertebrate fossils. *A.* A straight-shelled nautiloid about 15 centimeters (6 inches) long. *B.* A spiny trilobite that lived on the sediment surface. *C.* A smooth-shelled burrowing trilobite. *D.* A snail (gastropod). *E* and *F.* Two kinds of articulate brachiopods. *G.* 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

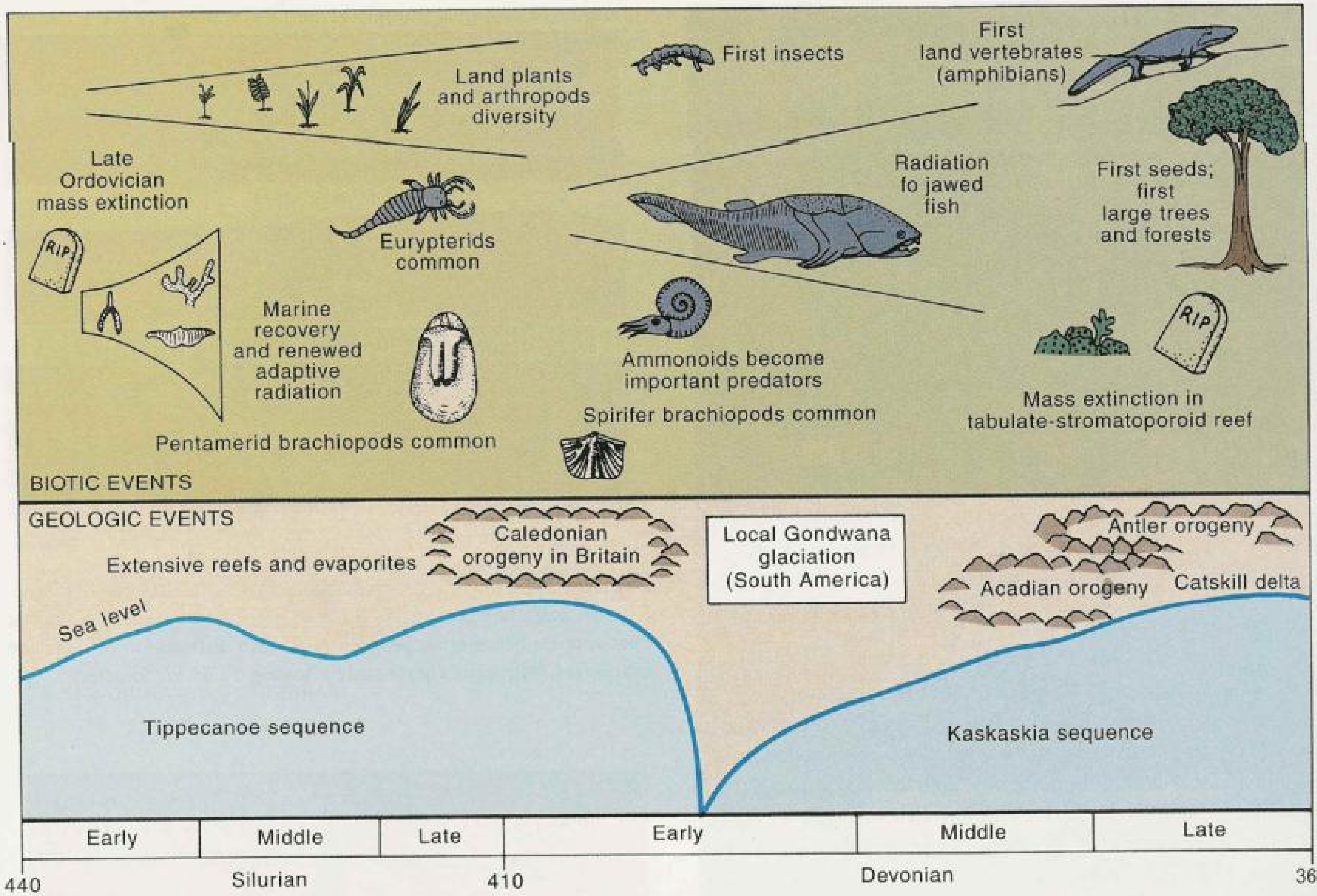
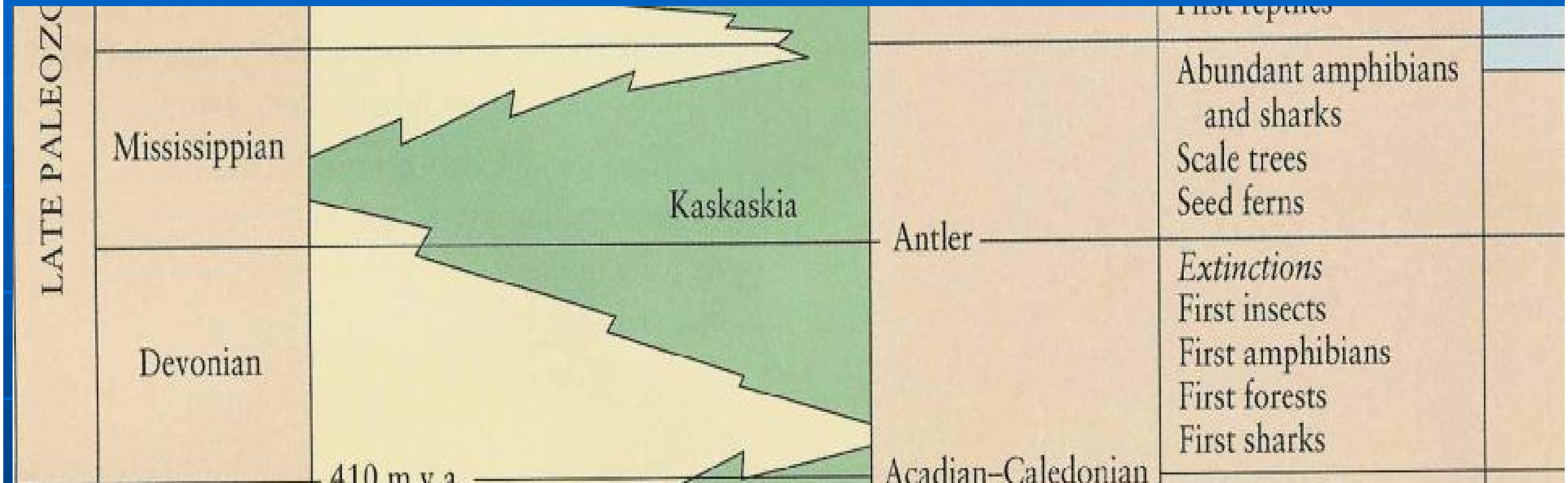
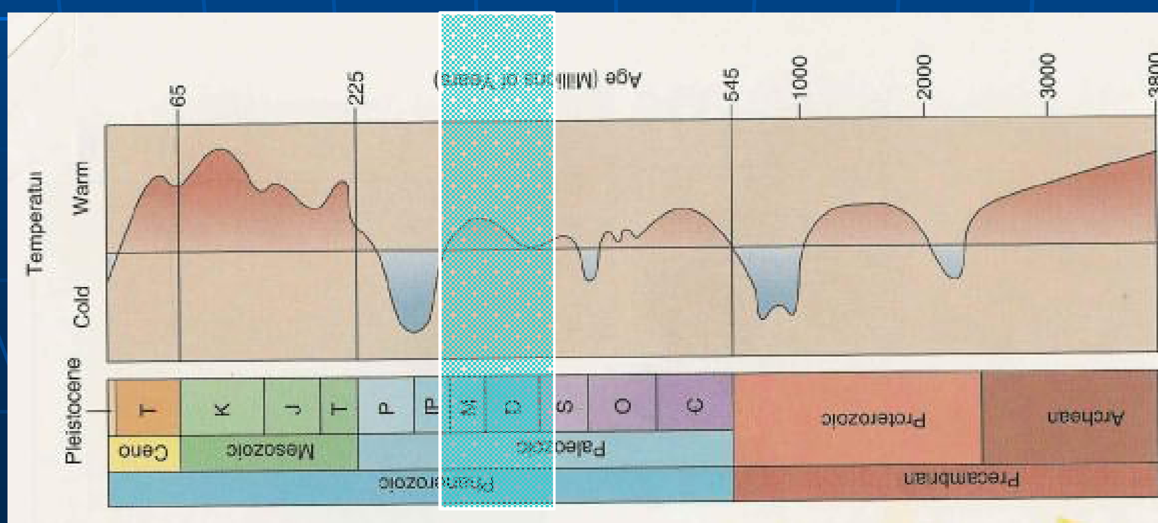


Figure 12.50 Summary time line of events of the Silurian and Devonian.

Devonian – Mississippian
416-359 – 318 Ma





Devonian environments

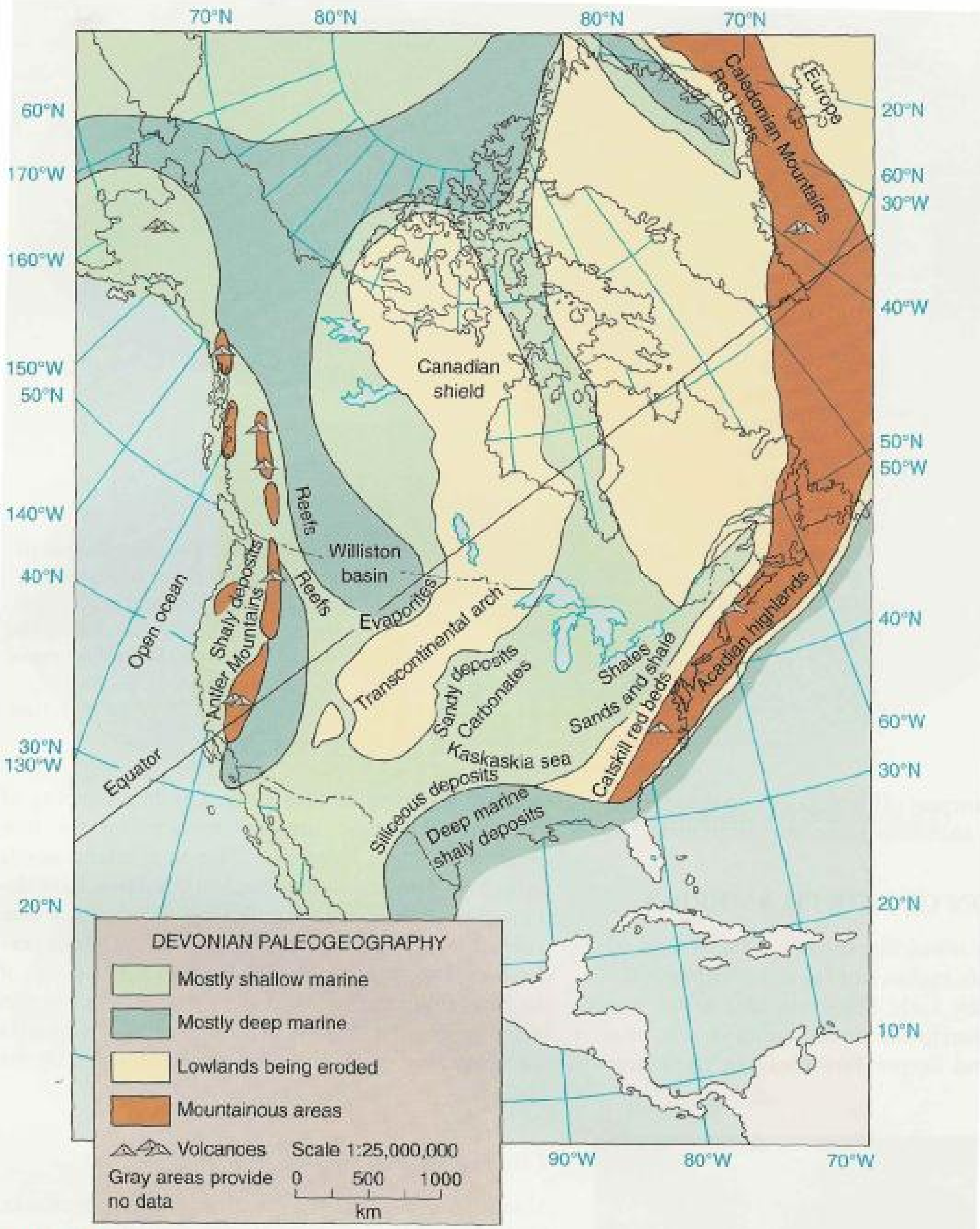
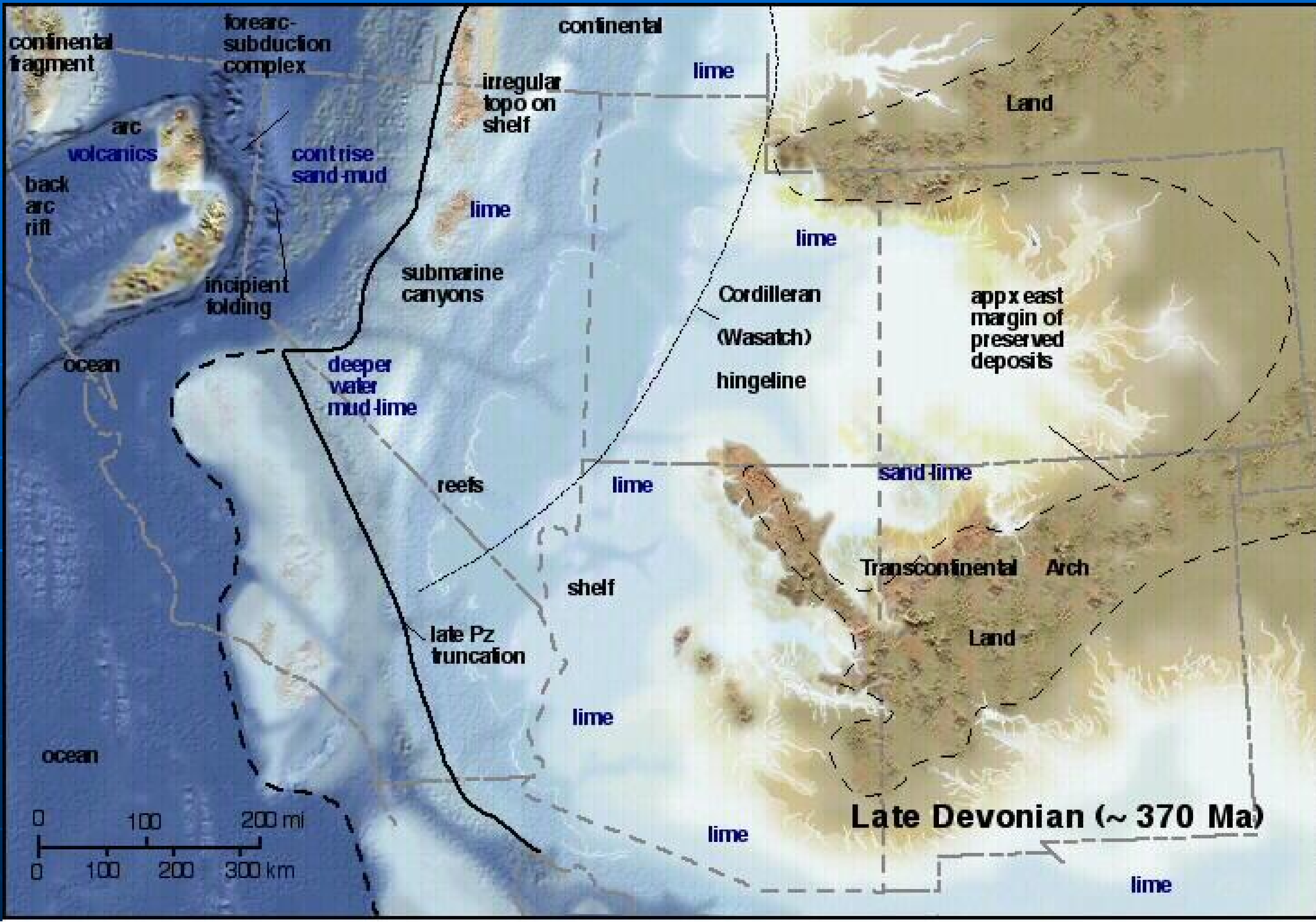


FIGURE 9-4 Paleography of North America during the Devonian Period.

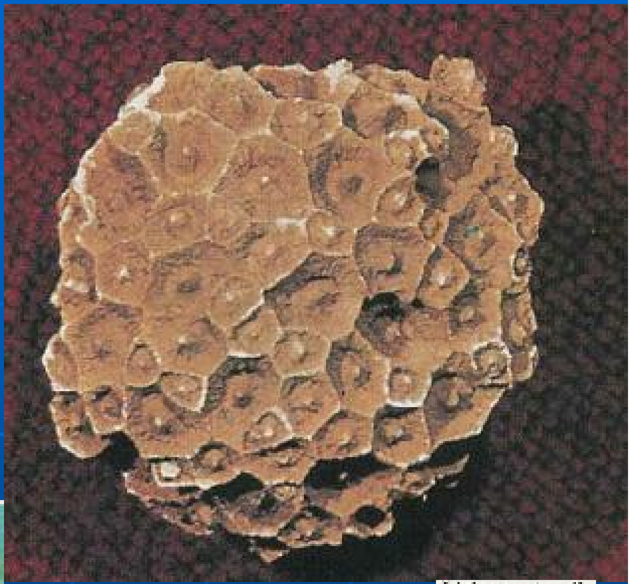
Devonian (416-359 Ma)



Devonian fossils

Mucrospirifer

e solitary horn coral *Zaphrenthis* v



Lithostrotionella.

Hexagonaria.

Platyrachella (

Devonian armored fish

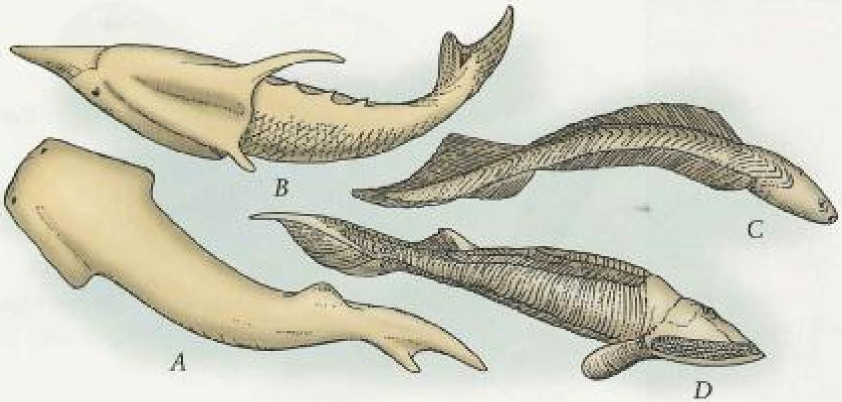


FIGURE 10-60 **Early Paleozoic ostracoderms.** (*A*) *Thelodus*, (*B*) *Pteraspis*, (*C*) *Jamoytius*, and (*D*) *Hemicyclaspis*, drawn to the same scale.

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.*)

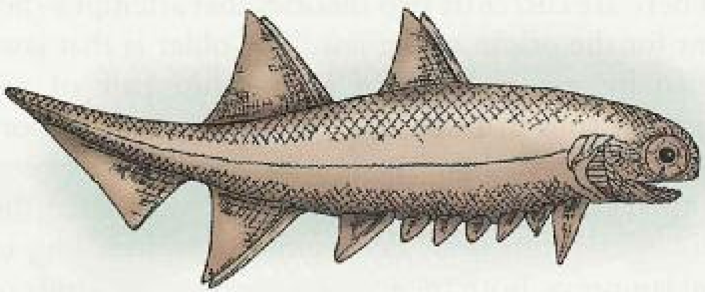


FIGURE 10-61 **The Early Devonian acanthodian fish *Climatius*.** (*After Romer, A. S. 1945.* Vertebrate Paleontology. *Chicago: University of Chicago Press.*)

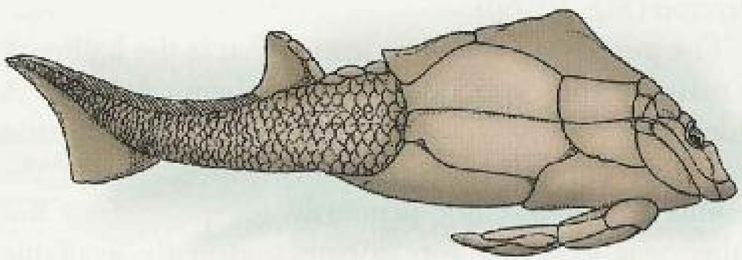


FIGURE 10-63 **The Devonian antiarch fish *Pterichthyodes*.** (*From Romer, A. S. 1945.* Vertebrate Paleontology. *Chicago: University of Chicago Press, p. 54, fig. 38.*)

