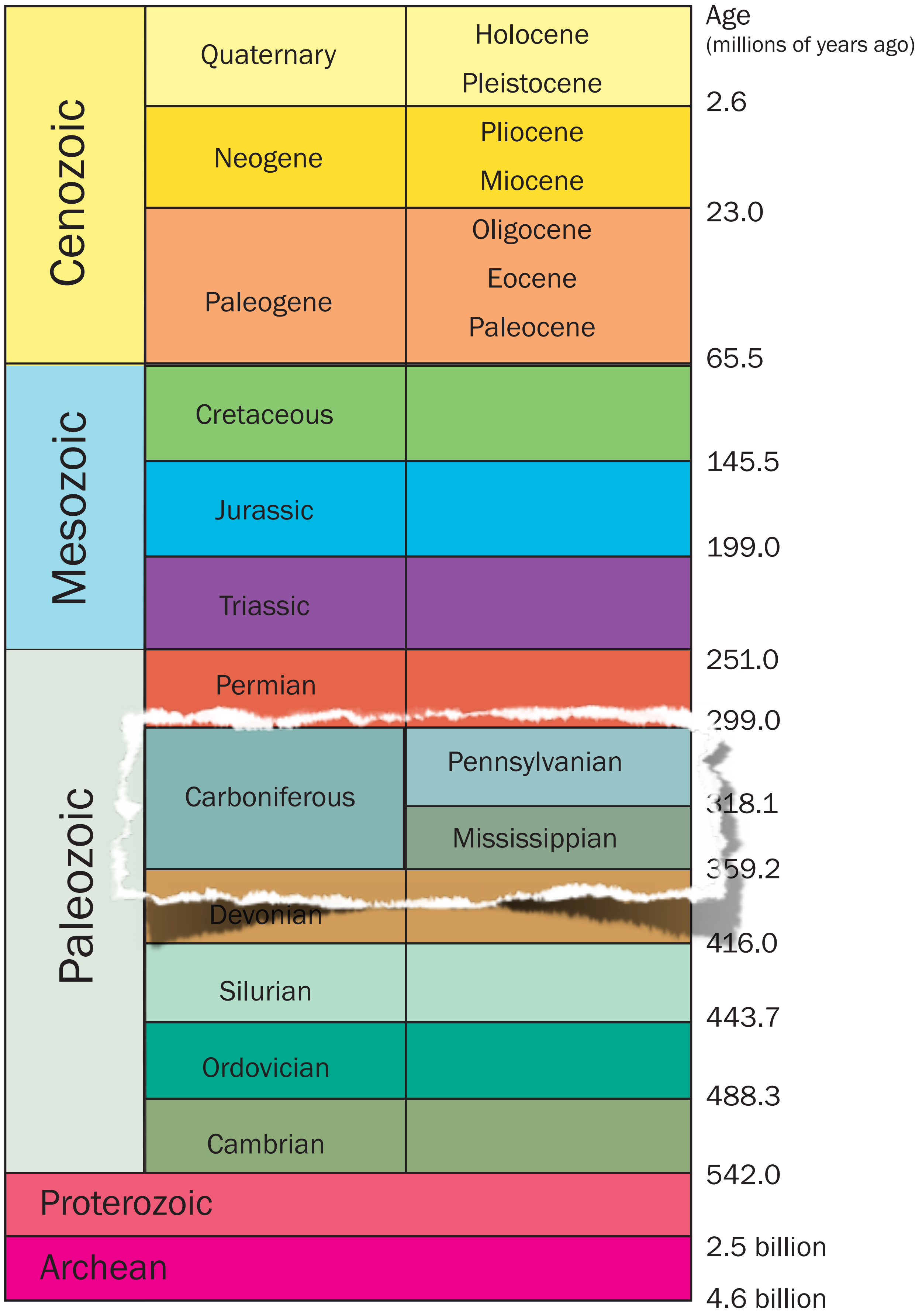
The Carboniferous Crisis

Introduction to Vertebrate Geobiology

Amphibian tracks left in the mud of a Pennsylvanian Age tidal flat in Martin County, Indiana. On display at Indiana Geological Survey. (photo by John Day)

