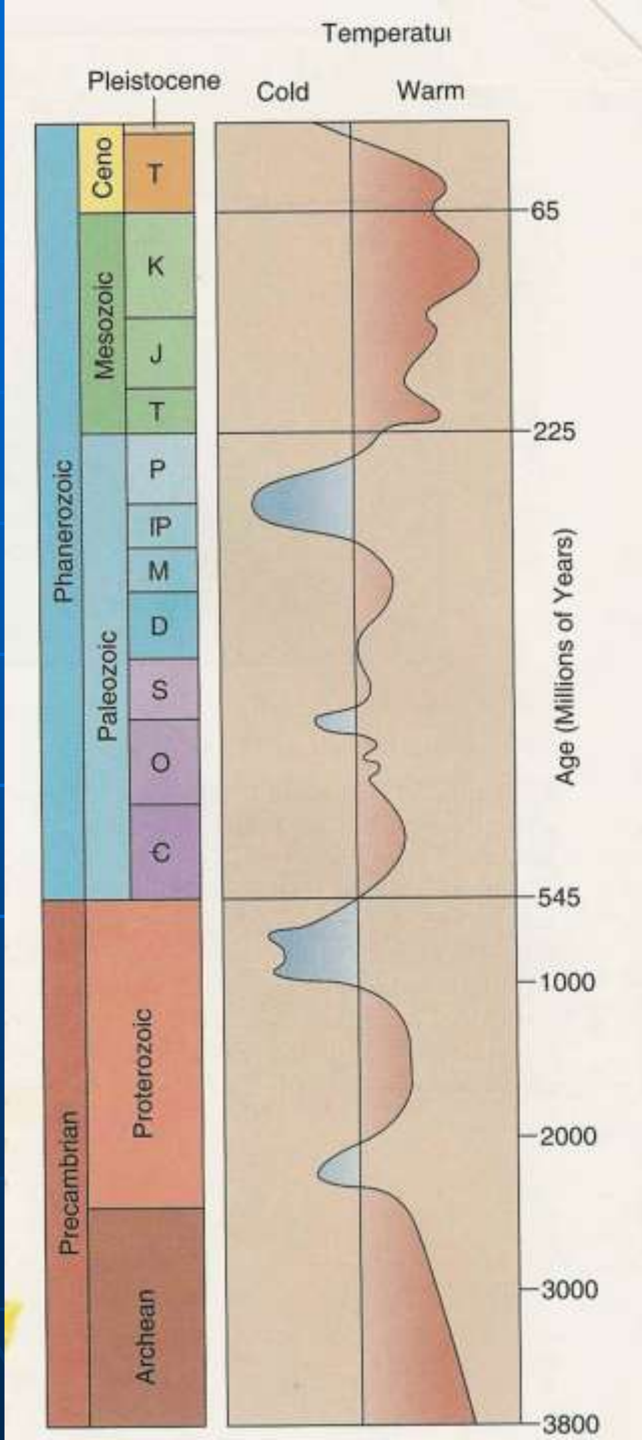
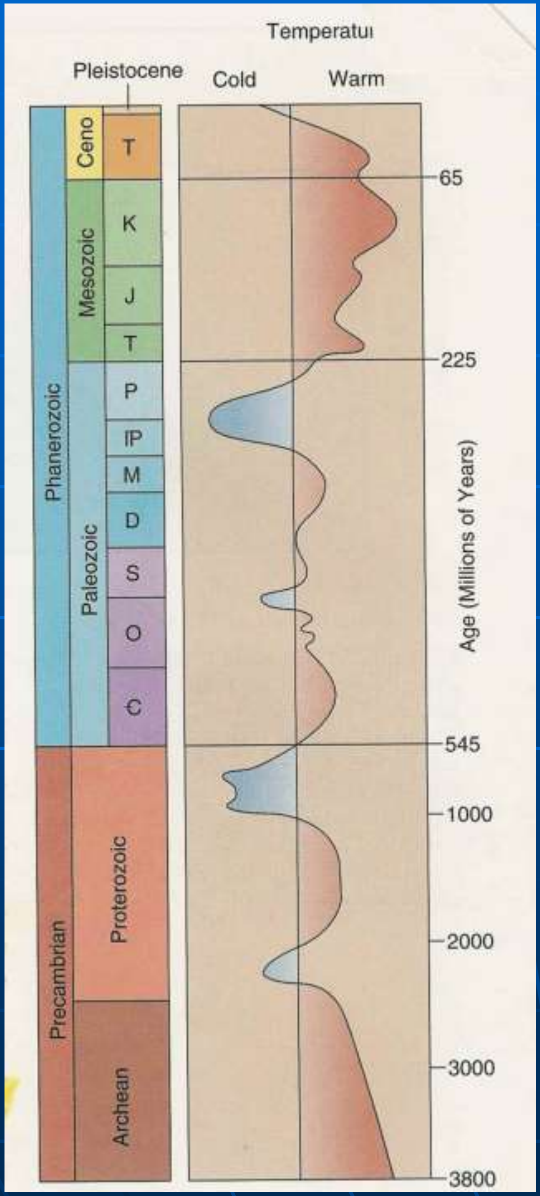


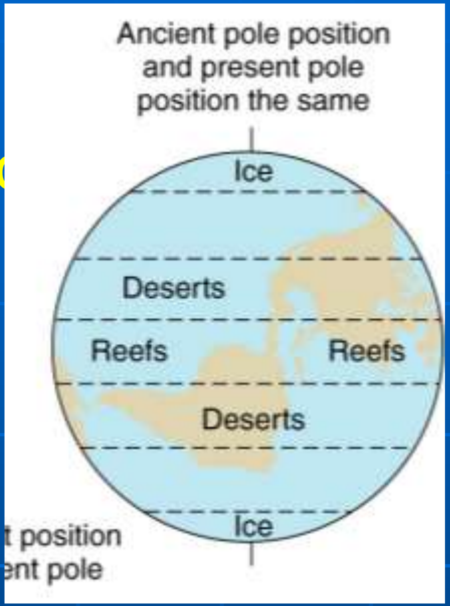
Arizona Climate through Geologic History

Jan C. Rasmussen, Ph.D.
www.janrasmussen.com

Arizona Paleoclimate



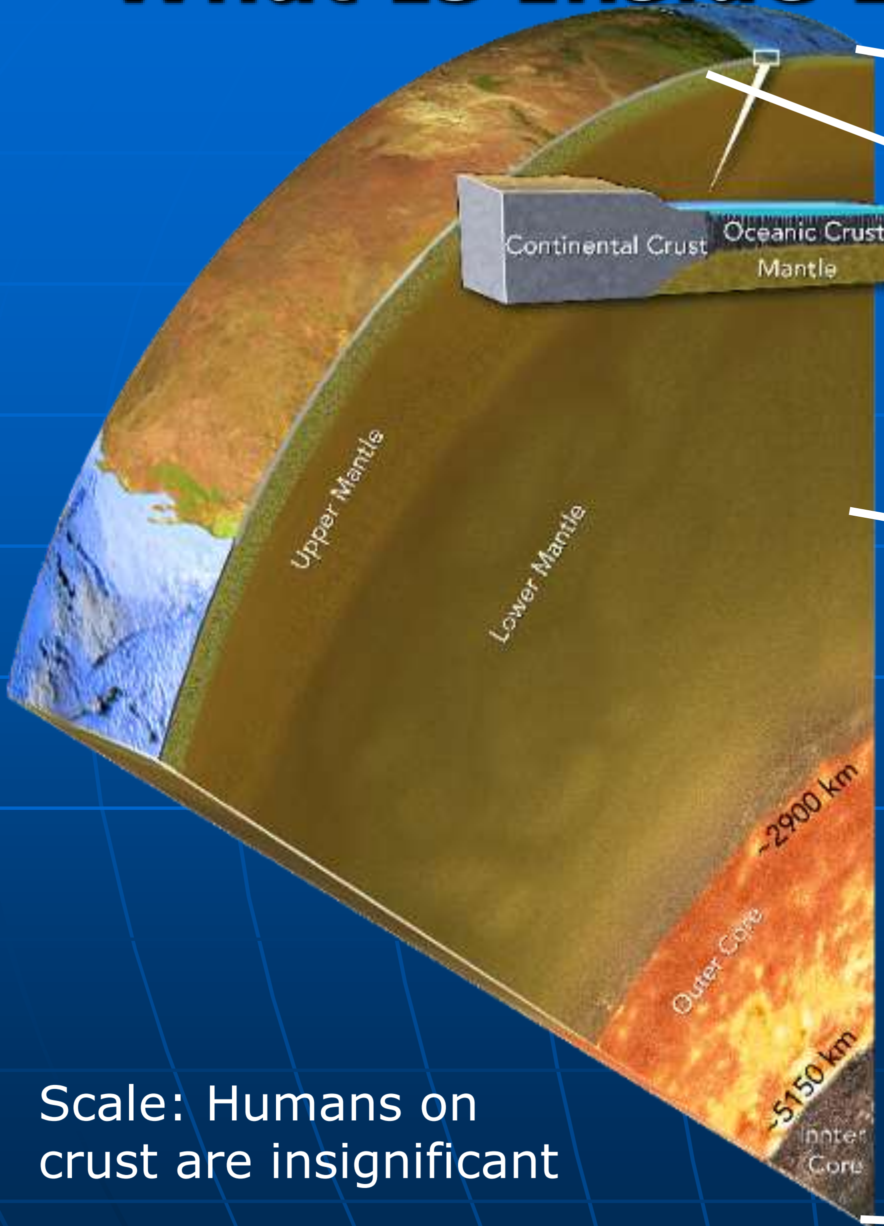
- Depends on plate position relative to equator through geologic history



Plummer et al., 2013

- Big climate changes through geologic time
- Seas go out (regression) = continental assembly with faster plate tectonics & seafloor spreading
- Mostly warm periods with ice ages ~ every 250 million years

What Is Inside Earth?



Upper layer is *crust;* two types:
continental *oceanic*

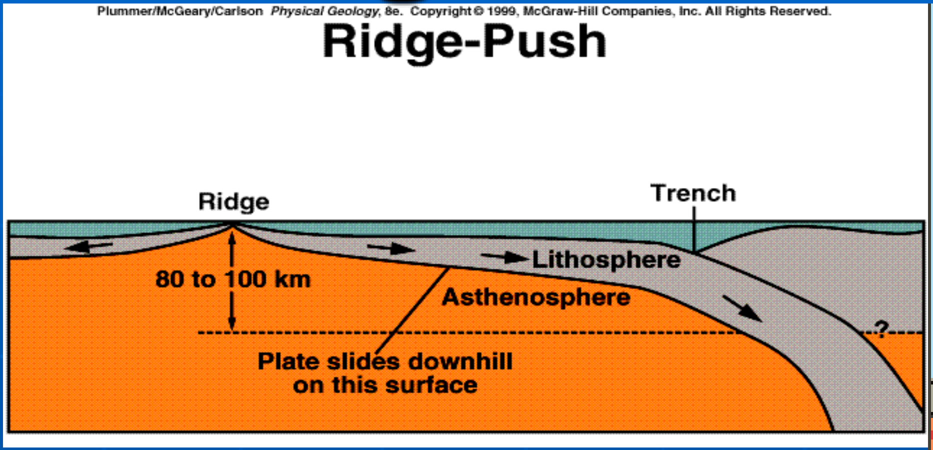
Thickest layer: *mantle*

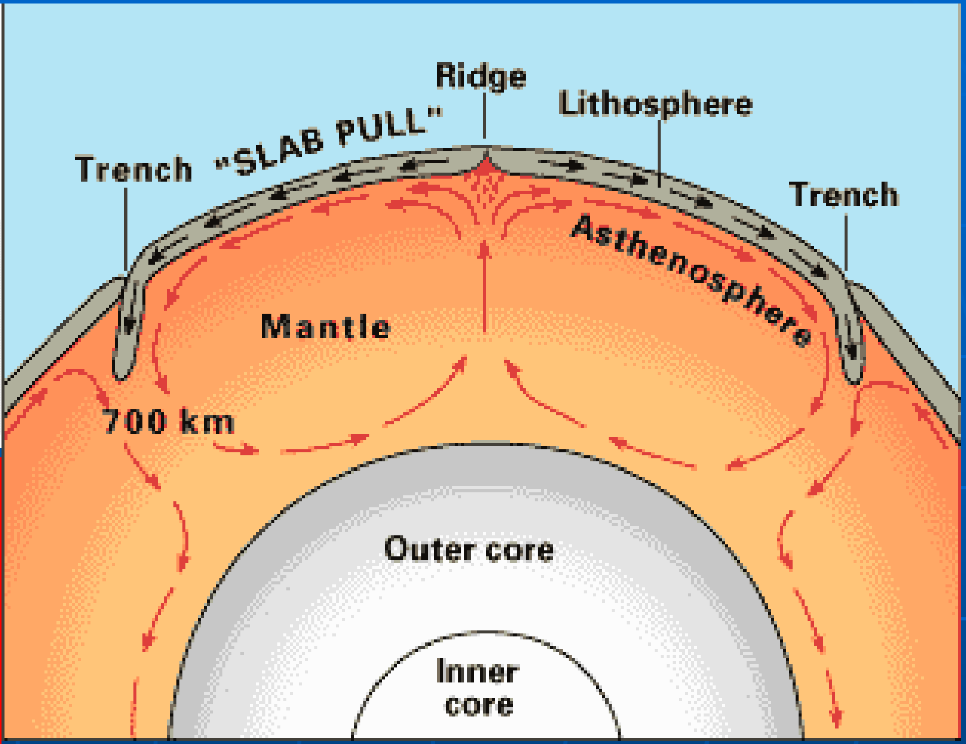
Lowest layer: iron-nickel core (molten outer core; solid inner core)

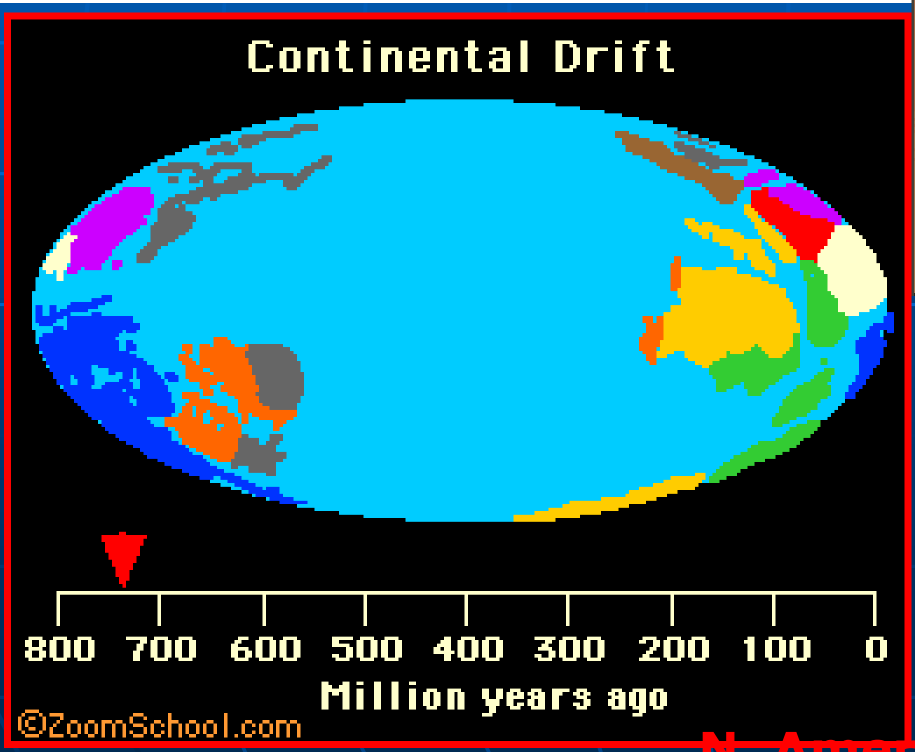
Iron meteorite from Canyon Diablo (Meteor Crater), AZ

Scale: Humans on crust are insignificant

Driving Force-Plate Tectonics







- Rising part of convection cell = rifting (mid-ocean ridge)
- Descending part of convection cell = subduction (deep sea trench)

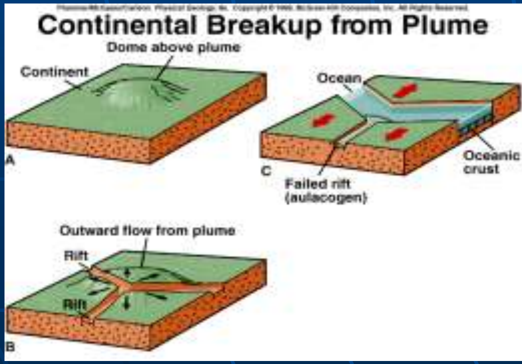
Source: U.S. Geological Survey

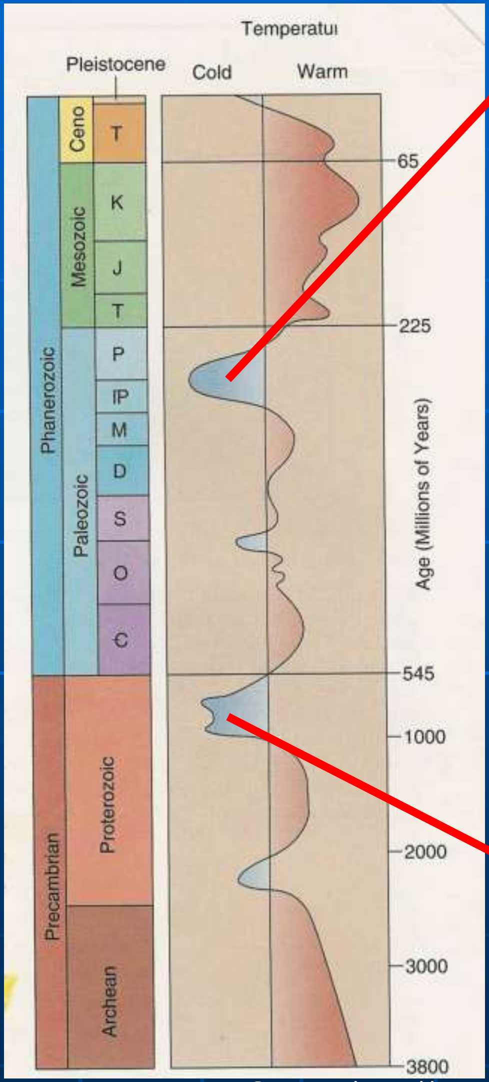
N. America = blue

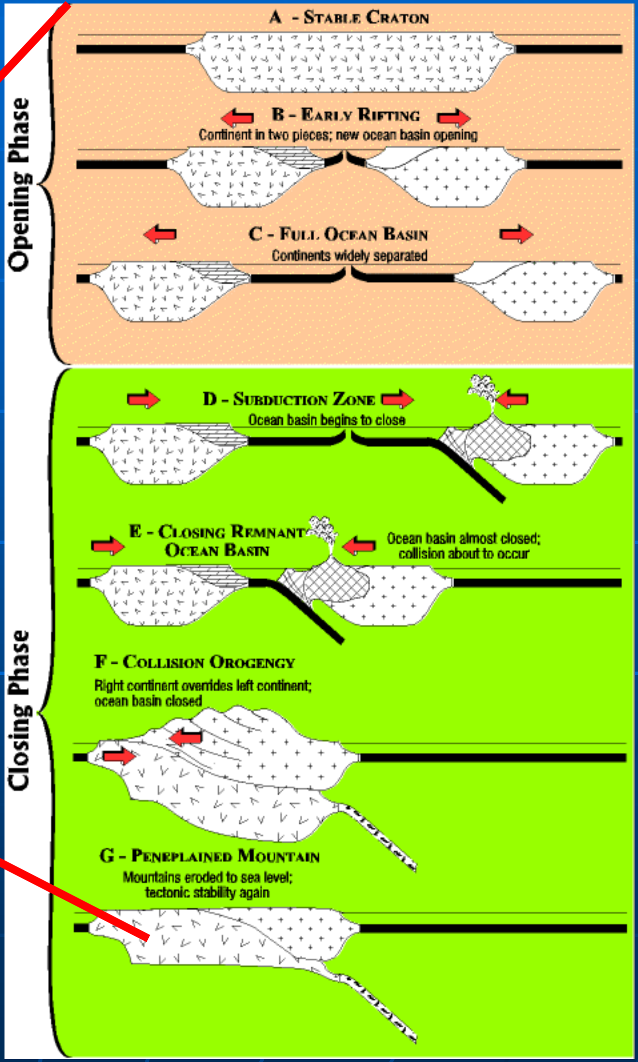
Wilson Cycle - opening/closing of ocean basin

Period of rotation of sun around center of Milky Way galaxy is 225-250 million terrestrial years

https://en.wikipedia.org/wiki/Milky_Way#/media/File:Wide_Field_Imager_view_of_a_Milky_Way_look-alike_NGC_6744.jpg



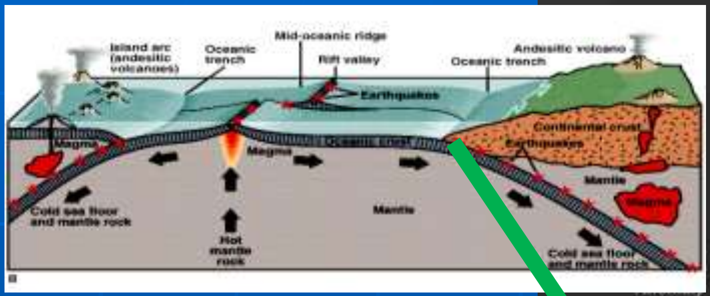


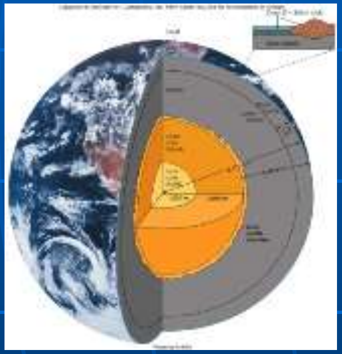


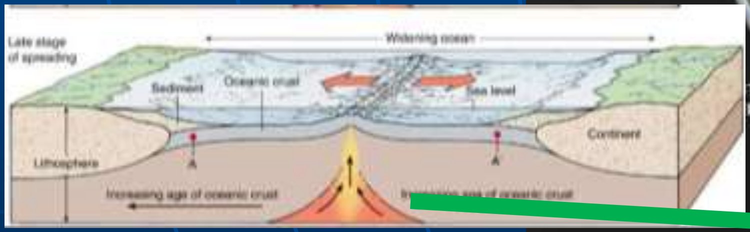
Source: http://csmres.jmu.edu/geollab/Fichter/Wilson/wilsonsimp.html

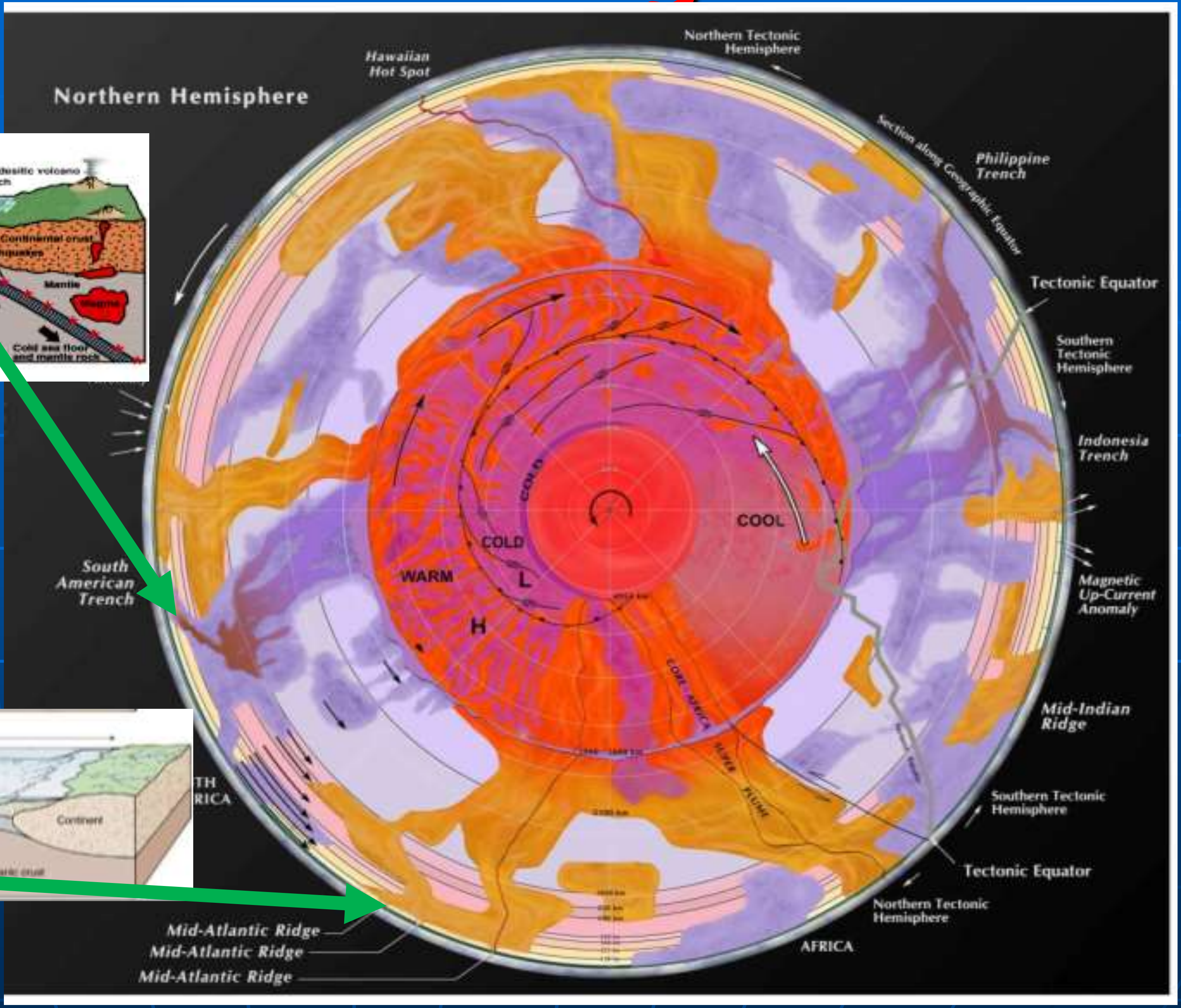
Slice through Core

Sea floor spreading and mid-ocean ridge volcanism





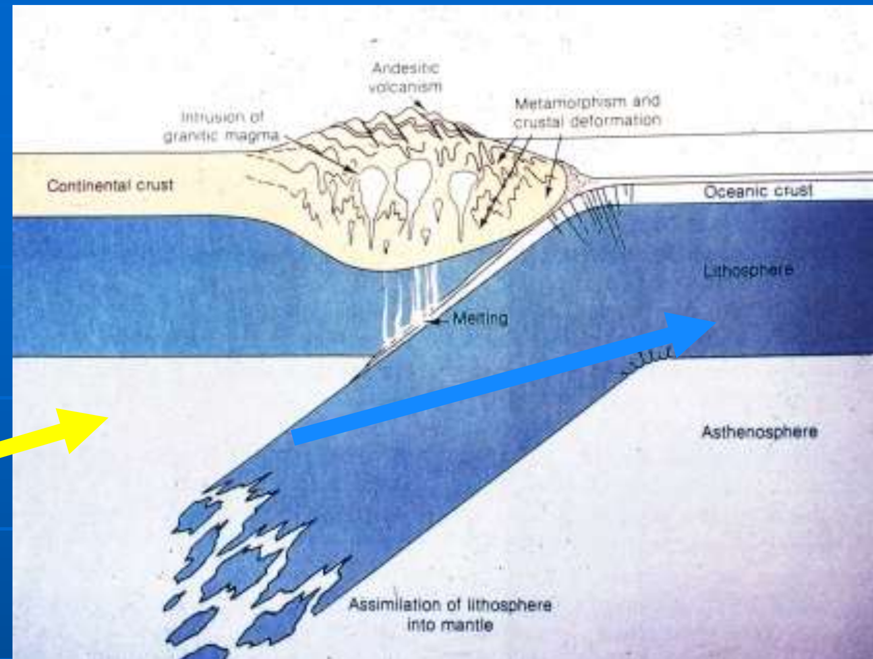




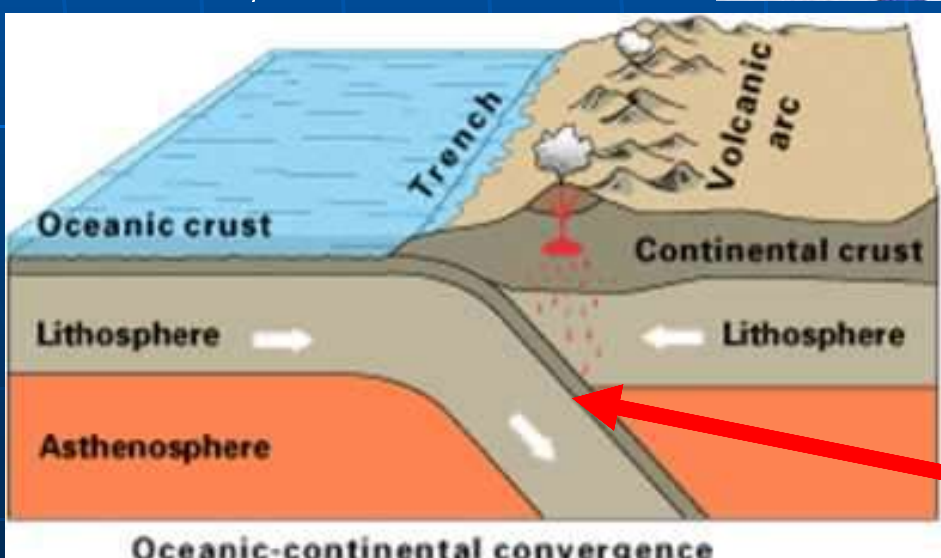
From Stan Keith

Plate Tectonics Effects on Arizona

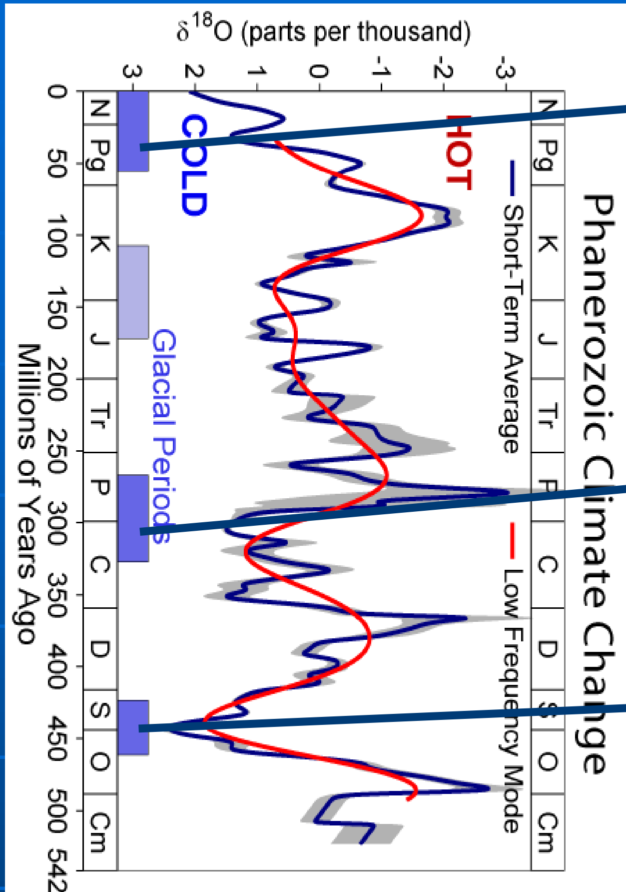
Paleozoic (540-252 Ma [million years ago]) = West-dipping subduction, volcanoes, mountains in Appalachian Mountains