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 environments

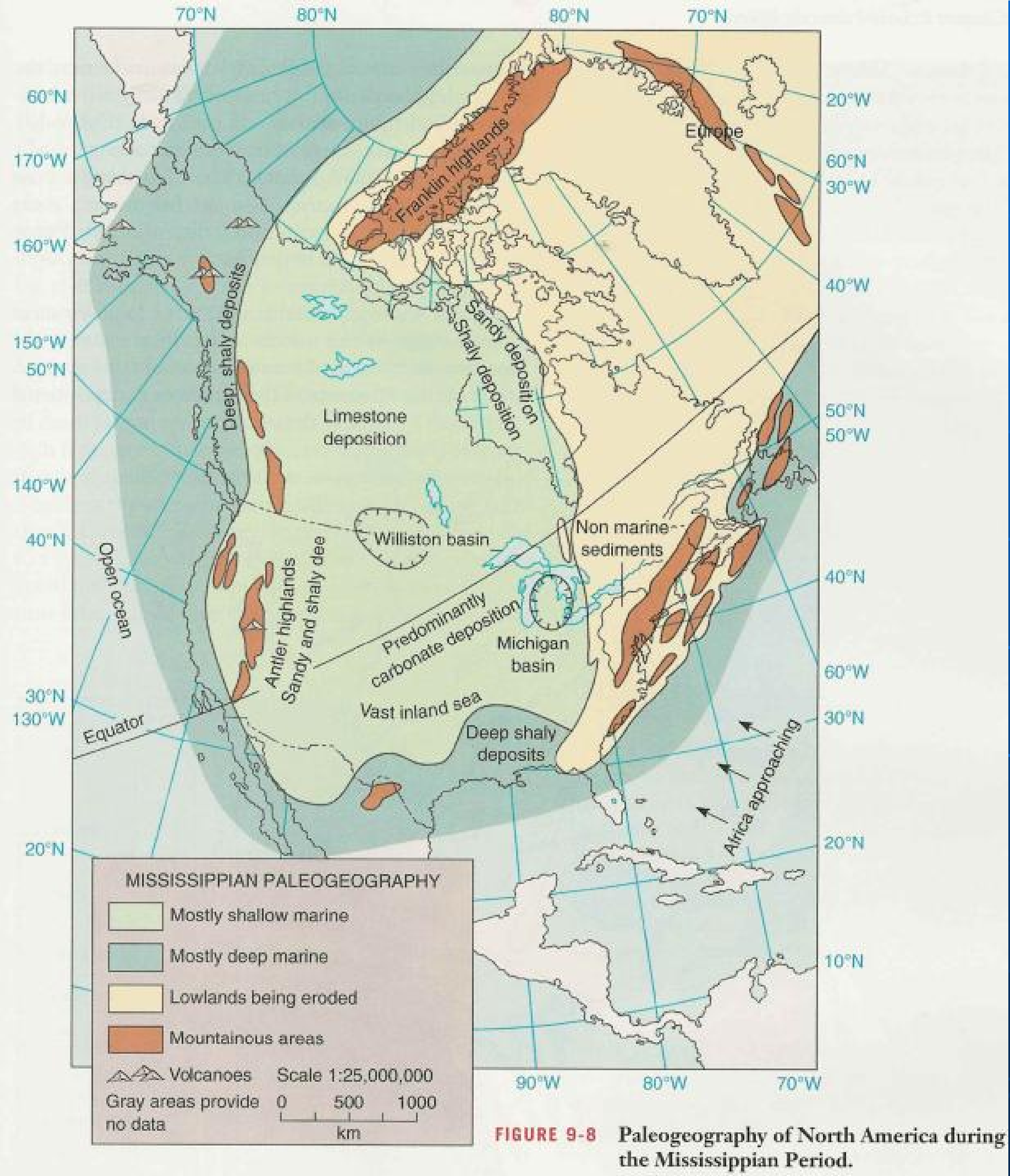
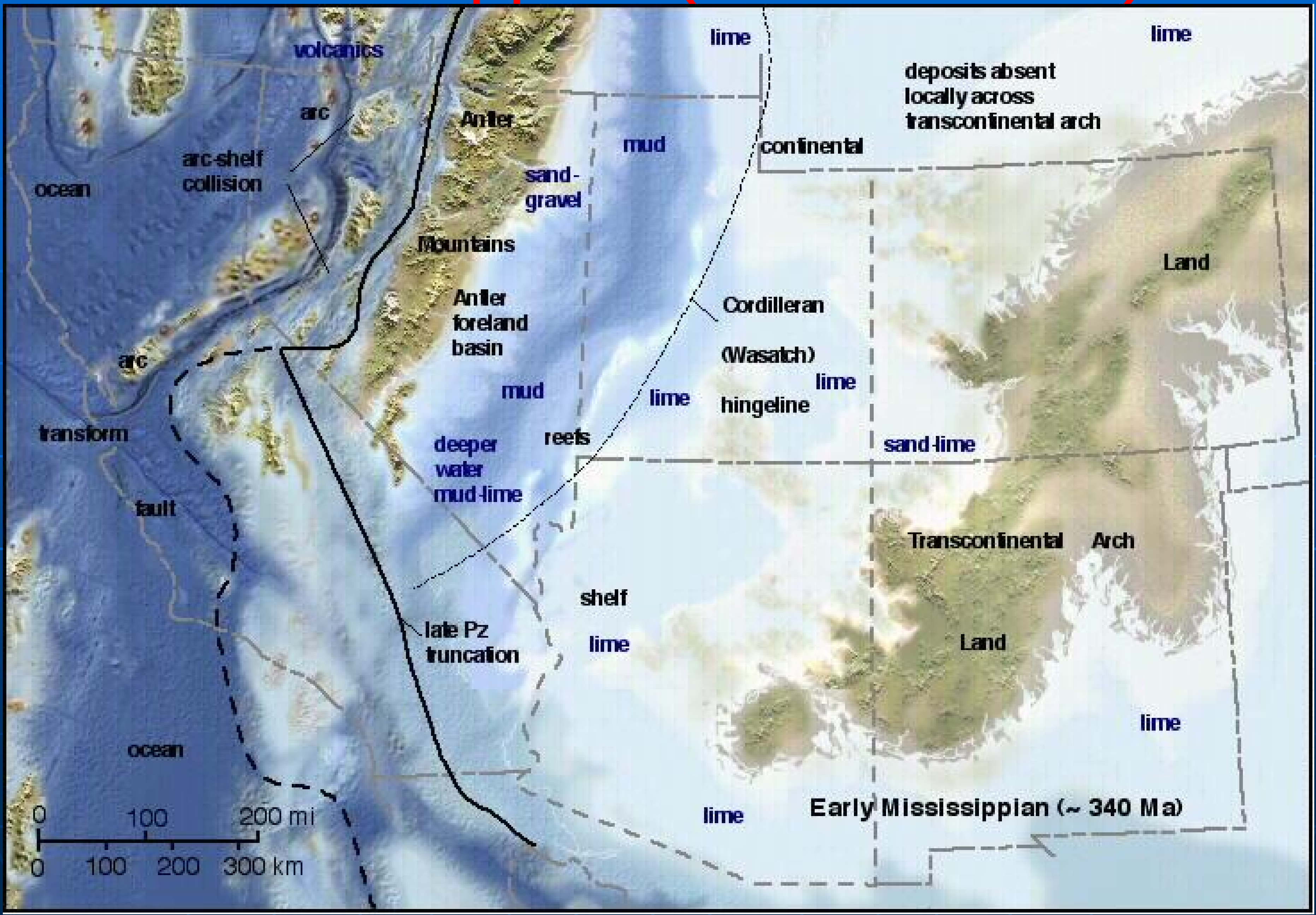
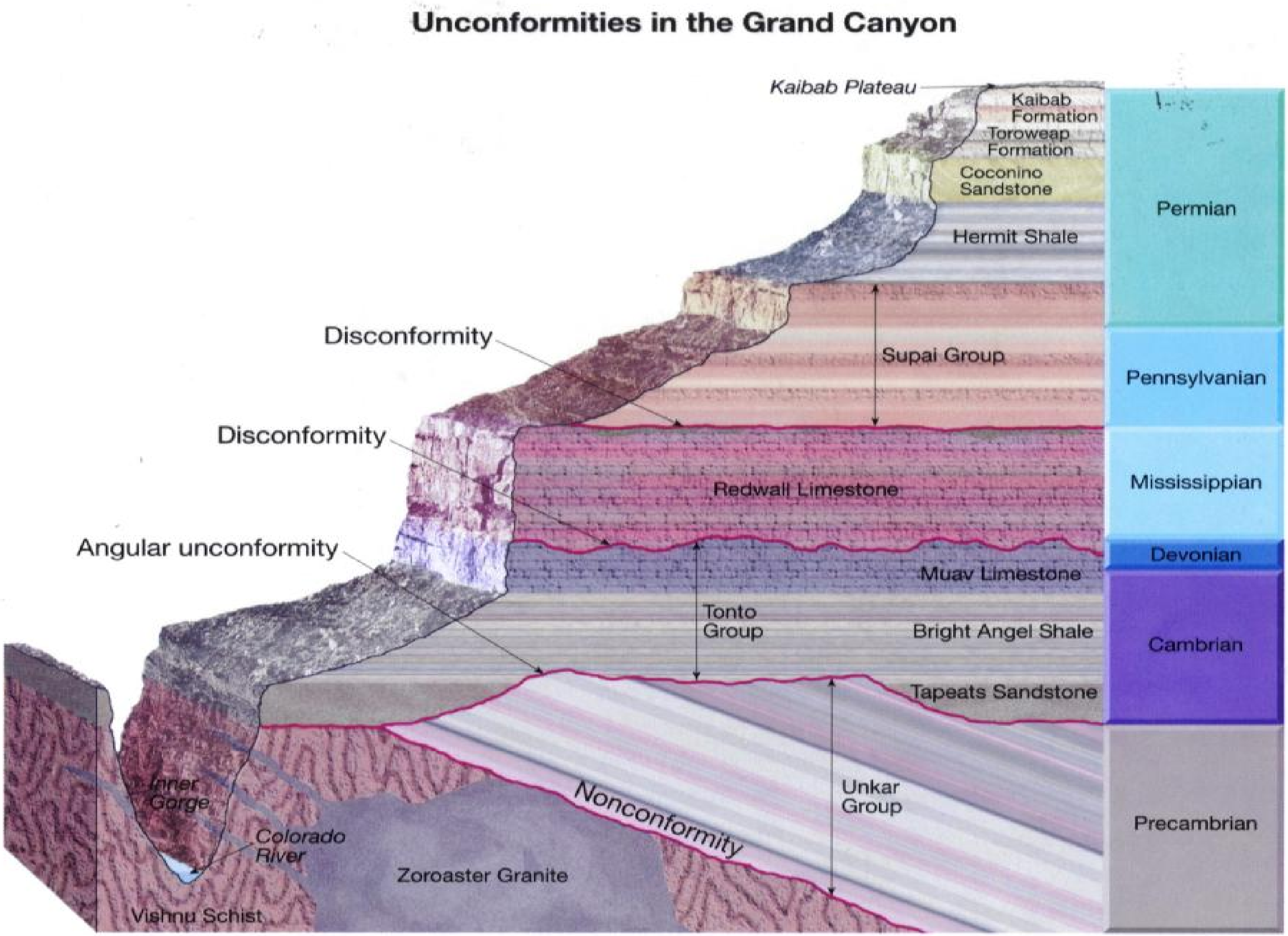


FIGURE 9-8 Paleogeography of North America during the Mississippian Period.

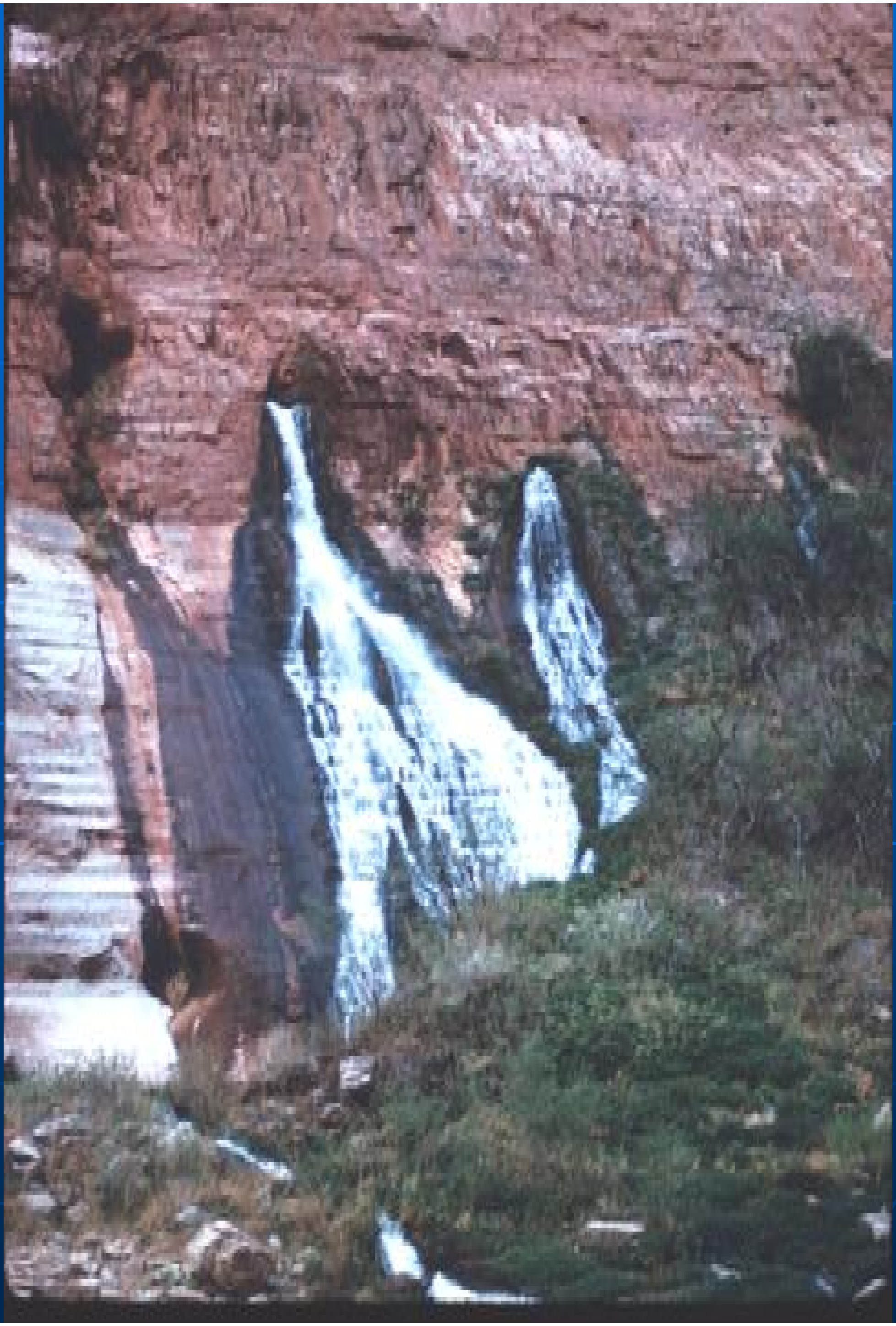
Mississippian (359-318 Ma)



Grand Canyon section



Redwall Limestone



Escabrosa Limestone

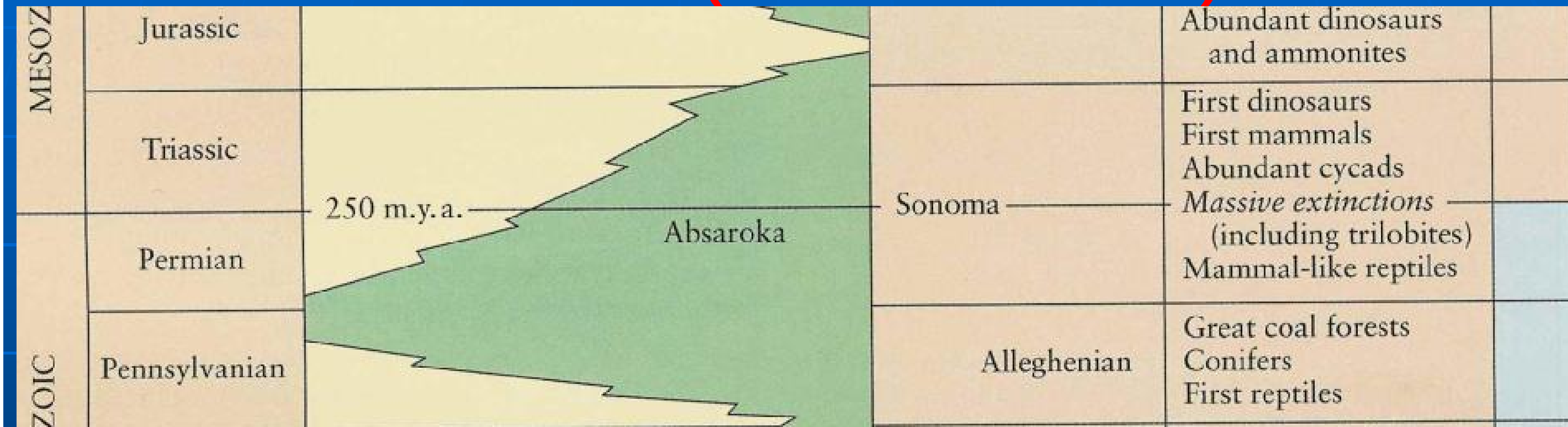
Crinoids

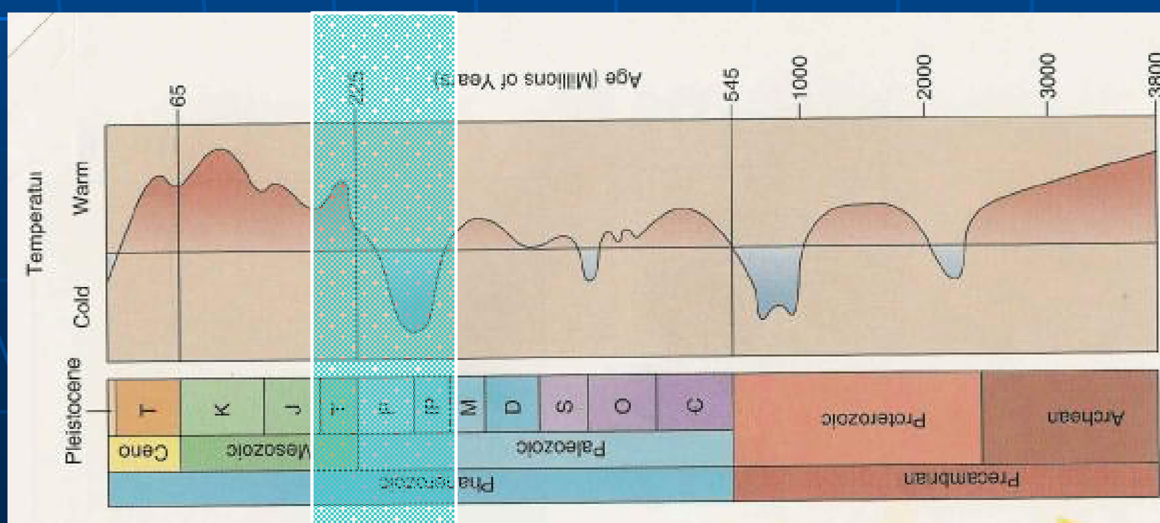
Syringopora - coral

Crinoids

(echinoids related to starfish, but called sea lilies)

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





Pennsylvanian environments

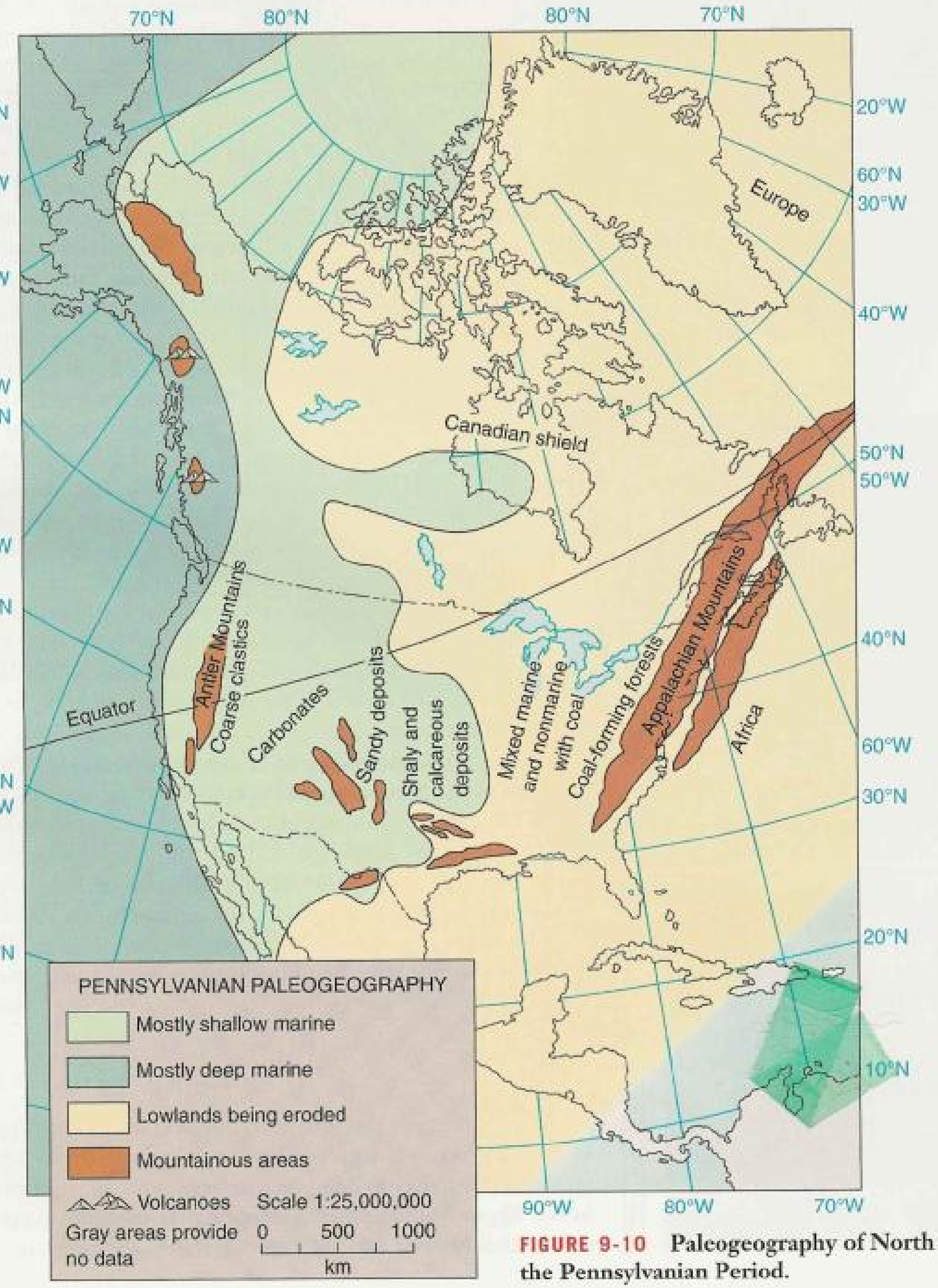
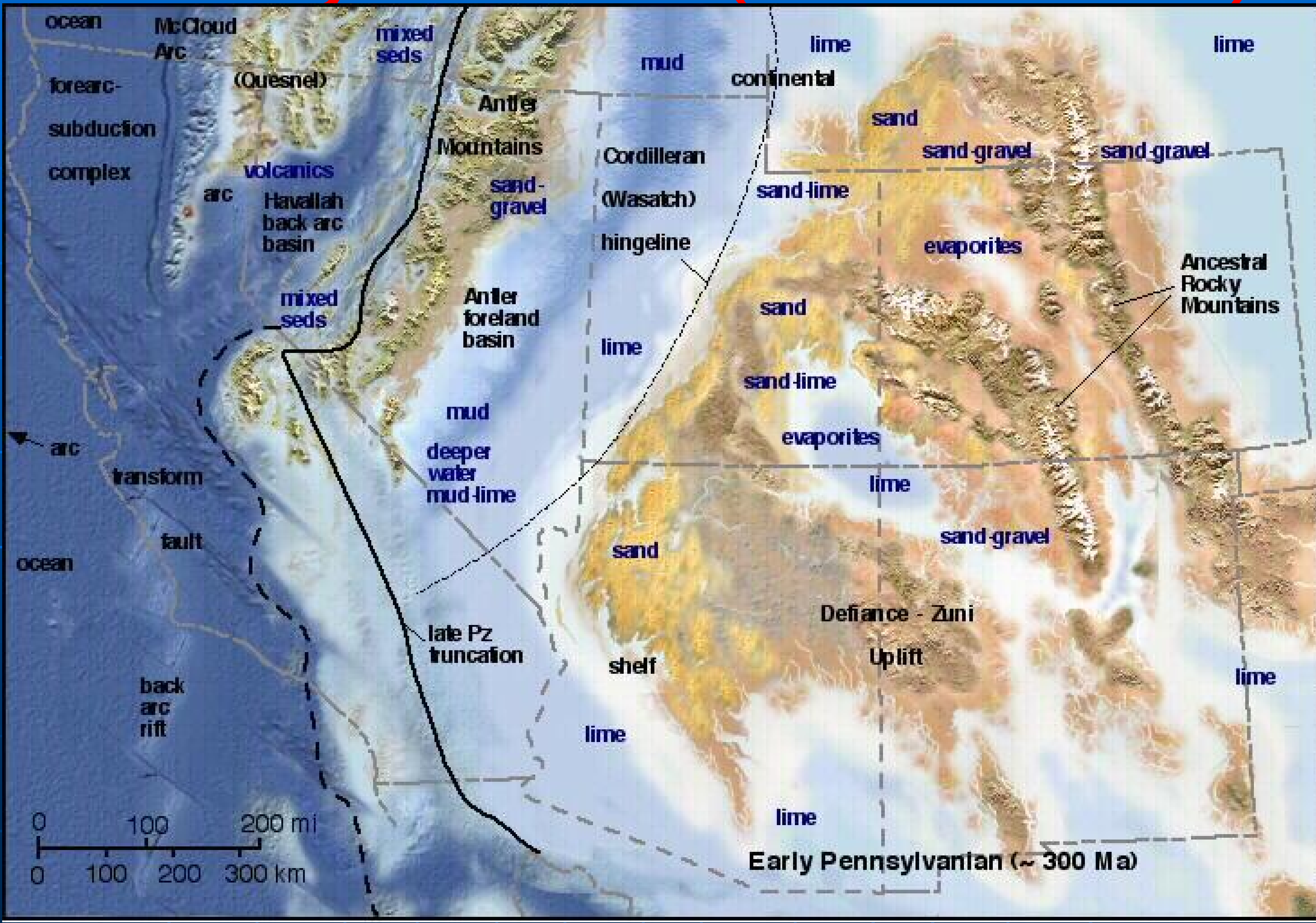


FIGURE 9-10 Paleogeography of North Am
the Pennsylvanian Period.