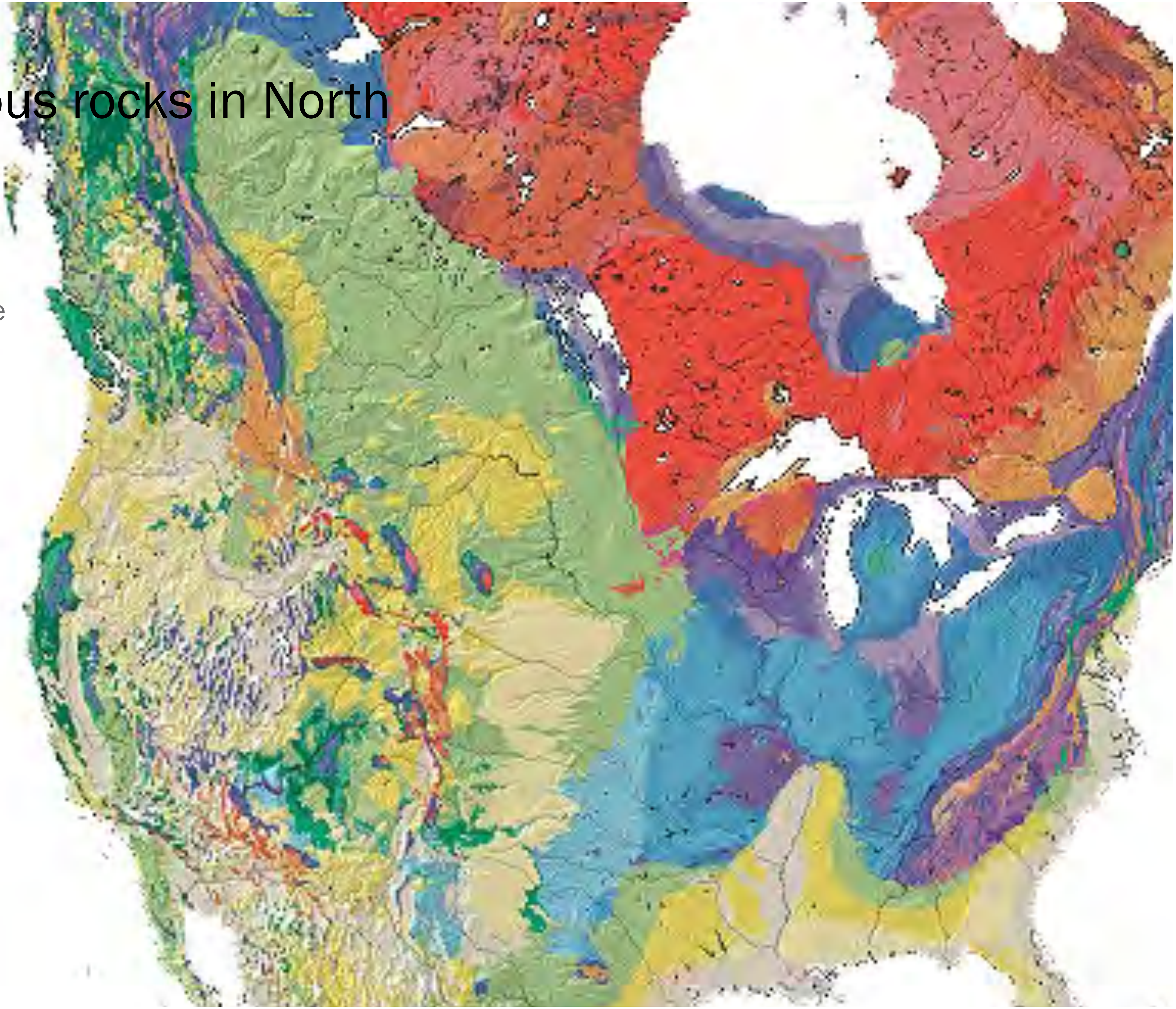
Reading: Benton, Chapter 1



			Age (millions of years ago)
Cenozoic	Quaternary	Holocene Pleistocene	2.6
	Neogene	Pliocene Miocene	23.0
	Paleogene	Oligocene Eocene Paleocene	65.5
Mesozoic	Cretaceous		145.5
	Jurassic		199.0
	Triassic		251.0
Paleozoic	Permian		299.0
	Carboniferous	Pennsylvanian	318.1
		Mississippian	359.2
	Devonian		416.0
	Silurian		443.7
	Ordovician		488.3
	Cambrian		542.0
Proterozoic			2.5 billion
Archean			4.6 billion

Carboniferous rocks in North America

Blue rocks are Carboniferous in Age



USGS Tapestry of Time and Terraine

Indiana’s Coal Mines

Seams of coal in layers of Pennsylvanian rocks in the southwest part of the state.