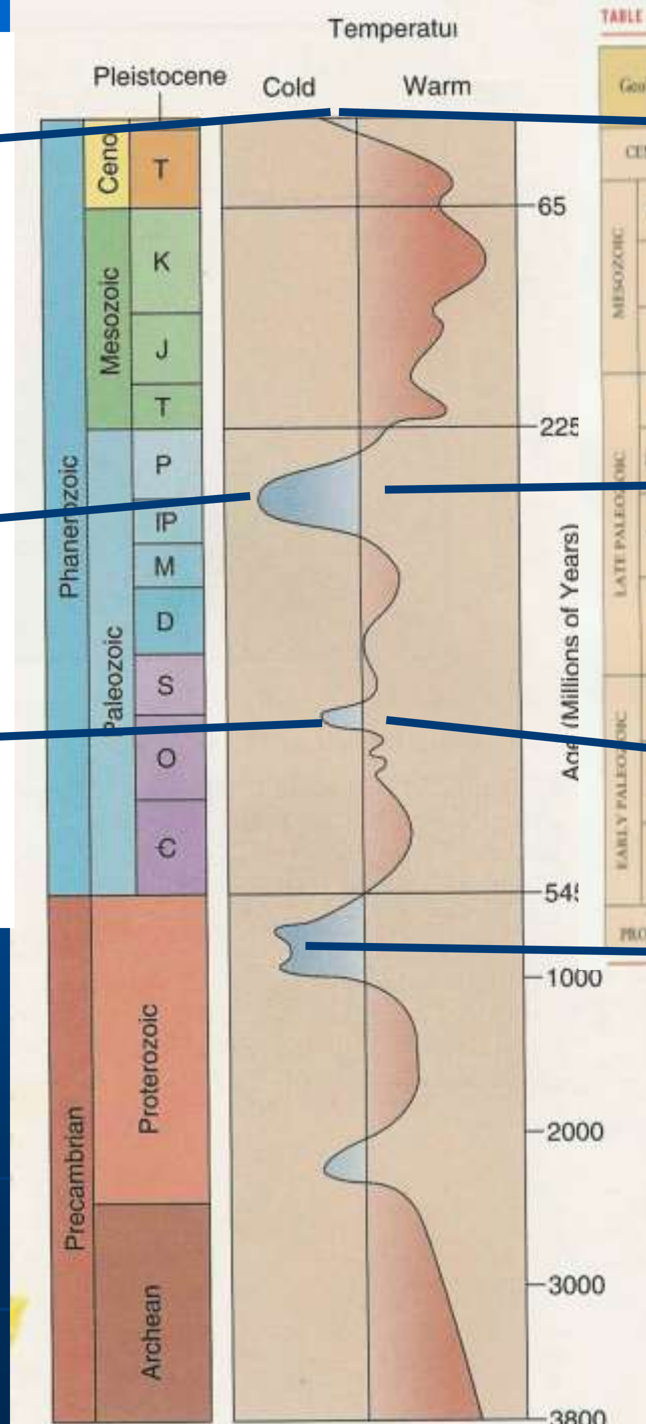


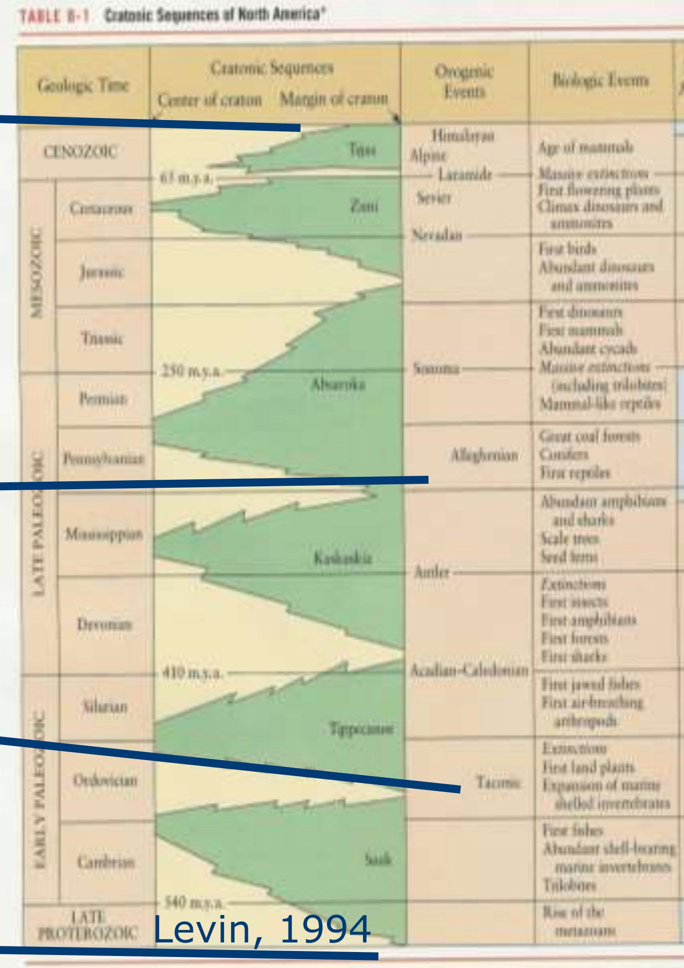
Plummer et al., 2013



Mesozoic (252-65 Ma) - Cenozoic (65-0 Ma) = East-dipping subduction, volcanoes, mountains in west coast of N. America







Temperature & Geologic Time Scale

Continental Assembly Events & Glaciation

Temperature & Geologic Time Scale

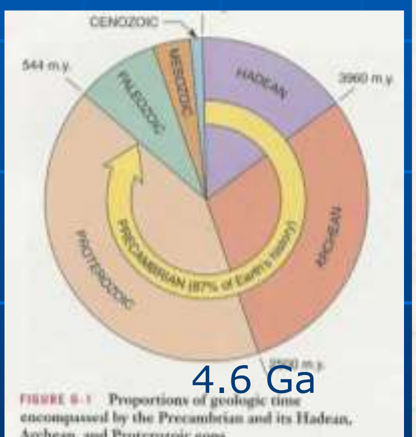
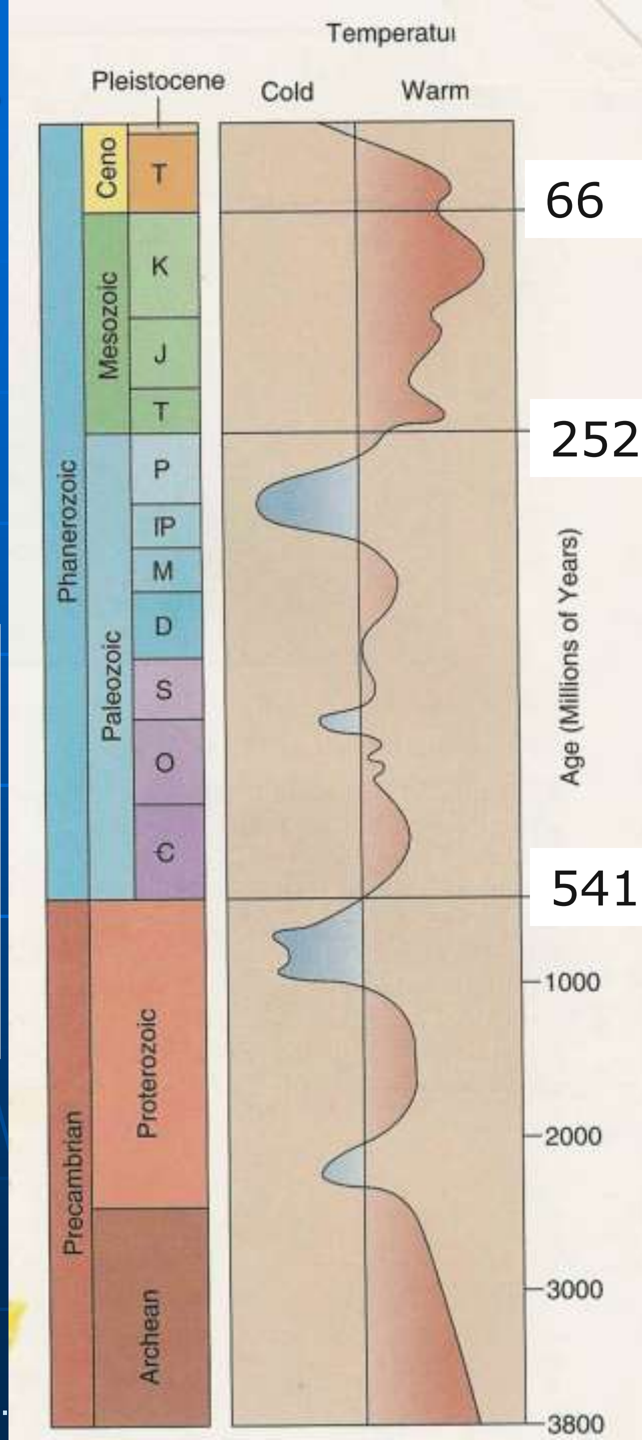


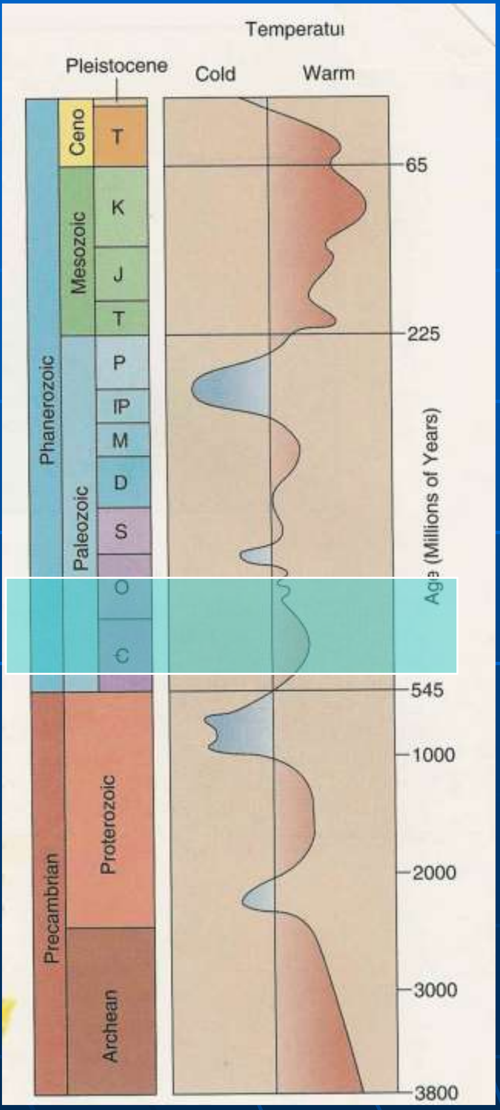
FIGURE 6-1 Proportions of geologic time encompassed by the Precambrian and its Hadean, Archean, and Proterozoic eons.

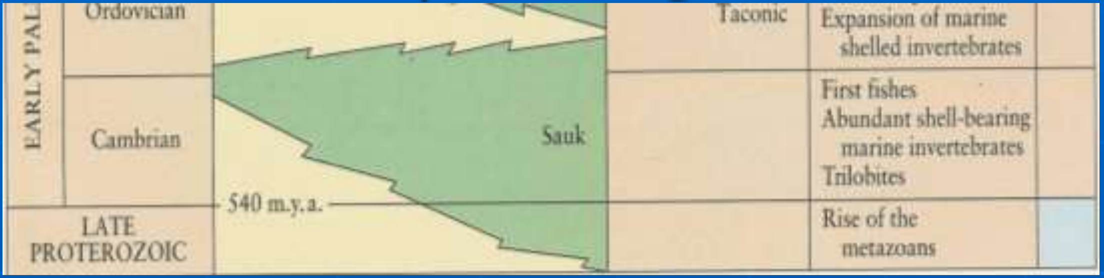


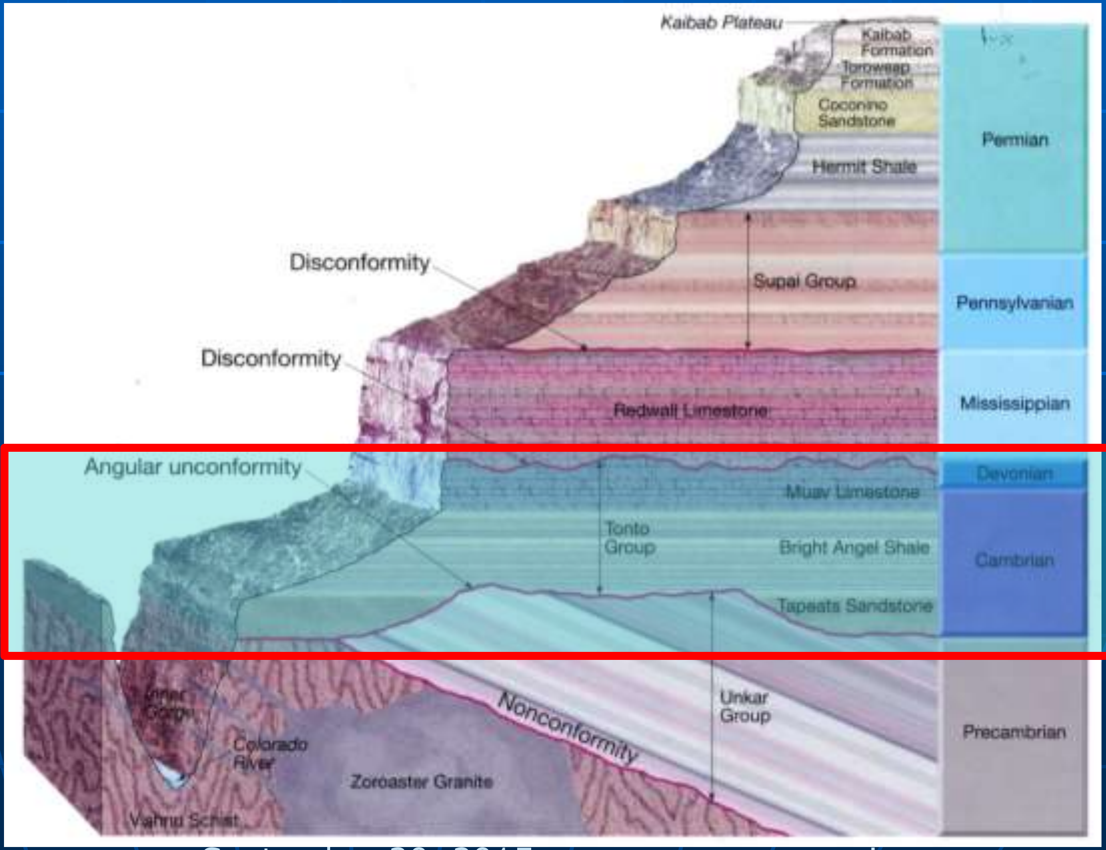
EON	ERA	PERIOD		EPOCH		Ma
Phanerozoic	Cenozoic	Quaternary		Holocene		0.01
Phanerozoic	Cenozoic	Quaternary		Pleistocene	Late	0.8
Phanerozoic	Cenozoic	Quaternary		Pleistocene	Early	1.8
Phanerozoic	Cenozoic	Tertiary	Neogene	Pliocene	Late	3.6
Phanerozoic	Cenozoic	Tertiary	Neogene	Pliocene	Early	5.3
Phanerozoic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

Cambrian – Early Ordovician

543 - 470 million years ago (Ma)







Grand Canyon formations

Photo by Jan Wilt Rasmussen

Cambrian environments (541-485 Ma)

From Ron Blakey

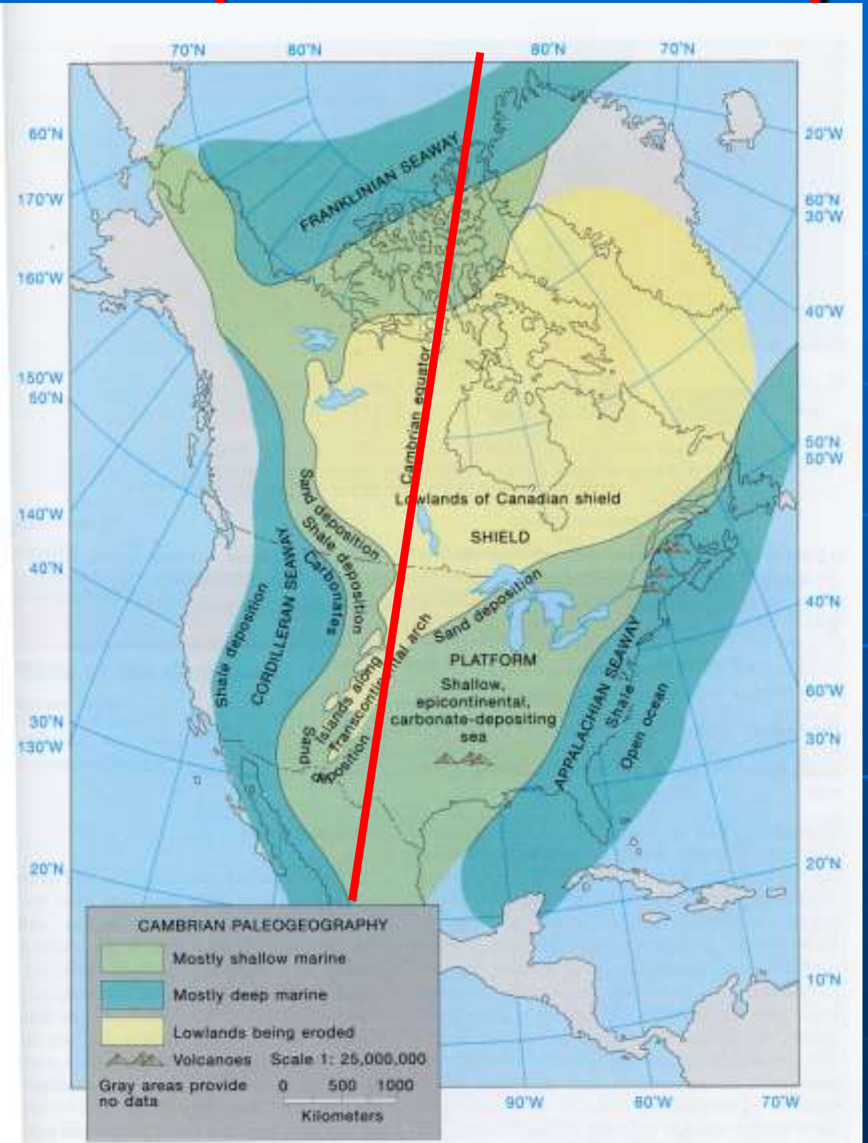
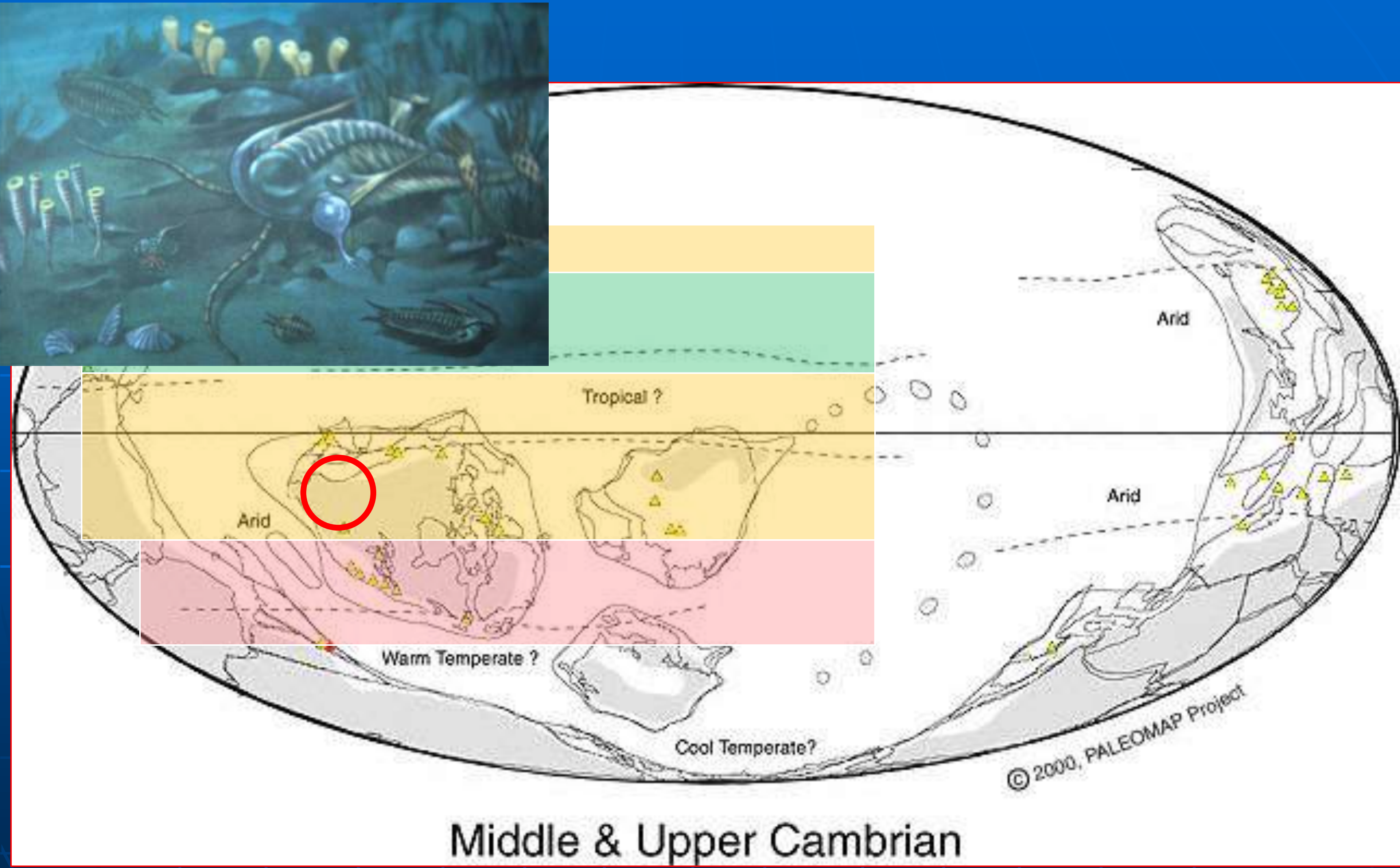


Figure 9–2 Paleogeographic and tectonic elements of North America during the Cambrian Period, showing position of the Cambrian paleoequator.

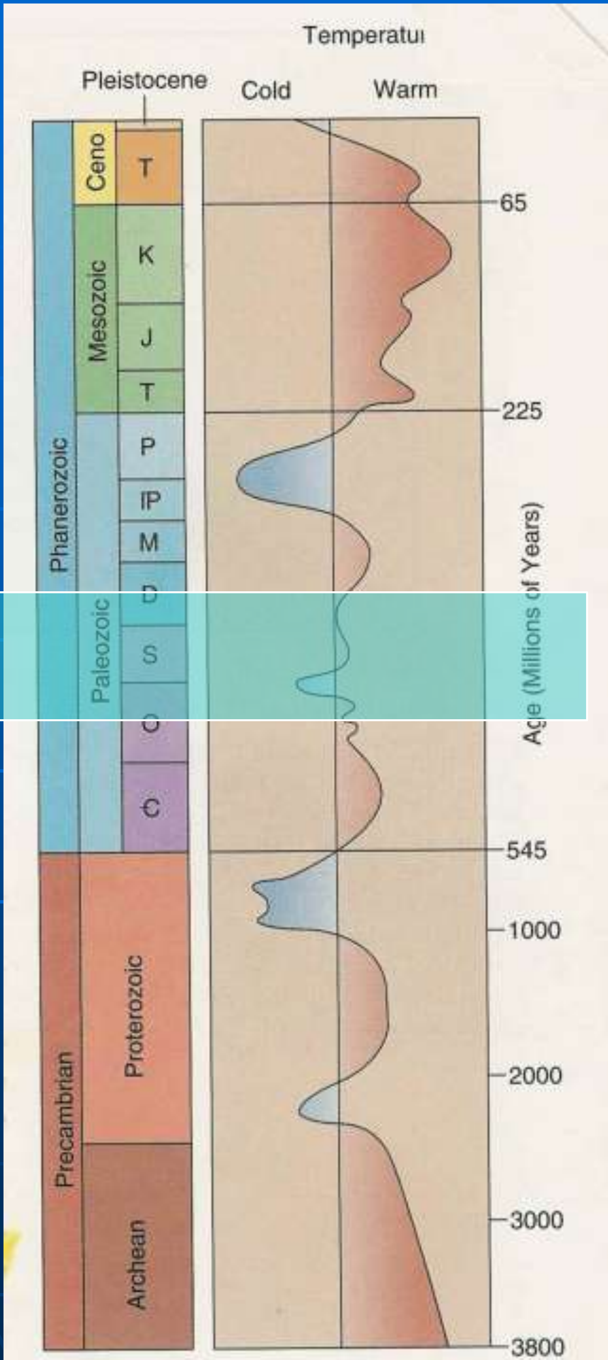
From Levin, 1994

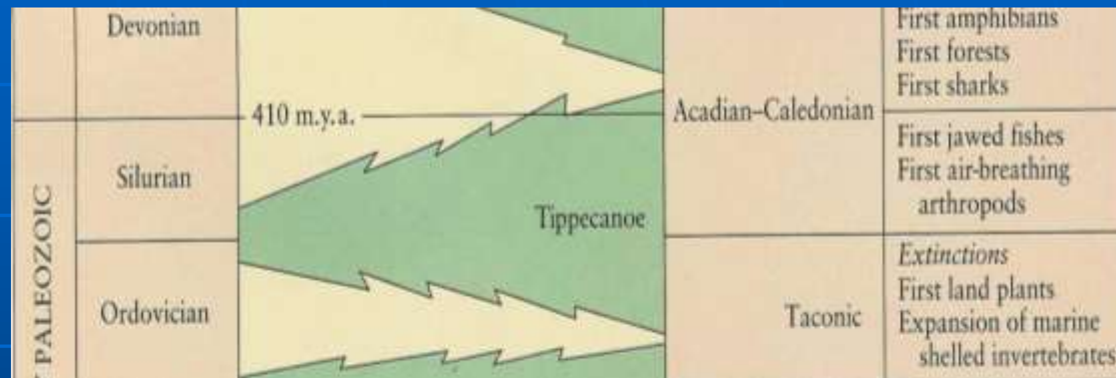
Climate zones 520-485 Ma

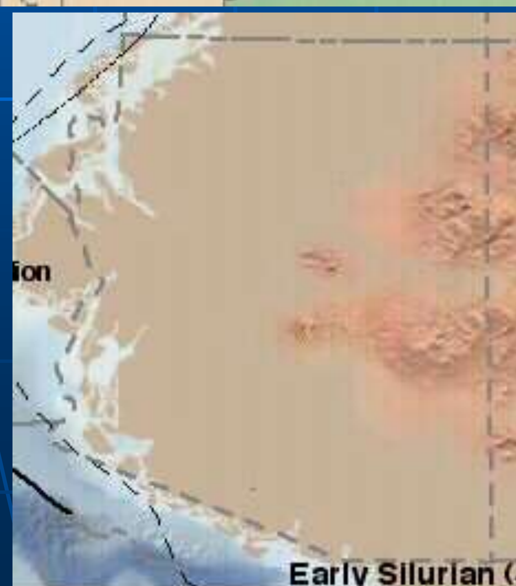


from www.scotese.com

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





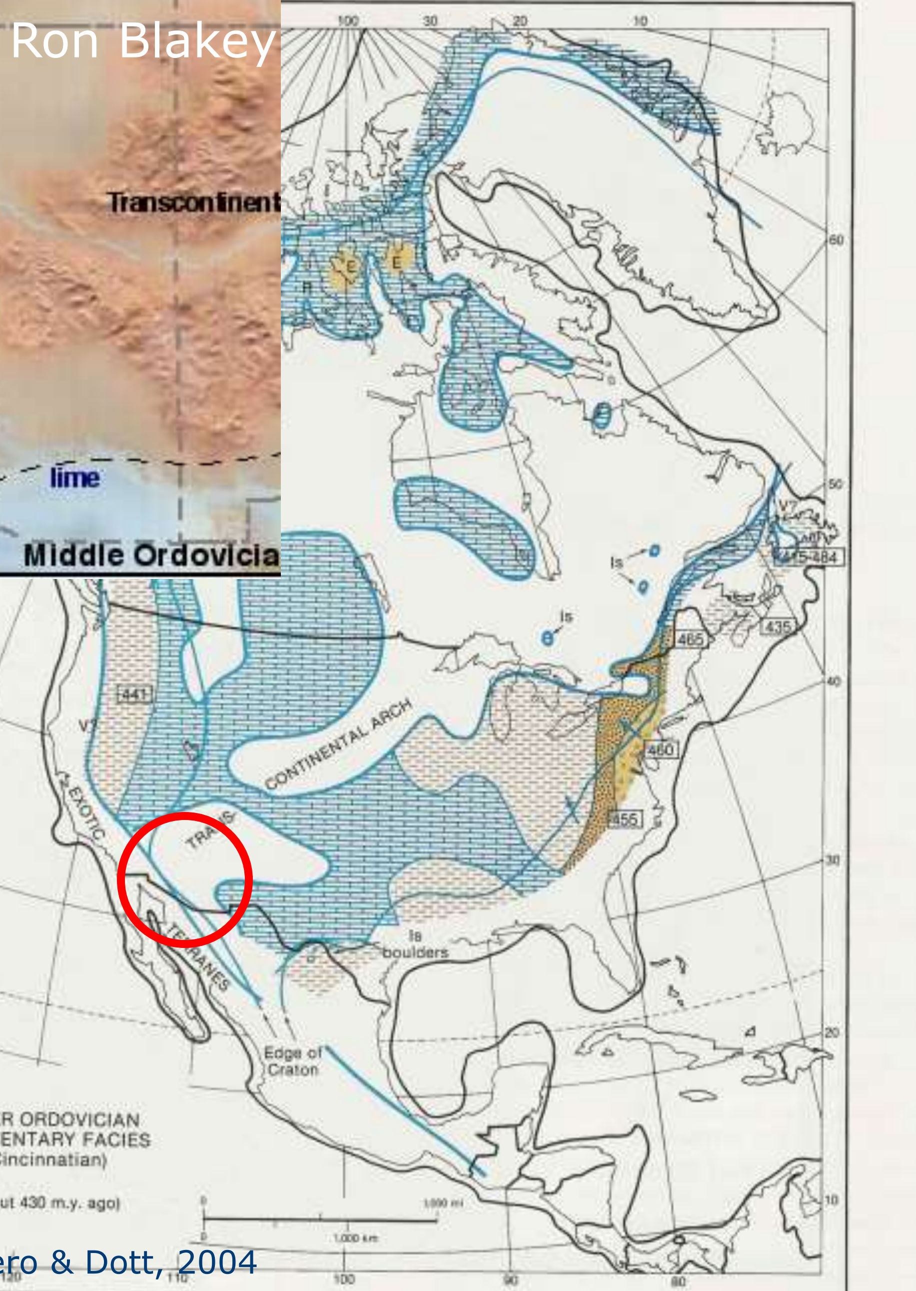


Continental assembly event = Taconic mountain building

Arizona mostly land = erosion = no fossils

Late Ordovician environments (460-440 Ma)

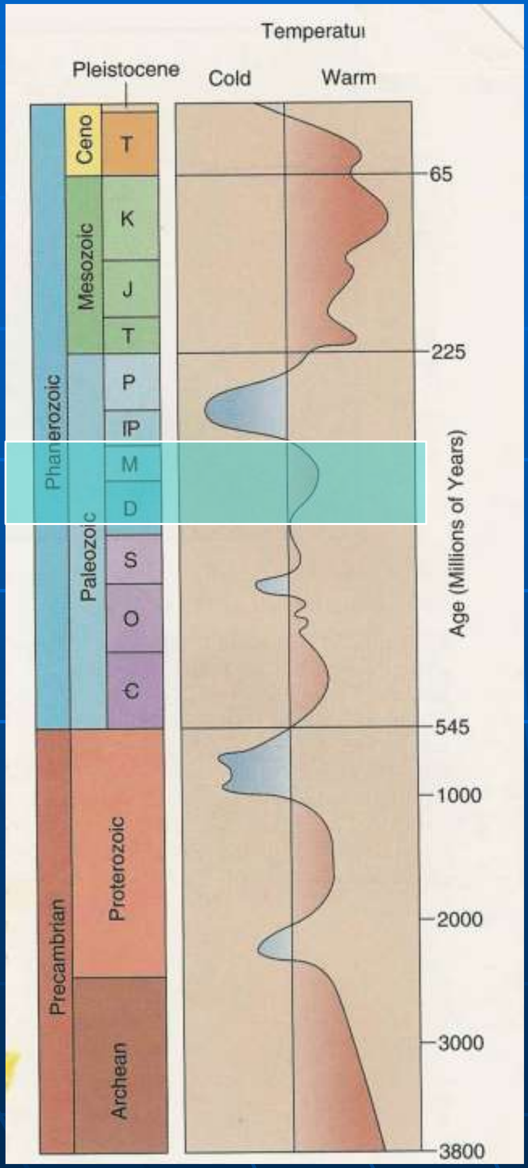
Figure 13-11
Ordovician invertebrate fossils. *A.* A straight-shelled nautiloid about 15 centimeters (6 inches) long. *B.* A spiny trilobite that lived on the sediment surface. *C.* A smooth-shelled burrowing trilobite. *D.* A snail (gastropod). *E* and *F.* Two kinds of articulate brachiopods. *G.*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