Pennsylvanian (318-299 Ma)



Amphibian fossils

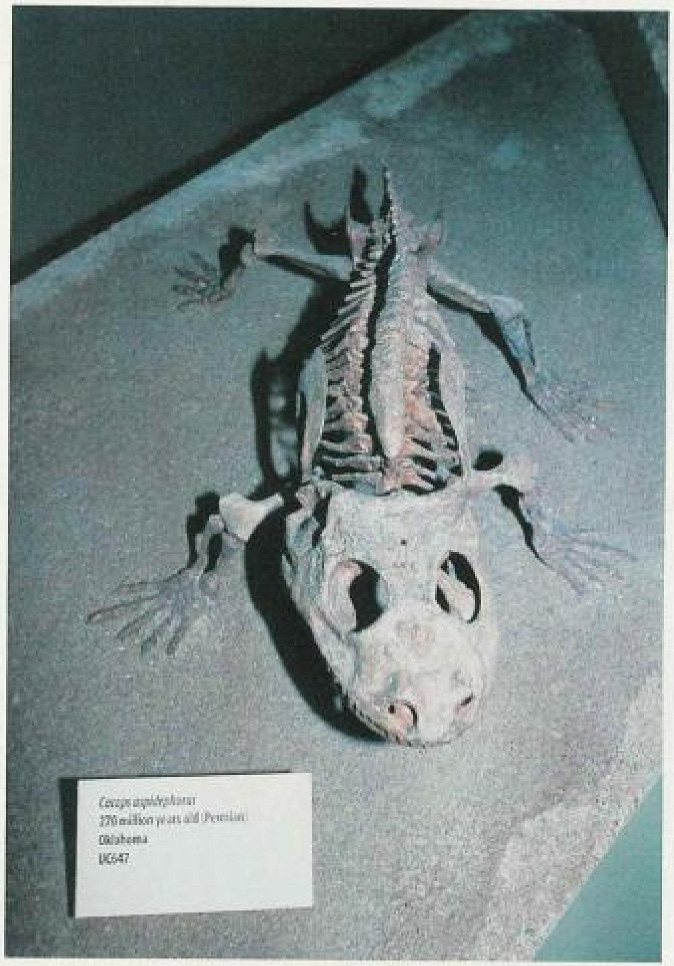


FIGURE 10-77 ***Cacops*, a small labyrinthodontic amphibian from the Lower Permian.** *(Photograph of a specimen on exhibit at the Field Museum in Chicago.)*

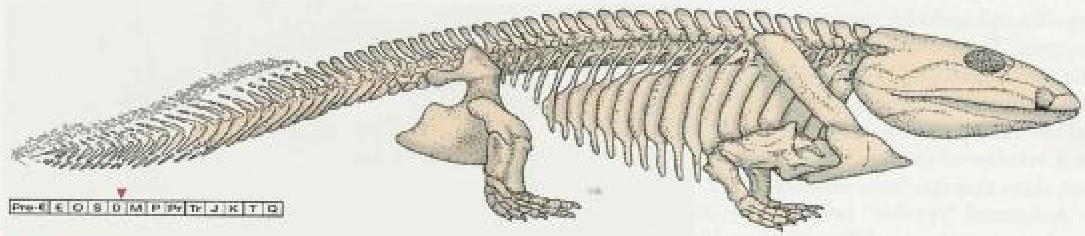


FIGURE 10-76 **The skeleton of *Ichthyostega* still retains the fishlike form of its crossopterygian ancestors.** *(From Levin, H. L. 1975.* Life Through Time. *Dubuque, Iowa: William C. Brown Co.)*

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)

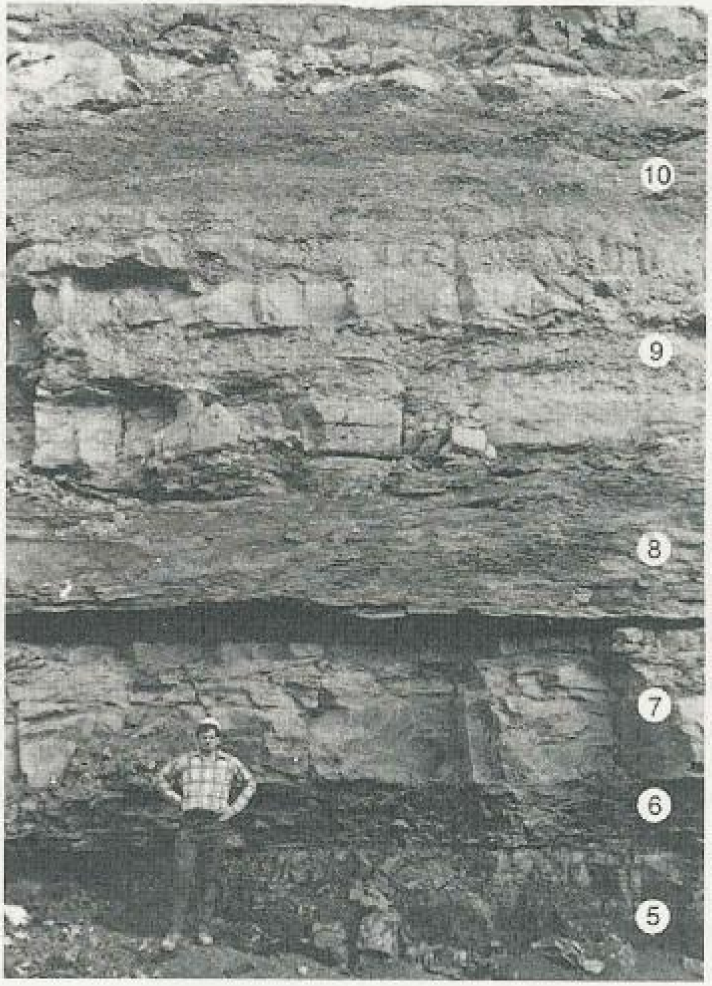


FIGURE 9-12 Part of an Illinois cyclothem. The lowermost layer is the coal seam (cyclothem bed 5), followed upward by shale (bed 6) near the geologist's hand, limestone (bed 7), shale (bed 8), another limestone (bed 9), and the upper shale (bed 10). Part of another sequence caps the exposure. This cyclothem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

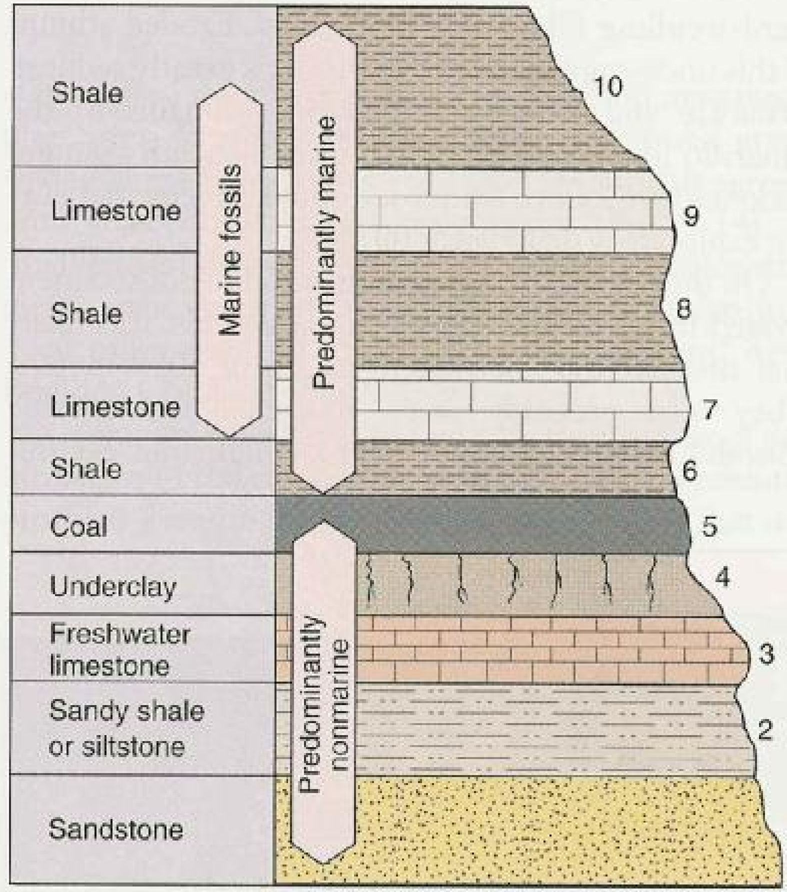


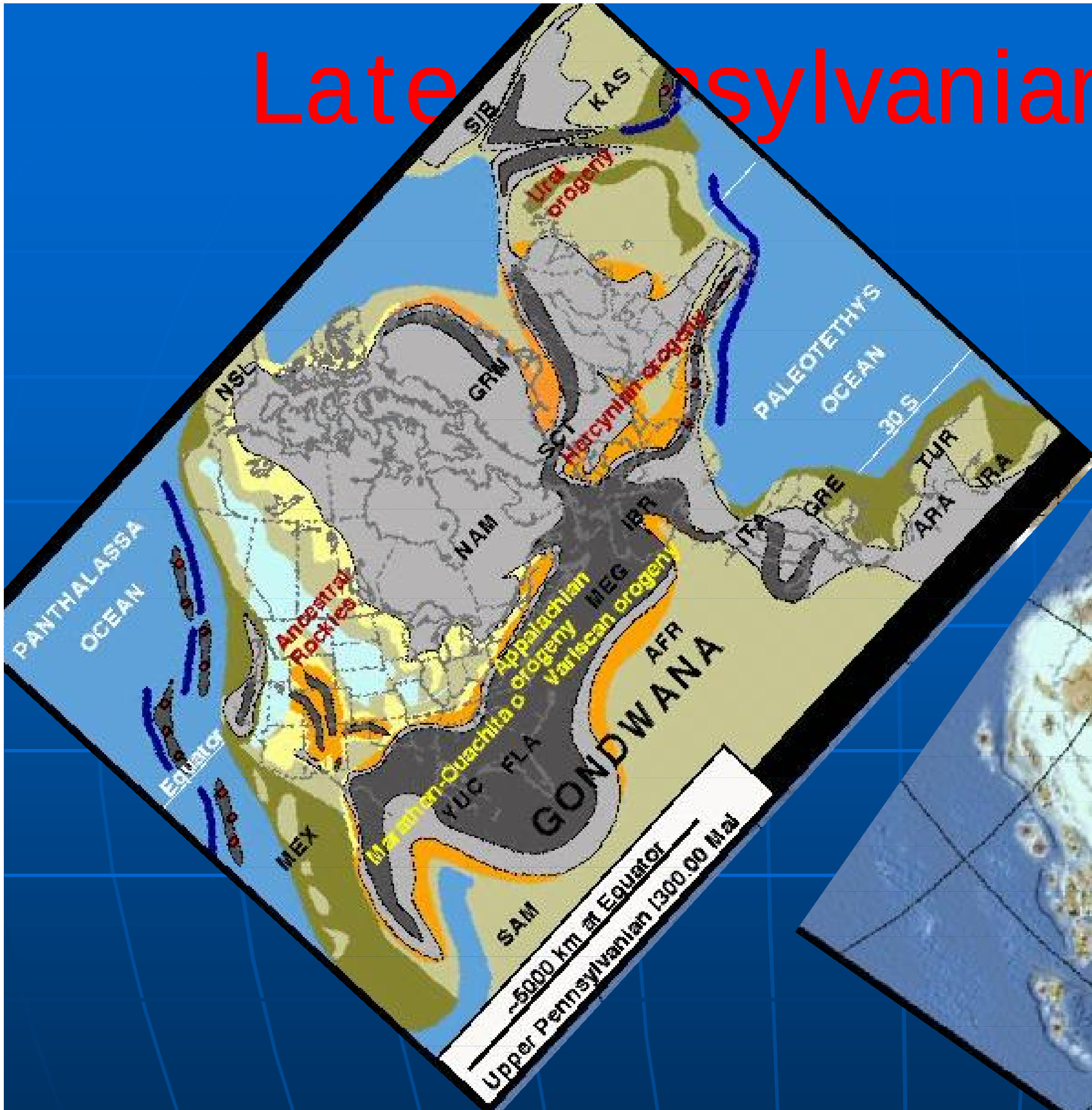
FIGURE 9-11 An ideal coal-bearing cyclothem, showing the typical sequence of layers. Many cyclothems do not contain all 10 units, as in this illustration of an idealized sequence. Some units may not have been deposited because changes from marine to nonmarine conditions may have been abrupt and/or units 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

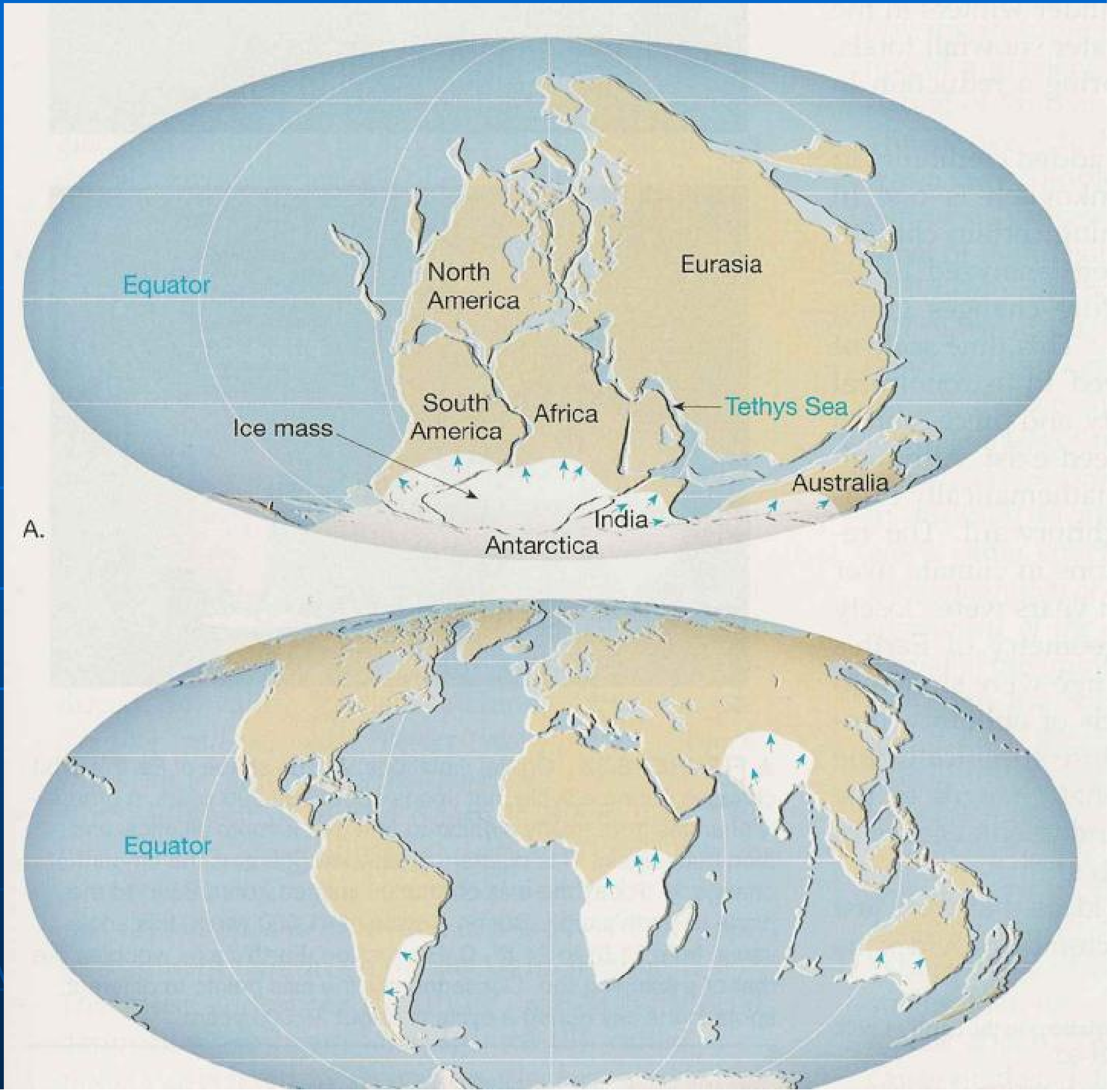
Earp Formation,
Government Draw SE of Tombstone

Late nsylvanian (300 Ma)



Permian Supai Group, Sedona

Permian Ice Age



Permian environments

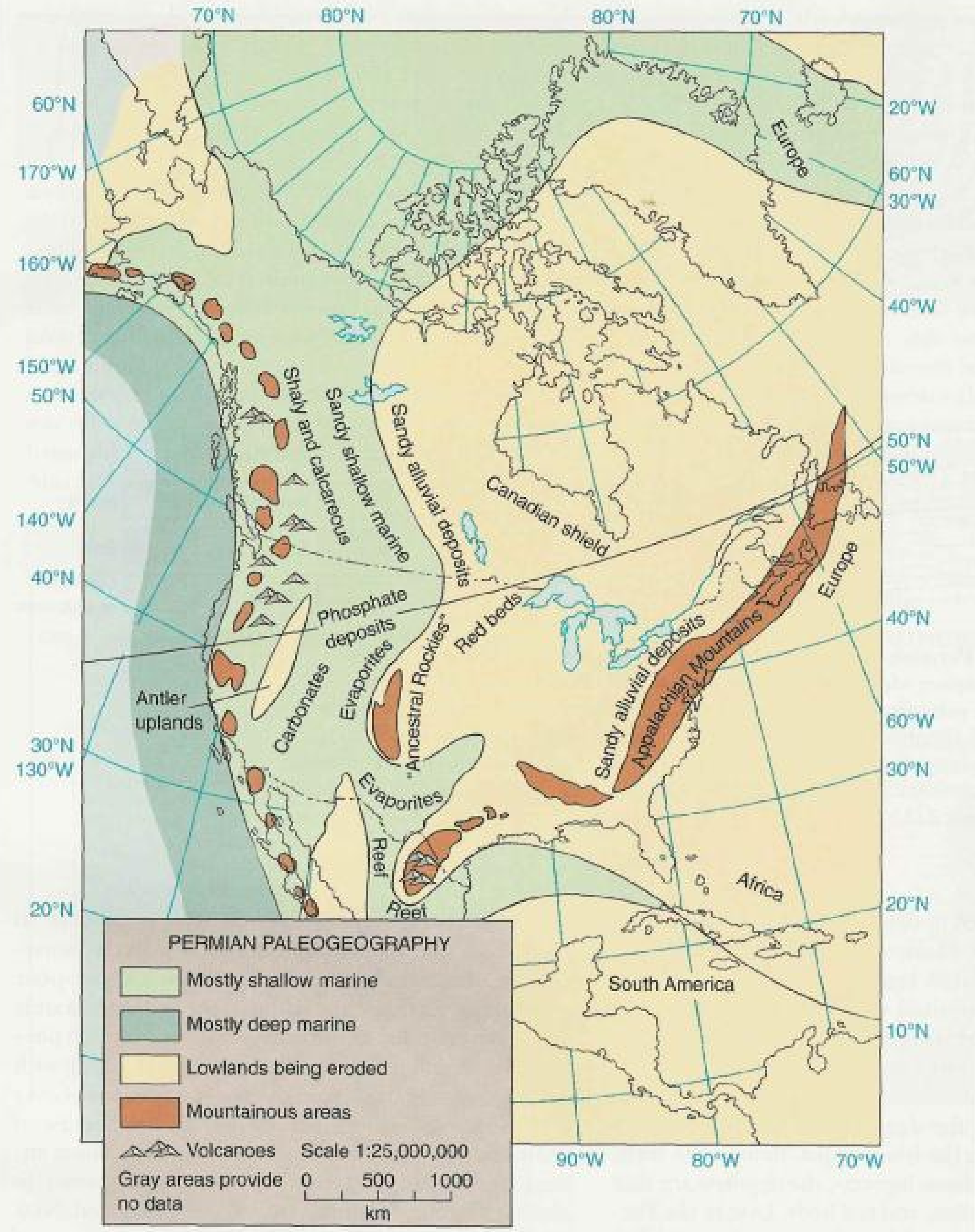
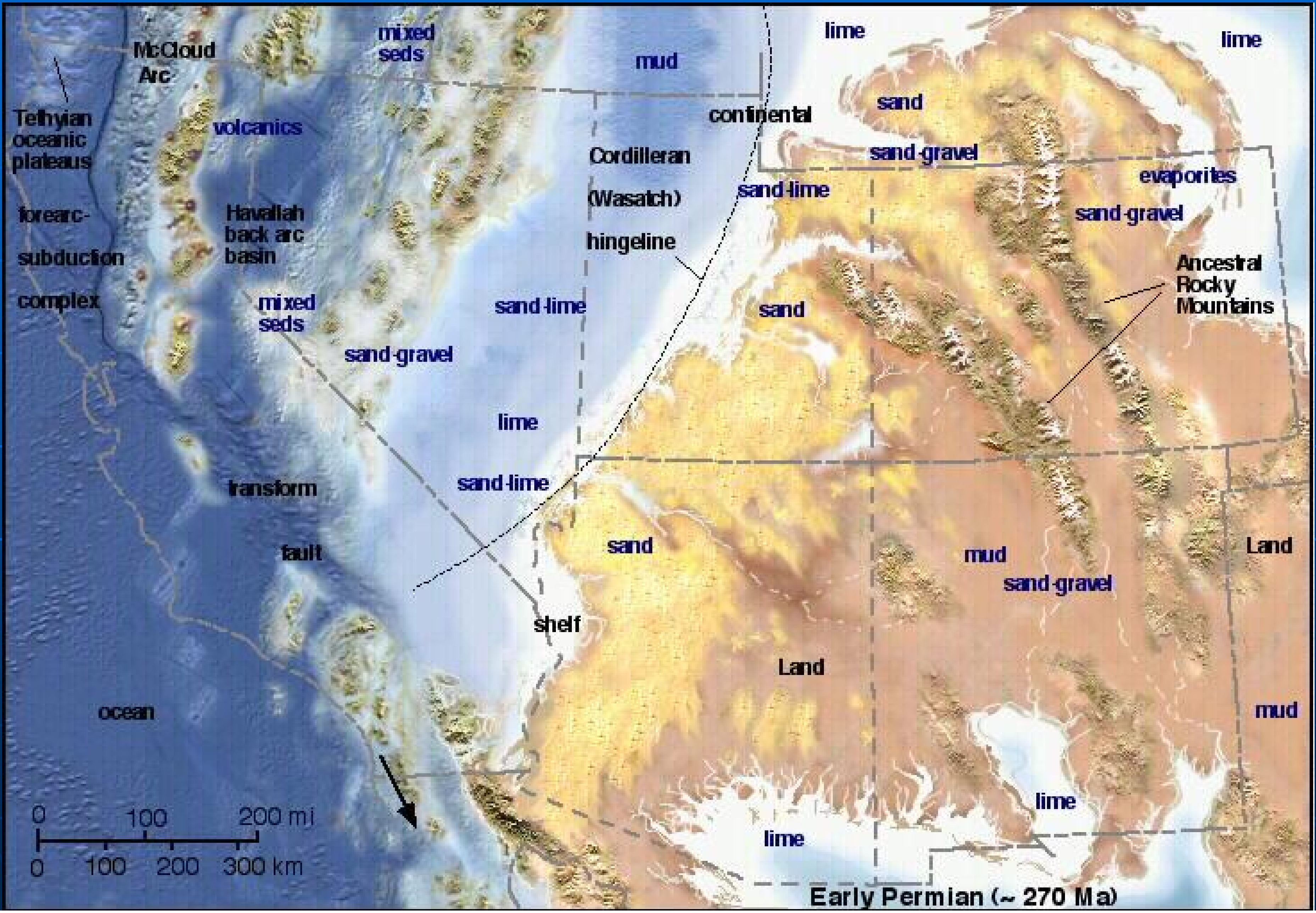
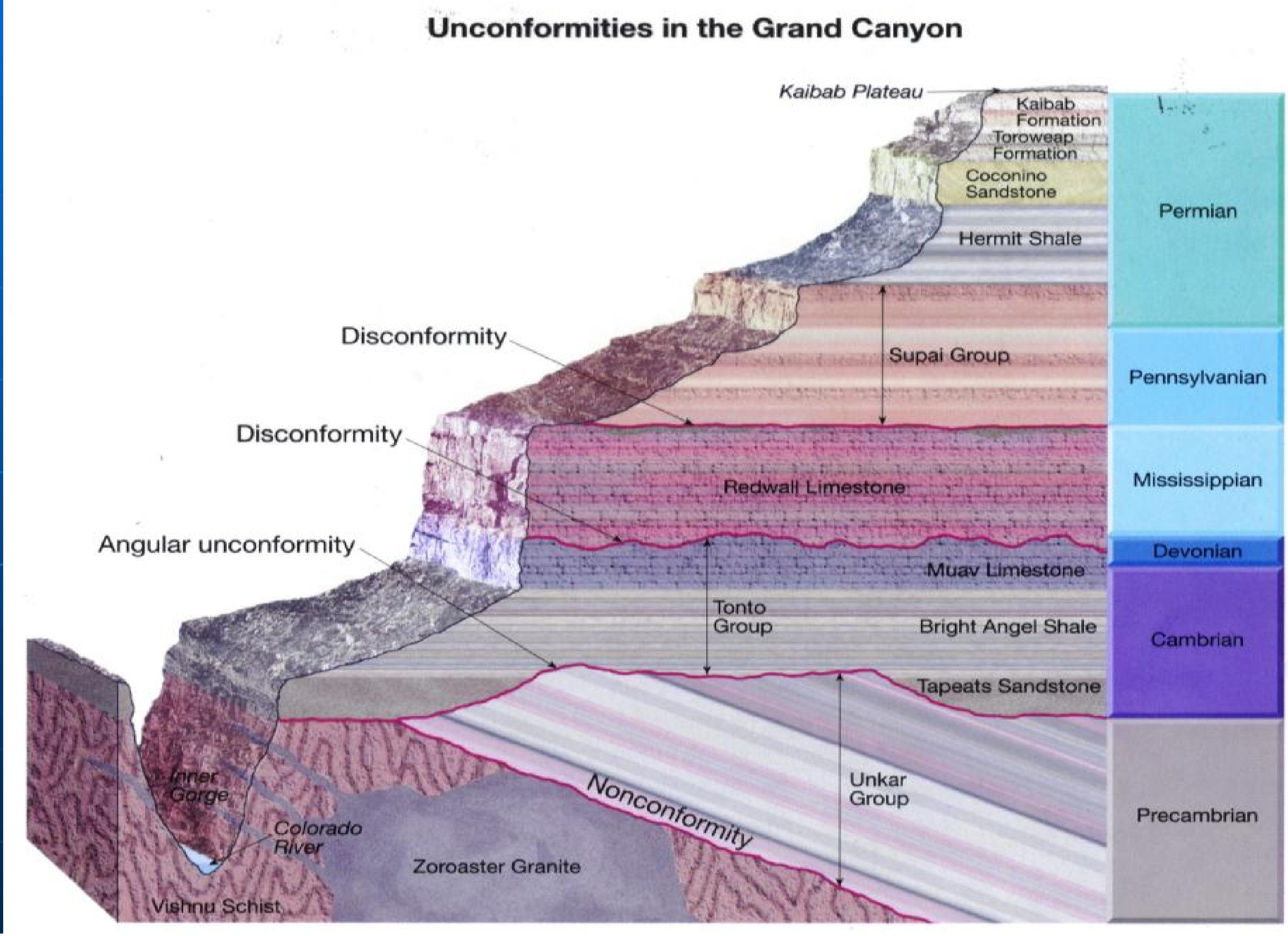


FIGURE 9-18 Generalized paleogeographic map for the Permian Period.