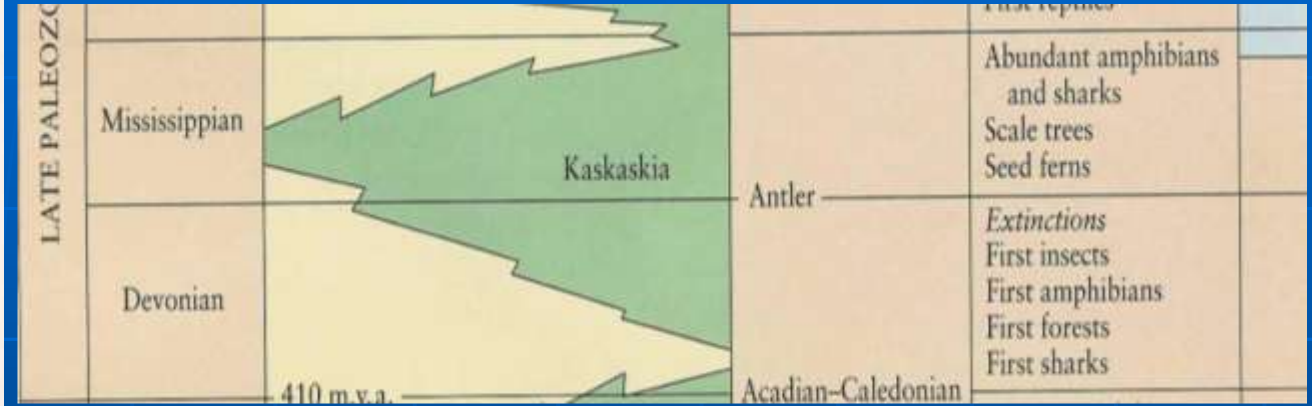


…e 11.15 Upper Ordovician sediment patterns for North America. Widely scattered patches of sediments on the Canadian Shield …he great extent of the Late Ordovician sea. Absence of Ordovician strata on several arches proves subsequent warping and erosion of …ches. Note the spread of red beds and marine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

Devonian – Mississippian

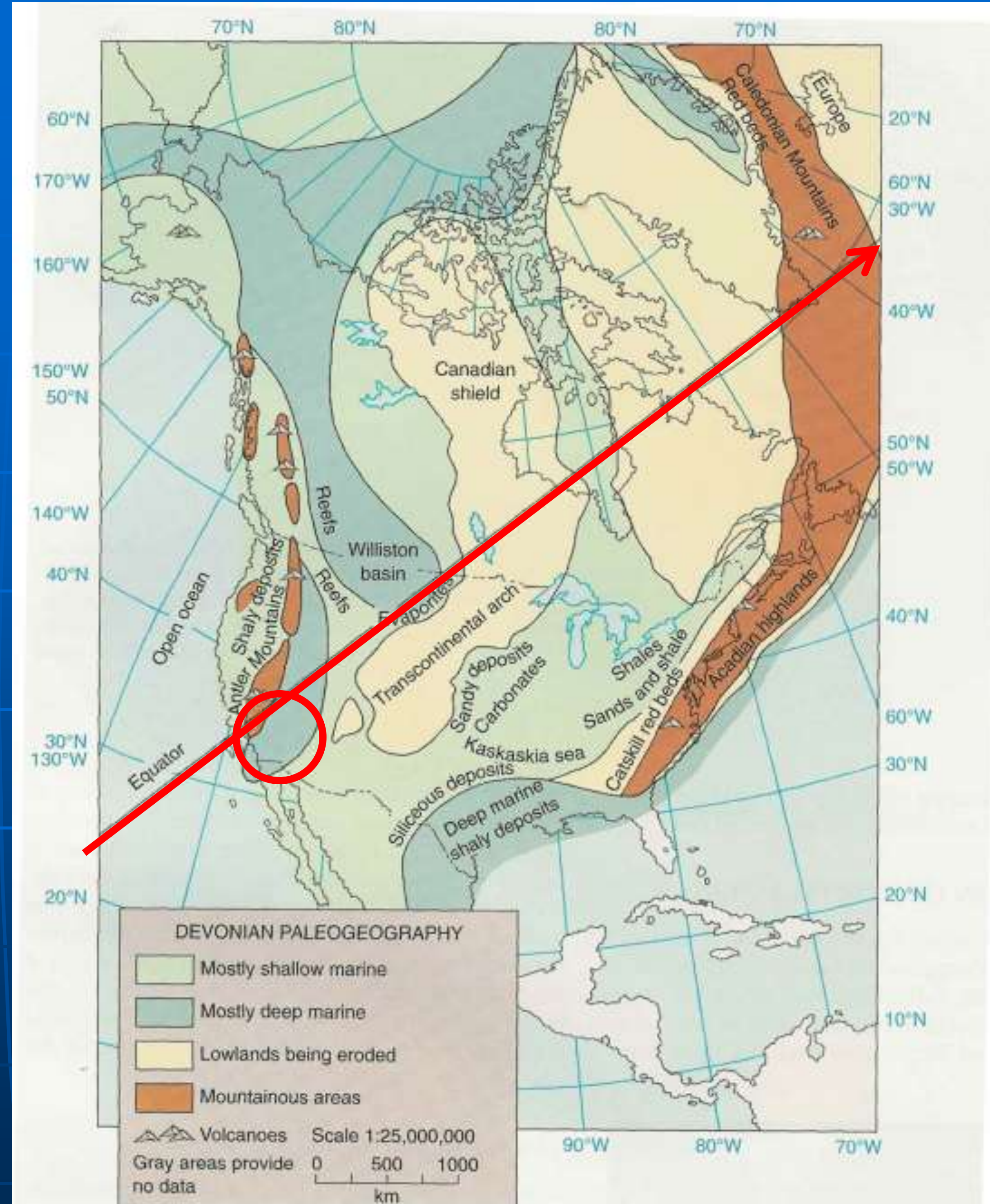
419-359 -- 323 Ma





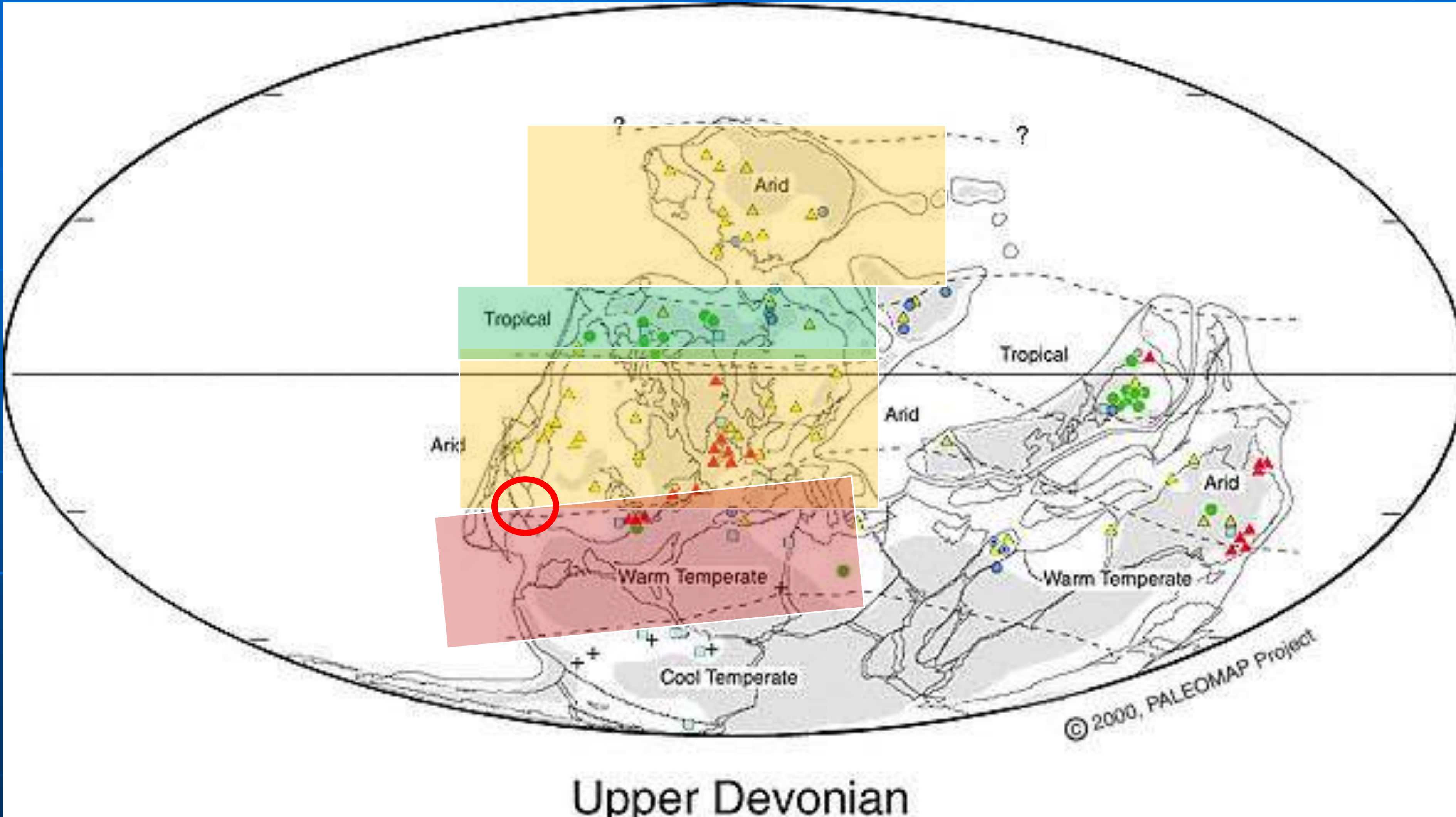
Devonian environments

From Ron Blakey



Levin 1994

Climate zones 420-390 Ma



from www.scotese.com

Devonian invertebrate fossils


Lithostrotionella


Platyrachella


Hexagonaria

Devonian armored fish

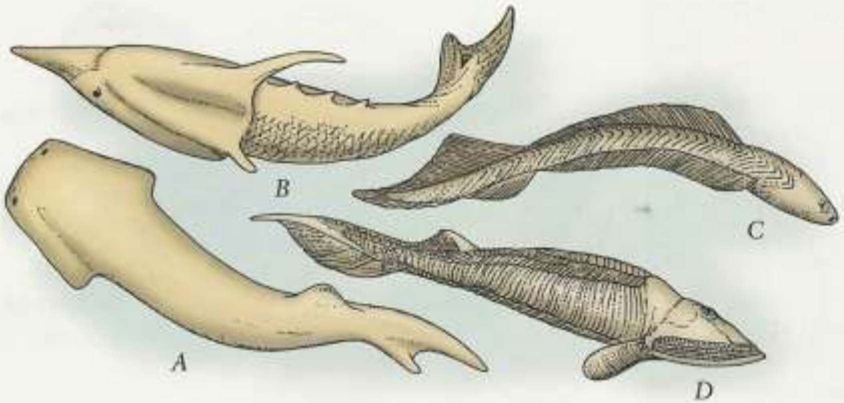


FIGURE 10-60 **Early Paleozoic ostracoderms.** (*A*) *Thelodus*, (*B*) *Pteraspis*, (*C*) *Jamoytius*, and (*D*) *Hemicyclaspis*, drawn to the same scale.

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.*)

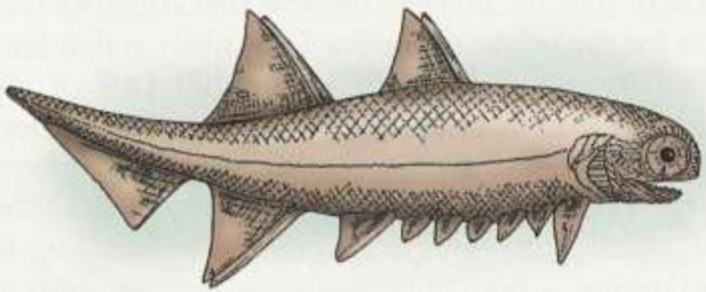


FIGURE 10-61 **The Early Devonian acanthodian fish *Climatius*.** (*After Romer, A. S. 1945.* Vertebrate Paleontology. *Chicago: University of Chicago Press.*)

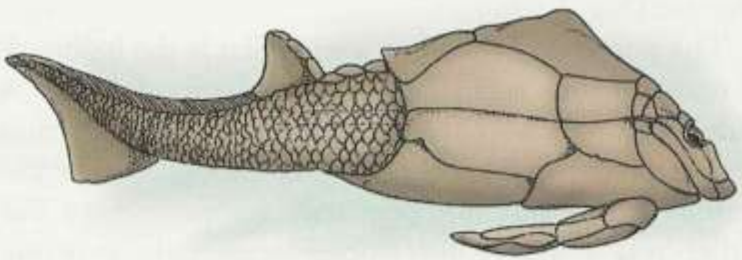
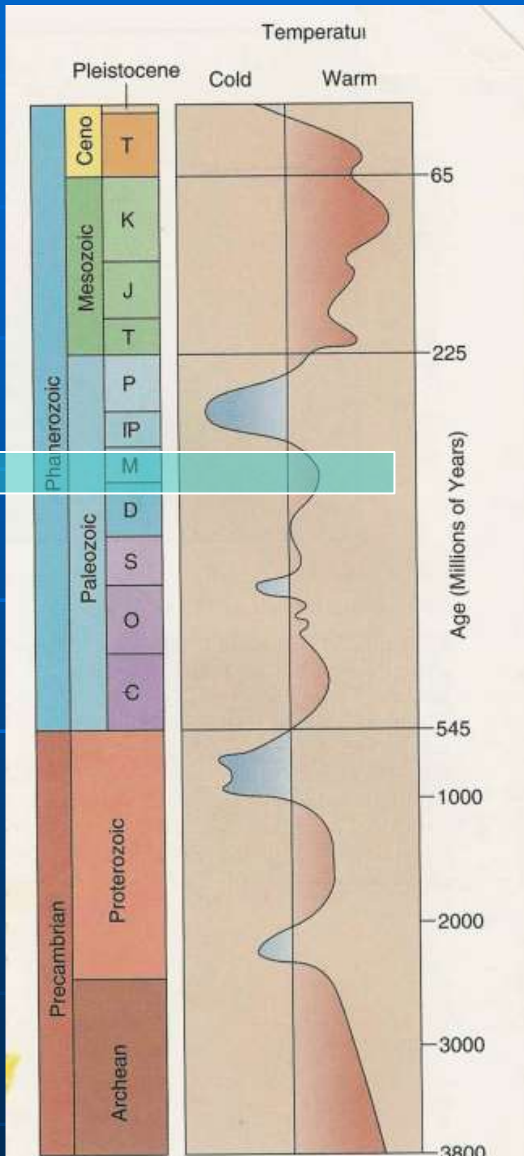


FIGURE 10-63 **The Devonian antiarch fish *Pterichthyodes*.** (*From Romer, A. S. 1945.* Vertebrate Paleontology. *Chicago: University of Chicago Press, p. 54, fig. 38.*)

Devonian plants

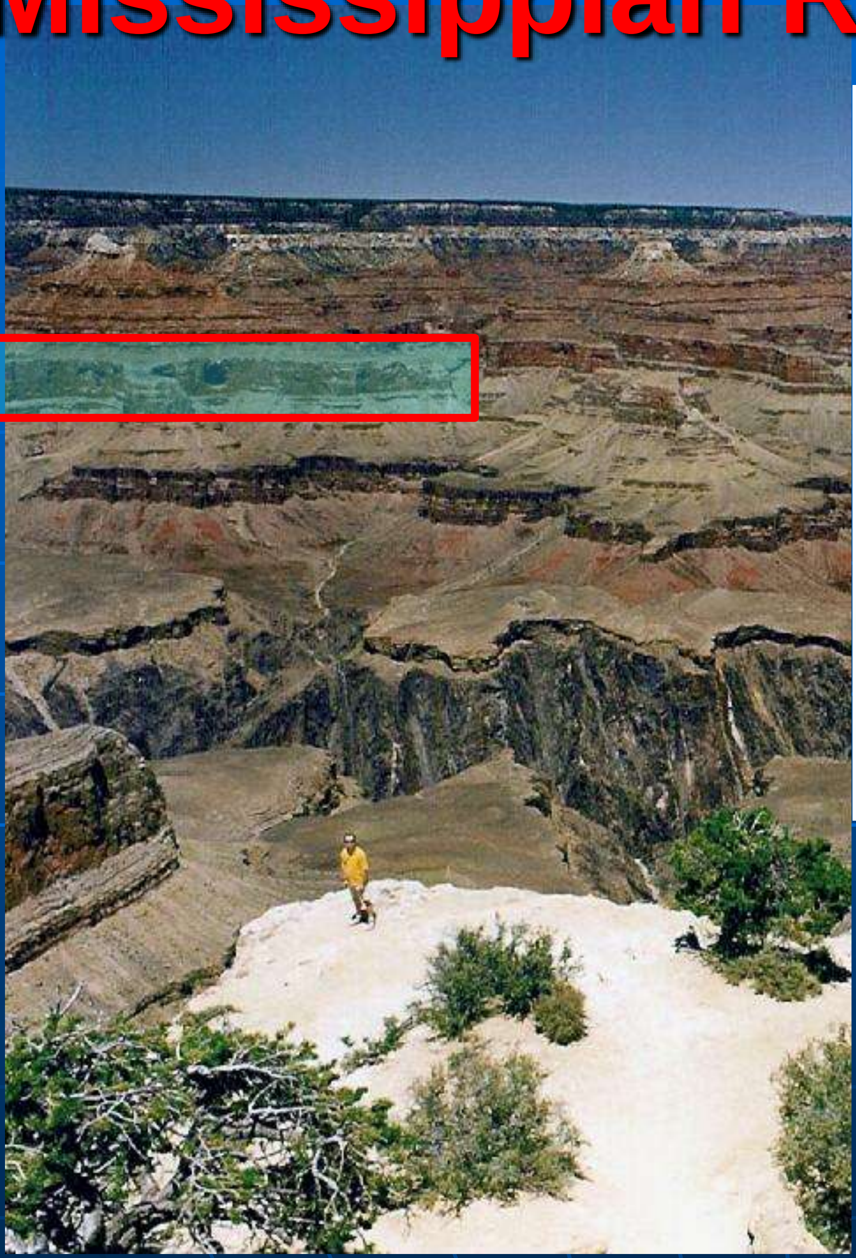
Source: Time-Life, The World We Live In, 1955

Mississippian (359-323 Ma)



Vasey's paradise in Grand Canyon

Mississippian Redwall Limestone



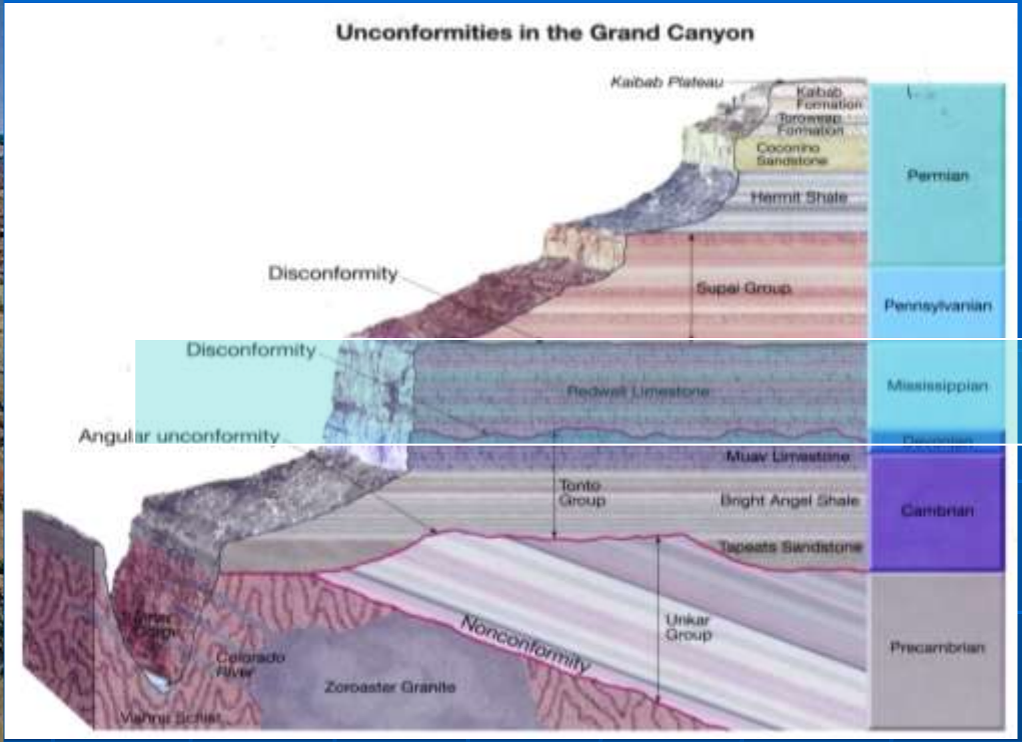


Photo by Jan Wilt Rasmussen

Mississippian environments

From Ron Blakey

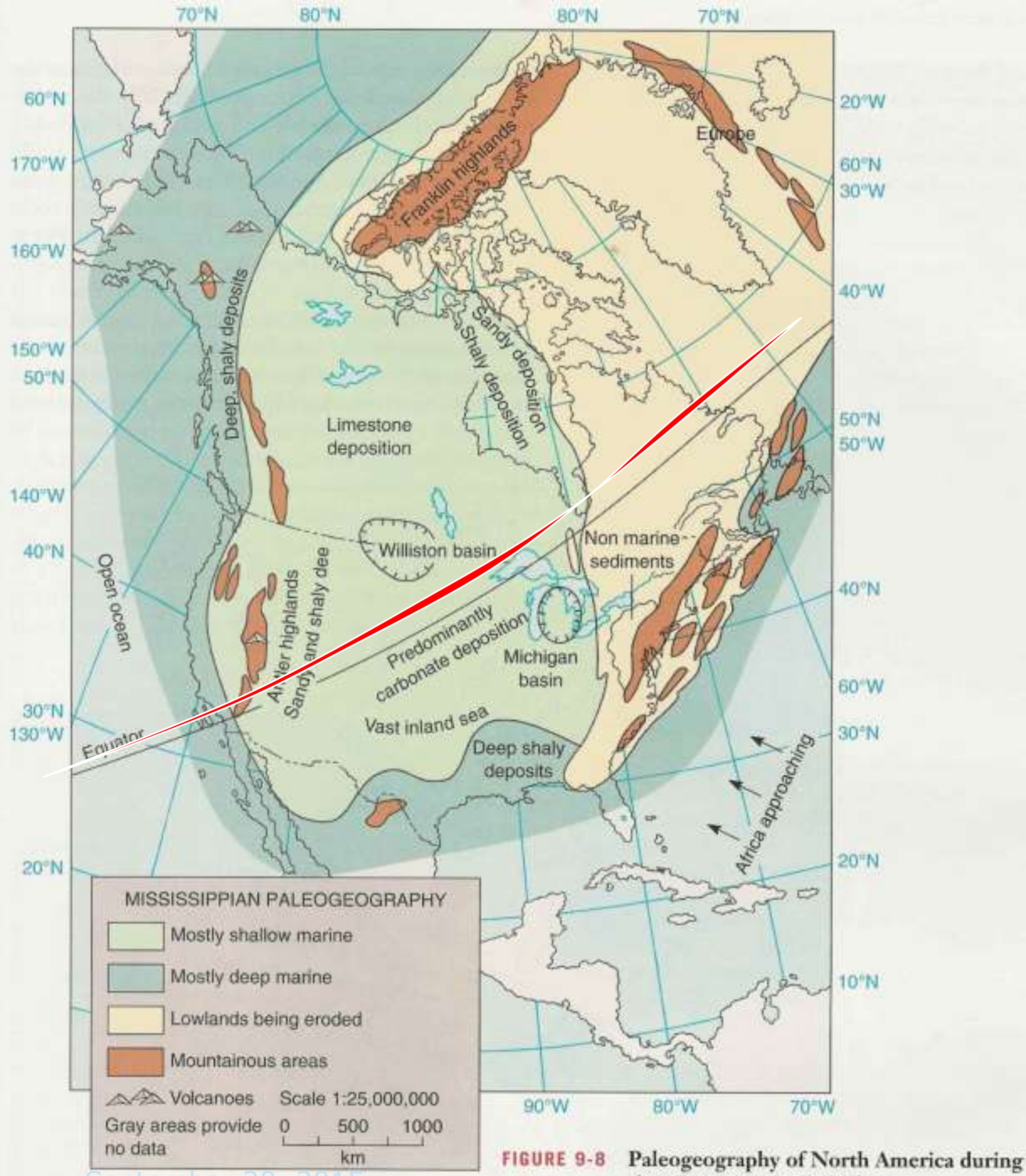
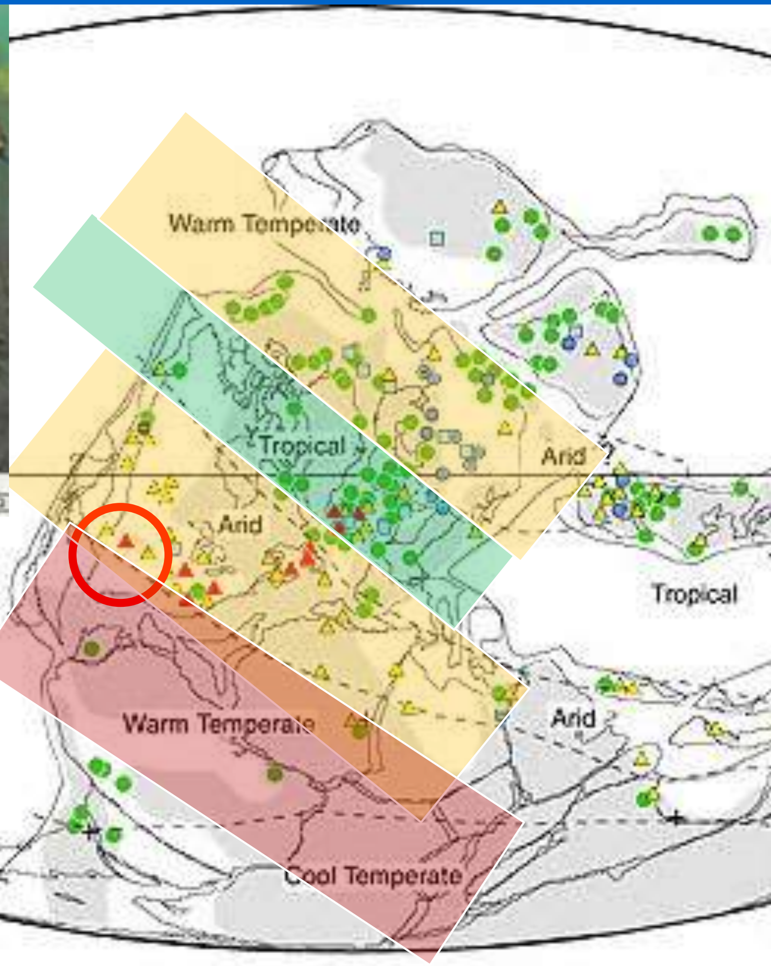


FIGURE 9-8 Paleogeography of North America during the Mississippian Period.

Levin 1994

Climate zones (359-330 Ma)

Levin, 1994



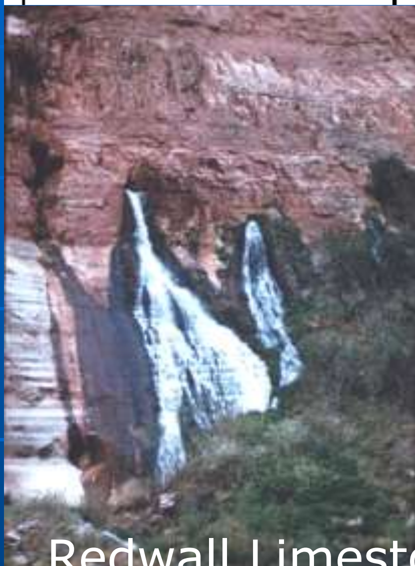
Lower Carboniferous (Tournaisian - Visean)

Photo by Jan Wilt Rasmussen

from www.scotese.com

Lull - Mississippian Limestones

Orogeny	Orogenic Phase	Age (Ma)	Age (period)	Arizona Magmatism	Alkalinity	Resources	Mining districts
Alleghenian (Ouachita)		325-220	Miss. – Triassic	None	-	U in sed. rocks	Payson uranium
Acadian/ Caledonian		410-380	Devonian	None	-	Limestone	



Redwall Limestone

Photo by Jan Rasmussen

Escabrosa Limestone

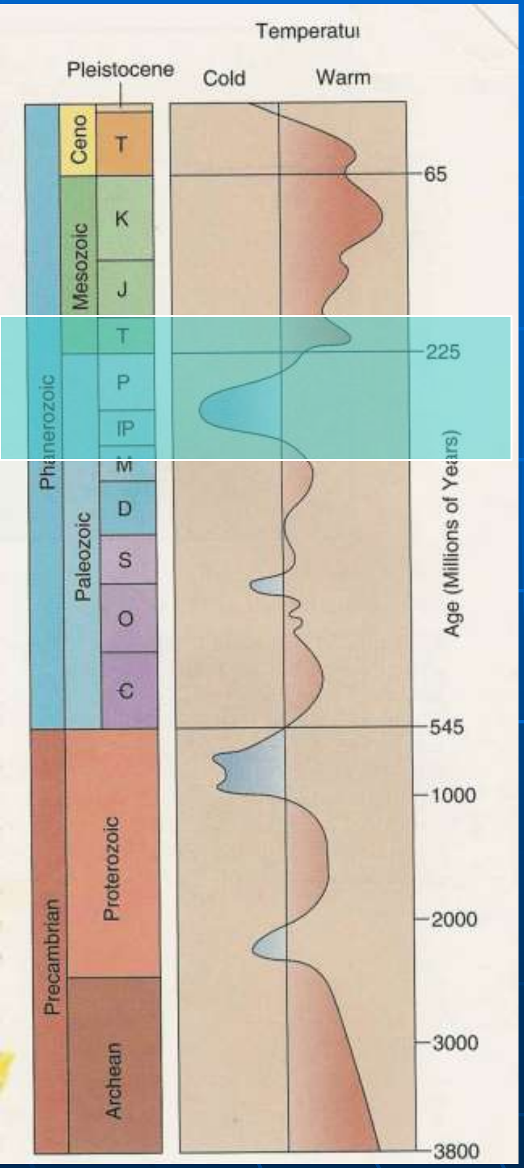
Clarkdale Cement plant

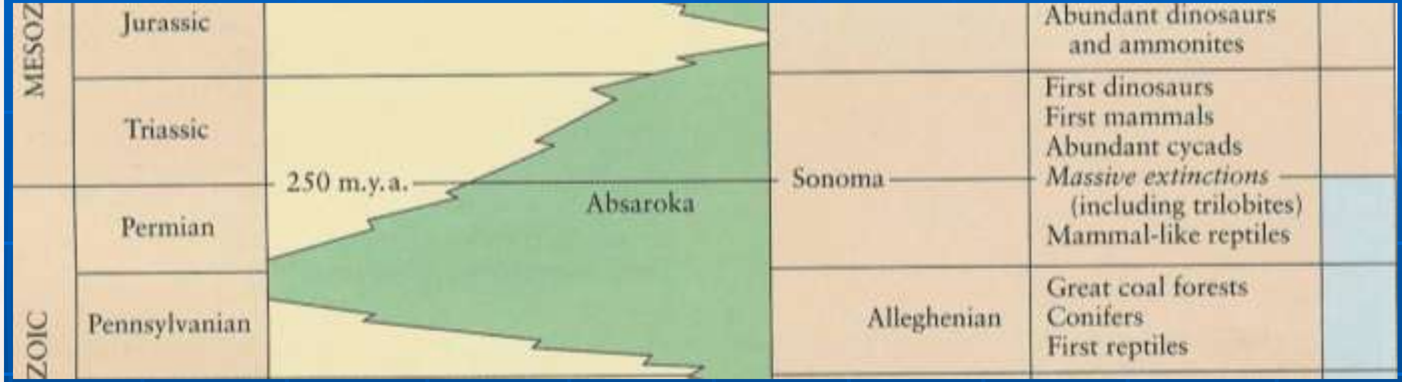
Rillito Cement plant

Sahuarita Marble

Photos by Jan Rasmussen

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





From Levin, 1994

Pennsylvanian environments

From Ron Blakey

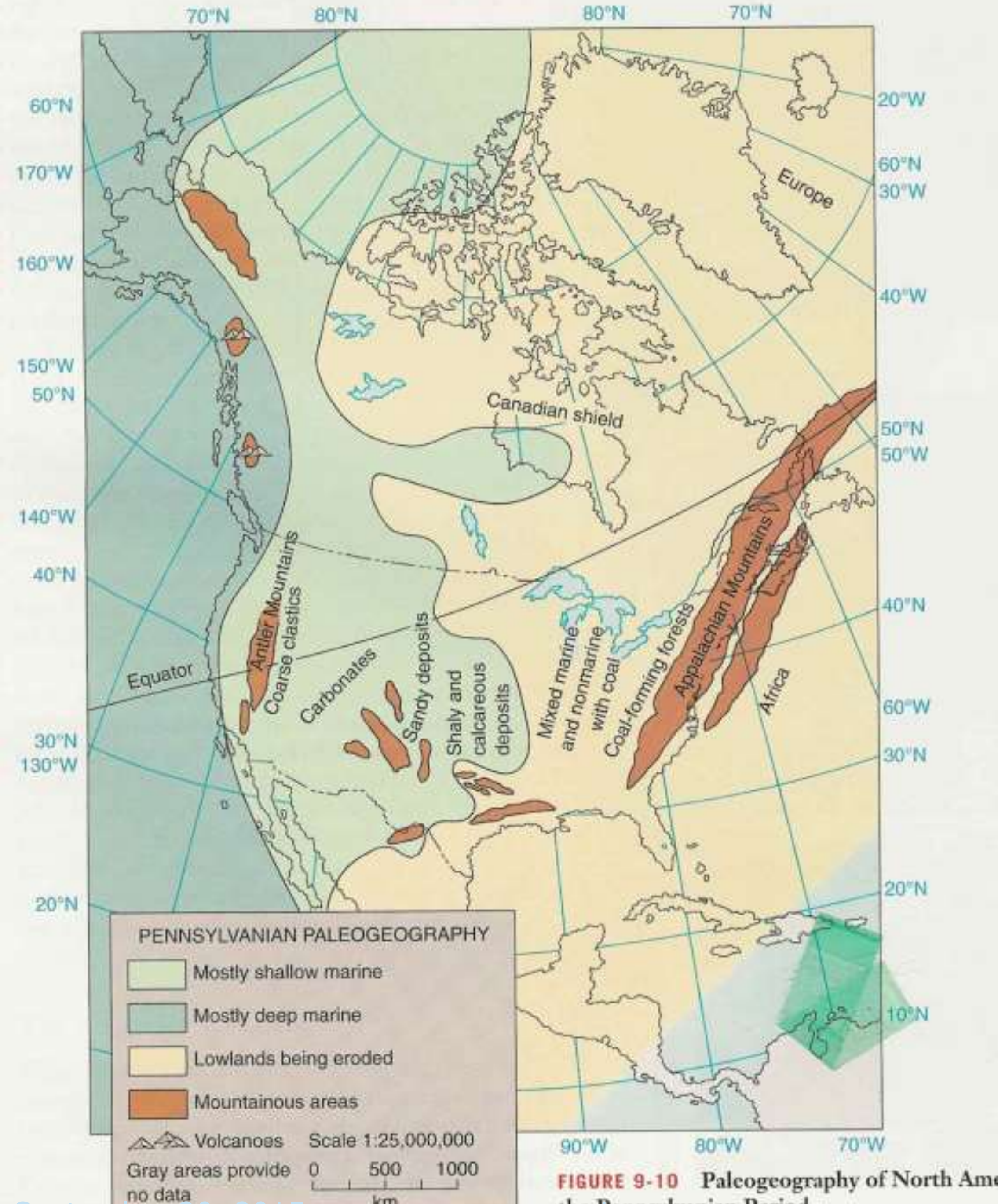
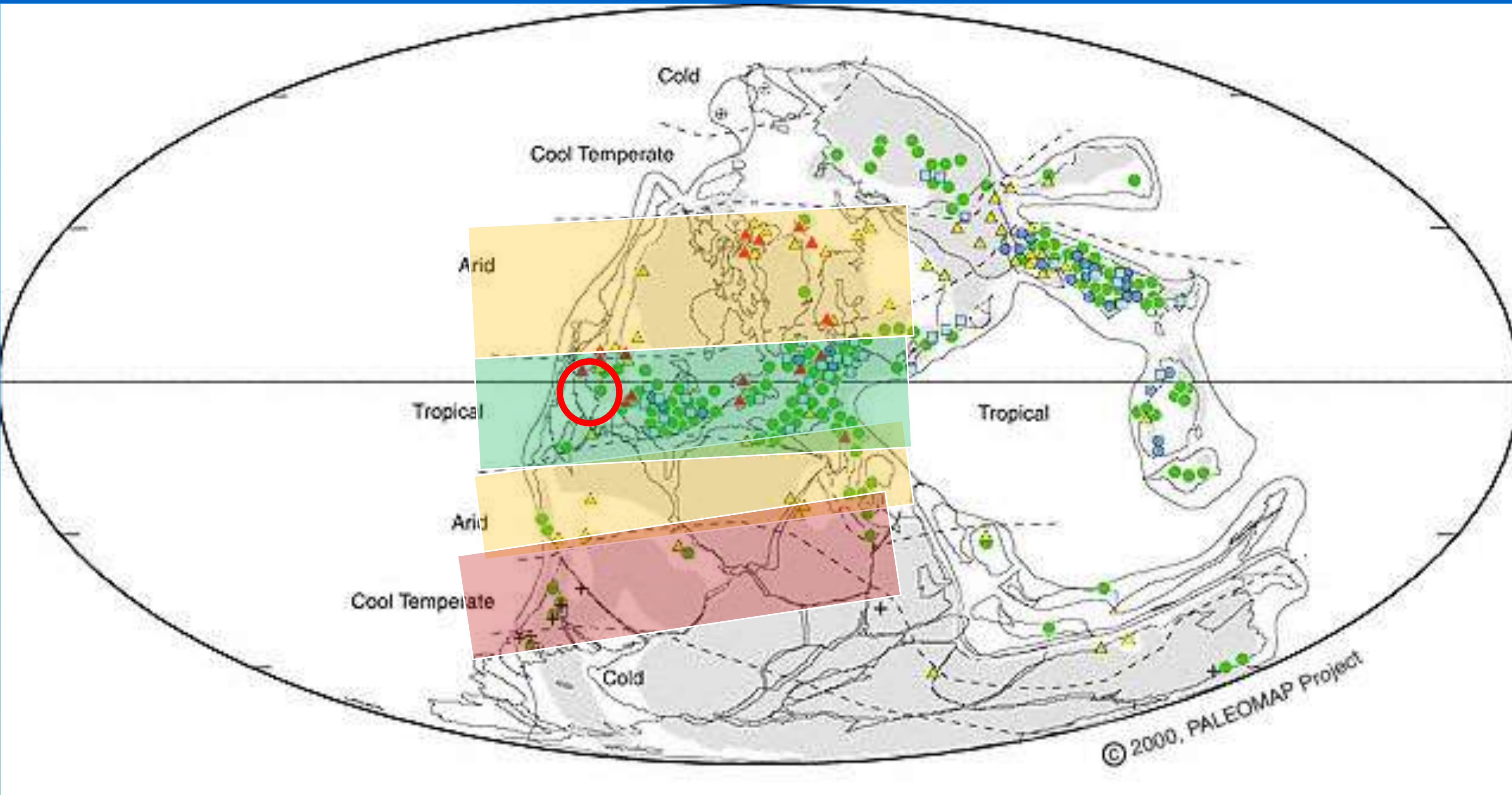


FIGURE 9-10 Paleogeography of North Ame[rica during] the Pennsylvanian Period.

Levin 1994

Pennsylvanian (323-307 Ma)



Upper Carboniferous (Bashkirian - Moscovian)

from www.scotese.com

Pennsylvanian amphibians, plants

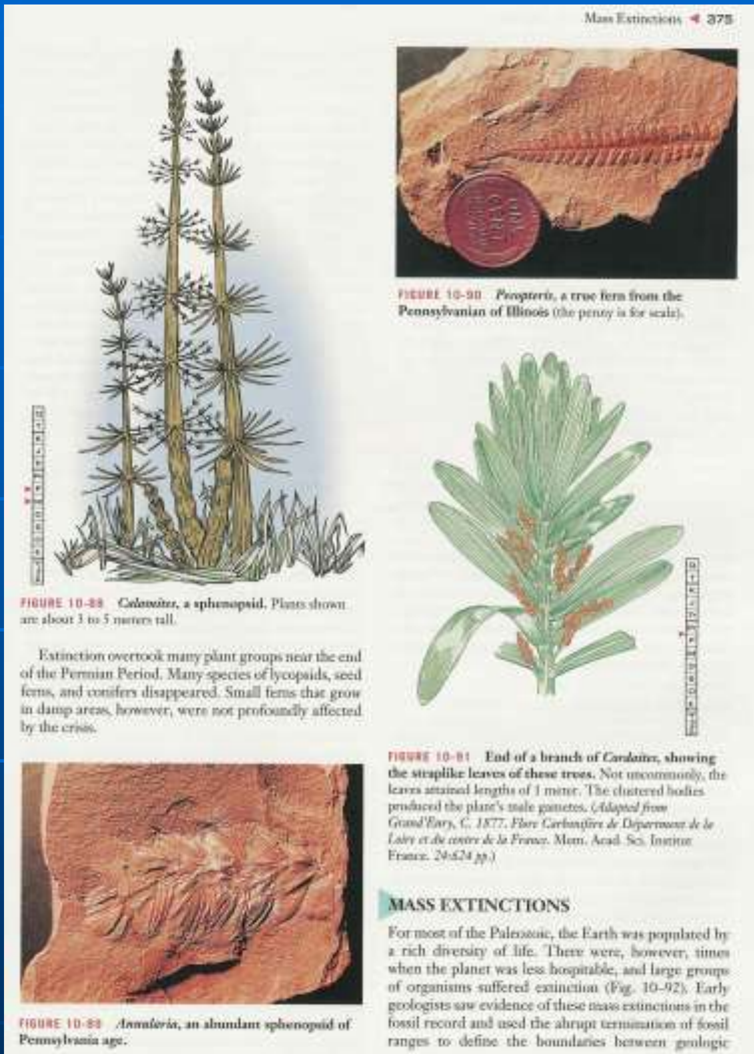


FIGURE 10-88 ***Calamites*****, a sphenopsid.** Plants shown are about 3 to 5 meters tall.

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

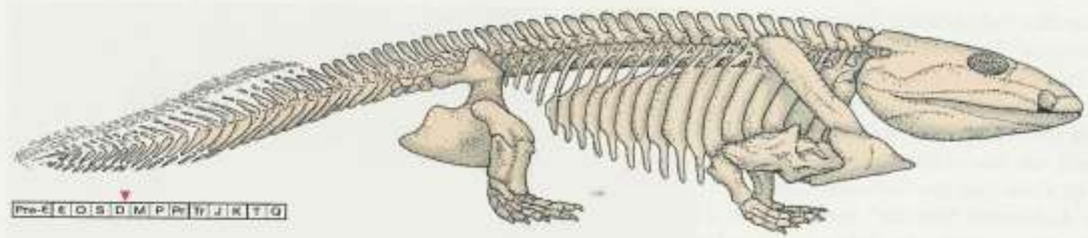


FIGURE 10-76 **The skeleton of** ***Ichthyostega*** **still retains the fishlike form of its crossopterygian ancestors.** (*From Levin, H. L. 1975.* Life Through Time. *Dubuque, Iowa: William C. Brown Co.*)

Cyclic coal beds (Cyclothems)

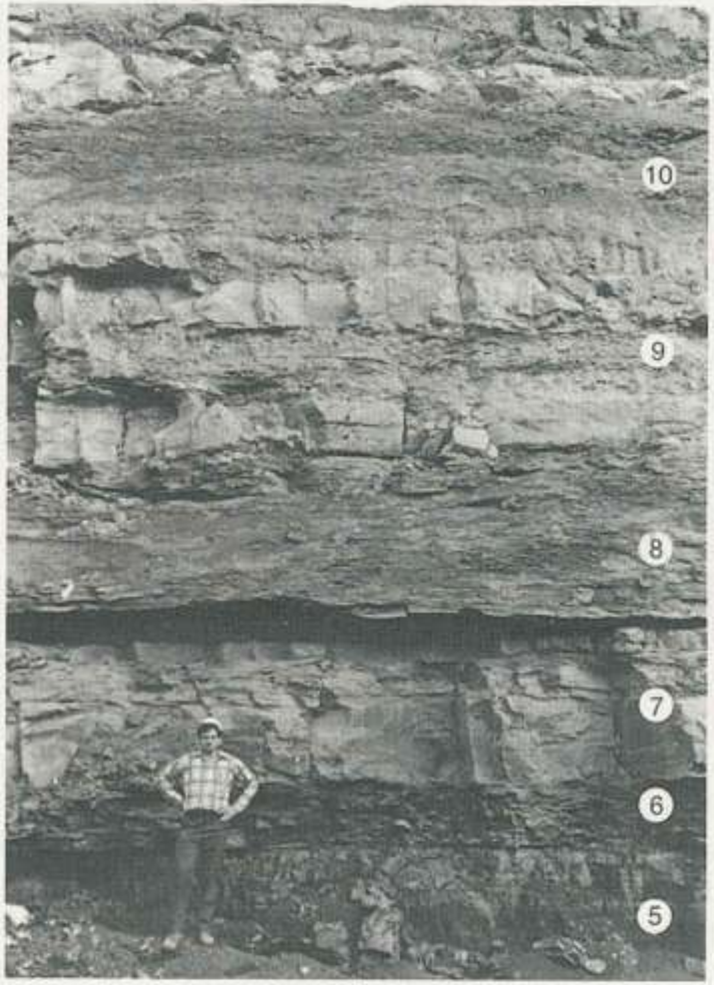


FIGURE 9-12 Part of an Illinois cyclothem. The lowermost layer is the coal seam (cyclothem bed 5), followed upward by shale (bed 6) near the geologist's hand, limestone (bed 7), shale (bed 8), another limestone (bed 9), and the upper shale (bed 10). Part of another sequence caps the exposure. This cyclothem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

Levin, 1994

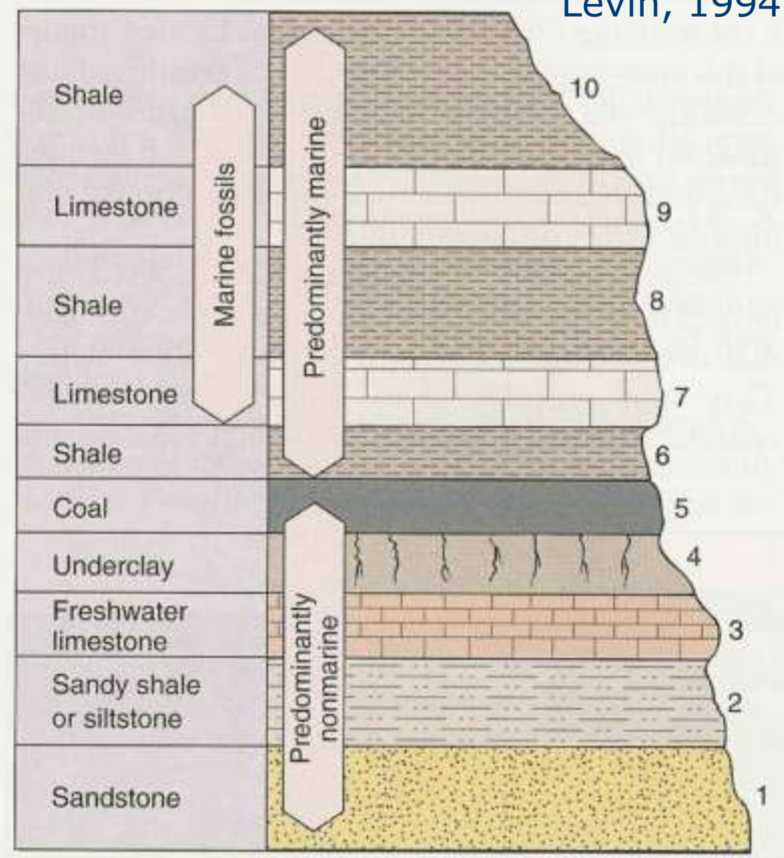
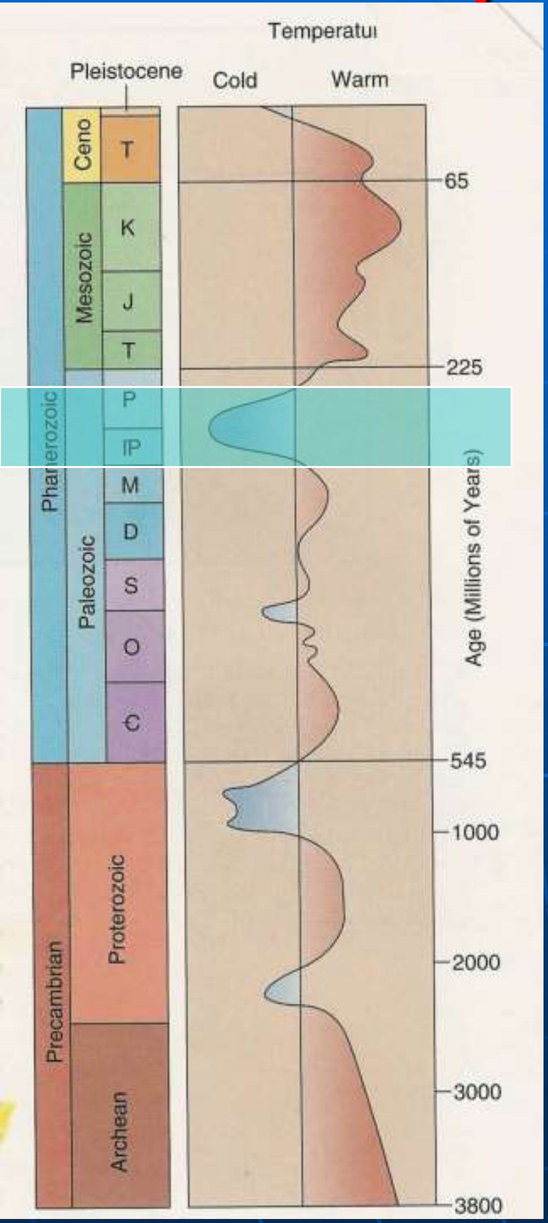


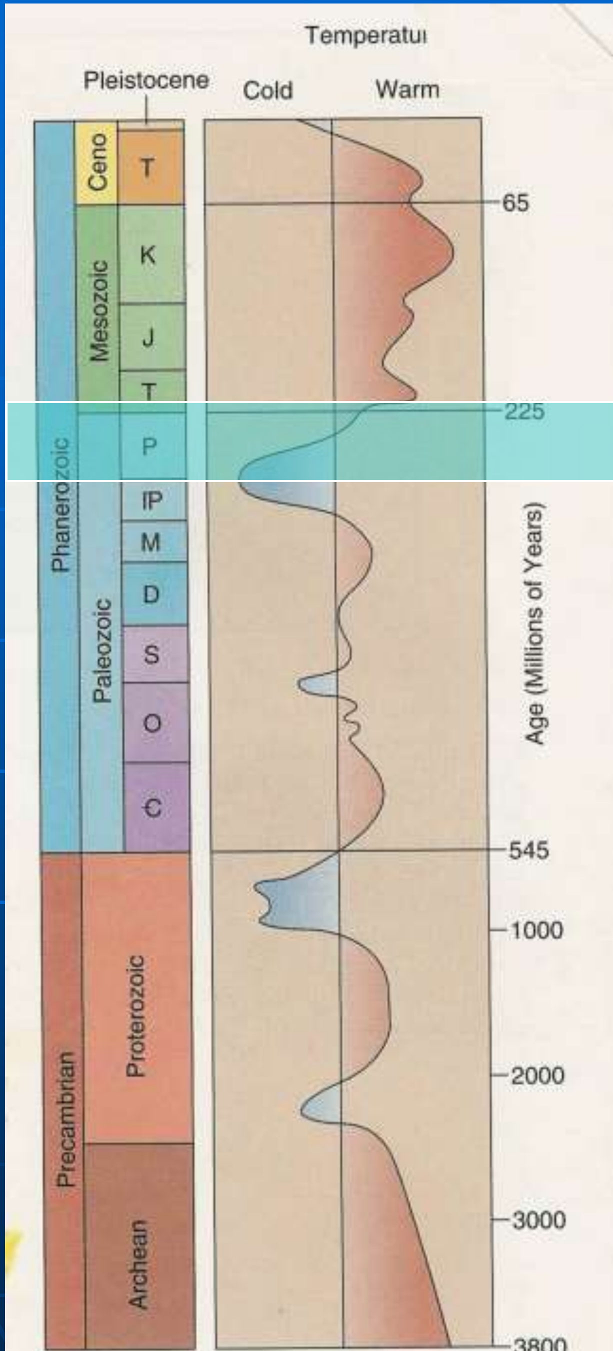
FIGURE 9-11 An ideal coal-bearing cyclothem, showing the typical sequence of layers. Many cyclothems do not contain all 10 units, as in this illustration of an idealized sequence. Some units may not have been deposited because changes from marine to nonmarine conditions may have been abrupt and/or units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

Pennsylvanian-Permian Ice Age



Penn.-Permian Earp Fm. SE of Tombstone

Permian (299-252 Ma)



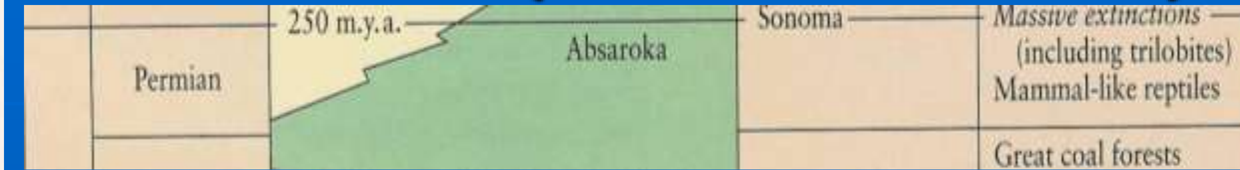


Photo by Jan Rasmussen

Supai Group, Sedona

Permian Grand Canyon section

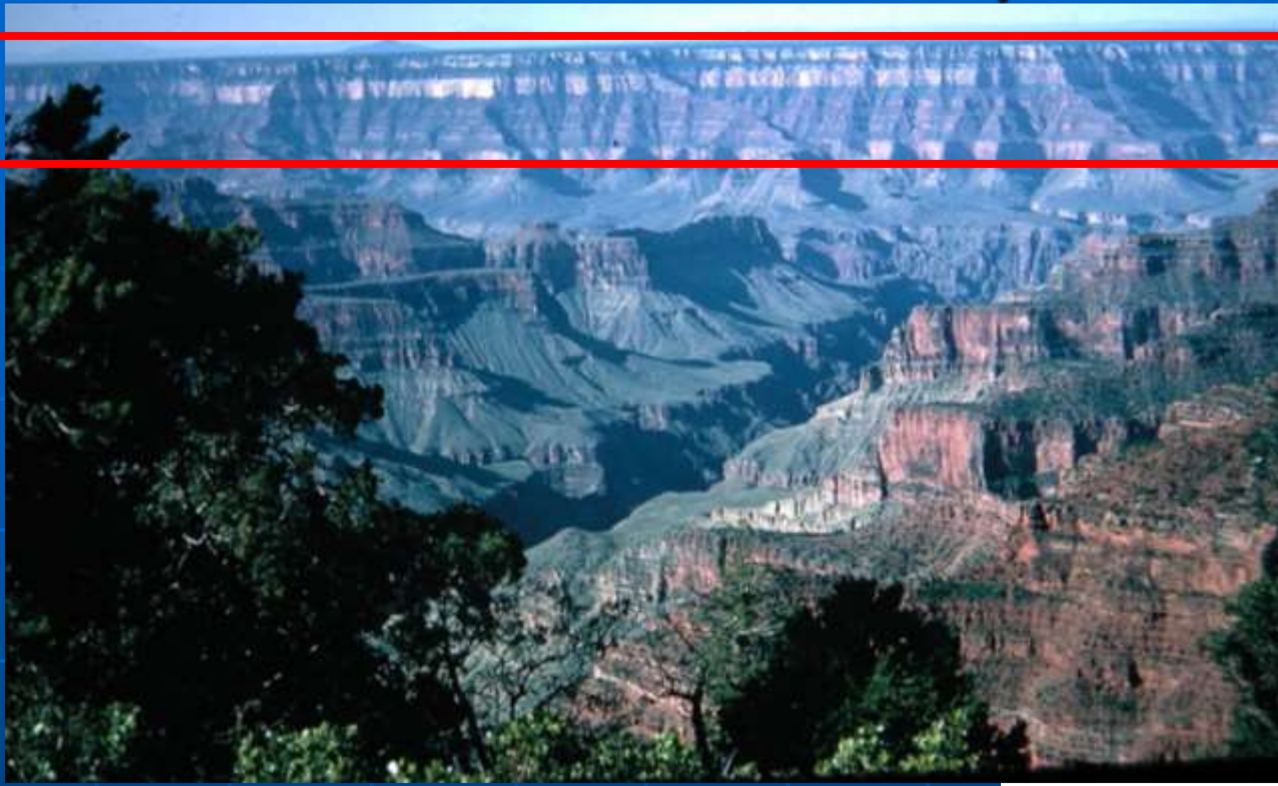
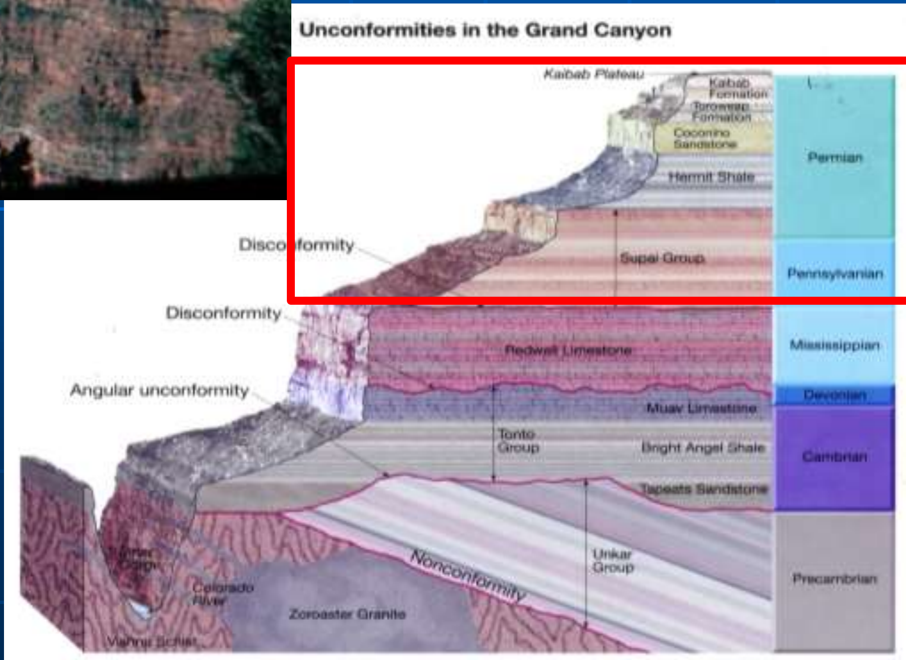
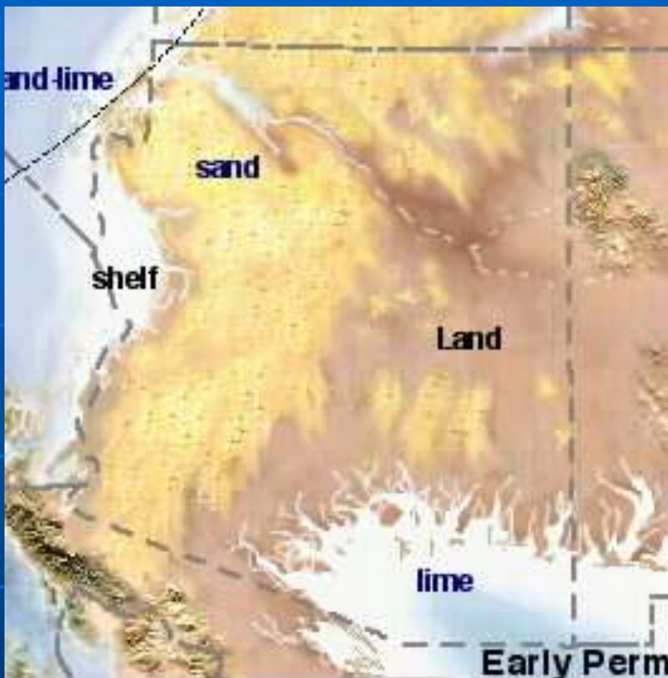


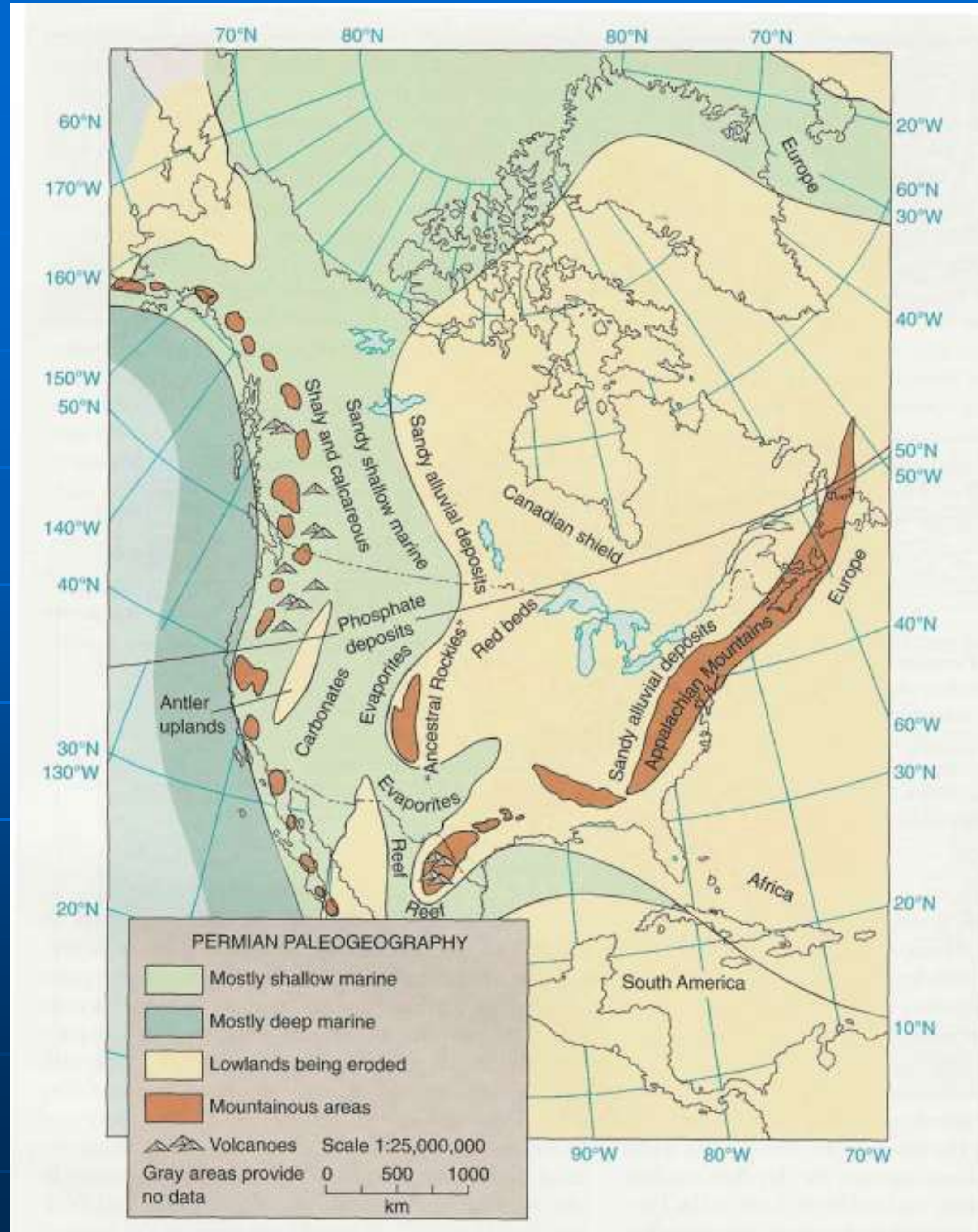
Photo by Jan Rasmussen



Permian environments



From Ron Blakey



Levin 1994

Climate zones (299-272 Ma)