Permian (290-248 Ma)



Grand Canyon section



Grand Canyon

Mammal-like Reptiles

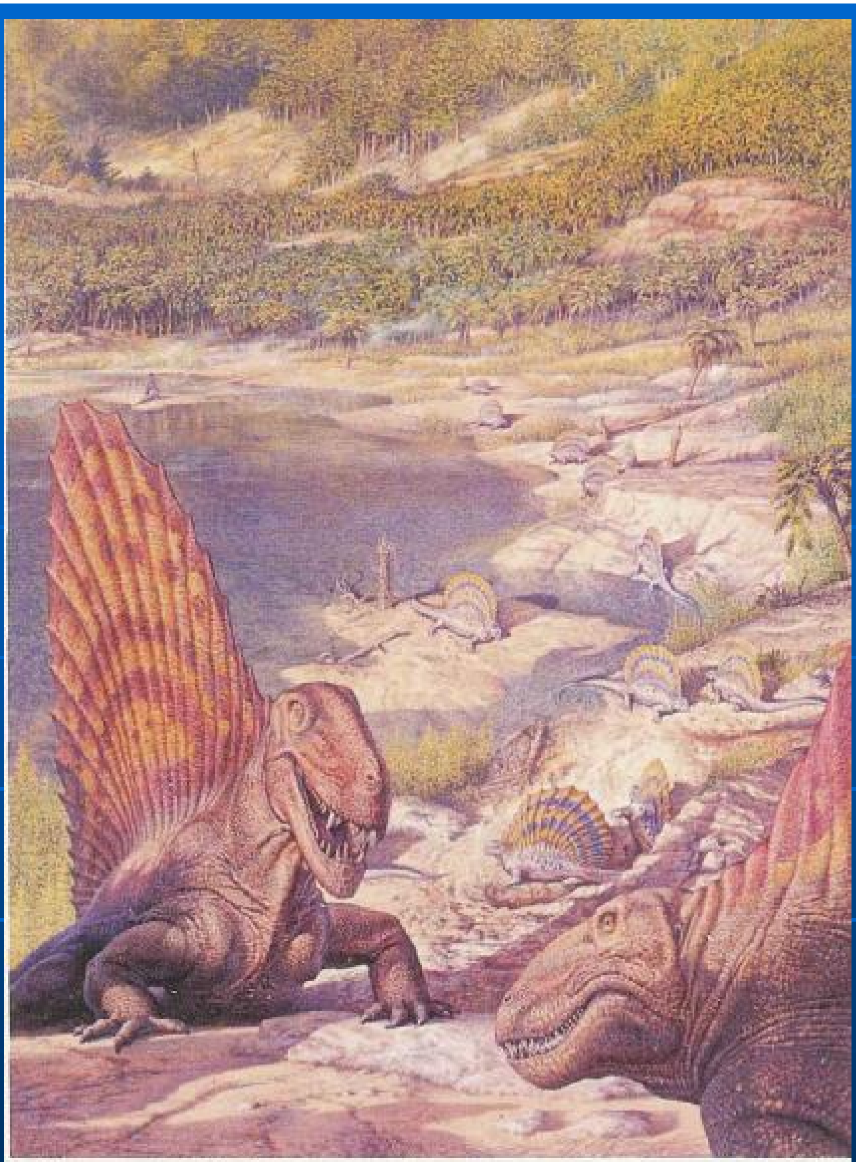


FIGURE 10-78 **Permian reptiles.** The prominent sailback reptile in the left foreground, with a larger skull and daggerlike teeth, is the carnivore *Dimetrodon*. The sailbacks with smaller heads and blunt cheek teeth, in the foreground at right and in the distance, are plant-eaters of the genus *Edaphosaurus*.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

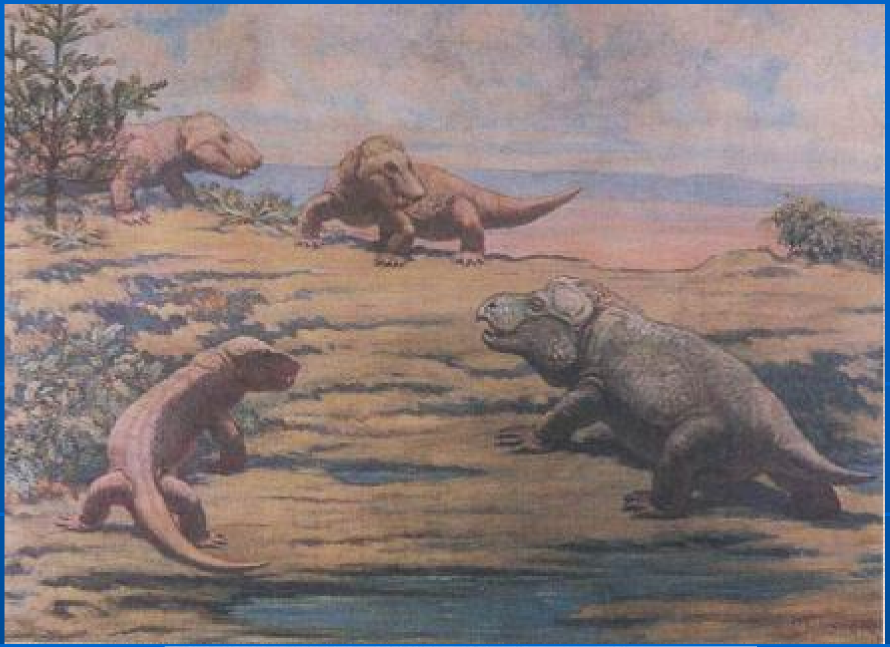
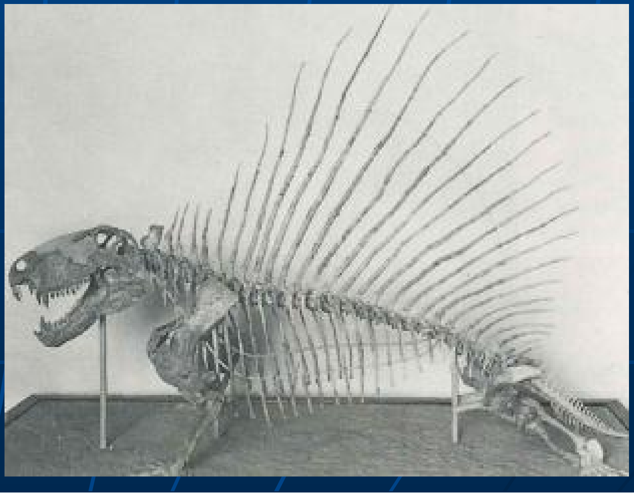


FIGURE 10-80 **Mammal-like reptiles.** The scene depicts three carnivorous forms (*Cynognathus*) about to attack a plant-eating therapsid reptile (*Kannemeyeria*). (*Courtesy of*



Triassic plate tectonics

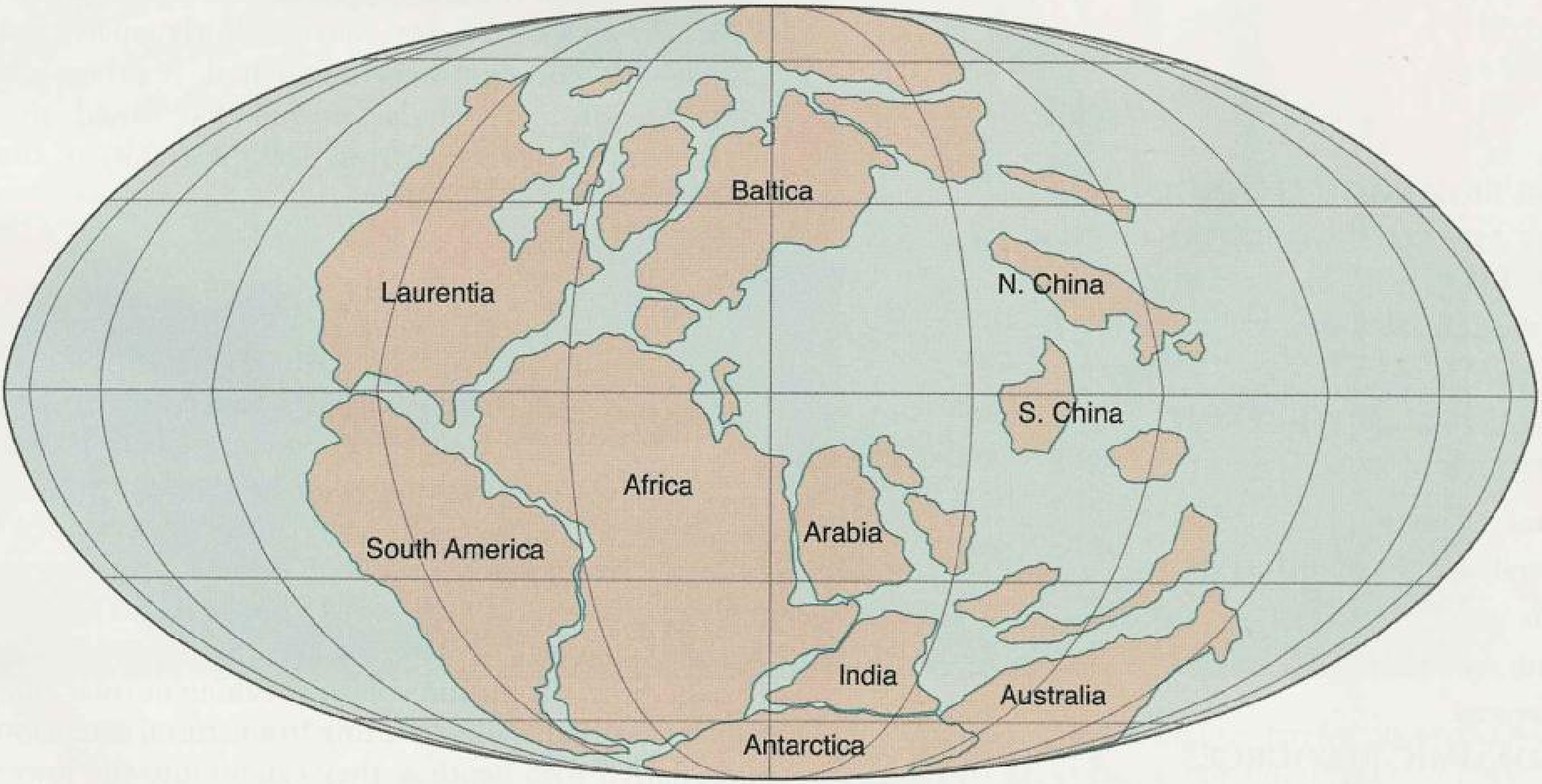


FIGURE 11–1 Paleogeographic reconstruction of the world about 180 million years ago, when the break-up of Pangea was beginning. (After Scotese, C. R. and McKerrow, W. S. 1990. Paleogeography and Biogeography, *Geol. Soc. London Mem. 12:1–21.*)

Triassic paleogeography

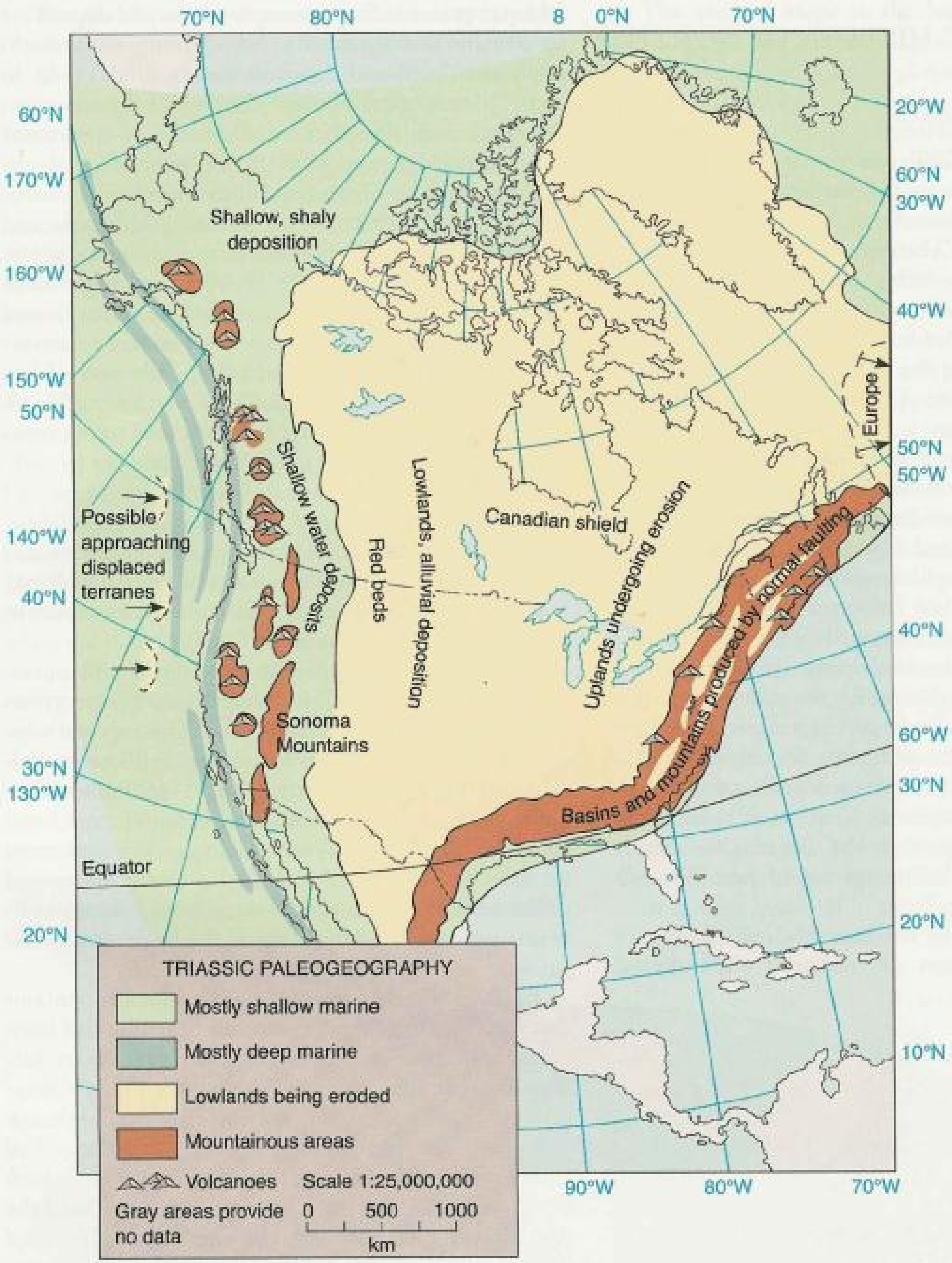
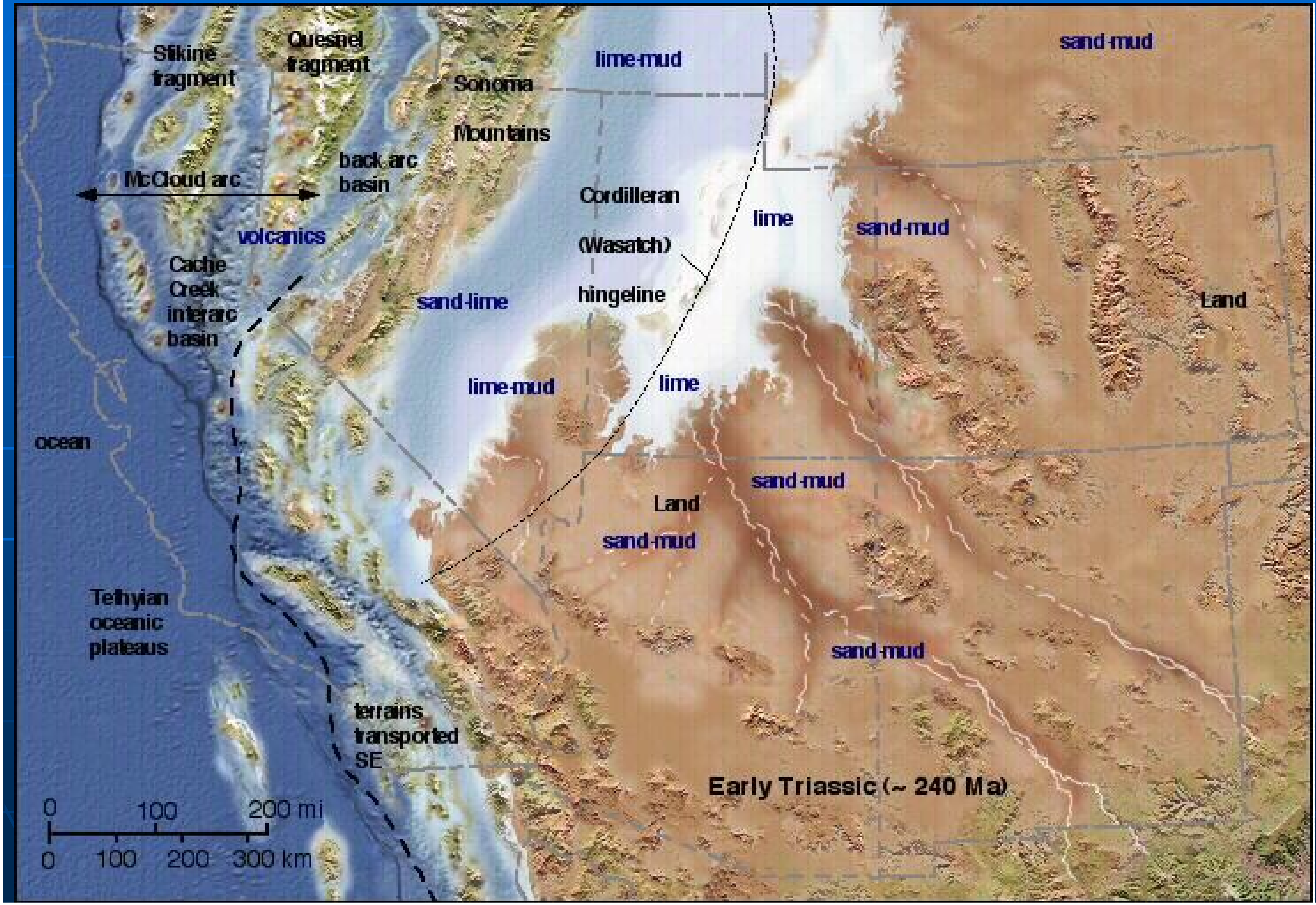


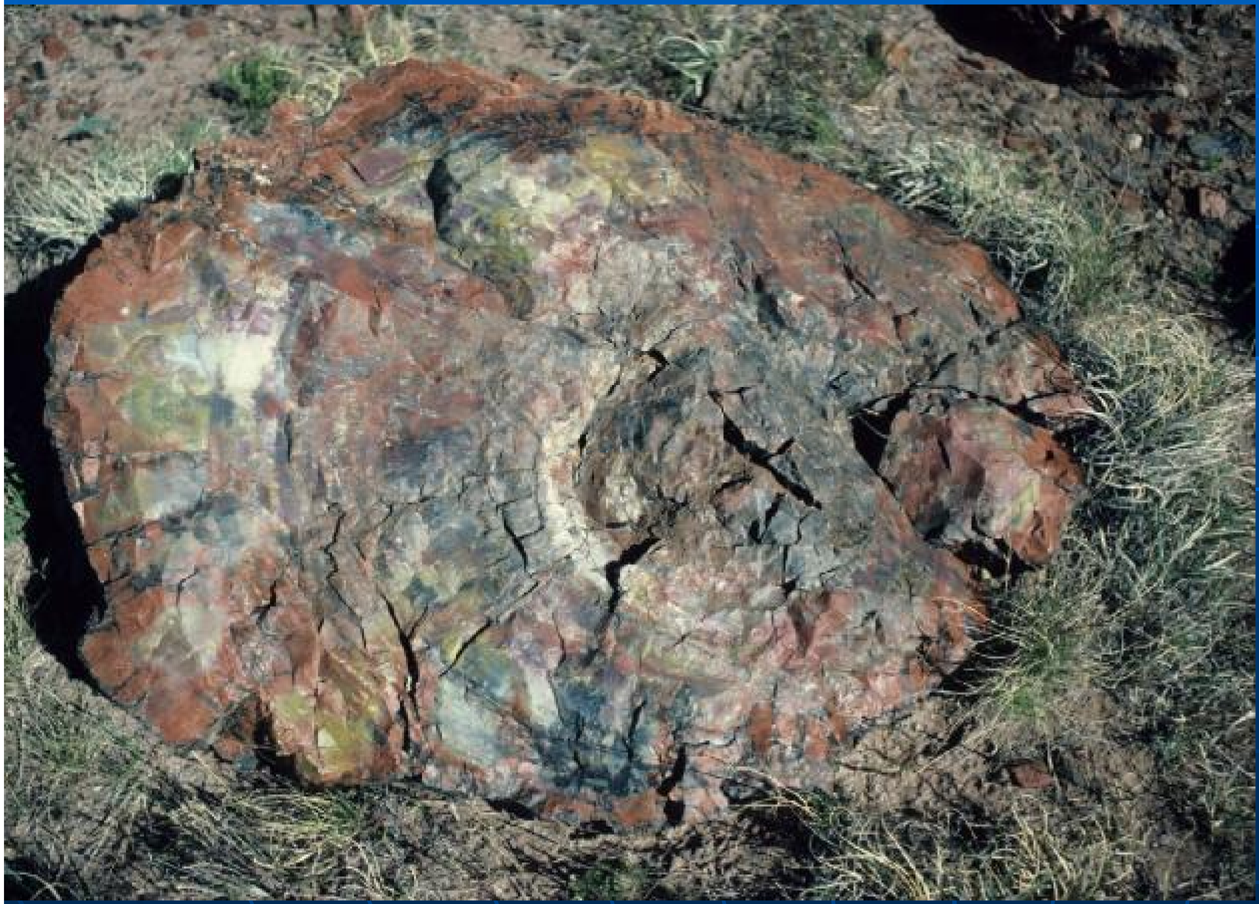
FIGURE 11-3 Generalized paleogeographic map for the Triassic of North America.
What was the cause of the faulting along the eastern margin of the continent?