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.*) *It is likely*

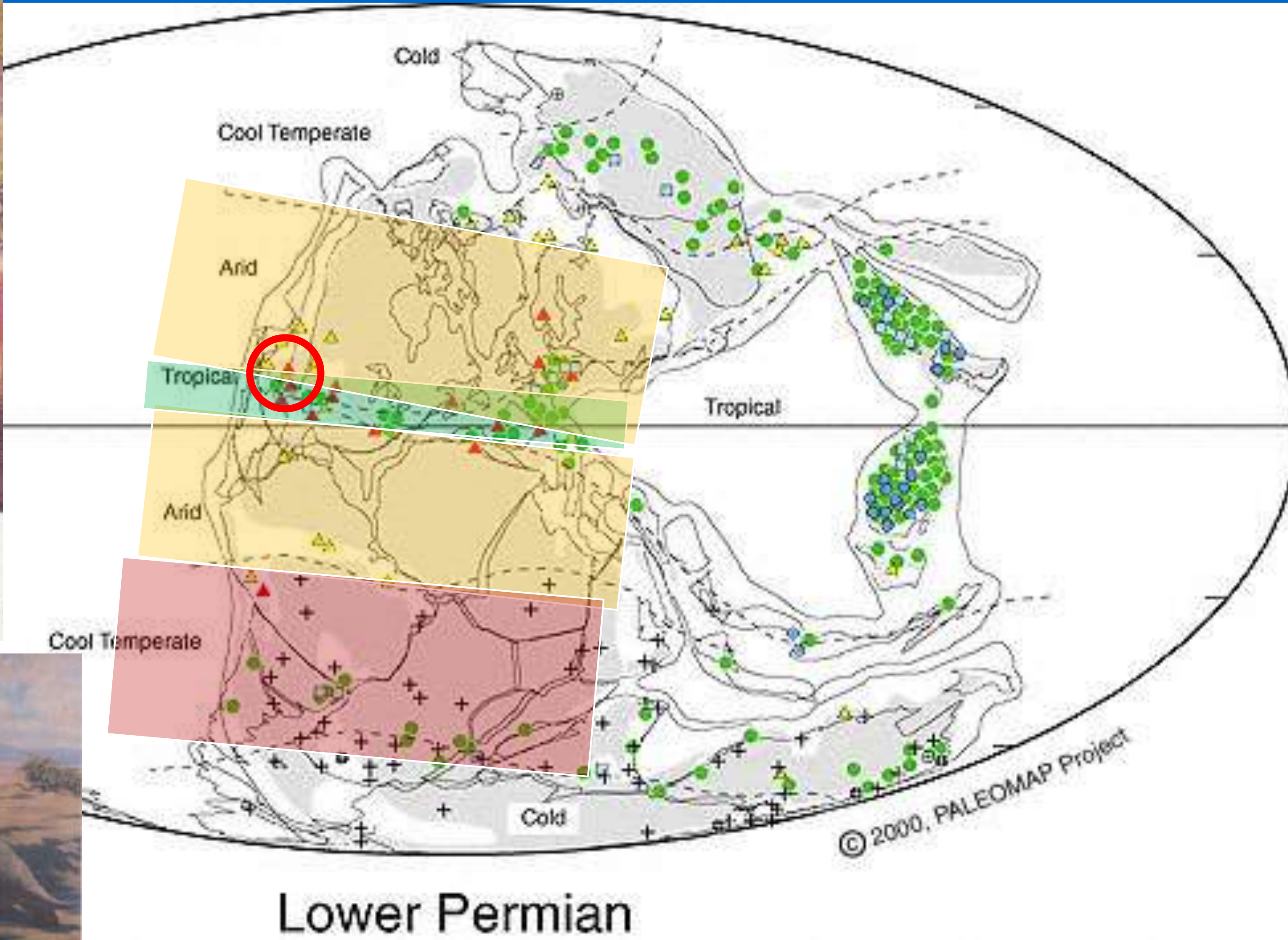
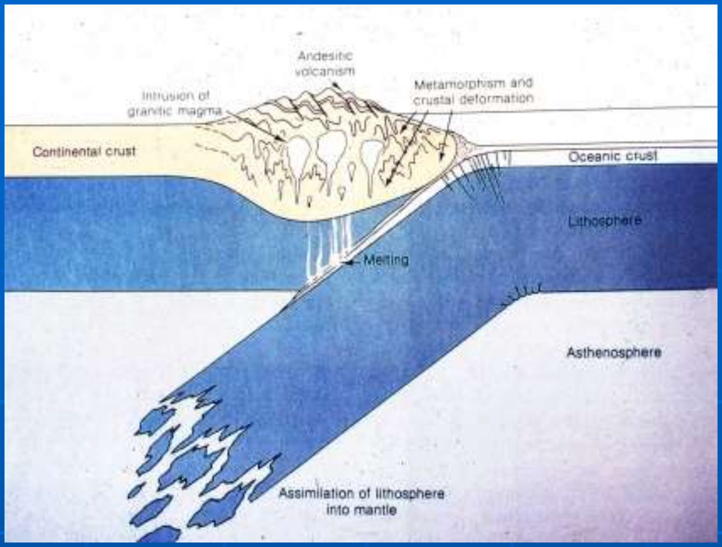


FIGURE 10-80 Mammal-like reptiles. The scene depicts three carnivorous forms (*Cynognathus*) about to attack a plant-eating therapsid reptile (*Kannemeyeria*). (*Courtesy of*

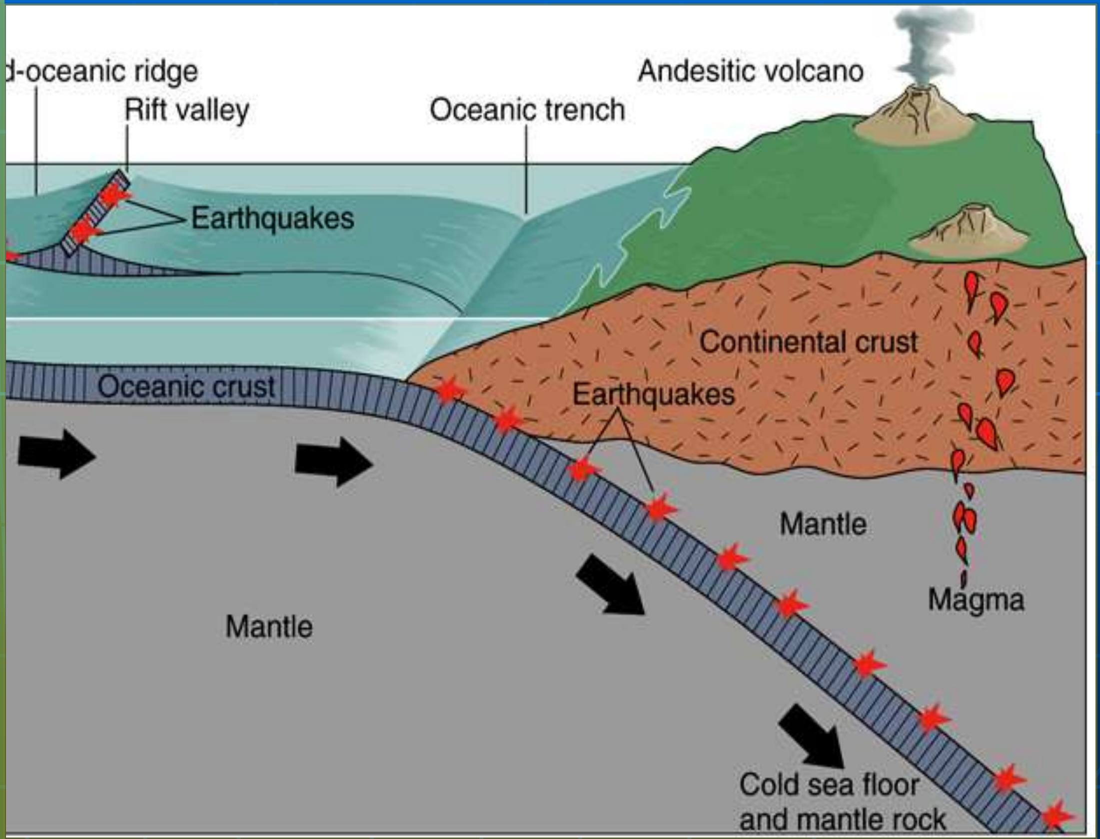
from www.scotese.com

Arizona's position w.r.t. plate tectonics in Paleozoic vs. Mesozoic

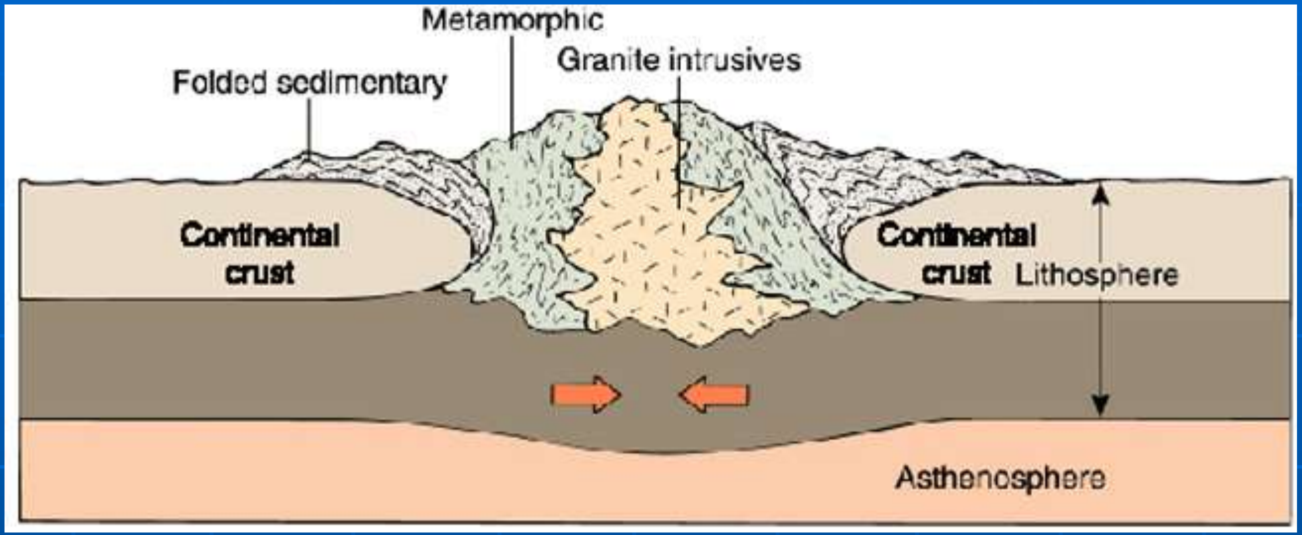


Paleozoic – Arizona was on trailing edge of North American continent = calm seaways – like Bahamas

Mesozoic – Arizona was on leading edge of N. American continent = mountain building, volcanoes, earthquakes, igneous intrusions

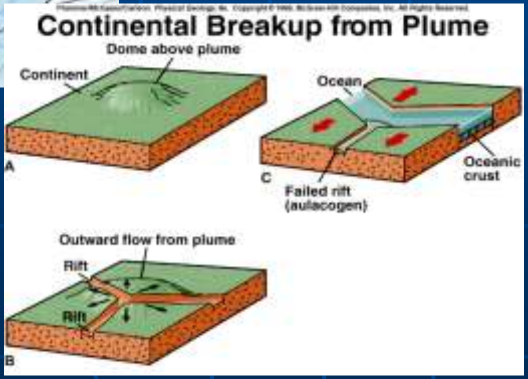


Triassic Plate Tectonics



Appalachian Mts. before breakup of Pangea

252 Ma



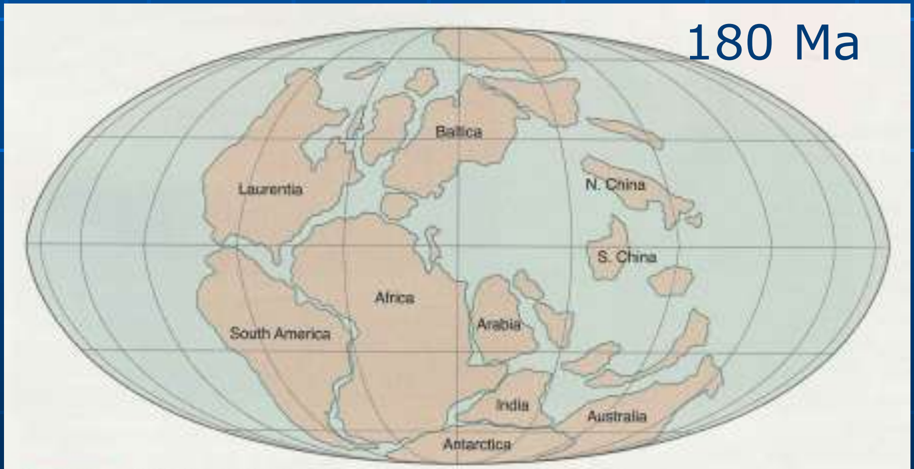
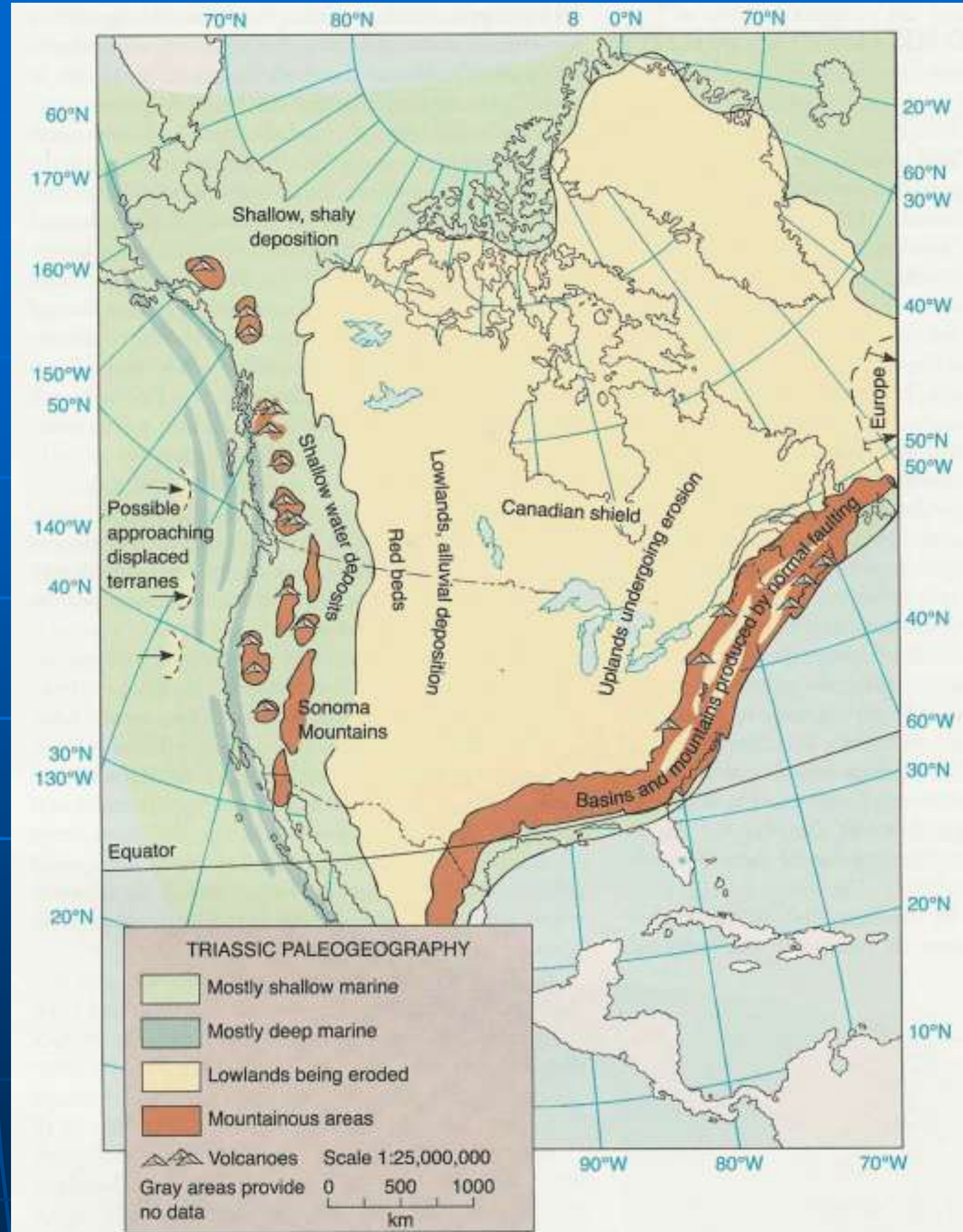


FIGURE 11-1 Paleogeographic reconstruction of the world about 180 million years ago, when the break-up of Pangea was beginning. (After Scotese, C. R. and McKerrow, W. S. 1990. Paleogeography and Biogeography, *Geol. Soc. London Mem.* 12:1–21.)

From Plummer et al., 2013

Triassic paleo-geography (252-201 Ma)

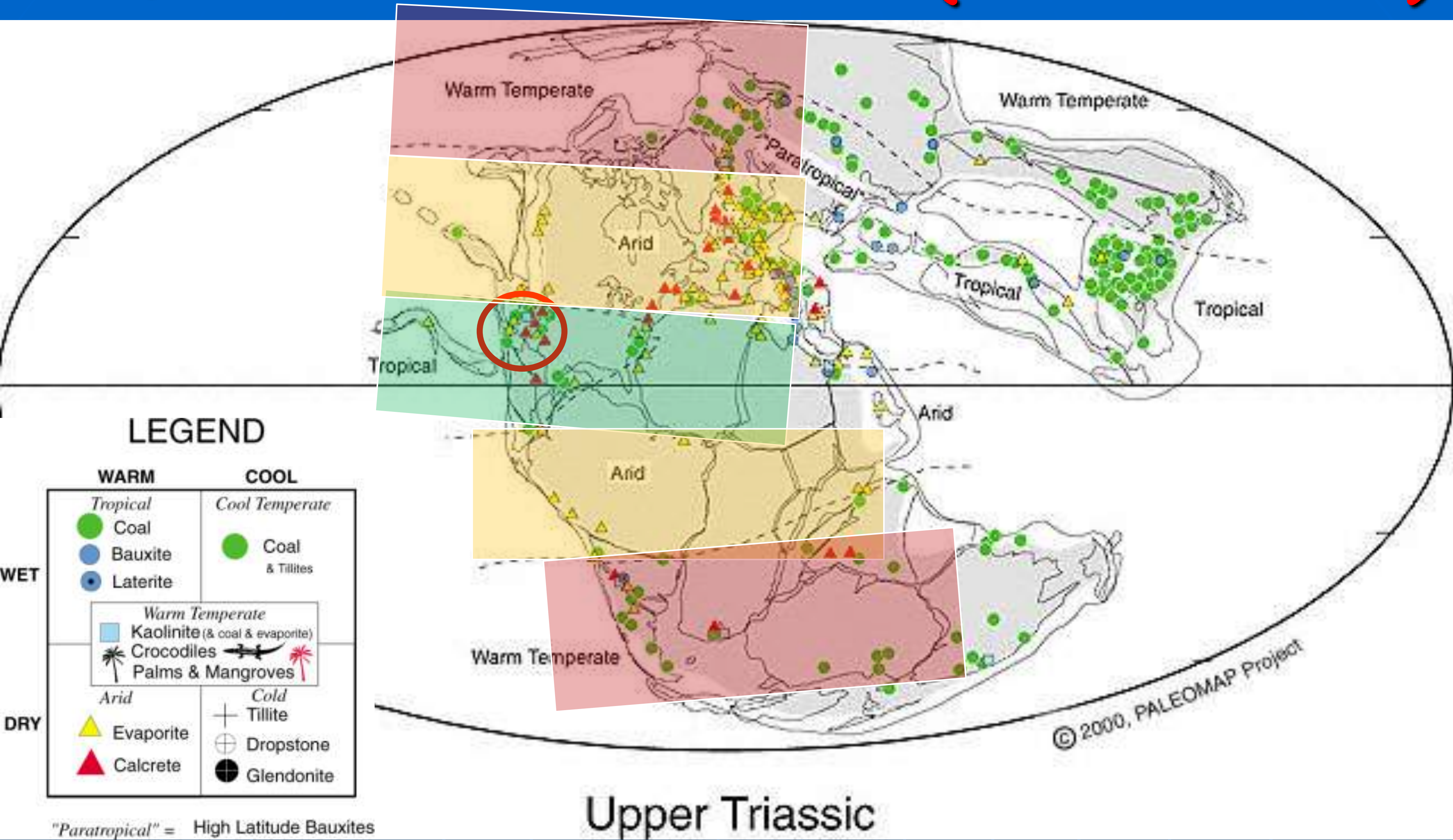
From Ron Blakey



Levin 1994

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?

Climate zones Triassic (252-201 Ma)



from www.scotese.com

Petrified Forest Fm. - late Triassic

Triassic Reptiles

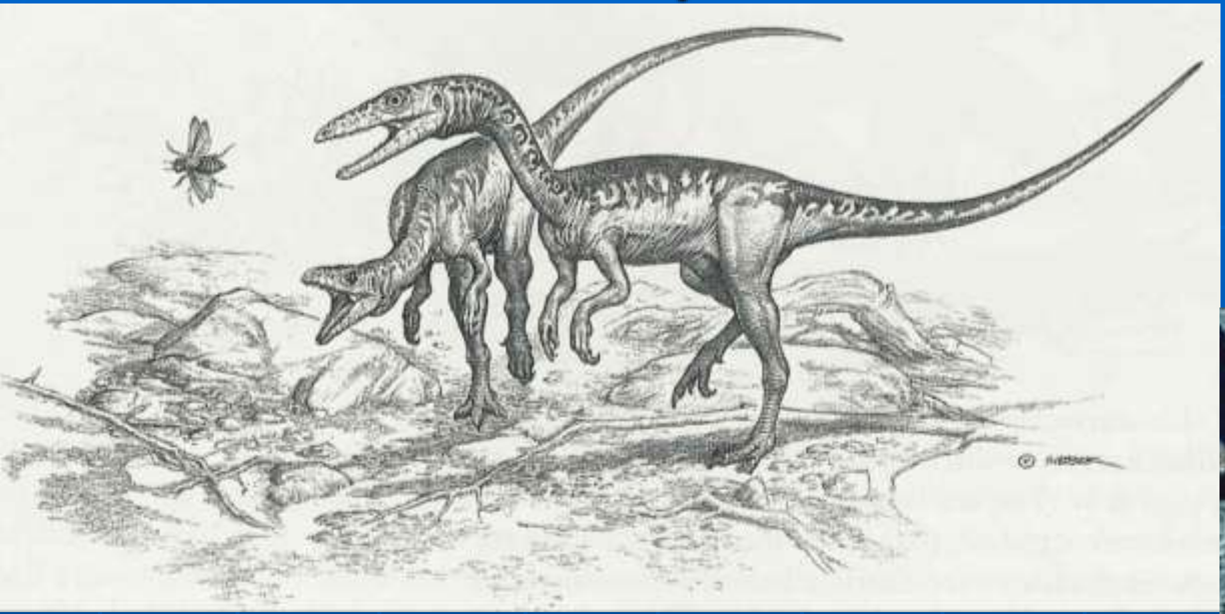
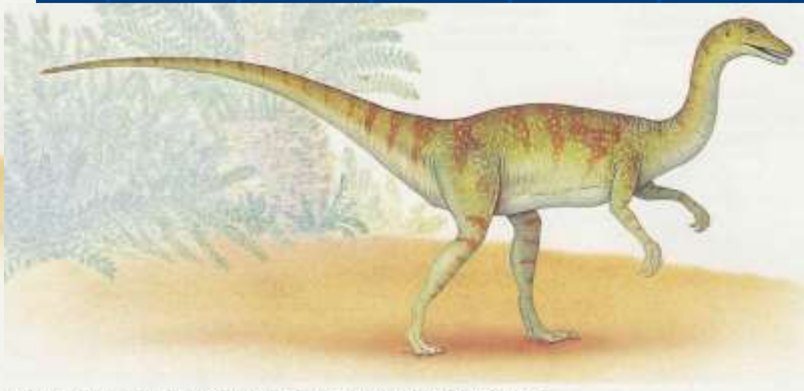


FIGURE 12-21 The small, agile theopod *Coelophysis* lived about 220 million years ago, during the Late Triassic. *Coelophysis* was about 3 meters in length. These fast, agile, bipedal predators may have pursued their prey in packs, and there is evidence that they occasionally even ate juveniles of their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

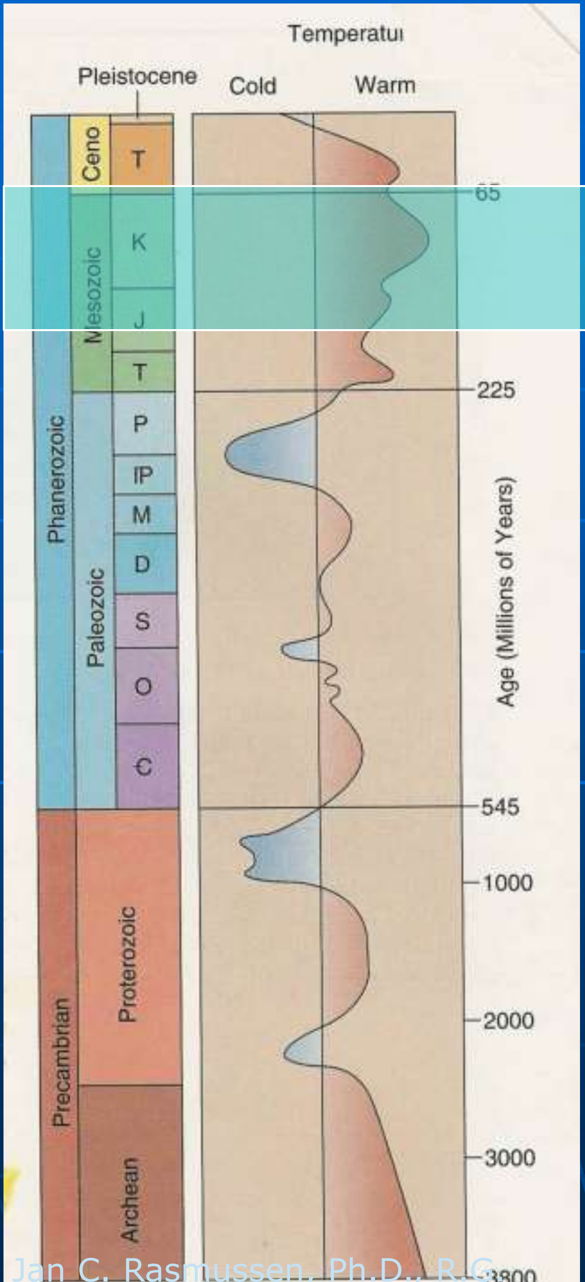
Photo by Jan Rasmussen

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.

Late Jurassic & Cretaceous 200-66 Ma



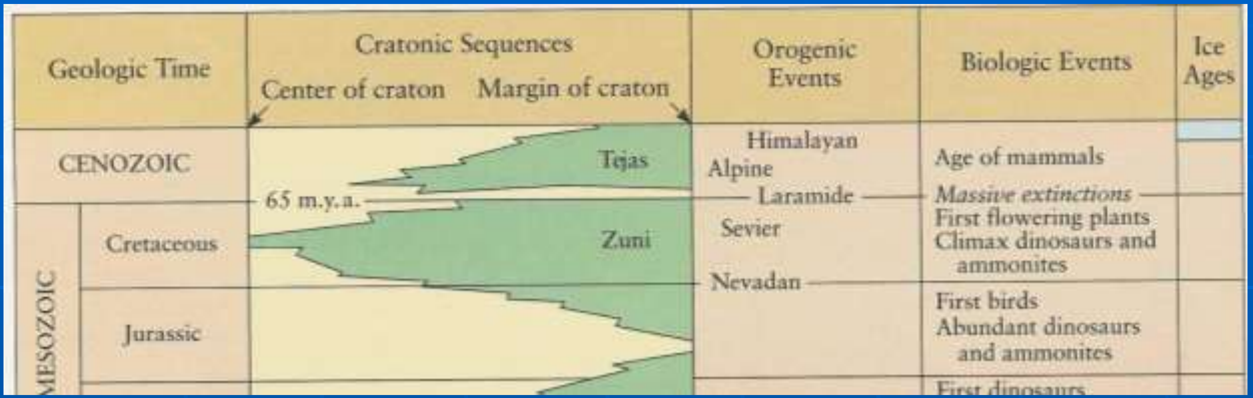
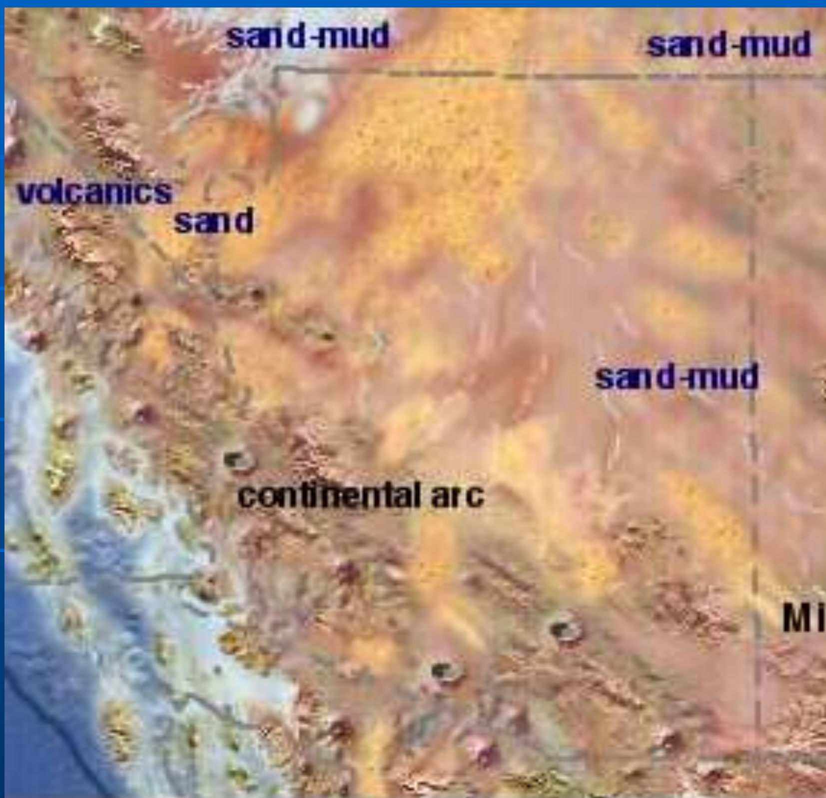


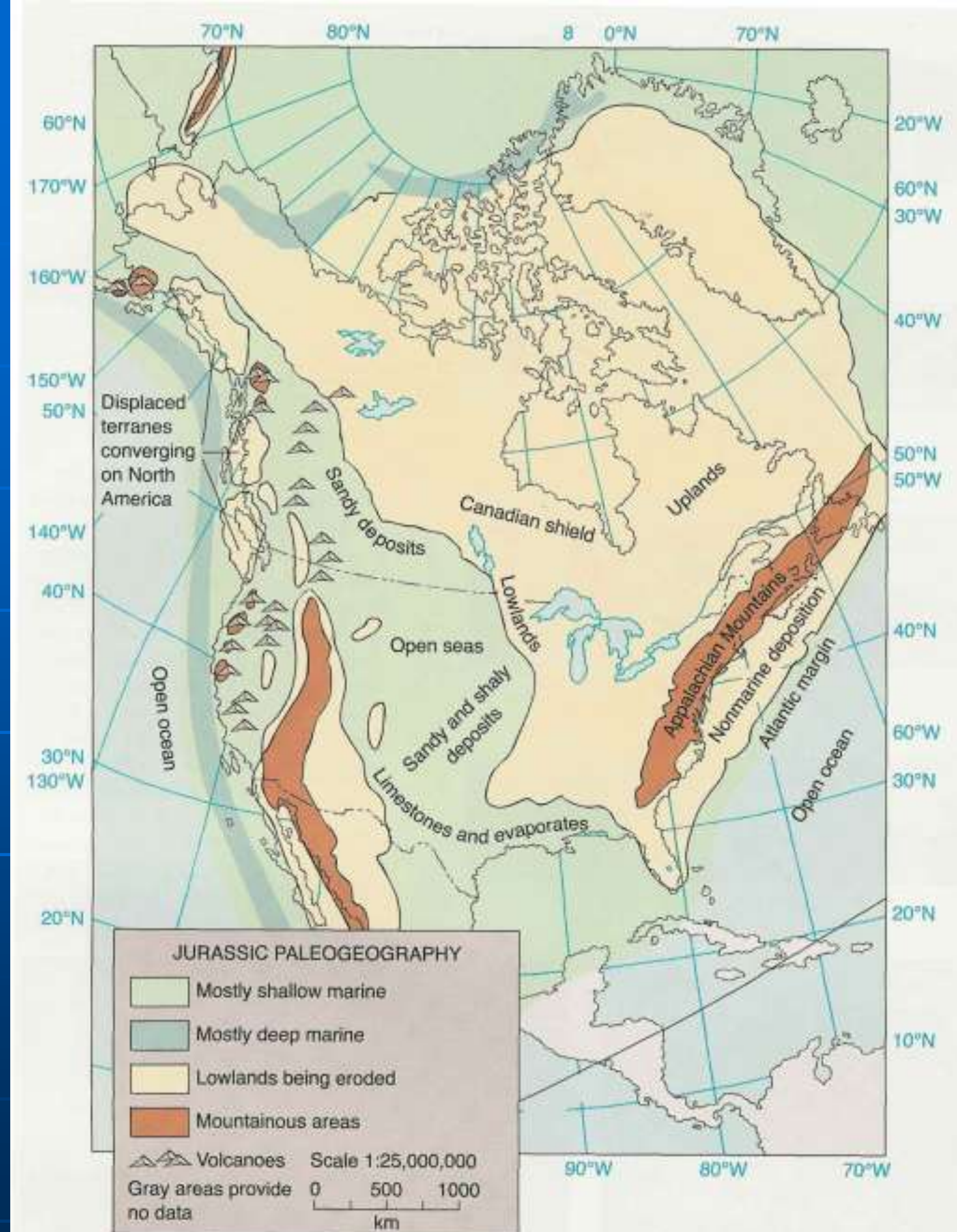
FIGURE 11-26 Paleogeographic map for the early Jurassic of the western United States, showing general extent of sea and land as well as paleolatitudes. (*From Stanley, K. O., Jordan, W. M., and Dott, R. H. 1971. Bull. Am. Assoc. Petrol. Geol. 55(1):13.*)

Zion National Park, Checkerboard Mesa Similar to current Namib desert
Levin 1994

Jurassic paleogeography



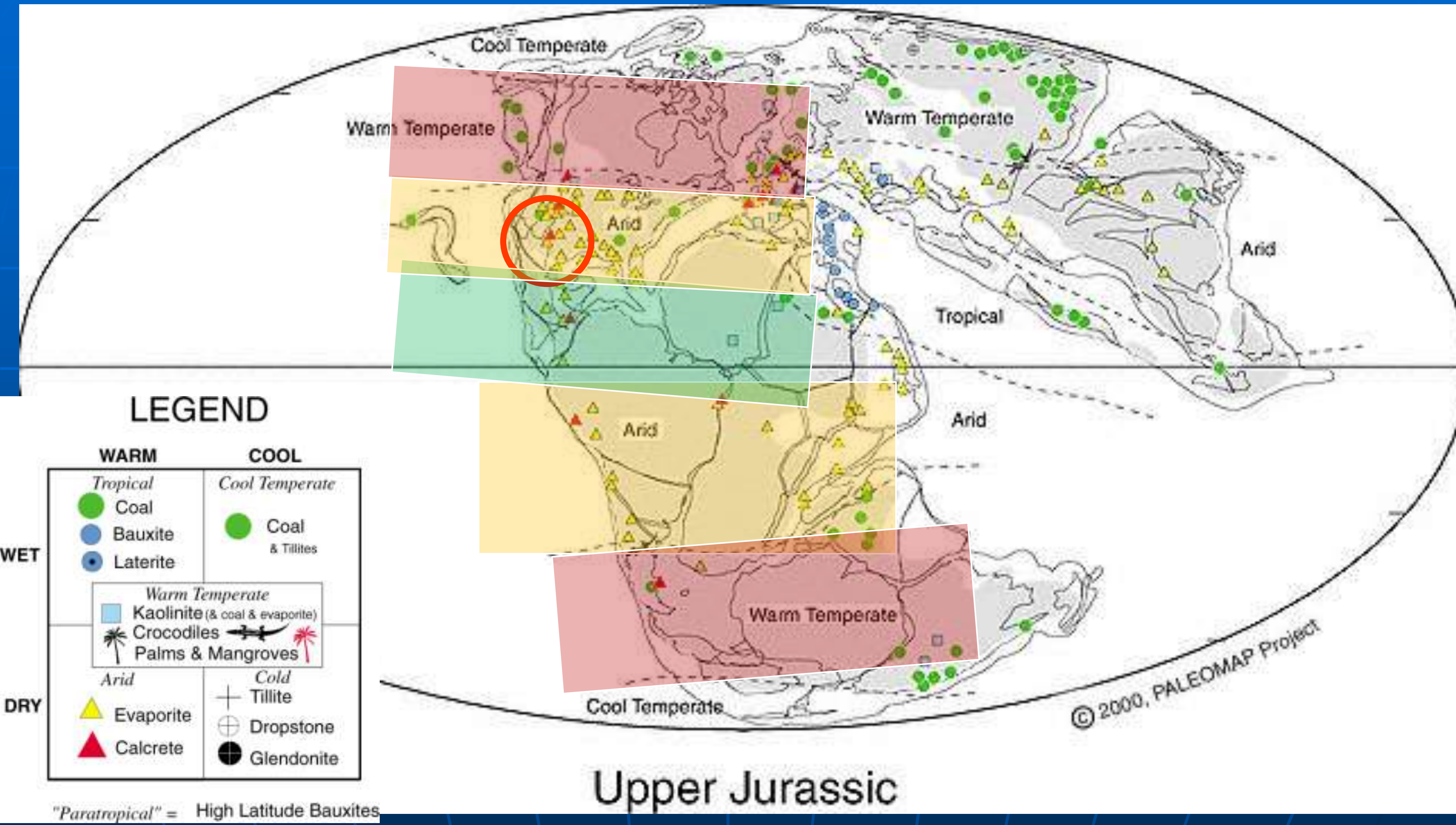
From Ron Blakey



Levin 1994

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.

Climate zones Jurassic (201-145 Ma)



from www.scotese.com

Echo Cliffs, Jurassic Sandstone

Plate 3. Jurassic (Morrison Formation) dinosaurs. The spiney dinosaur to the right of center is *Stegosaurus*. The large dinosaur in the upper left is *Apatosaurus*. The carnivore in the lower left is *Allosaurus*. (*Painting by Margaret Colbert, reprinted by permission. Courtesy Museum of Northern Arizona.*)

Photo by Jan Rasmussen

Photo by Jan Rasmussen

Jurassic volcanics Santa Rita Mts.

Santa Rita Mts., Mt. Wrightson, looking West from Sonoita

Mustang Mts. (right side), looking East from Sonoita

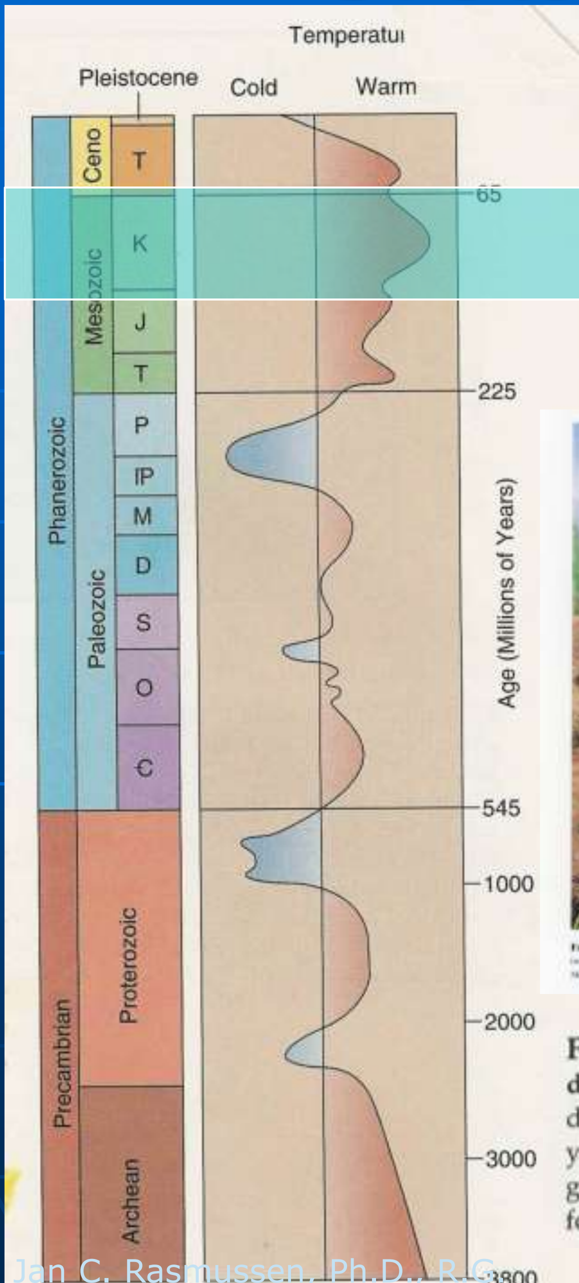
Middle Nevadan - Warren m.d. (Bisbee)

Orogeny	Orogenic Phase	Age (Ma)	Aluminum & Alkalinity	Resources	Mining districts
Nevadan	Middle	205-180	MQA	porphyry Cu-Au	Warren (Bisbee mine), Turquoise (Courtland), Yuma King

Campbell shaft

Sacramento Stock = 190 Ma – Cu-Au;

Cretaceous (145-66 Ma)



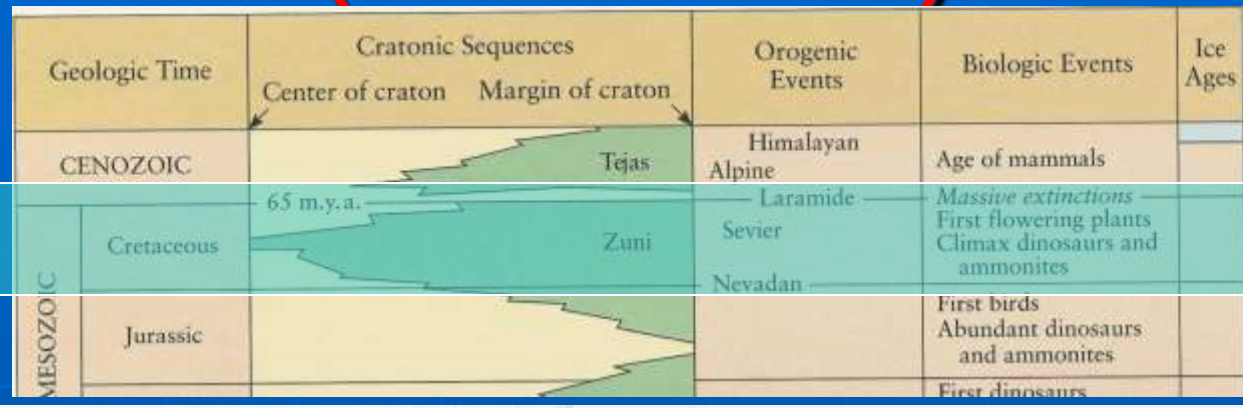
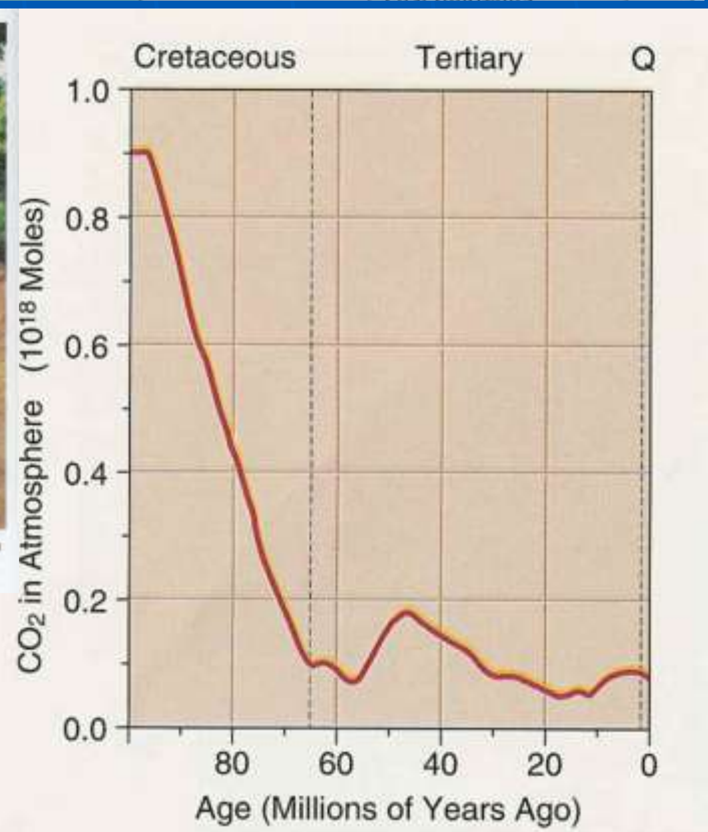
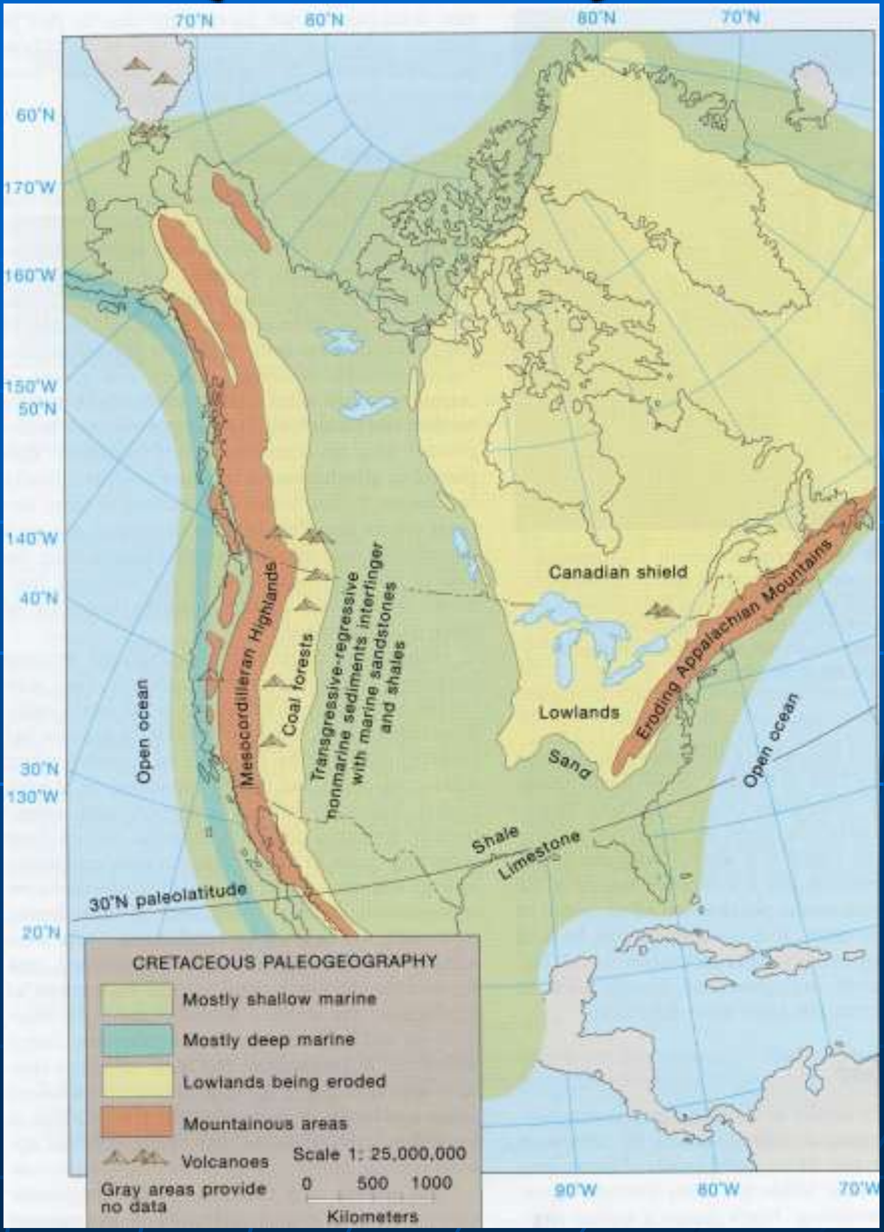


Figure 14.40 The abundance of carbon dioxide in Earth's atmosphere has declined dramatically during the last 100 million years. Loss of this important greenhouse gas may have allowed Earth to cool enough for glaciers to accumulate.



Middle Cretaceous (100 Ma)

From Ron Blakey

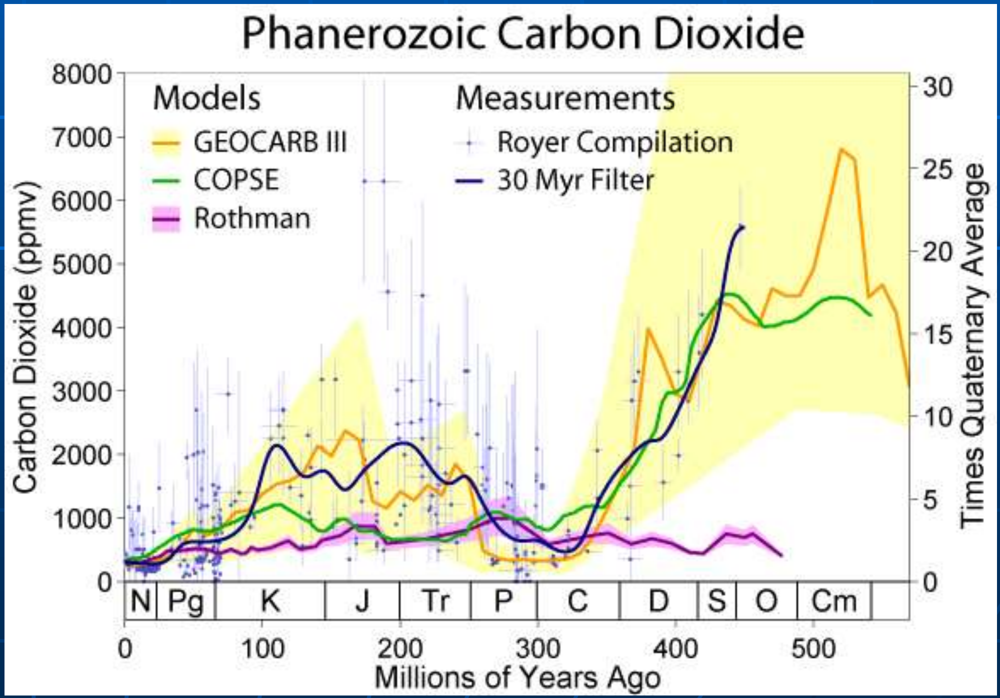


Levin, 1994

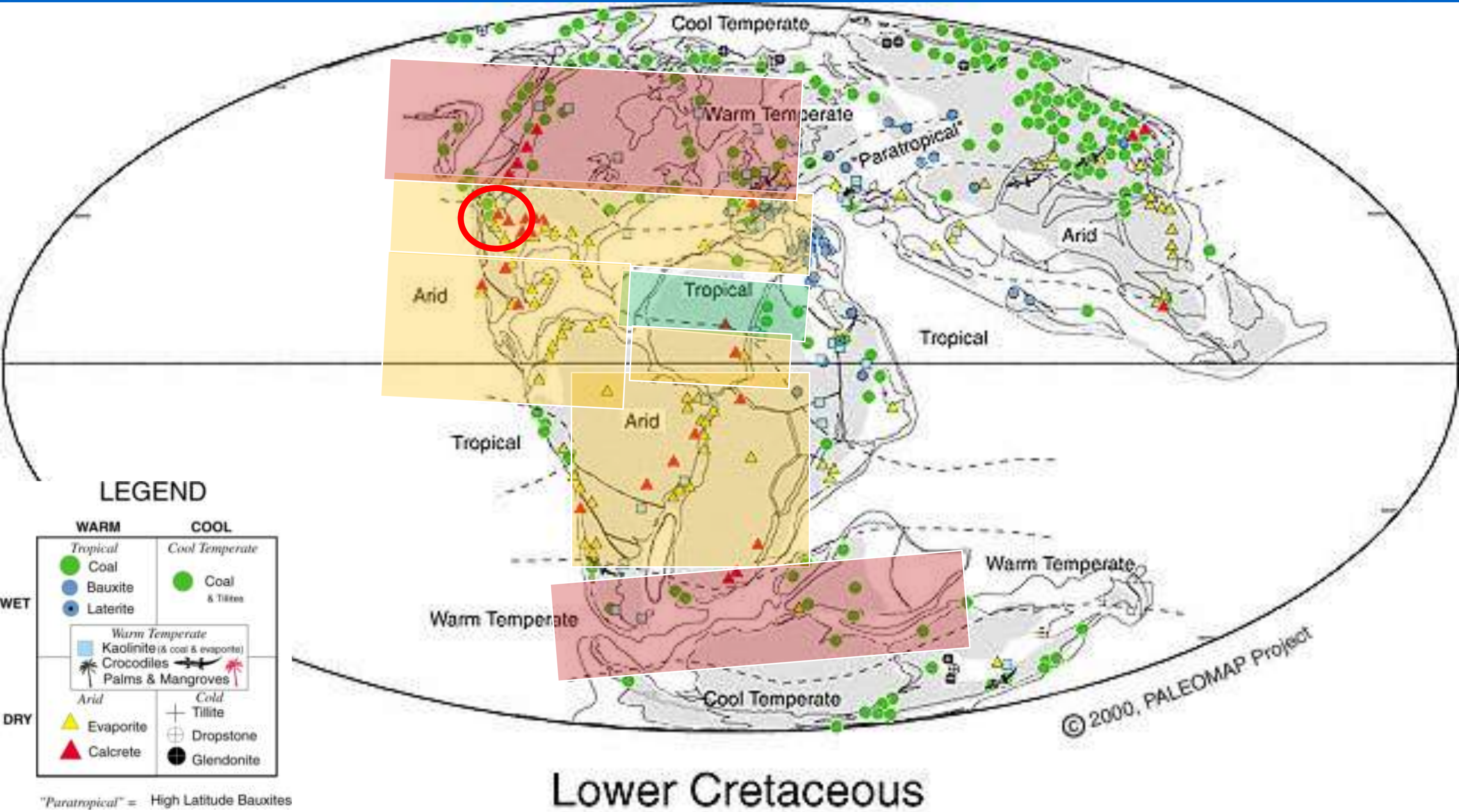
Bisbee Grp., Mural Limestone 100 Ma

Photo by Jan Rasmussen

White Cliffs of Dover, England



Climate zones (145-100 Ma)



from www.scotese.com

Coal swamps N. AZ - (89-85 Ma)

N. Arizona – coal in Wepo Fm. at Black Mesa

Photo by Jan Rasmussen

Photo from Peabody Coal (Freeport-McMoran)

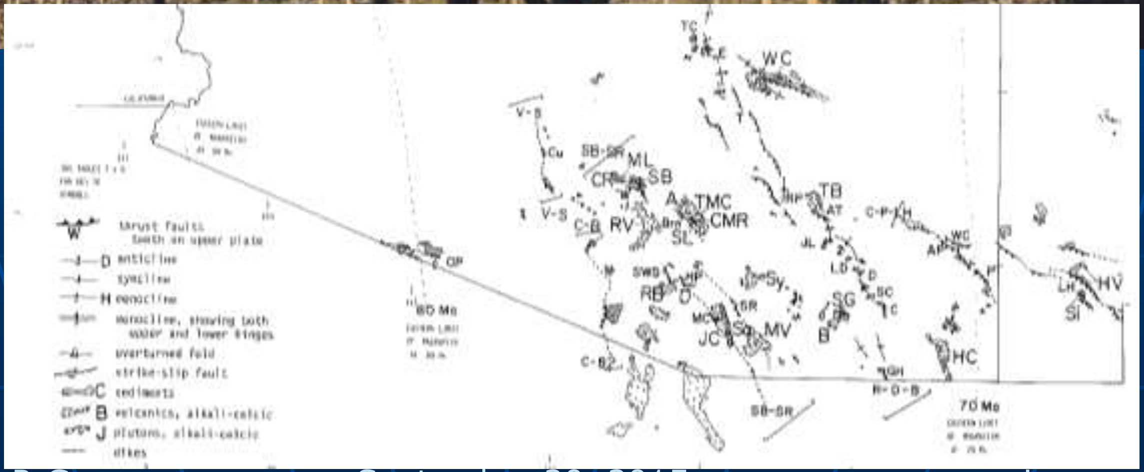
Late Cretaceous – volcanics, Mts.

From Ron Blakey

Mt. Pinatubo, Philippines 1991, USGS photo

Gates Pass, Tucson – 74 Ma rhyolite

Photo by Jan Rasmussen

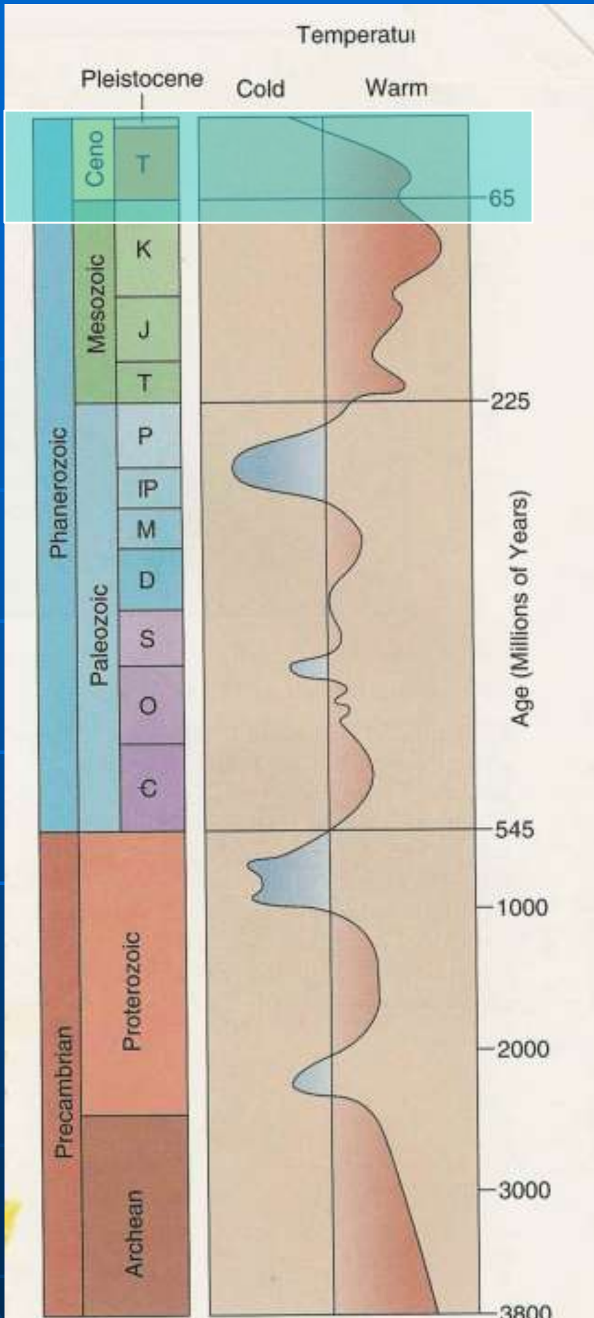


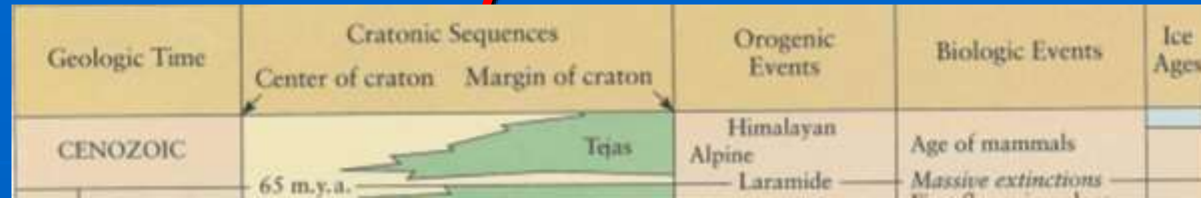
From Keith & Wilt, 1985

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

Single jackers working in a stope in the Goodenough Mine, circa 1880.
Macia-Devere Collection

Tertiary – 66-0 Ma

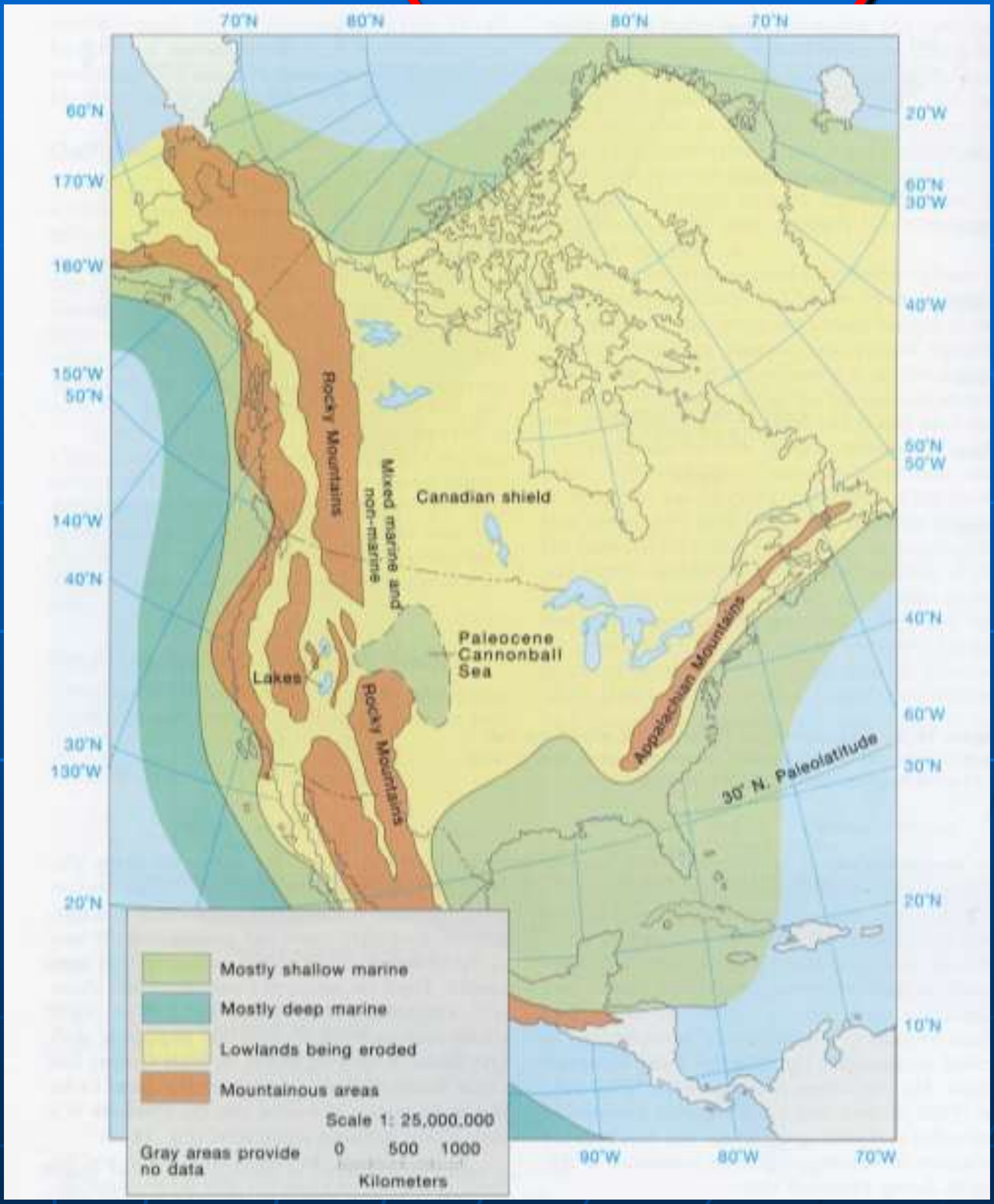




Geologic Time	Cratonic Sequences: Center of craton	Cratonic Sequences: Margin of craton	Orogenic Events	Biologic Events	Ice Ages
CENOZOIC	65 m.y.a.	Tejas	Himalayan Alpine Laramide	Age of mammals Massive extinctions	