Triassic (248-206 Ma)



Petrified Forest Fm. – late Triassic

Petrified log, Pet. Forest



Triassic Reptiles

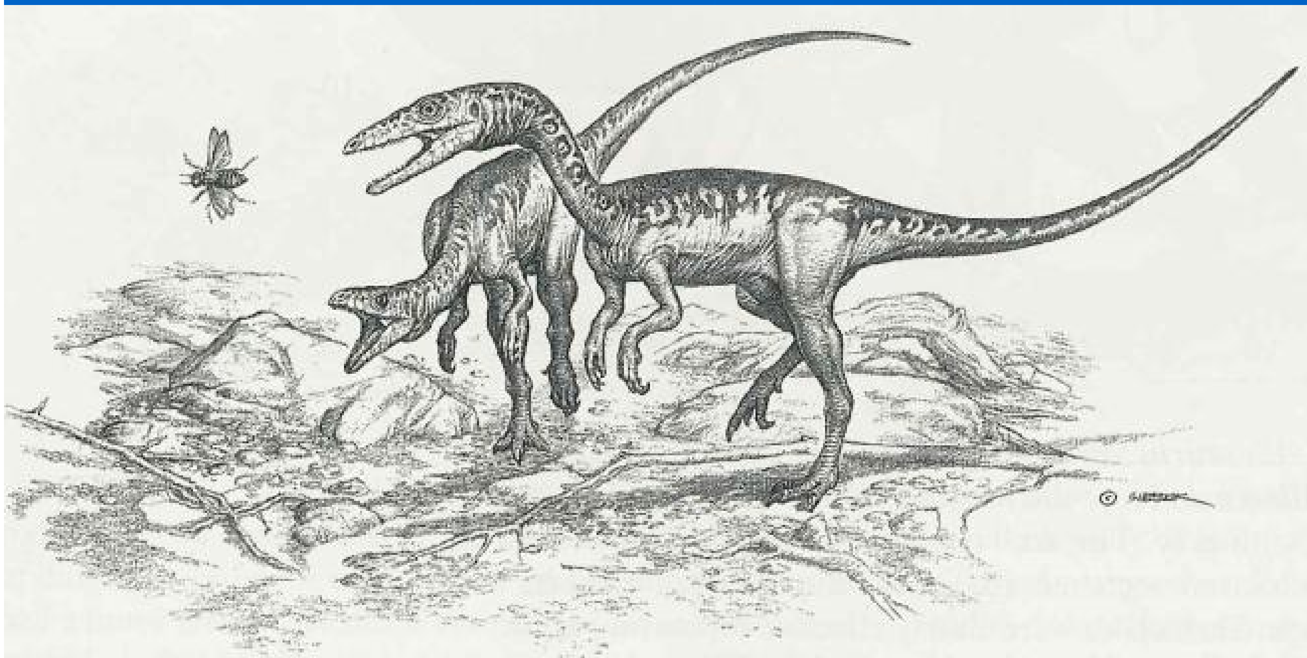


FIGURE 12-21 **The small, agile theopod *Coelophysis* lived about 220 million years ago, during the Late Triassic.** *Coelophysis* was about 3 meters in length. These fast, agile, bipedal predators may have pursued their prey in packs, and there is evidence that they occasionally even ate juveniles of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

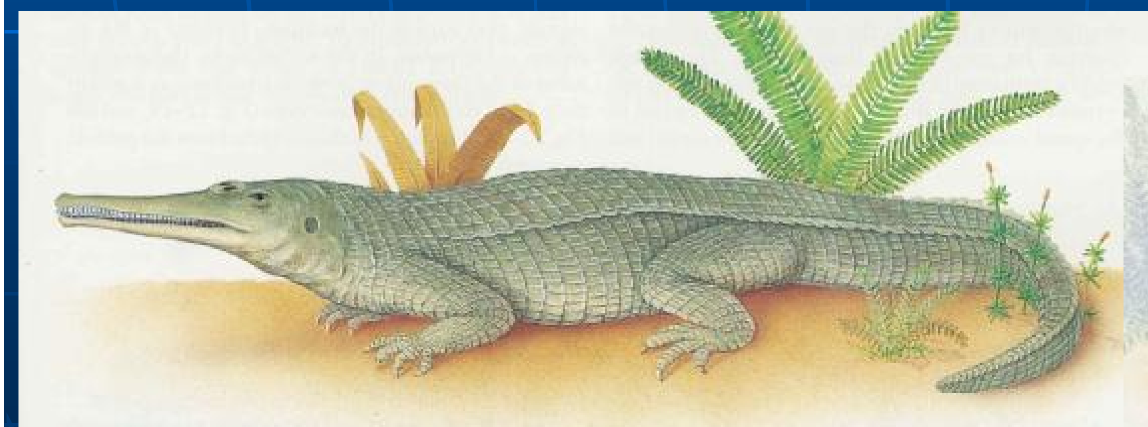
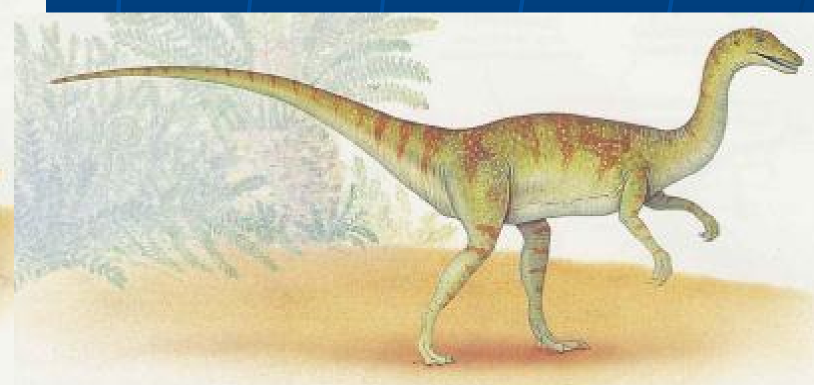


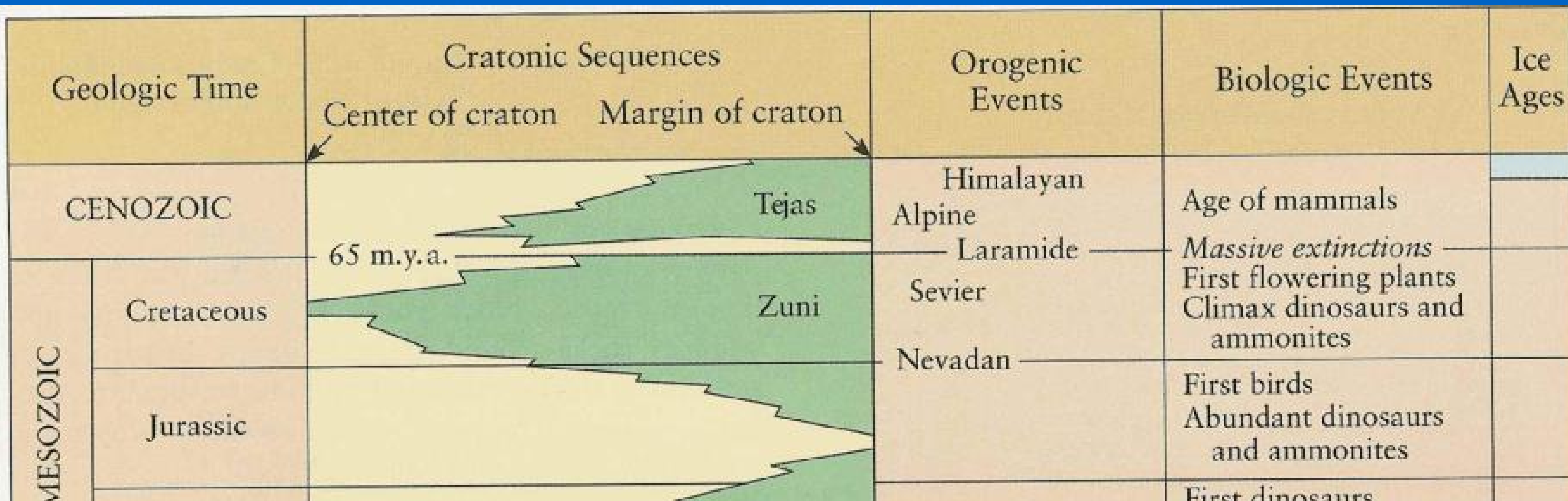
FIGURE 12-17 ***Rutiodon*, a Triassic phytosaur.** Like many other phytosaurs, *Rutiodon* grew to lengths of 10 or more feet. (*Illustration by Carlyn Iverson.*) ? *What living reptile is an example of convergent evolution with Rutiodon?*

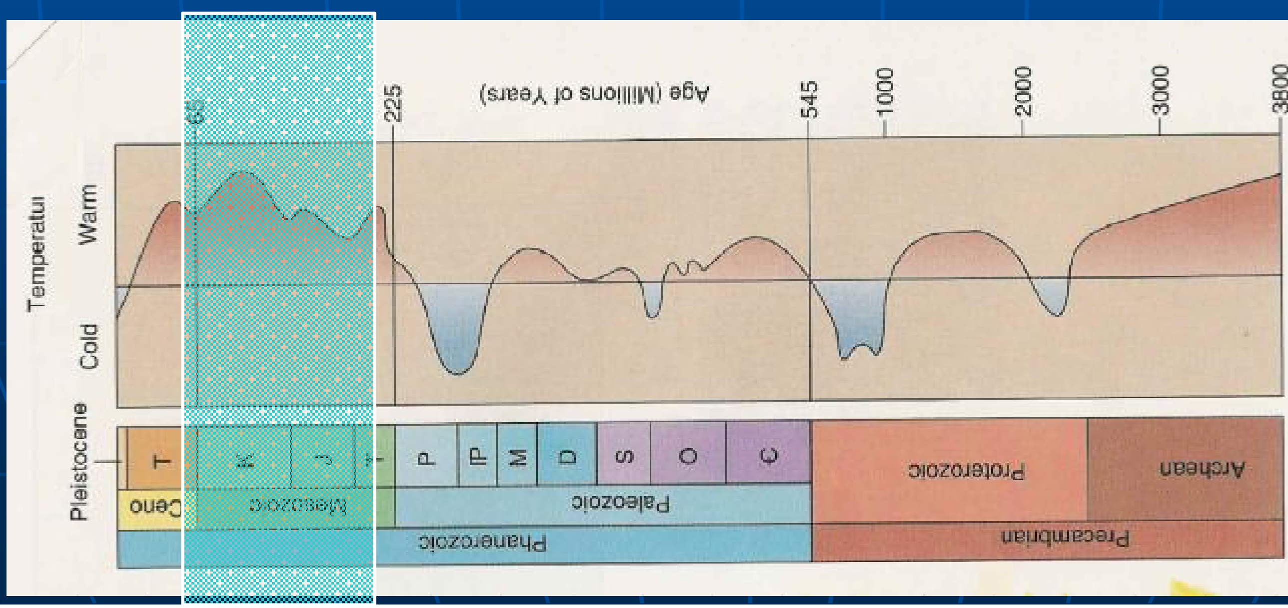


Hesperosuchus from the Triassic of the southwestern United States.

Pet. For. Labyrinthodont teeth

Late Jurassic & Cretaceous
200-65 Ma





Jurassic paleogeography

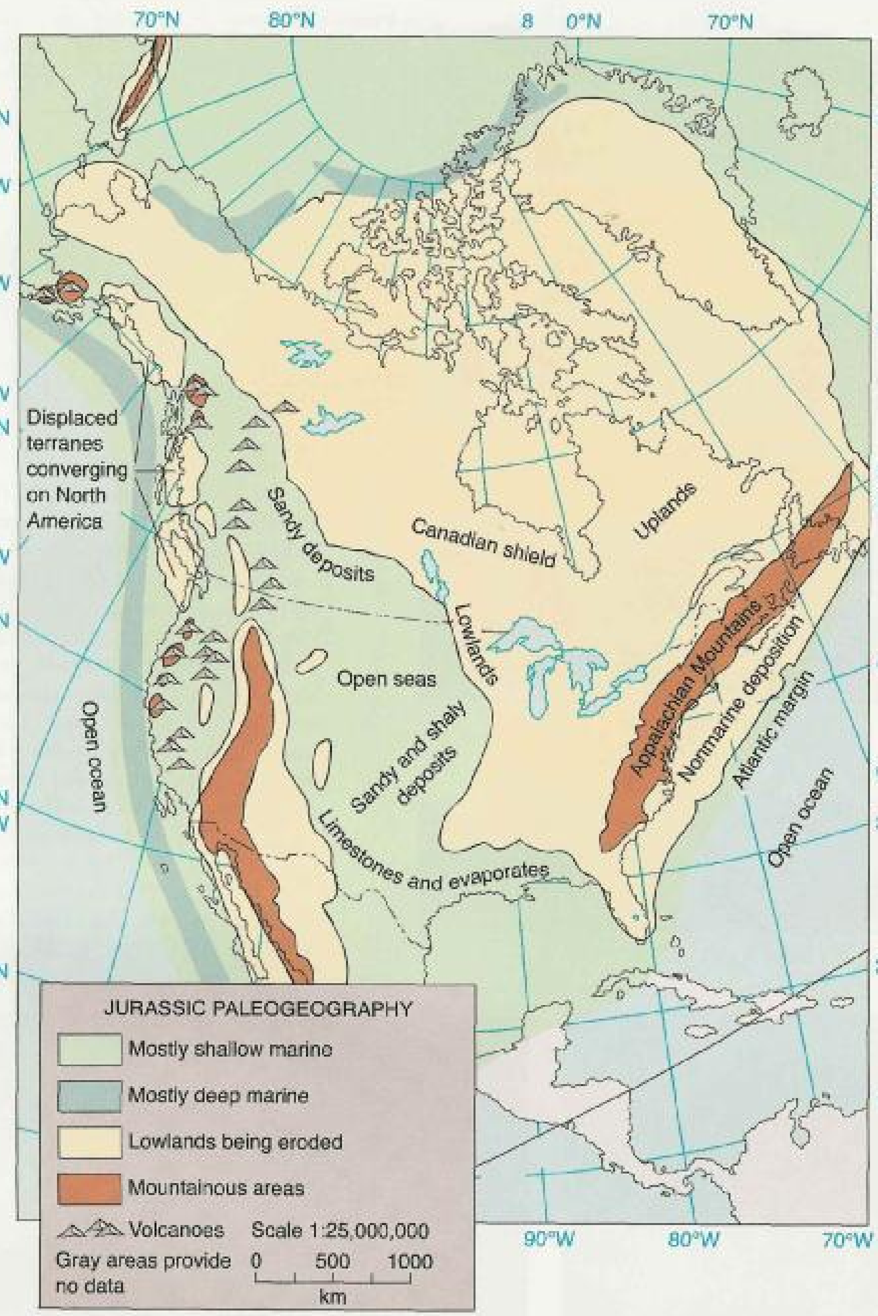
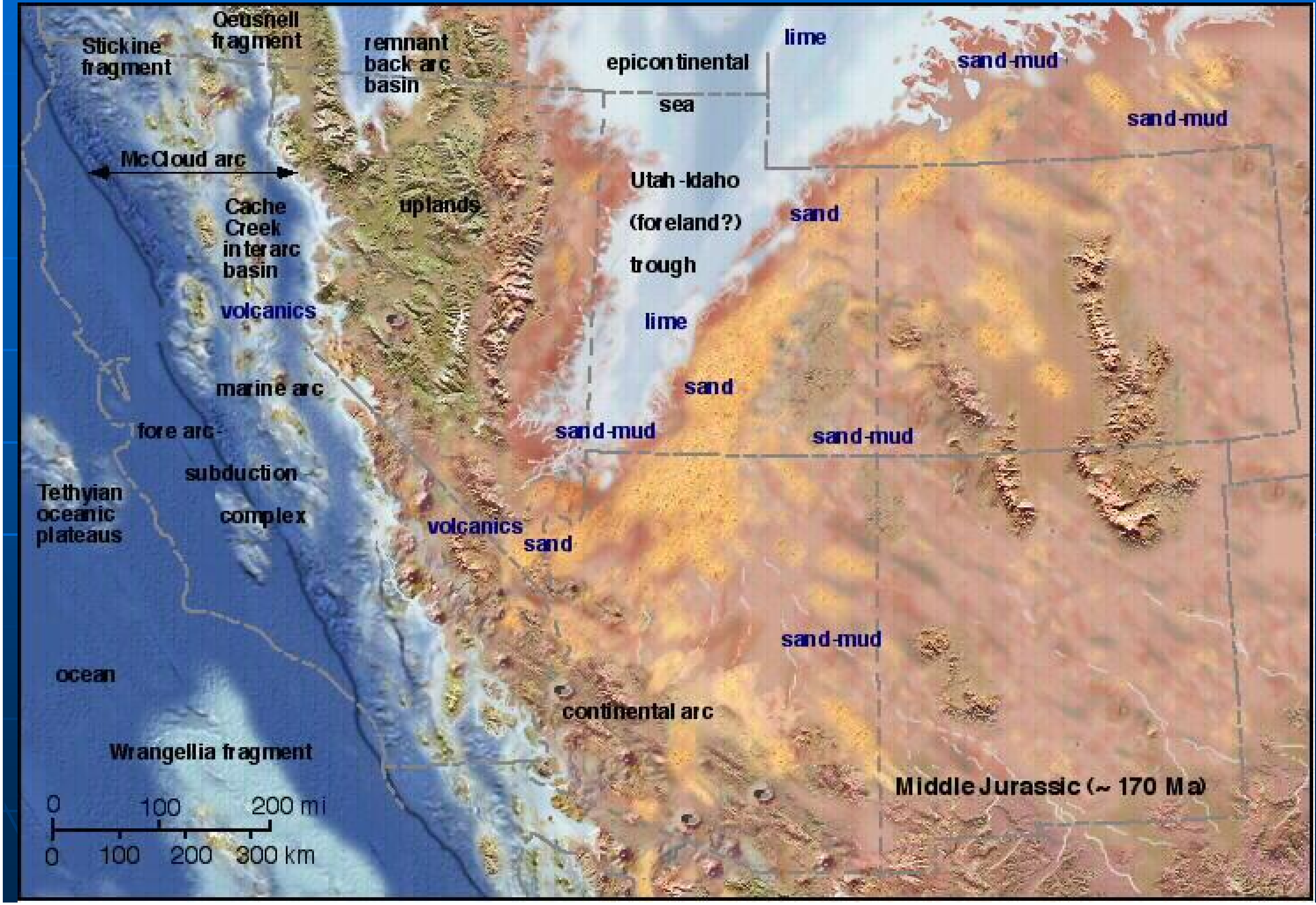
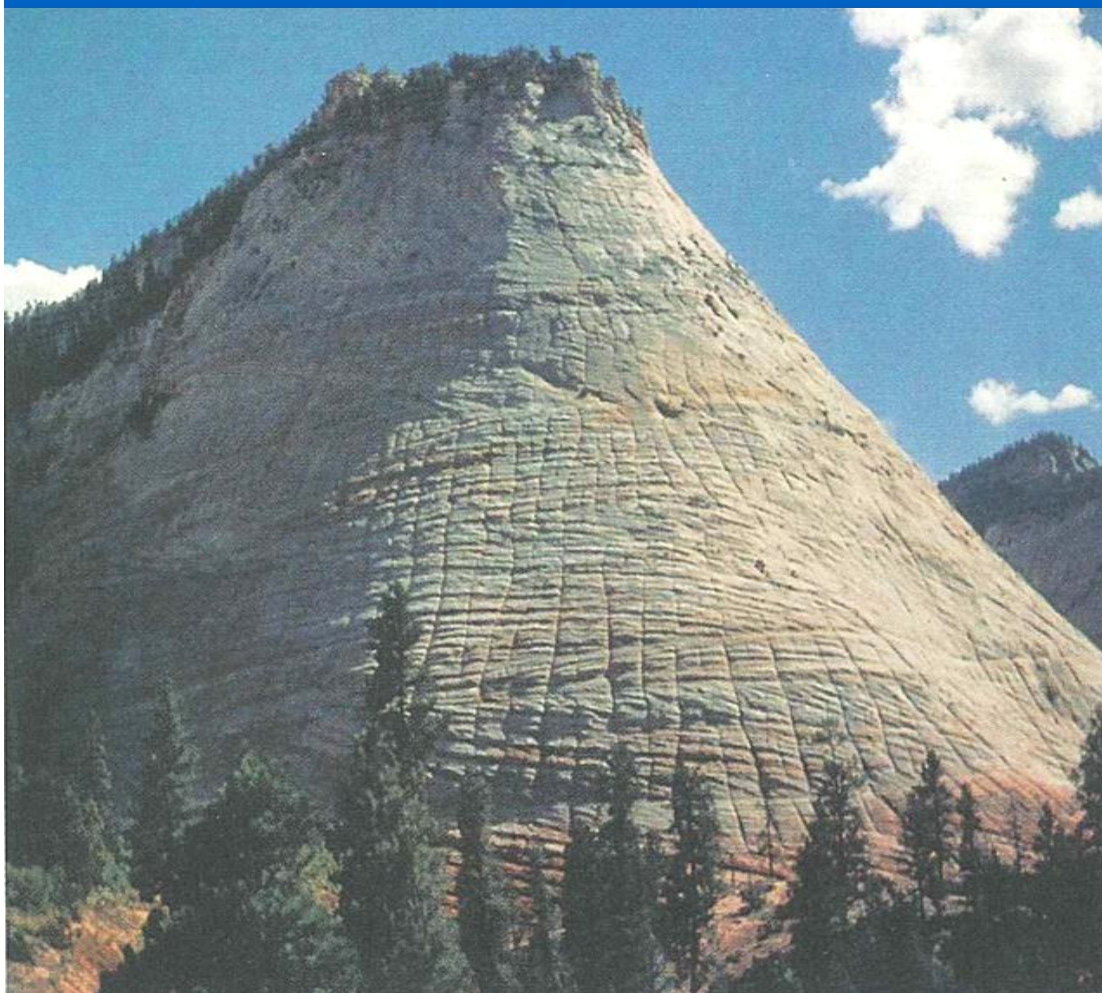


FIGURE 11–7 Generalized paleogeographic map for the Jurassic of North America.
Describe the conditions at the site of your school during the Jurassic Period.