Tertiary environments (66-0 Ma)

From Ron Blakey



Levin 1994

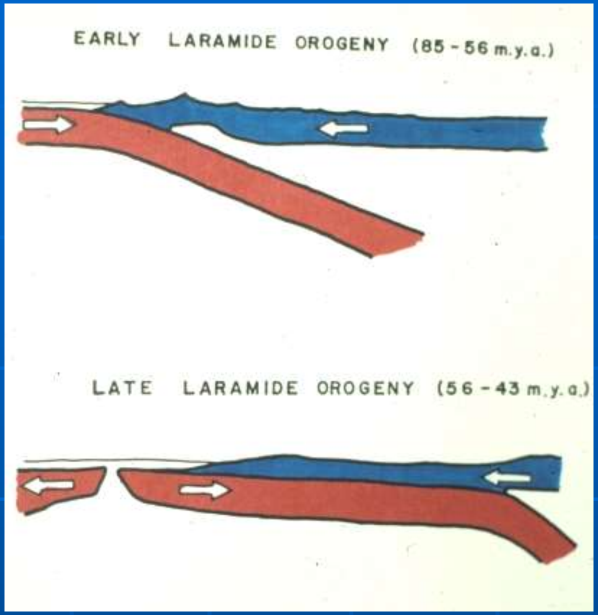
Laramide porphyry copper (65-55 Ma)

Photo by Jan Rasmussen

Ray mine shovel, haul truck
Dave Briggs photos

Ray mine, ASARCO photo

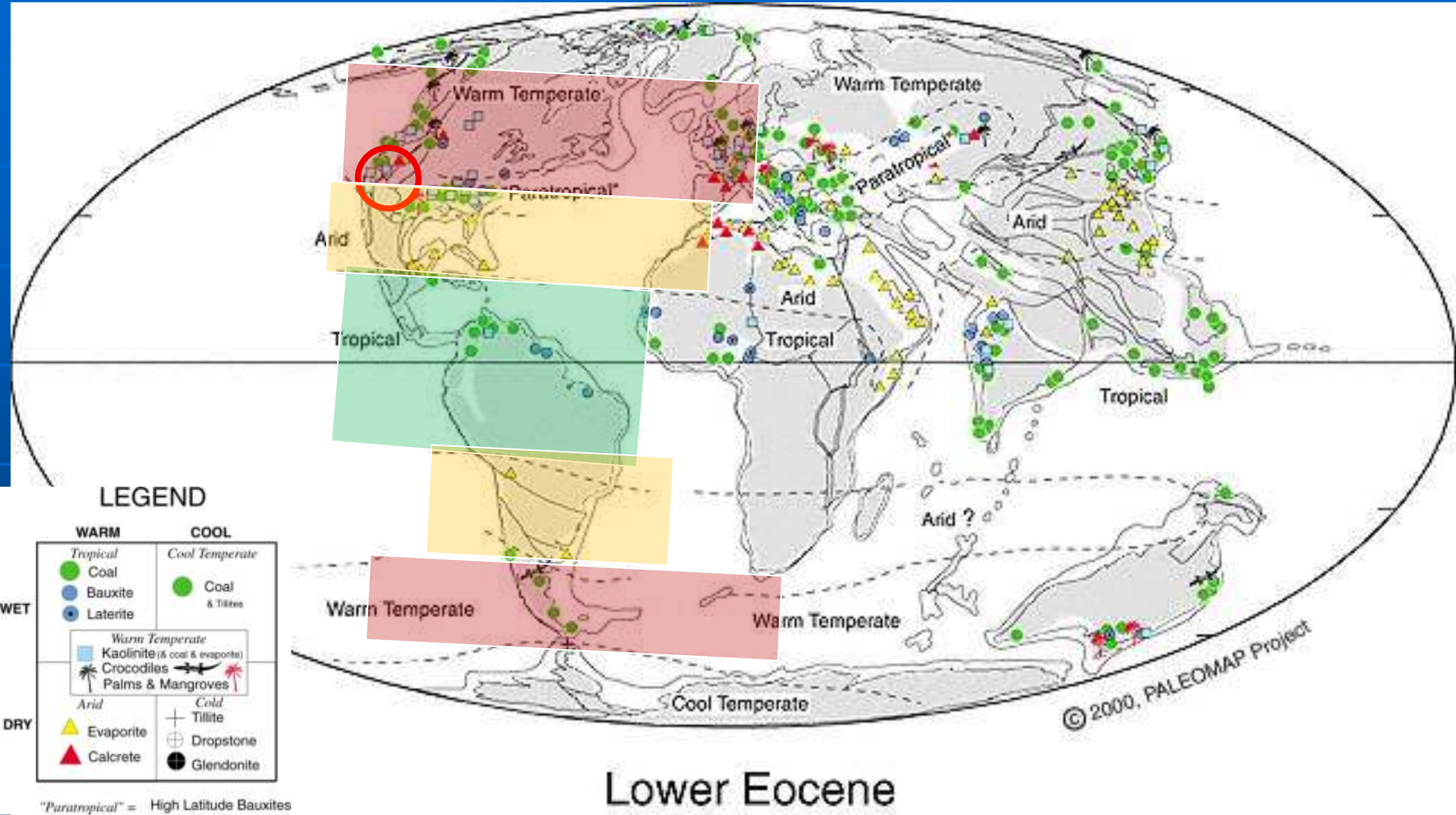
Early Tertiary– (55-43 Ma)



Flat subduction

Wilderness granite

Climate zones (56-34 Ma)

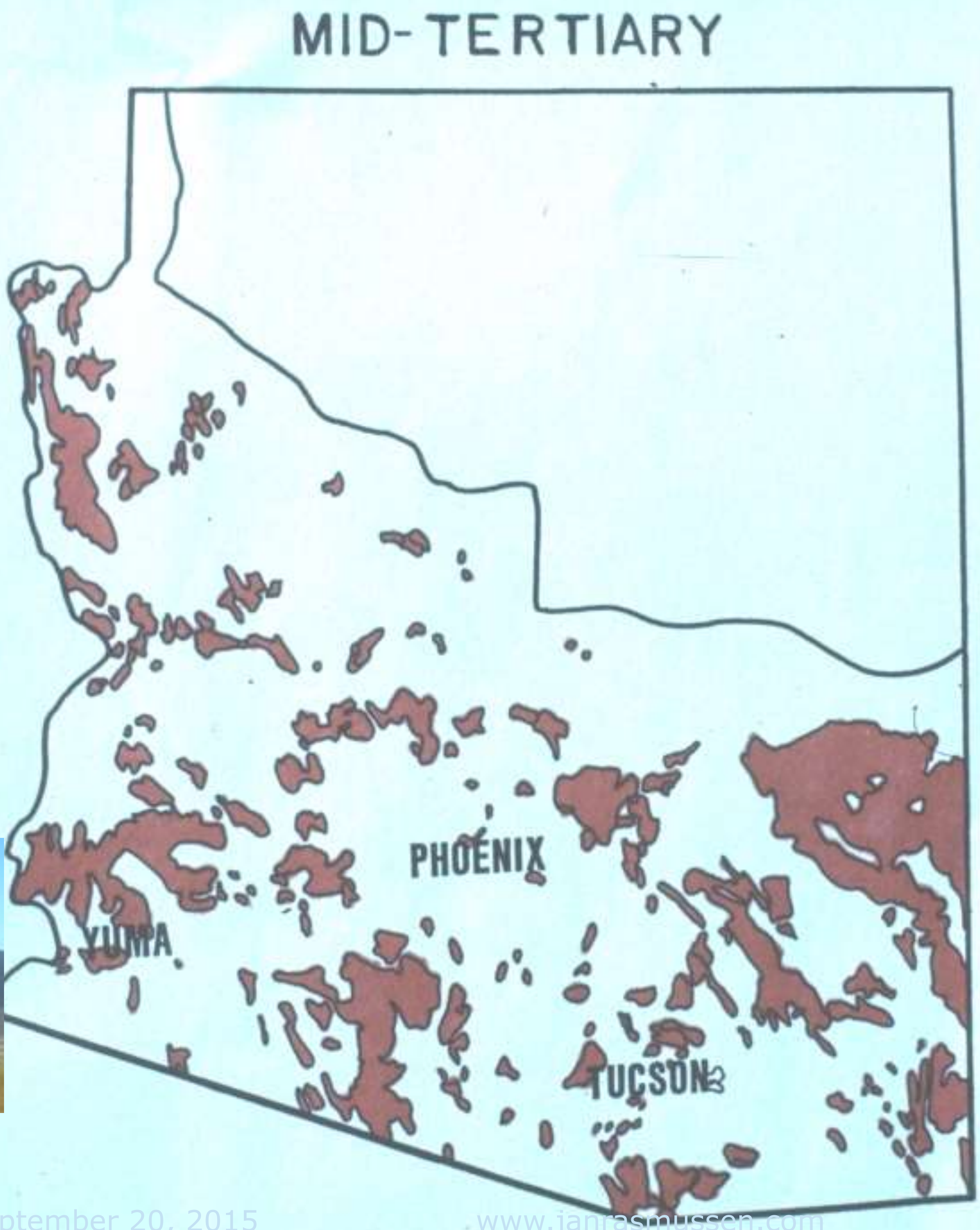


from www.scotese.com

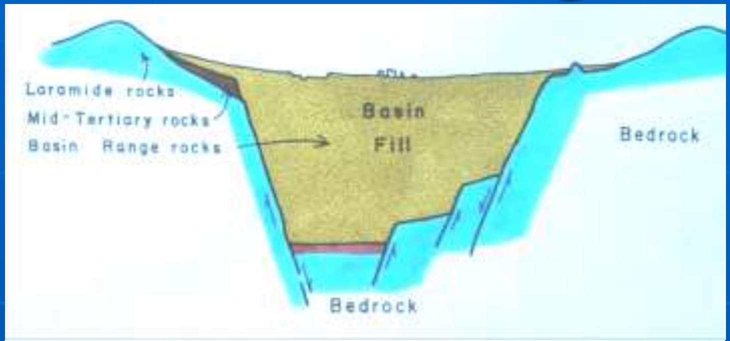
Mid-Tertiary volcanics & deeper plutons

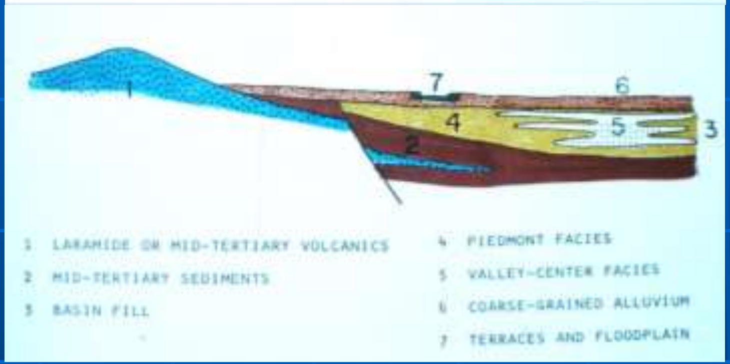
Cochise Stronghold

Superstition Volcanics



Basin and Range (10 Ma) - Valleys filled with sand, gravel, clay, gypsum, & salt





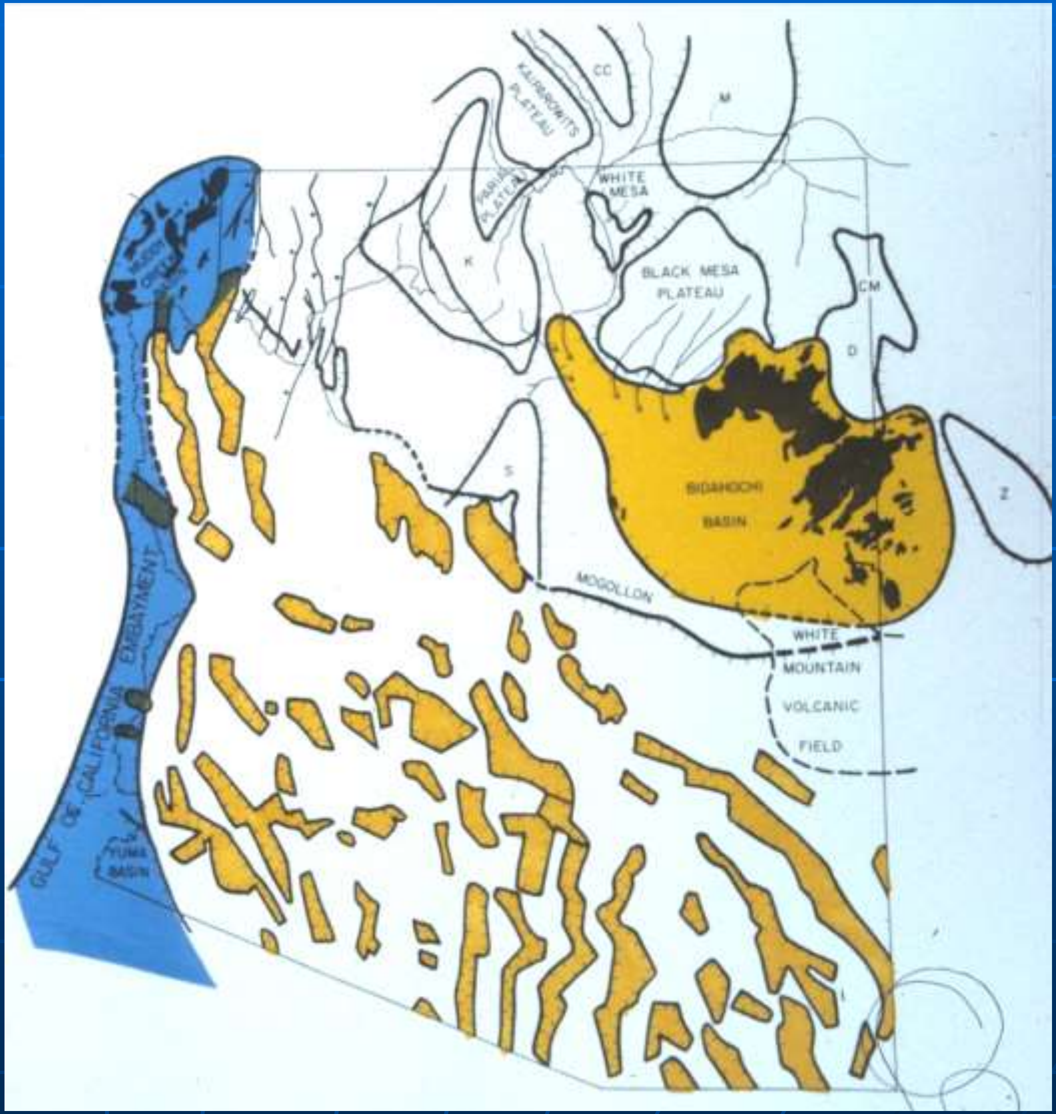


Photo by Jan Rasmussen

Industrial Minerals - Late Tertiary

Sand & gravel

Kalamazoo Clay - 1987

Gypsum rose
St. David

Basin fill, gravel, sand, clay, gypsum

Photos by Jan Rasmussen

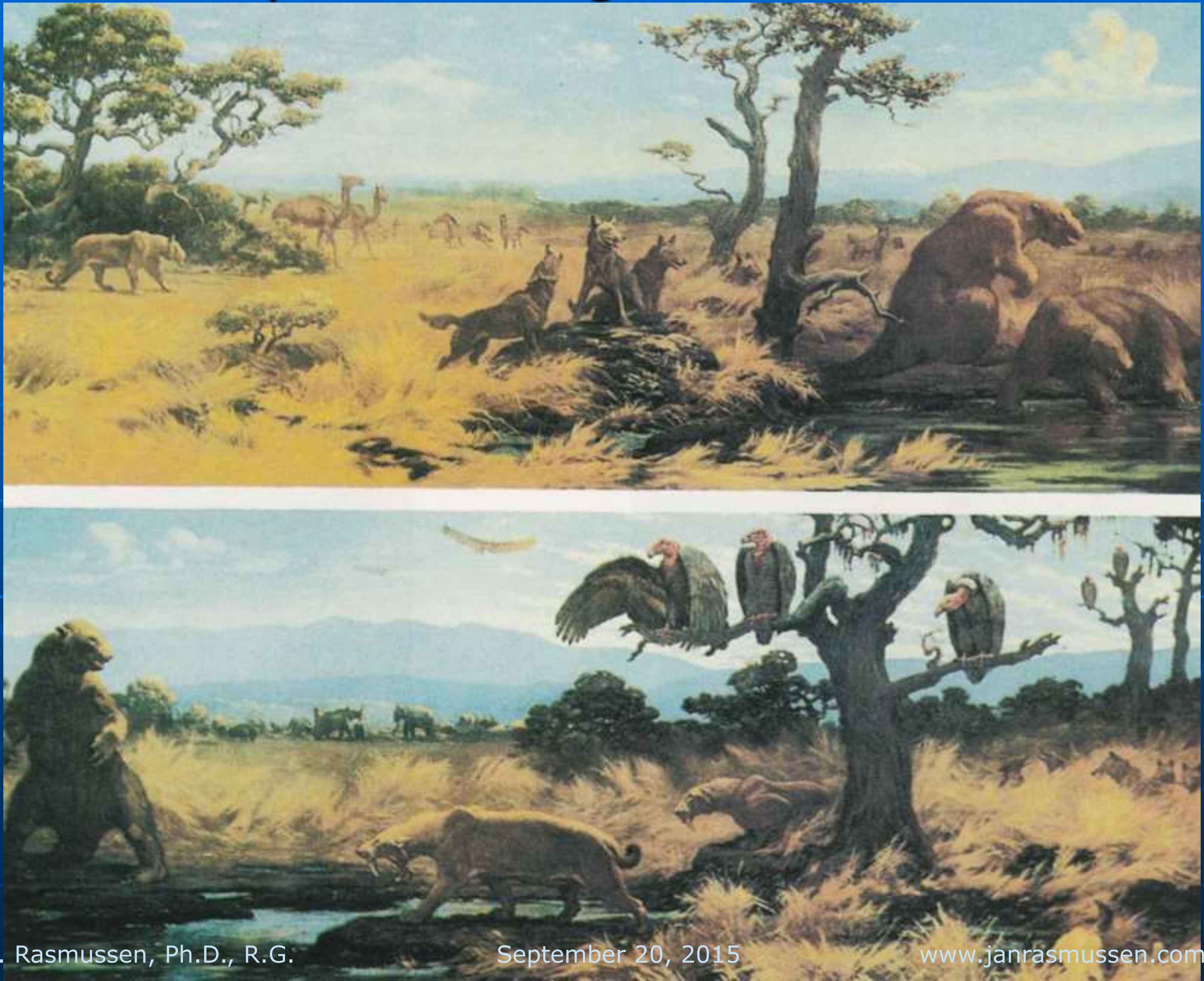
Late Cenozoic volcanics

Lava Falls

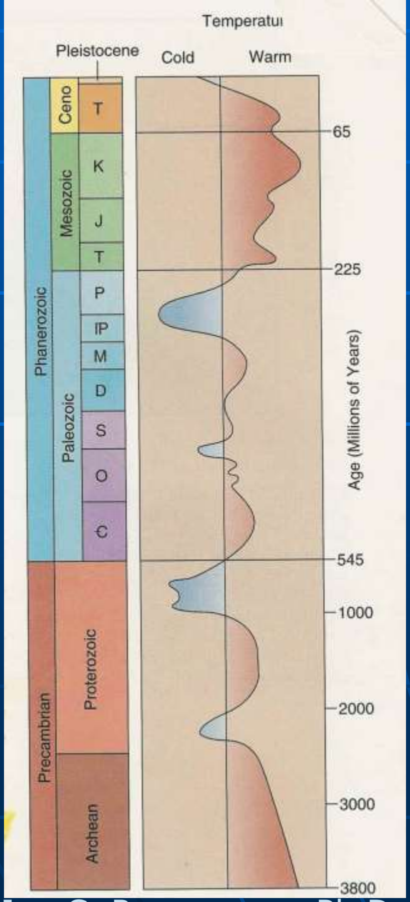
Photos by Jan Rasmussen

San Francisco Mountain, north of Flagstaff

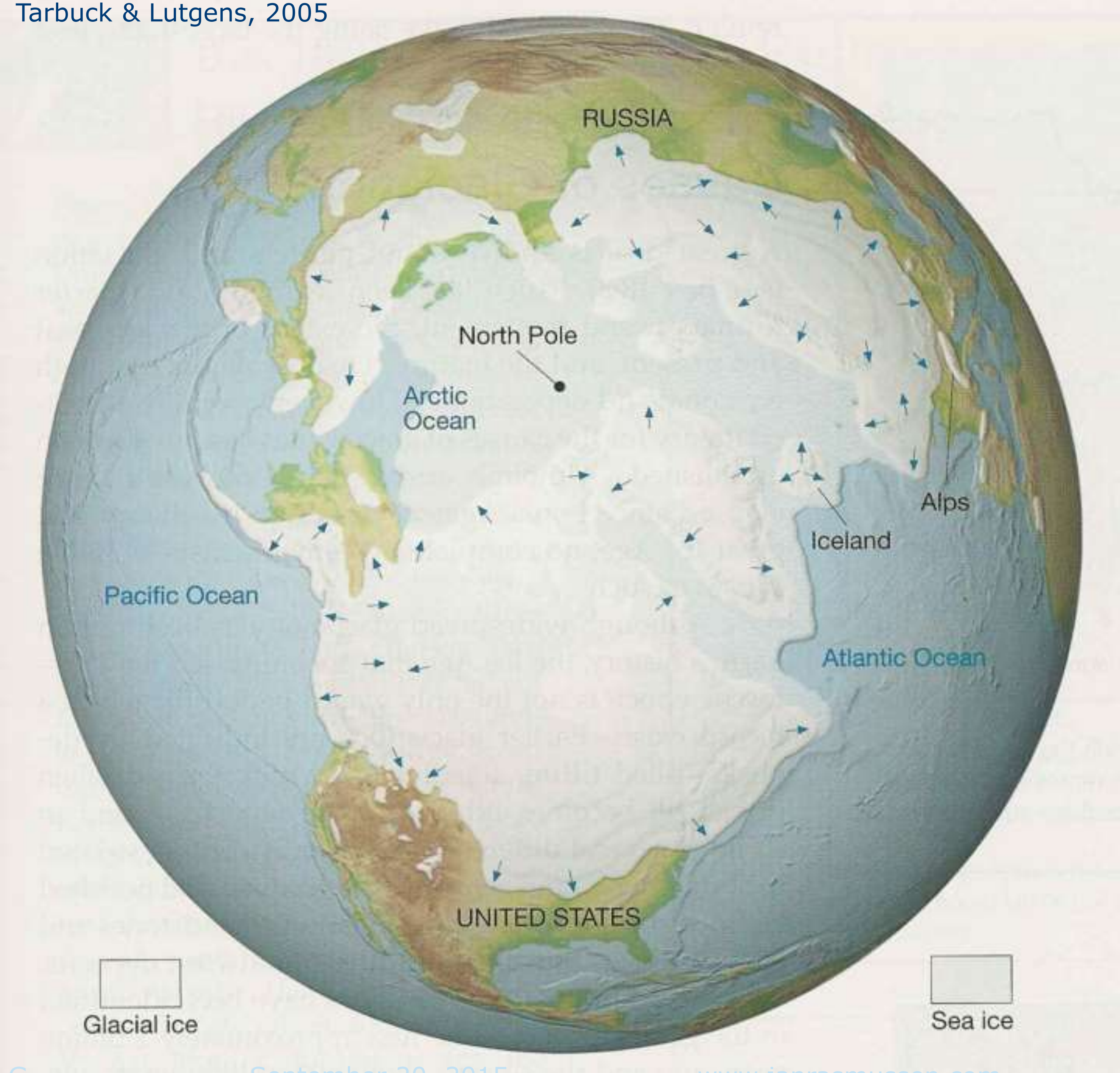
La Brea tarpits, Los Angeles – Pleistocene 1 Ma



Pleistocene maximum glaciation – 18,000 years ago



Tarbuck & Lutgens, 2005

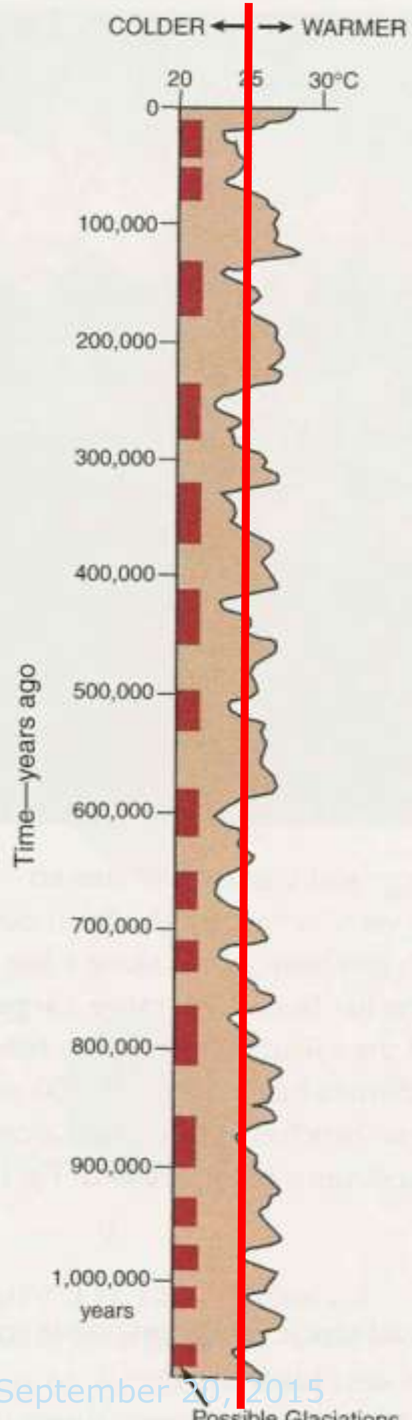


2,000,000 years of temperature change

100,000 years cold,
20,000 years warm

Prothero & Dott, 2004

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

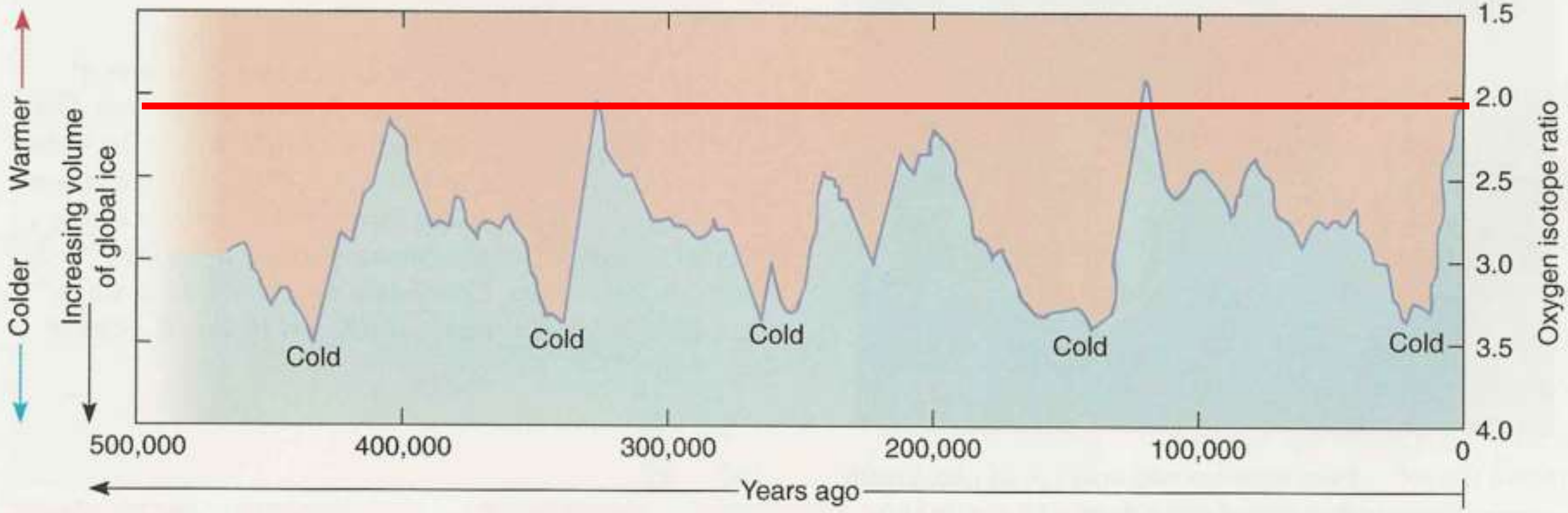


FIGURE 13-43 Curve reflecting variations in the global volume of ice (and, indirectly, paleotemperatures) during the past 500,000 years. Data are from radiometric dating and isotope measurements of cores from the Indian Ocean. (*Data from Hays, J. D., and Shackleton, N. J.* 1976. Science *194:1121–1132.*)