Middle Jurassic



Navajo Sandstone – Jurassic age



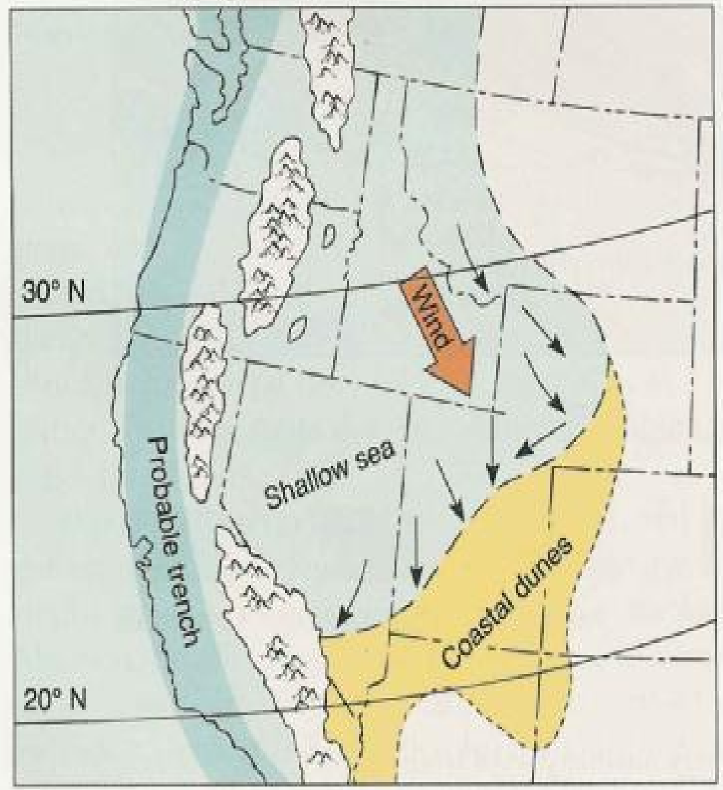


FIGURE 11-26 Paleogeographic map for the early Jurassic of the western United States, showing general extent of sea and land as well as paleolatitudes. (*From Stanley, K. O., Jordan, W. M., and Dott, R. H. 1971.* Bull. Am. Assoc. Petrol. Geol. 55(1):13.)

Rainbow Bridge in Jurassic Ss

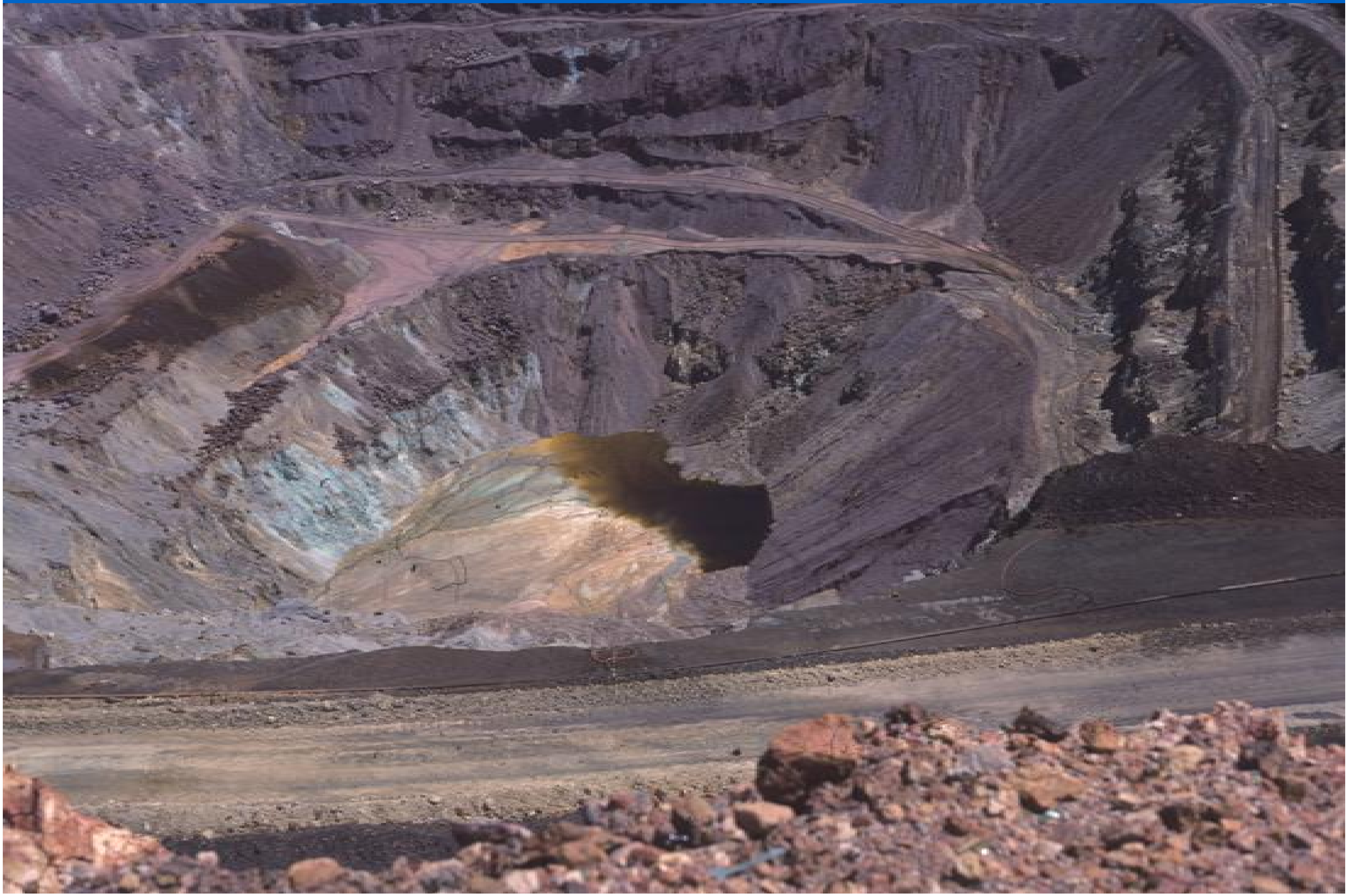
Jurassic tracks N.AZ

Jurassic - Stegosaurus

Vermilion Cliffs, Jurassic Ss

Jurassic volcanics Santa Rita Mts.

Jurassic – Bisbee copper-gold mine



Middle Cretaceous (~90 Ma)

Bisbee Grp., Mural Limestone 100 Ma

Late Cretaceous – volcanics, Mts.

Tombstone – early Laramide (78-65 Ma – silver deposits)

Gates Pass, Tucson – 74 Ma rhyolite

Porphyry copper deposits ~ 70-65 Ma

Tertiary – 65-0 Ma

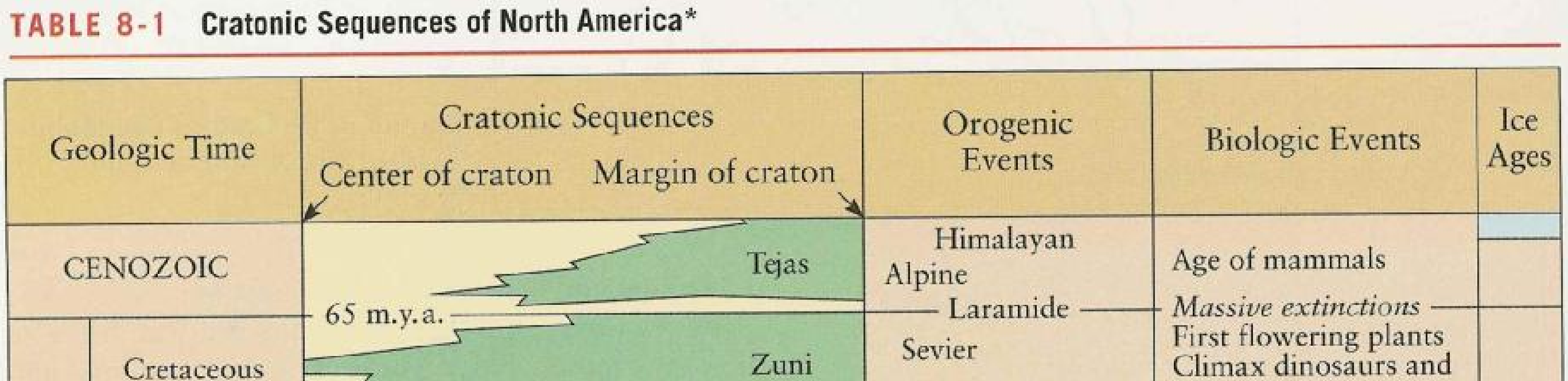
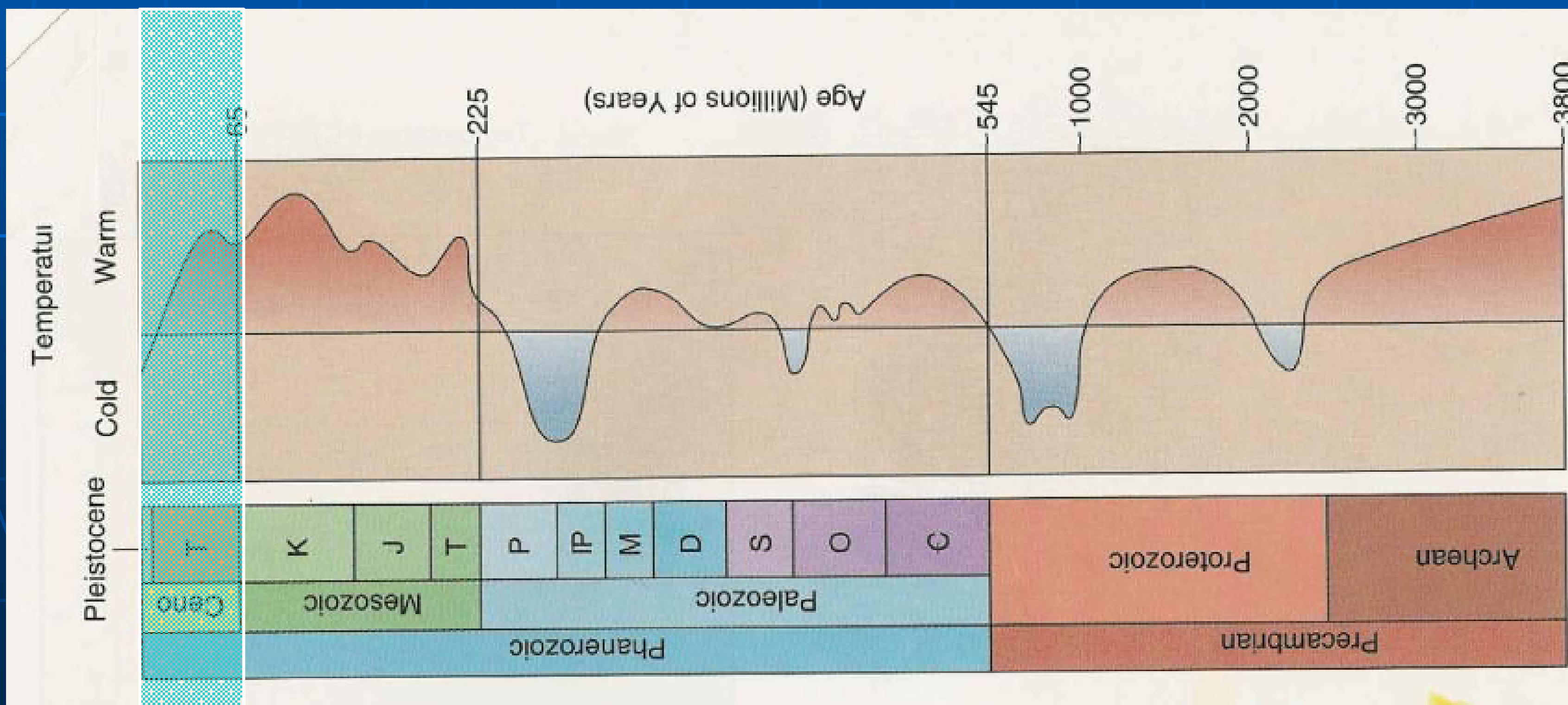
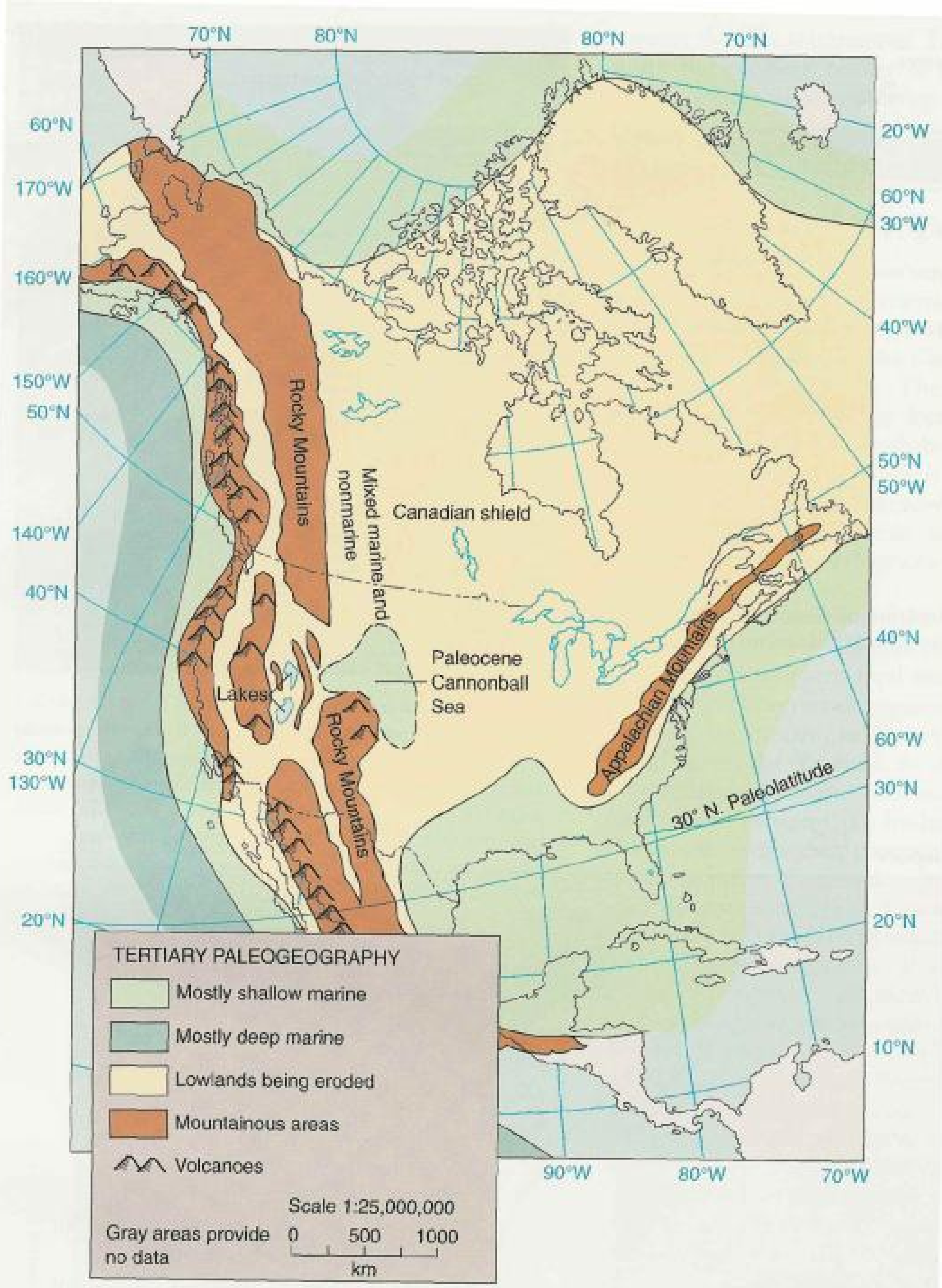


TABLE 8-1 Cratonic Sequences of North America*

Geologic Time		Cratonic Sequences: Center of craton / Margin of craton	Orogenic Events	Biologic Events	Ice Ages
CENOZOIC		Tejas	Himalayan Alpine	Age of mammals	
		65 m.y.a.	Laramide	*Massive extinctions*	
	Cretaceous	Zuni	Sevier	First flowering plants Climax dinosaurs and	



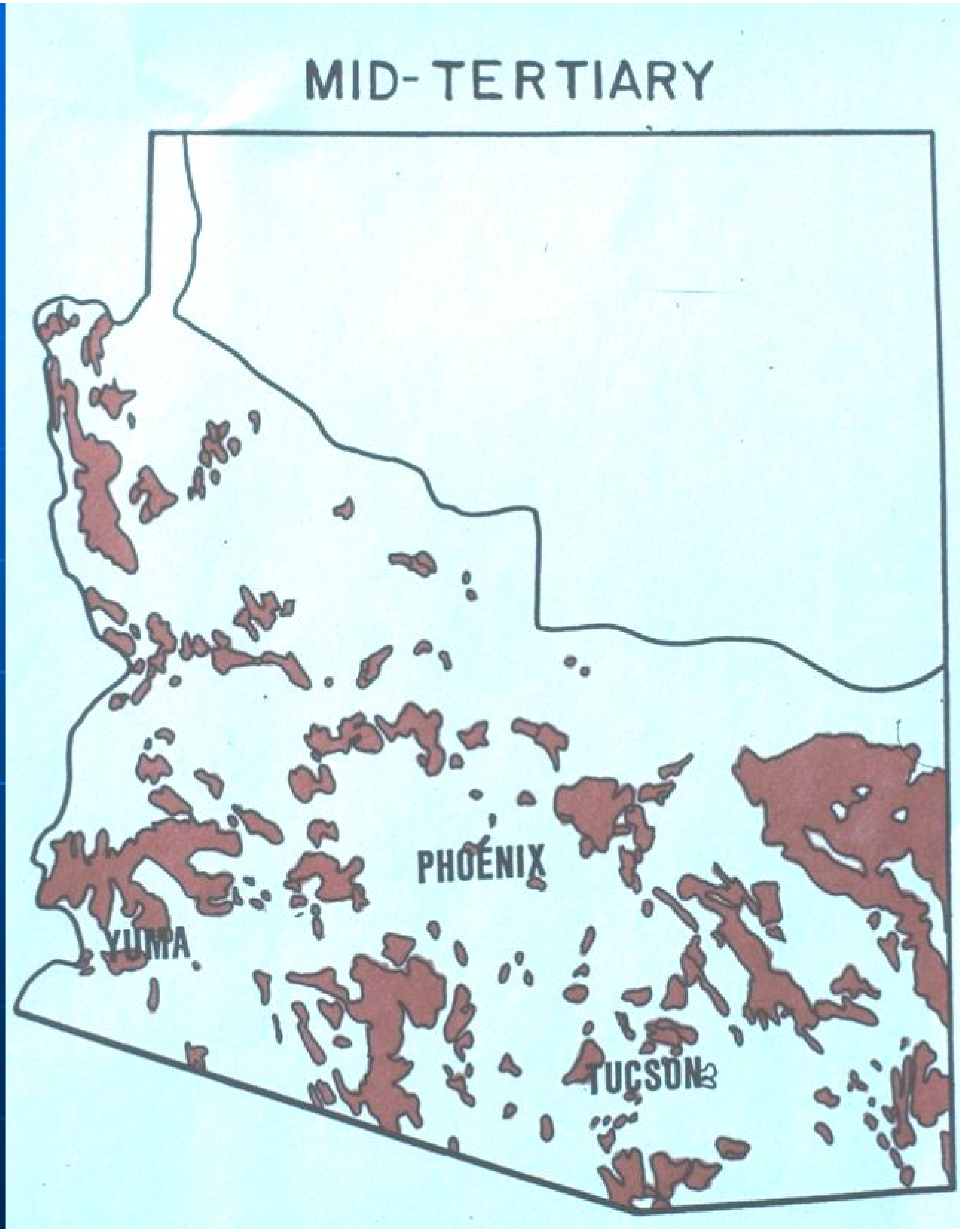
Early Tertiary paleogeography



Tertiary (65-1.8 Ma)

Texas Canyon granite – ~45 Ma

Mid-Tertiary volcanics

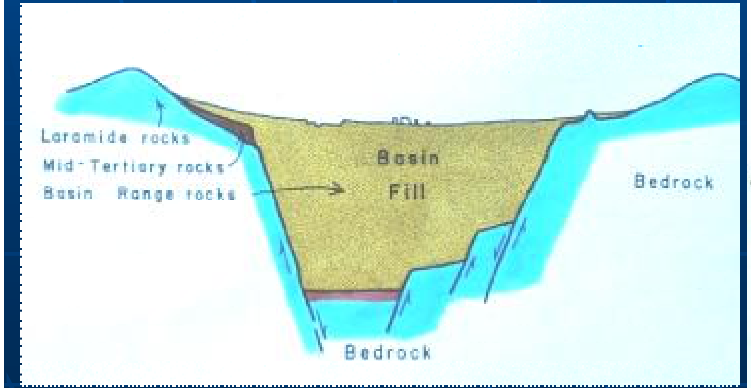


Cochise Stronghold Granite – Dragoon Mts.

SUPERSTITION MOUNTAINS

TAFONI in late Tertiary sedimentary rocks contain holes produced by weathering

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



Basin fill – sand, gravel, & clay

Basin fill at Sonoita

Late Cenozoic volcanics

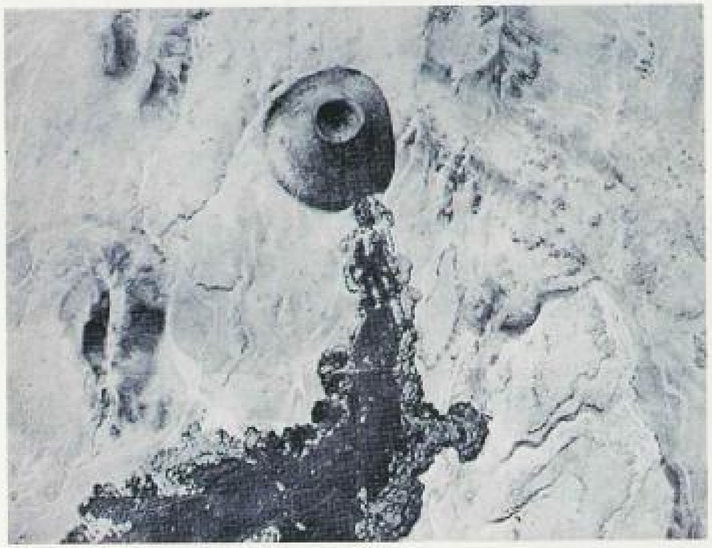
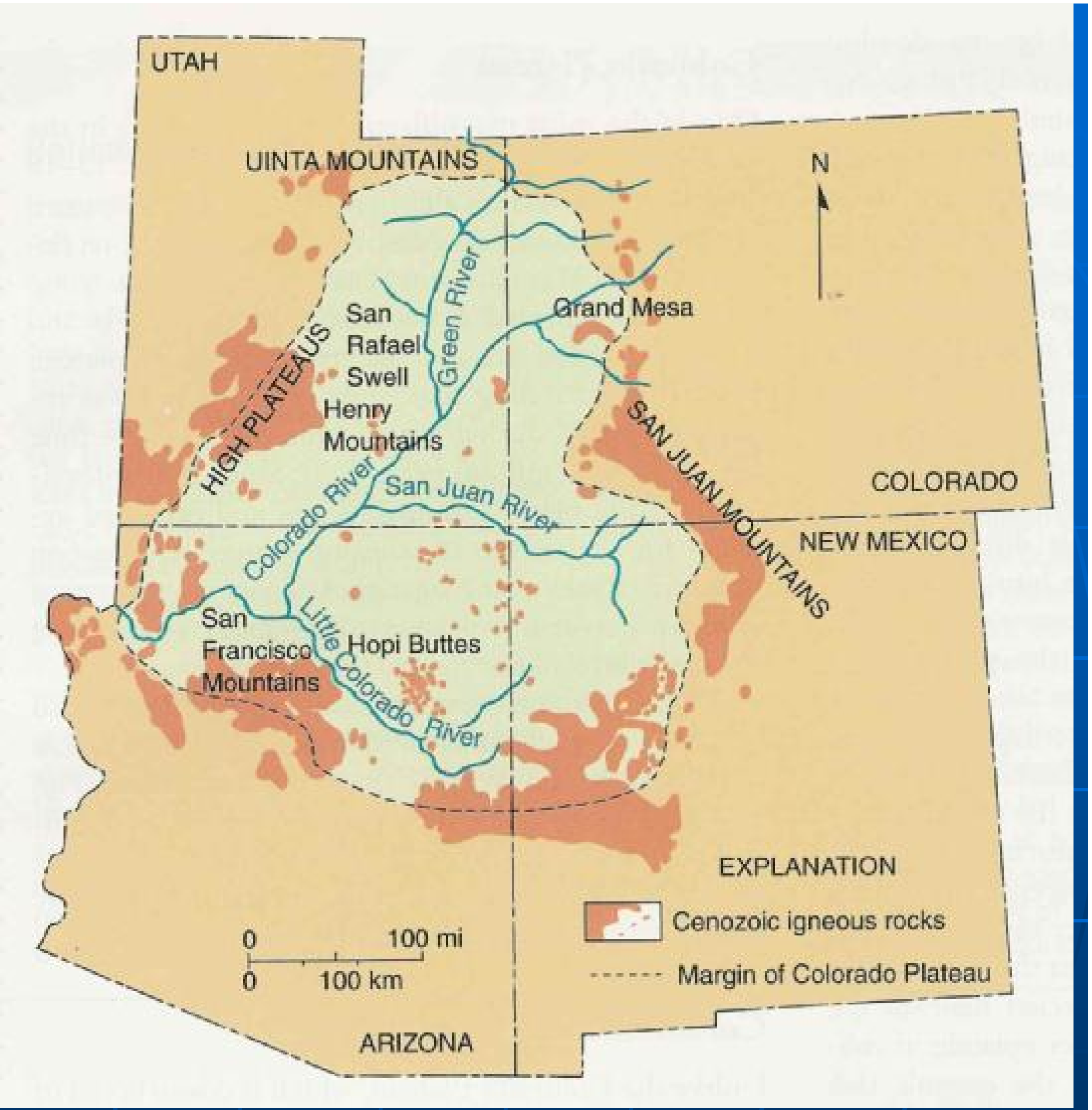


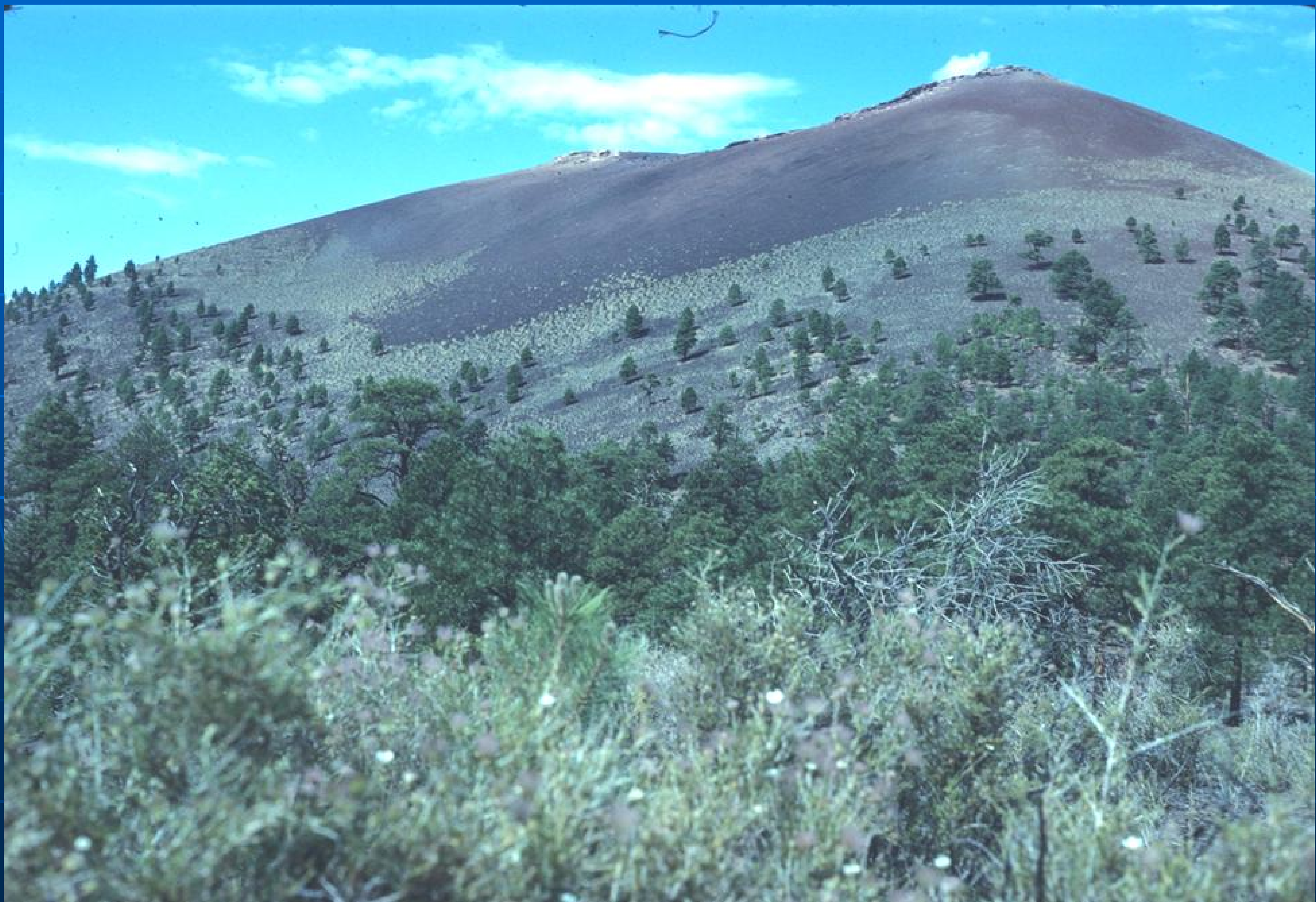
FIGURE 13-20 Vertical aerial photograph of a large cinder cone in the San Francisco volcanic field of northern Arizona. The solidified flow issuing from the cone is 7 kilometers long and more than 30 meters thick.



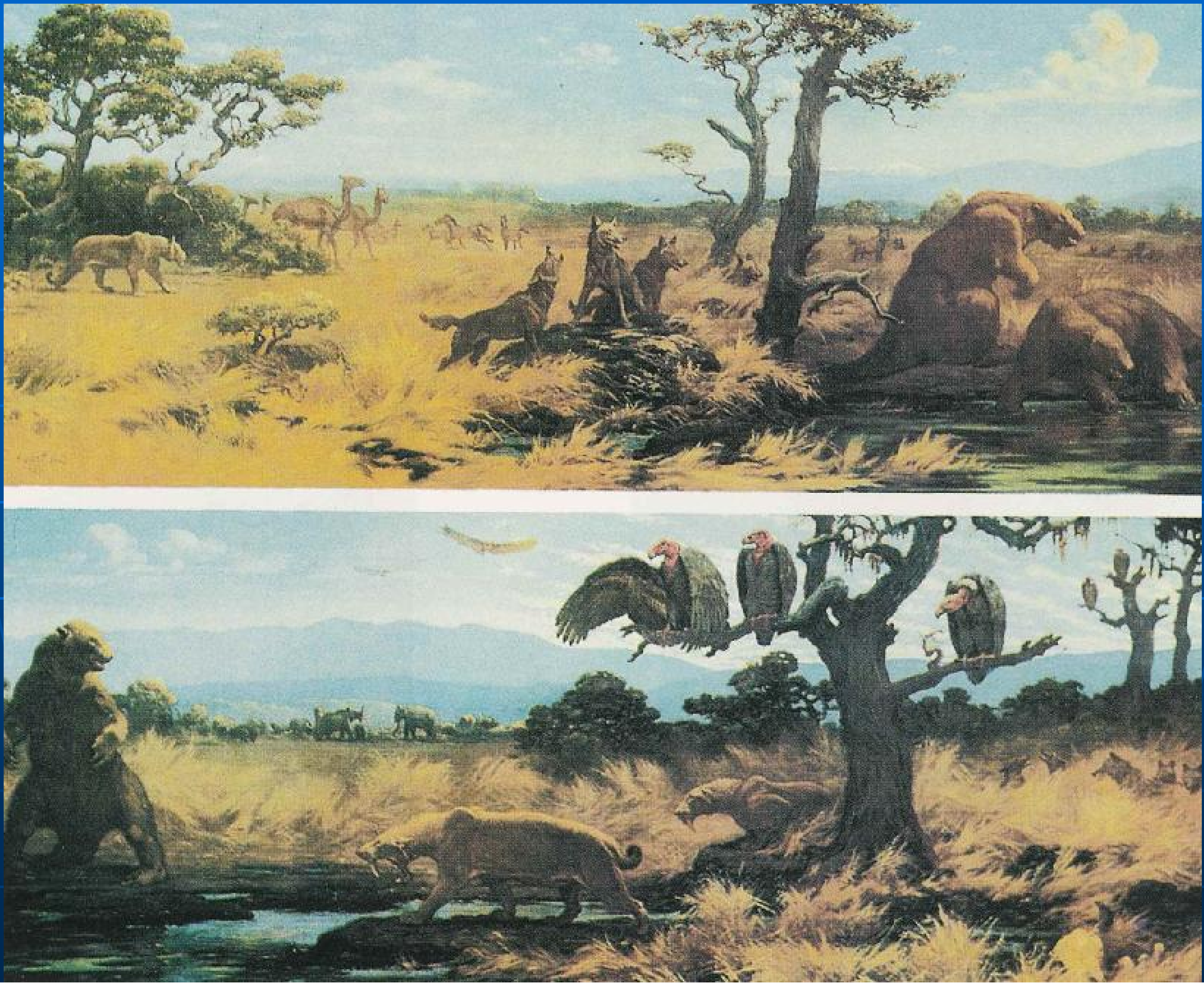
San Francisco Peaks volcanism 5-0 Ma

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

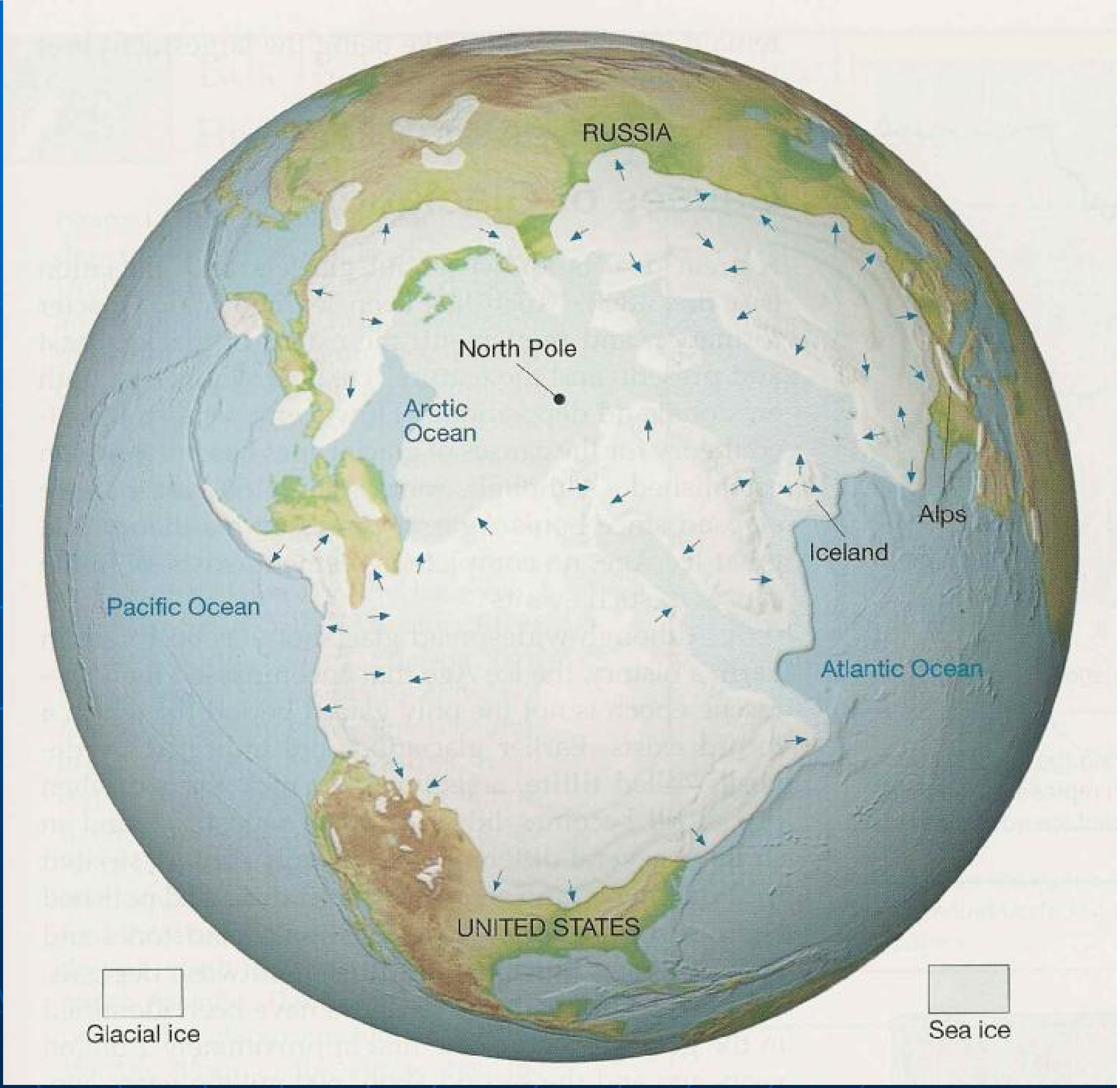
Sunset Crater
1066 AD eruption



LaBrea tarpits, Los Angeles – Pleistocene 1 Ma



Pleistocene maximum glaciation – 18,000 years ago



Pleistocene glaciation

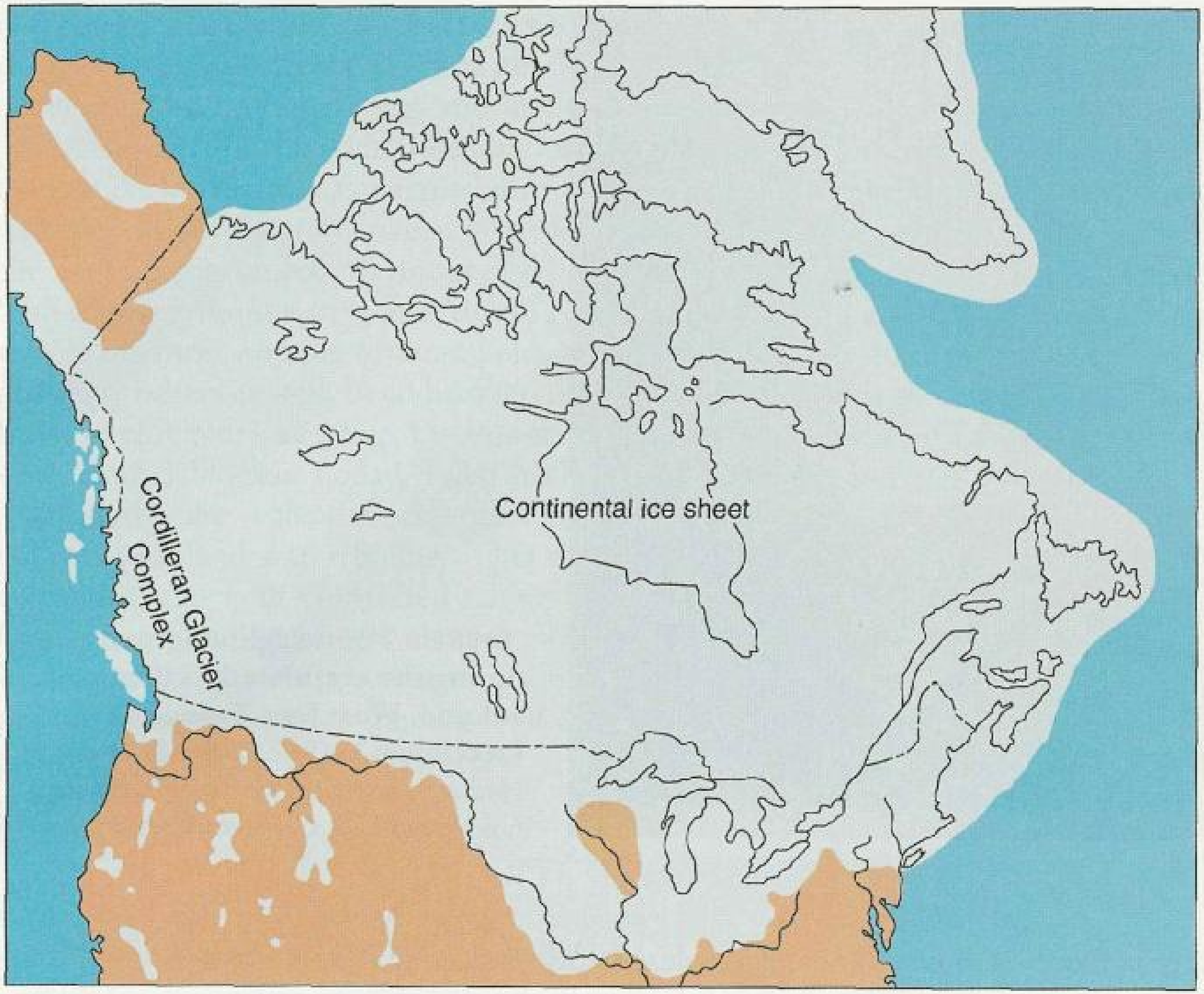


FIGURE 13-36 Areal coverage of continental glaciers in North America during the latest glacial advance, about 18,000 years ago. (*Courtesy of Thompson, G.R. and Turkl, J. 1997,* Modern Physical Geology, *Philadelphia: Saunders College Publishing.*)

Carbon dioxide, last 100,000,000 years

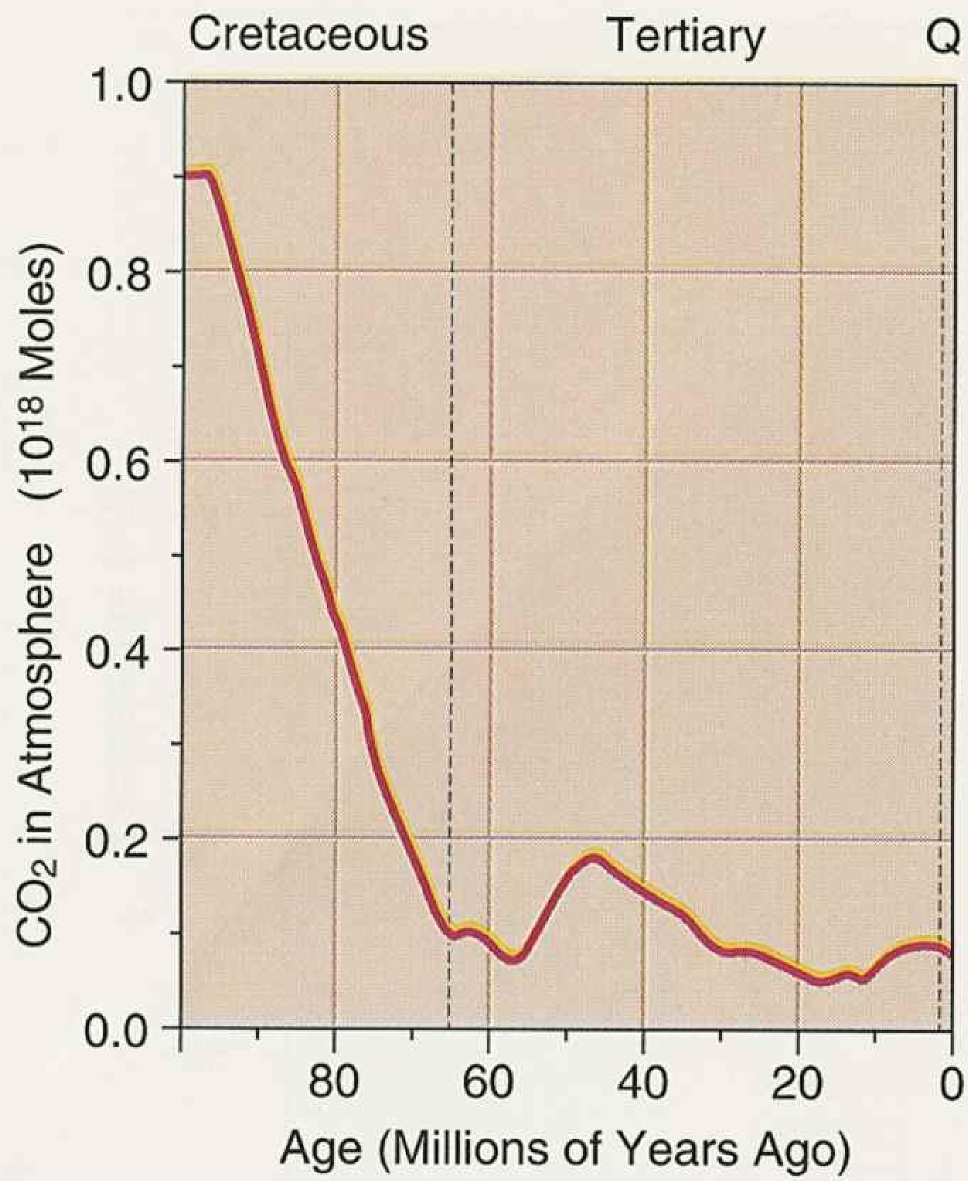


Figure 14.40 The abundance of carbon dioxide in Earth's atmosphere has declined dramatically during the last 100 million years. Loss of this important greenhouse gas may have allowed Earth to cool enough for glaciers to accumulate.