Levin, 1994

Climate Change, last 160,000 years

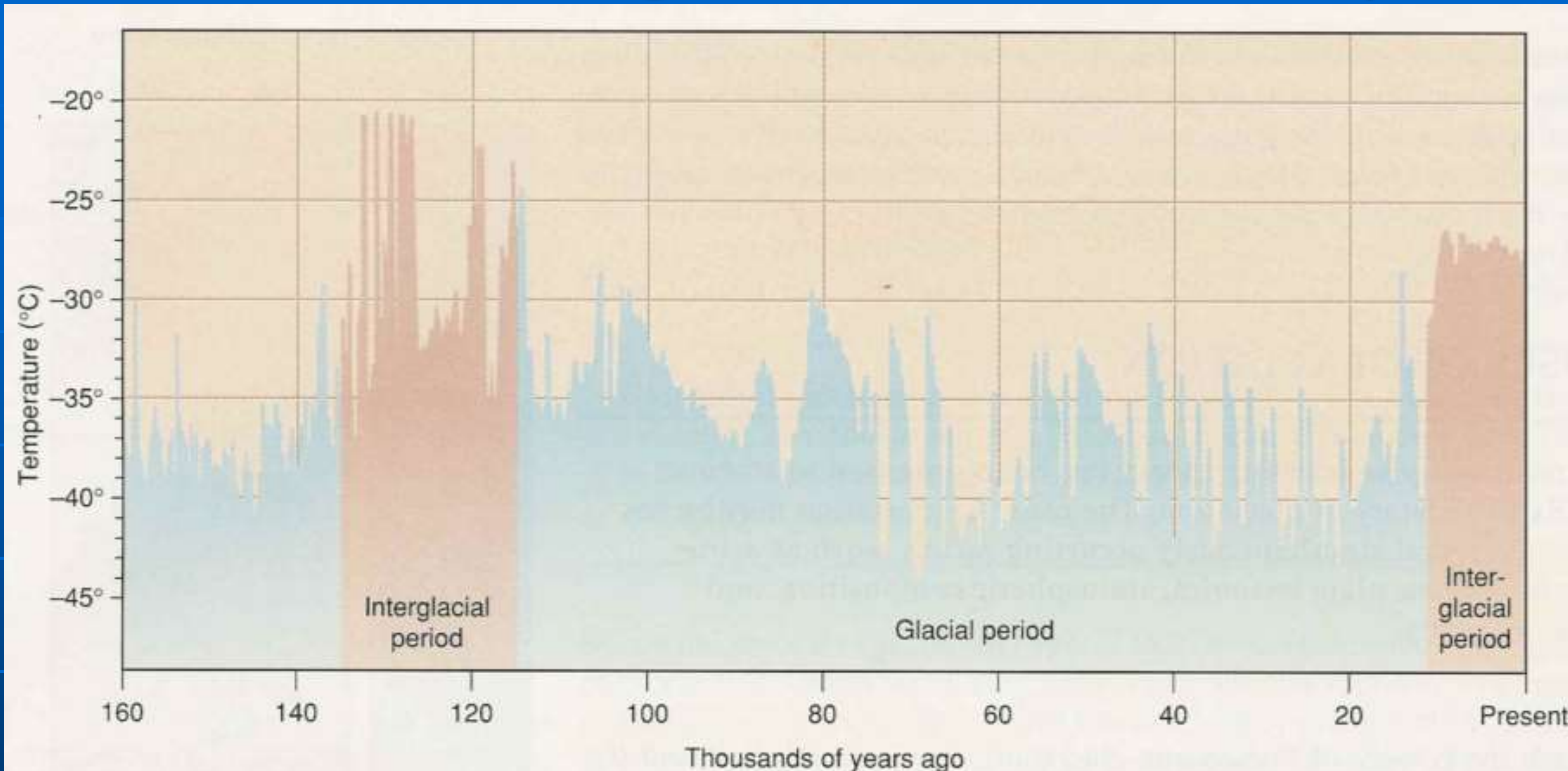
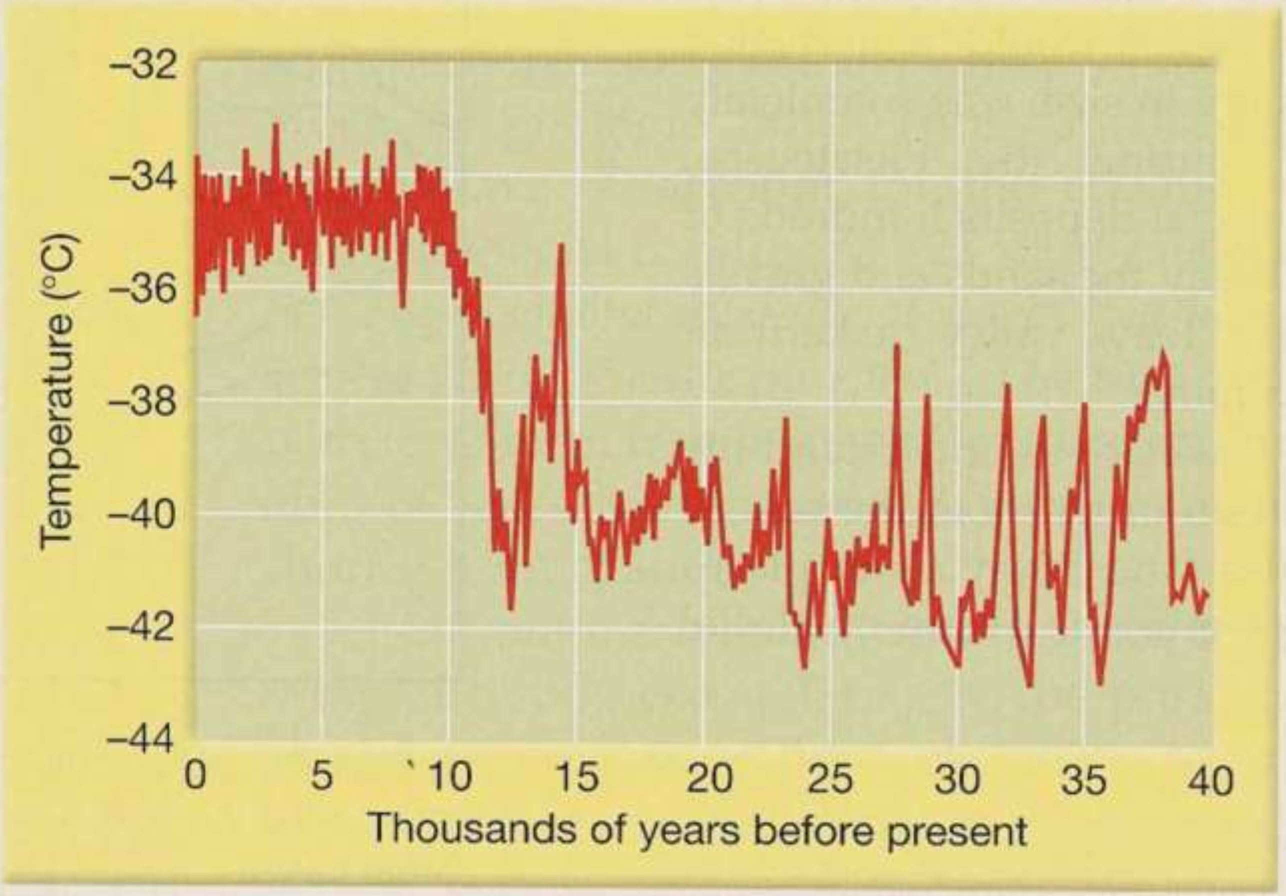


Figure 14.38 A record of climatic change during the last 160,000 years was assembled from studies of ice cores from Greenland's glacier. It shows that the normal pattern of change involves numerous rapid fluctuations in temperature—not only during glacial periods, but throughout interglacial periods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

40,000 yrs temp change

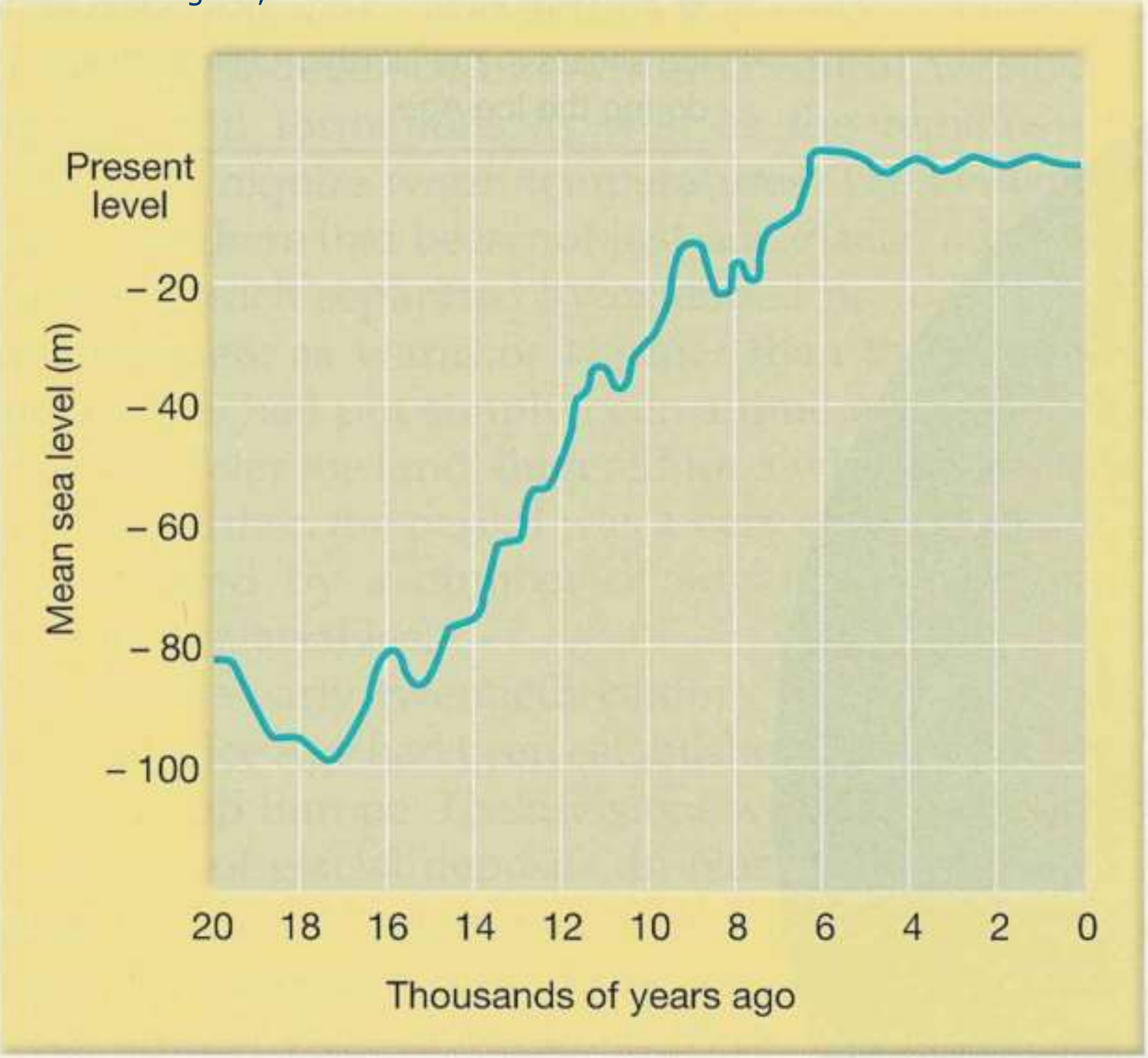


▲ **FIGURE 18.E** This graph showing temperature variations over the past 40,000 years is derived from oxygen isotope analysis of ice cores recovered from the Greenland ice sheet. *(After U.S. Geological Survey)*

Tarbuck & Lutgens, 2005

Sea level curve – 20,000 yrs

Tarbuck & Lutgens, 2005

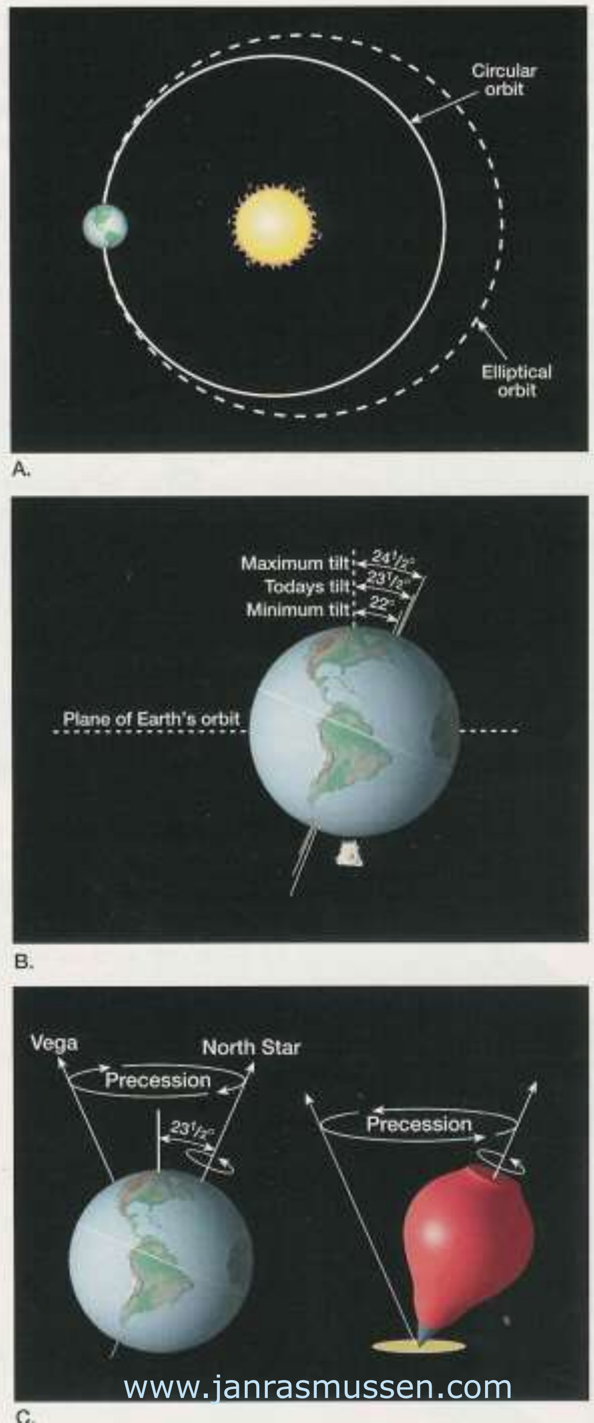


▲ **FIGURE 18.29** Changing sea level during the past 20,000 years. The lowest level shown on the graph represents the time about 18,000 years ago when the most recent ice advance was at a maximum.

Milankovitch causes of glaciation

▲ **FIGURE 18.32** Orbital variations. **A.** The shape of Earth's orbit changes during a cycle that spans about 100,000 years. It gradually changes from nearly circular to one that is more elliptical and then back again. This diagram greatly exaggerates the amount of change. **B.** Today the axis of rotation is tilted about 23.5° to the plane of Earth's orbit. During a cycle of 41,000 years, this angle varies from 21.5° to 24.5°. **C.** Precession. Earth's axis wobbles like that of a spinning top. Consequently, the axis points to different spots in the sky during a cycle of about 26,000 years.

Tarbuck & Lutgens, 2005



Milankovitch curves

Table 16.2 Milankovitch Orbital Factors

Parameter	Relative Variation	Approximate Periods
Eccentricity of the orbit (ellipticity)	0.017–0.053	100,000 years
Tilt of the axis (obliquity)	21½–24½°	41,000 years
Precession of the axis (wobble)	0–360°	23,000 years

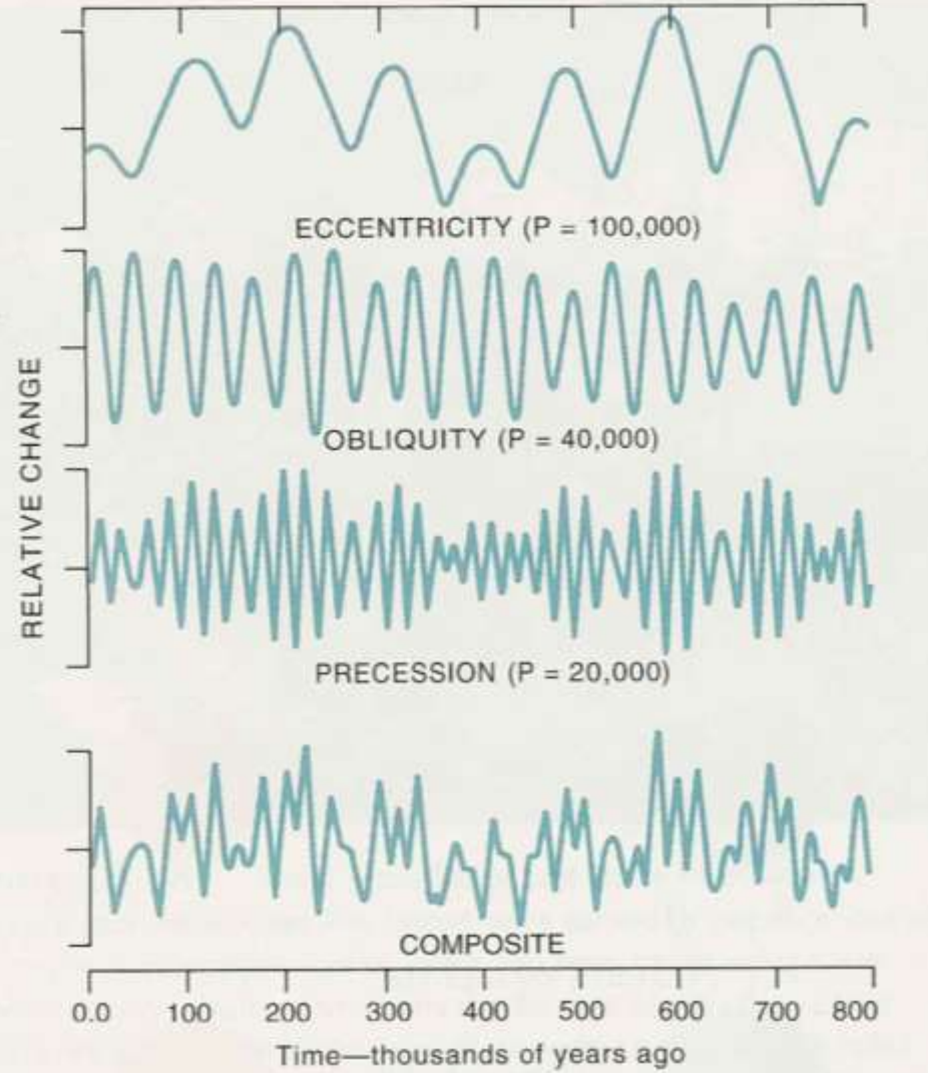


Figure 16.20 Variations in the Milankovitch orbital factors, eccentricity of the earth's orbit, obliquity of the axis, and precession of the equinoxes. The different approximate periods (P) for each of these factors are indicated (see Table 16.2), and a composite curve shows the result of adding all three curves together. *(Adapted from Berger, 1976: Celestial Mechanics, v. 15, pp. 53–74.)*

Prothero & Dott, 2004

Last 10,000 yrs temperature

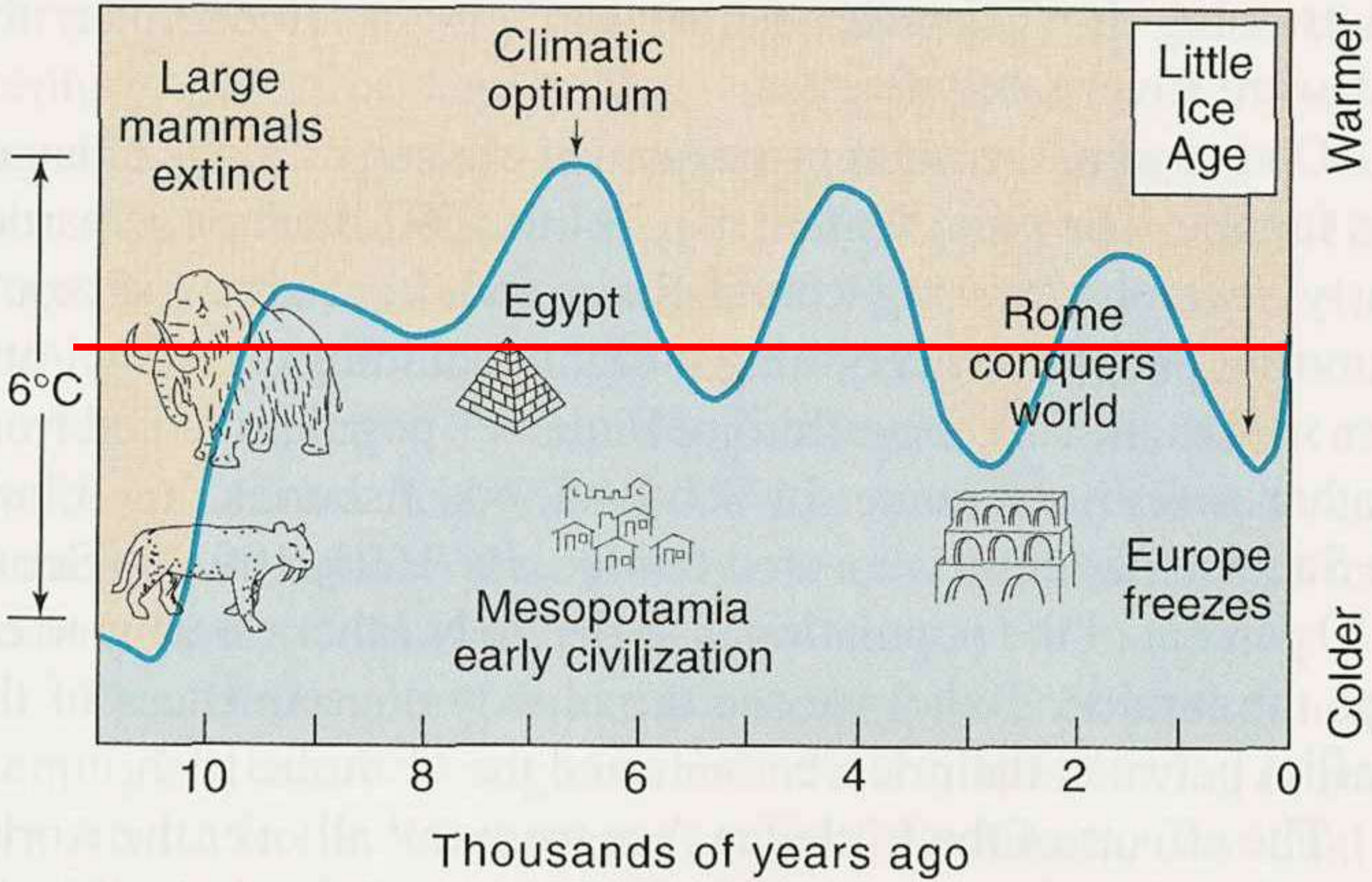


Figure 16.35 The effects of climatic cycles on the past 10,000 years of human history.

From Prothero & Dott, 2004

Temperature change, last 5,500 years

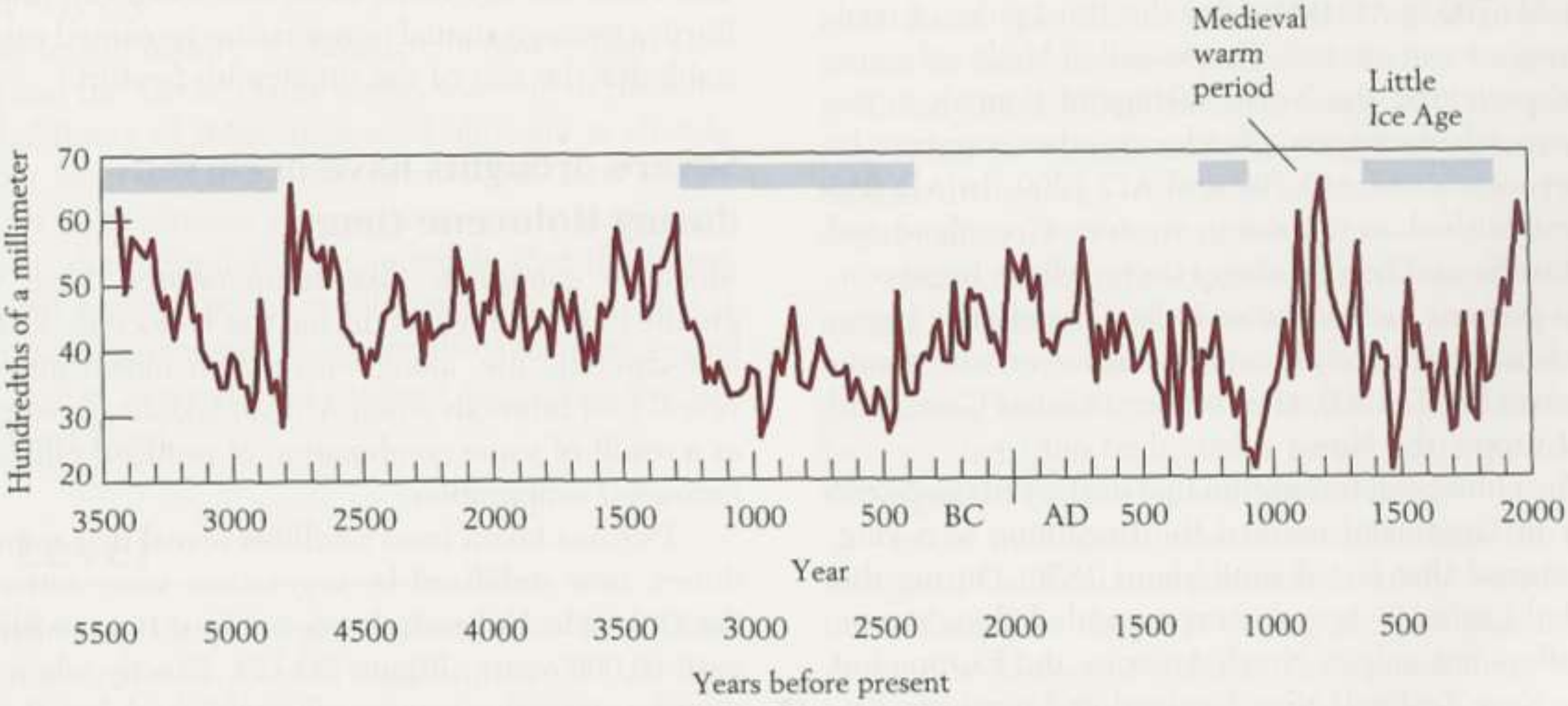
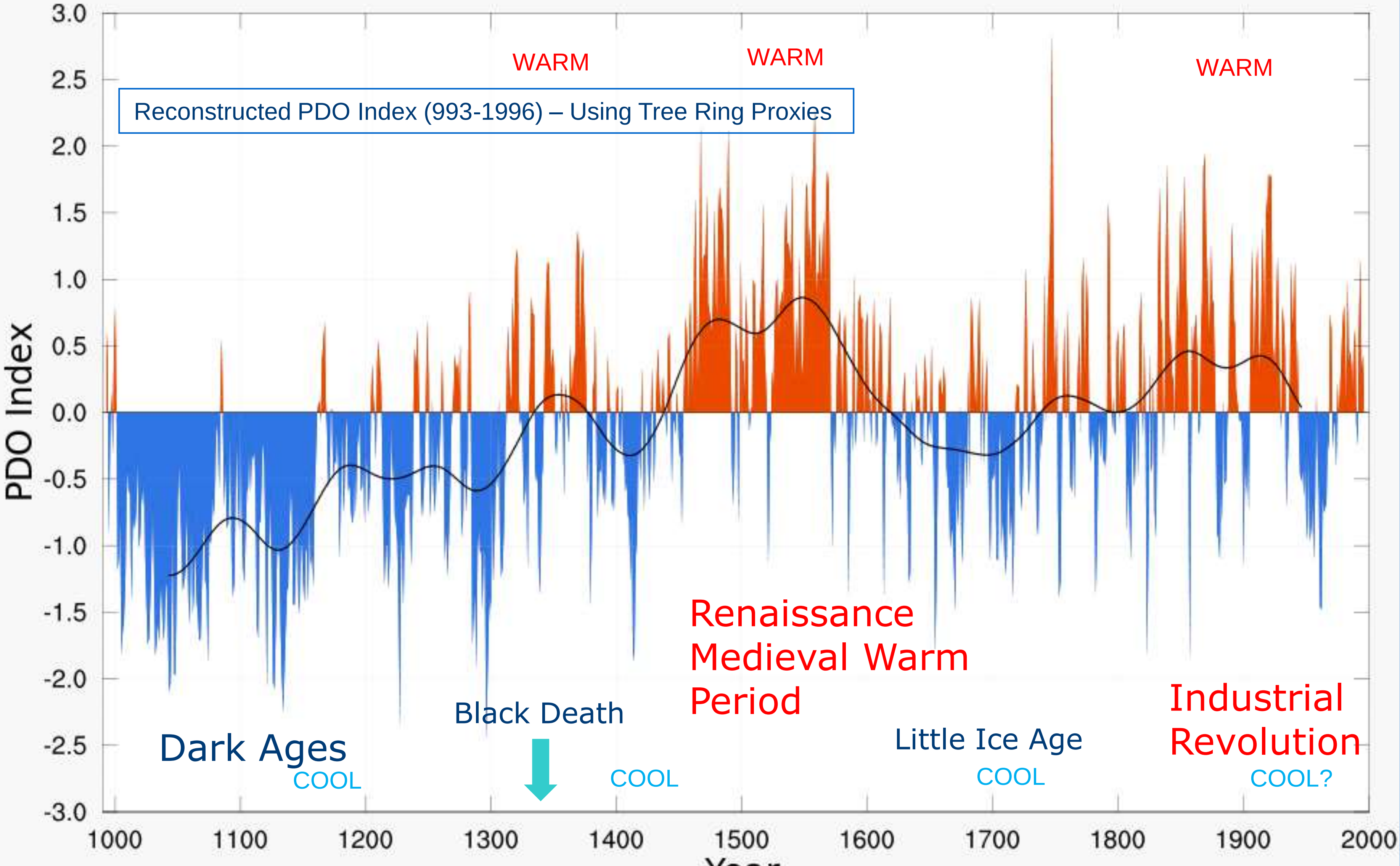


Figure 20-10 Cold intervals of the past 5500 years recorded by widths of annual growth rings in bristlecone pines near the upper tree line of the White Mountains of California. (Data from V. C. La Marche, in H. H. Lamb, *Climate History and the Modern World*, Routledge, London, 1995.)

Stanley, 2009

Pulsed Heat from the Deep

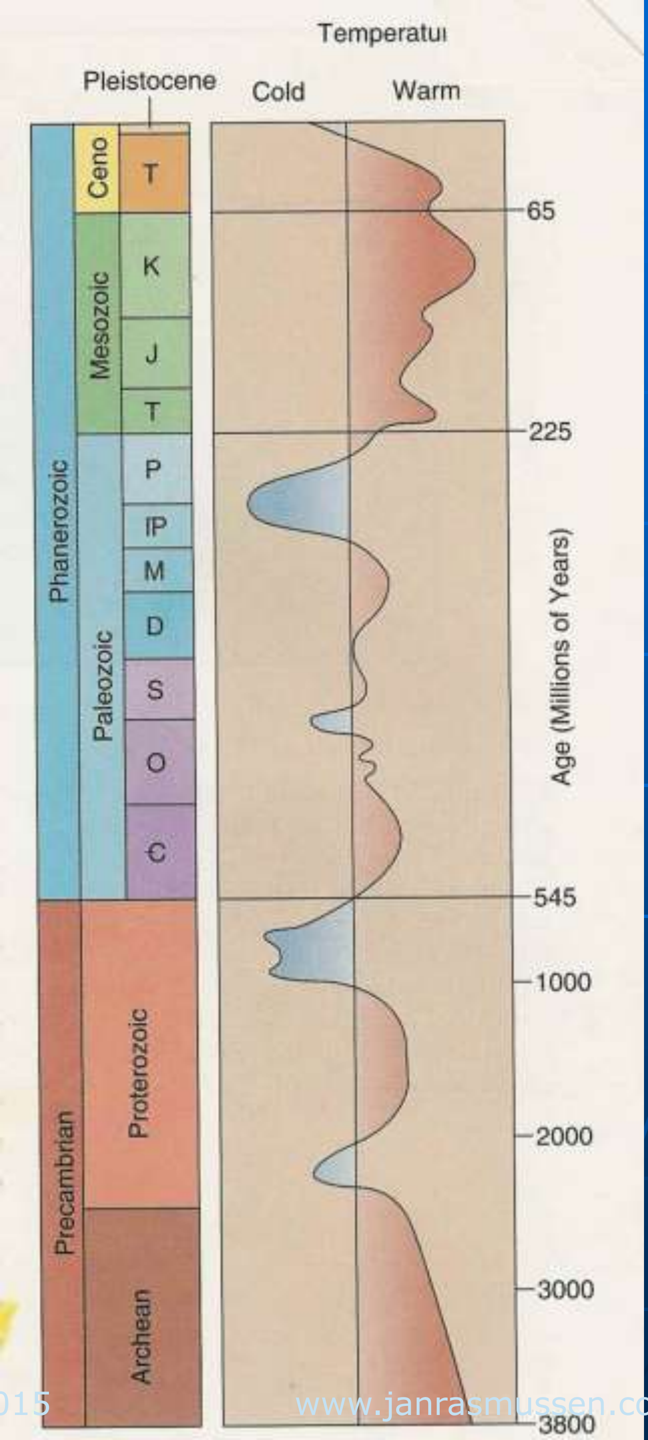


Modified from "PDO1000yr" by Giorgiogp2 - Own work. Licensed under CC BY-SA 3.0 via Commons - https://commons.wikimedia.org/wiki/File:PDO1000yr.svg#/media/File:PDO1000yr.svg

From Stan Keith

AZ Climate through Geologic Time

- Depends on plate tectonics driven by heat from the core
- Continental collisions = ice ages = every 250 million years
- Big climate changes through geologic time
- Mostly warm periods
- Now in an ice age interglacial period



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