1,000,000 years of temperature change

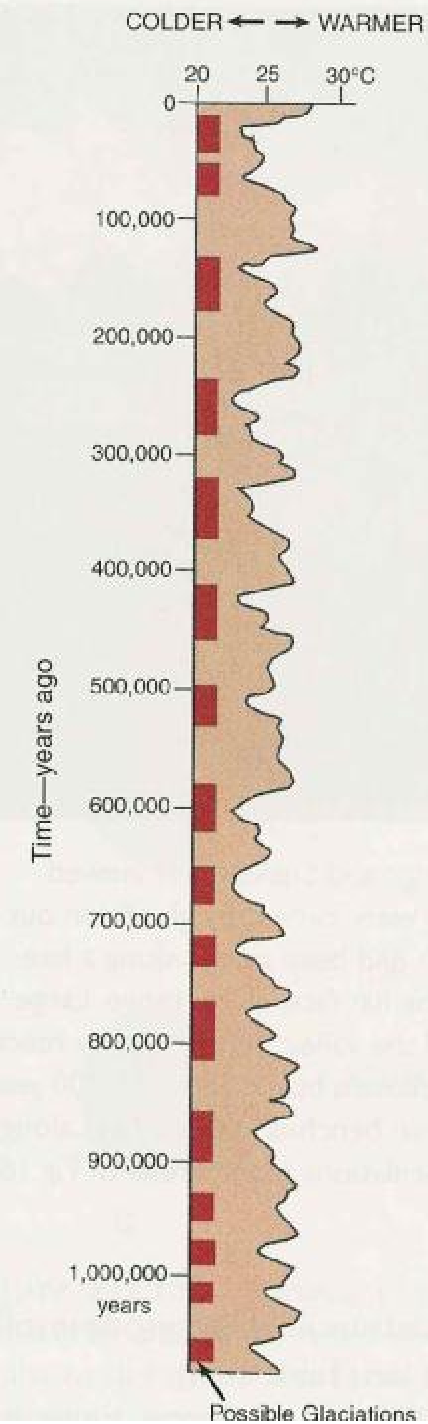


Figure 16.16 Late Pleistocene standard marine paleotemperature curve *(left)* based upon oxygen-isotope analyses of calcium carbonate in microfossil shells from deep-sea cores of three oceans. Magnetic polarity measurements on the same cores *(right)* and limited isotopic dating of cores provide a time scale. Note that, for the last 600,000 years, cold intervals had a periodicity of about 100,000 years; from then back to about 1.4 million years, the period was about 40,000 years (J—Jaramillo brief normal polarity event). *(Adapted from Emiliani and Shackleton, 1974: Science, v. 183, pp. 511–514; and Shackleton and Opdyke, 1976:* Geological Society of America Memoir *145, pp. 449–464.)*

Glacial and Interglacial stages, last 2 million years

TABLE 13–2 Classic Nomenclature for Glacial and Interglacial Stages of the Pleistocene Epoch

NORTH AMERICA	ALPINE REGION	YEARS BEFORE PRESENT
		—10,000
WISCONSIN	Würm	—75,000
Sangamon	Riss-Würm	—125,000
ILLINOIAN	Riss	—265,000
Yarmouth	Mindel-Riss	—300,000
KANSAN	Mindel	—435,000
Aftonian	Günz-Mindel	—500,000
NEBRASKAN	Günz	—1,800,000
Pre-Nebraskan	Pre-Günz	

500,000 years - Pleistocene temperatures

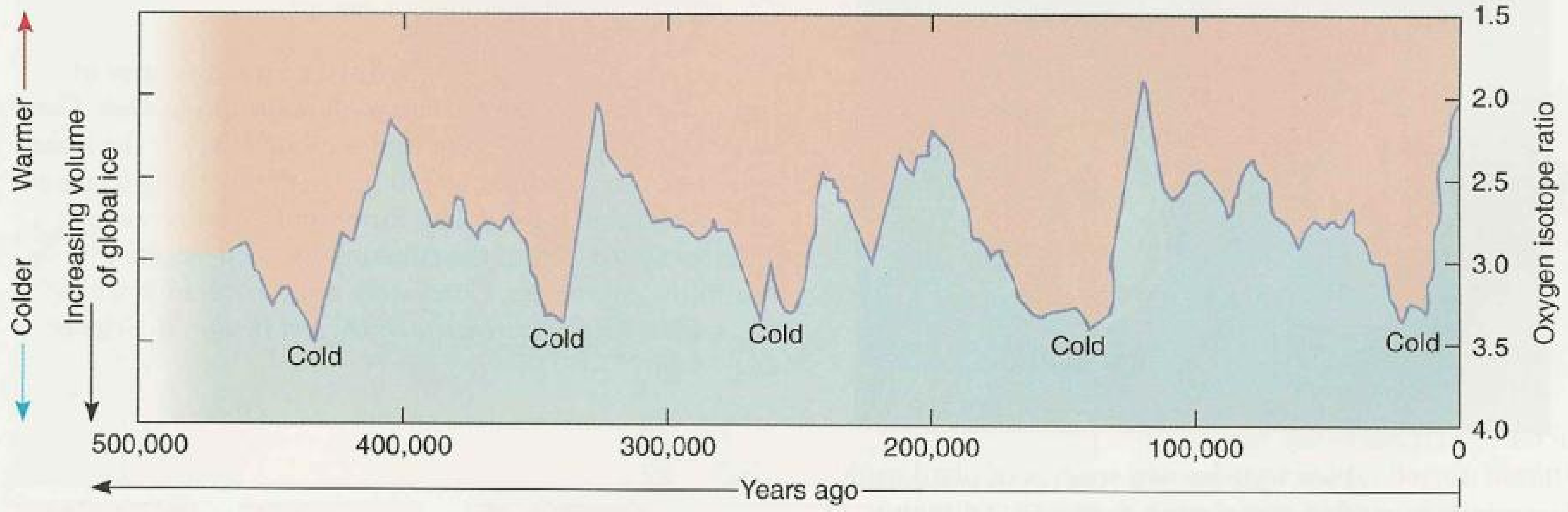
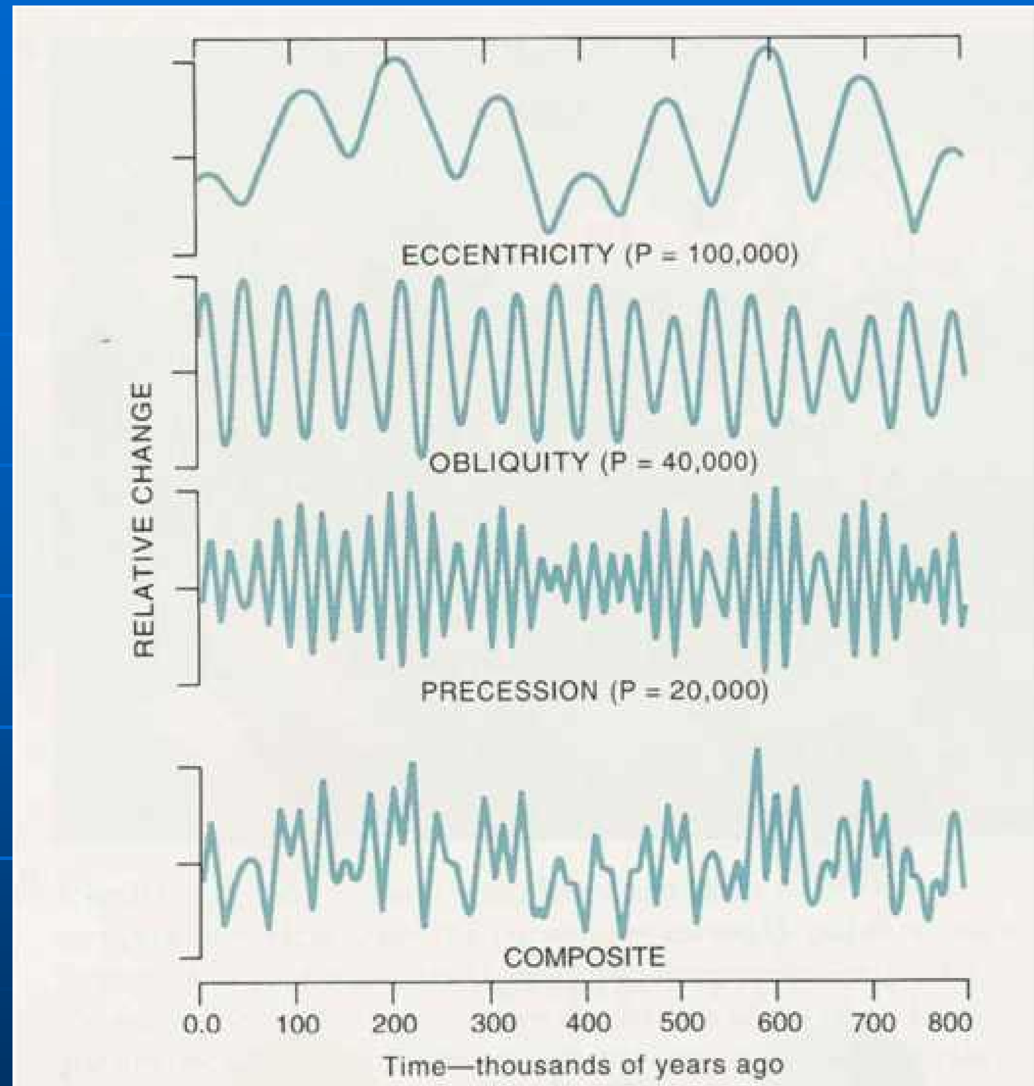
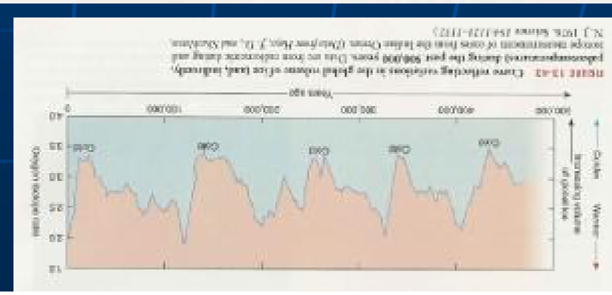


FIGURE 13-43 Curve reflecting variations in the global volume of ice (and, indirectly, paleotemperatures) during the past 500,000 years. Data are from radiometric dating and isotope measurements of cores from the Indian Ocean. (*Data from Hays, J. D., and Shackleton,* N. J. 1976. Science *194:1121–1132.*)

800,000 years – astronomical variations





Climate Change, last 160,000 years

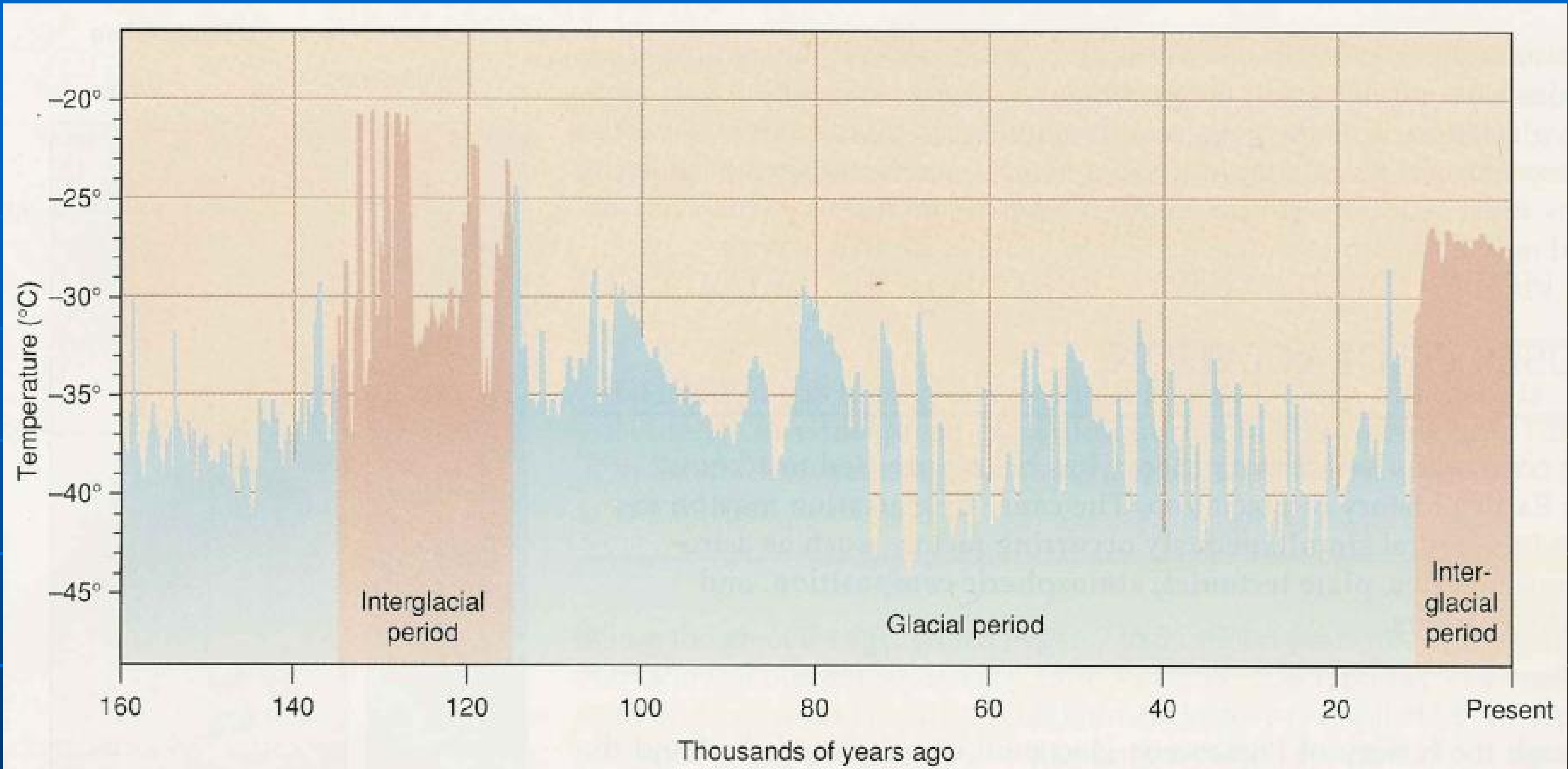
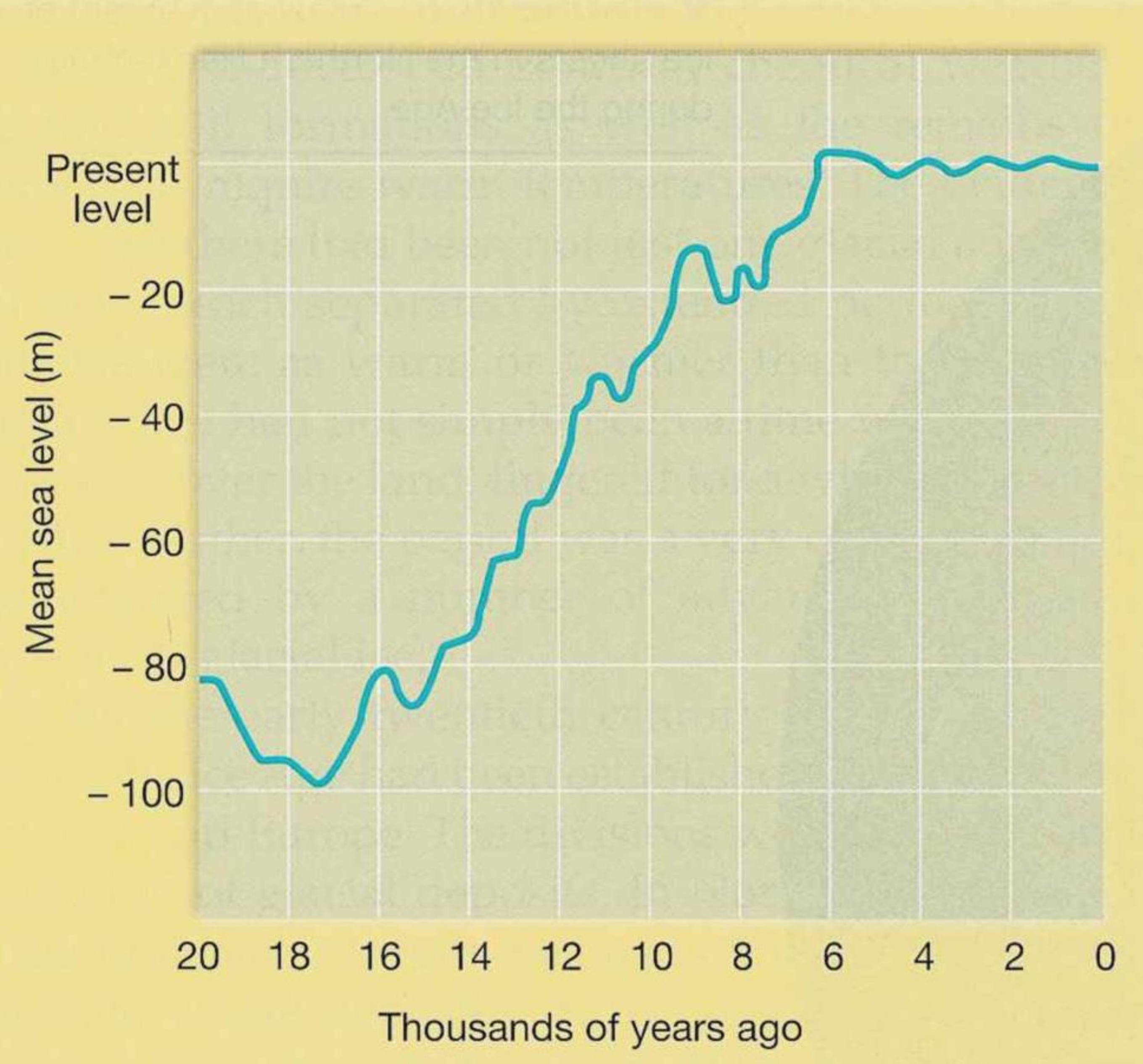
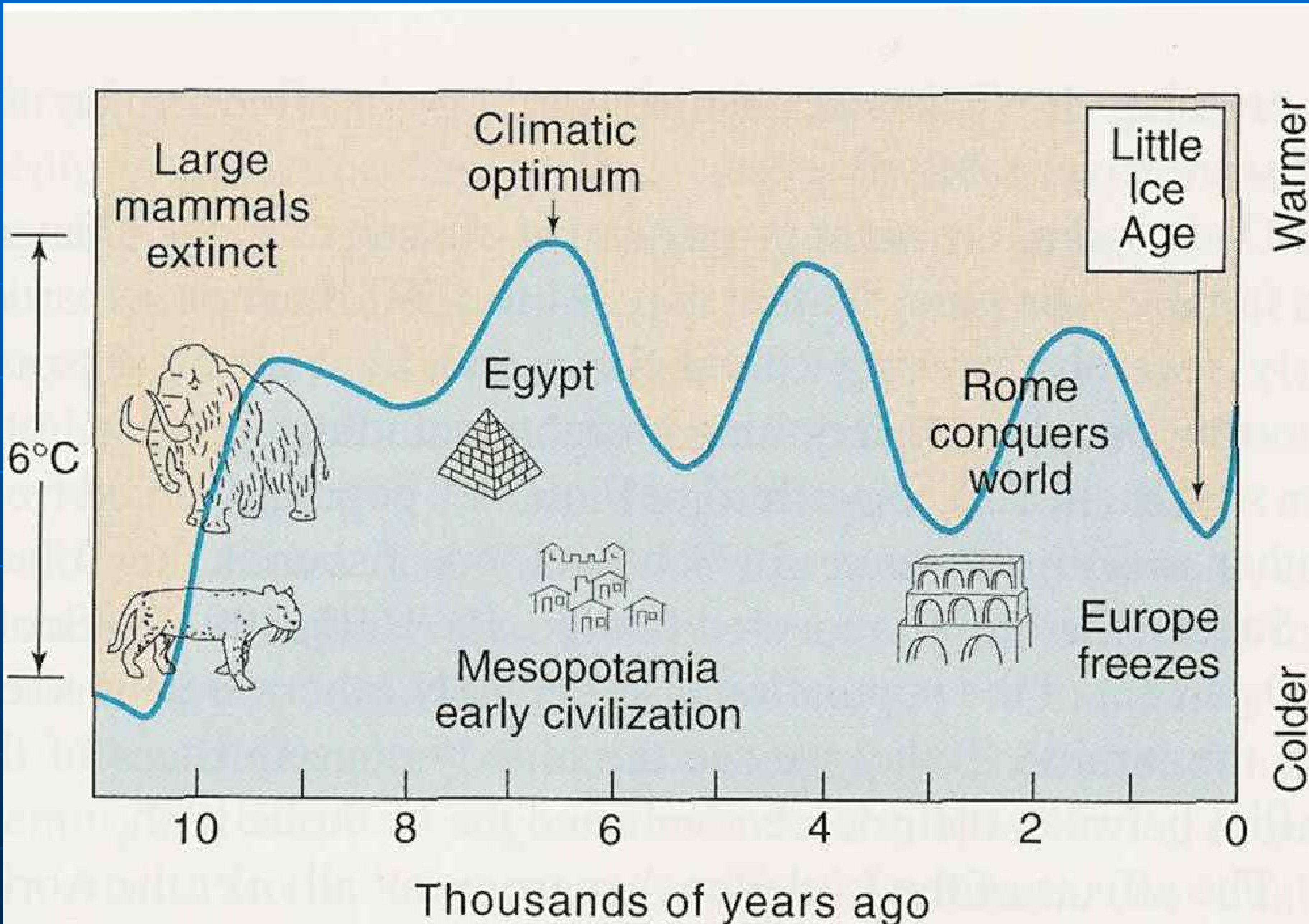


Figure 14.38 A record of climatic change during the last 160,000 years was assembled from studies of ice cores from Greenland's glacier. It shows that the normal pattern of change involves numerous rapid fluctuations in temperature—not only during glacial periods, but throughout interglacial periods as well. The stable warm temperature of the present interglacial period is distinctly abnormal.

Sea Level curve – last 20,000 years



Temperature, last 10,000 years



Temperature change, last 5,500 years

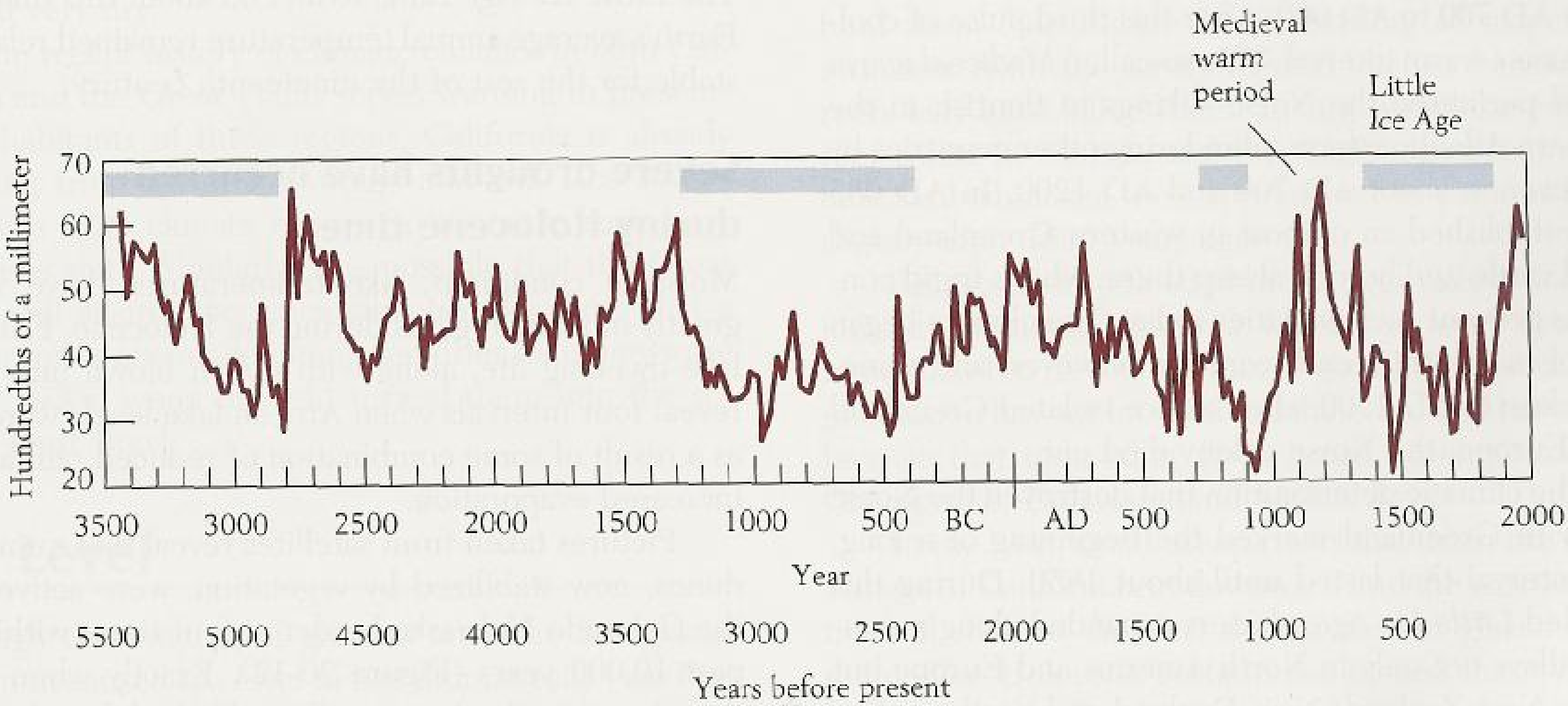


Figure 20-10 Cold intervals of the past 5500 years recorded by widths of annual growth rings in bristlecone pines near the upper tree line of the White Mountains of California. (Data from V. C. La Marche, in H. H. Lamb, *Climate History and the Modern World*, Routledge, London, 1995.)

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**