Known for coal, sandstones, plant fossils, tetrapod trackways.

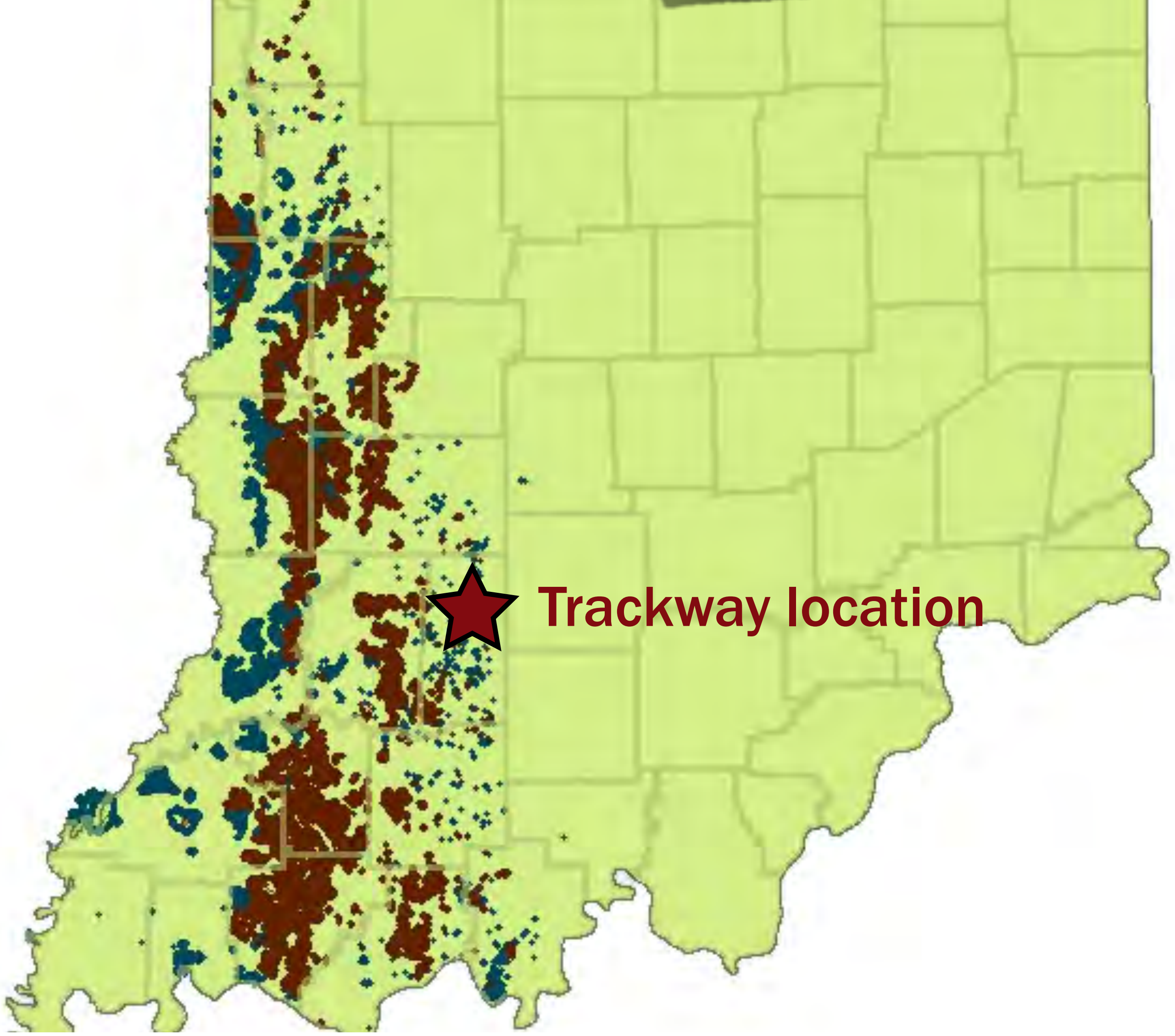
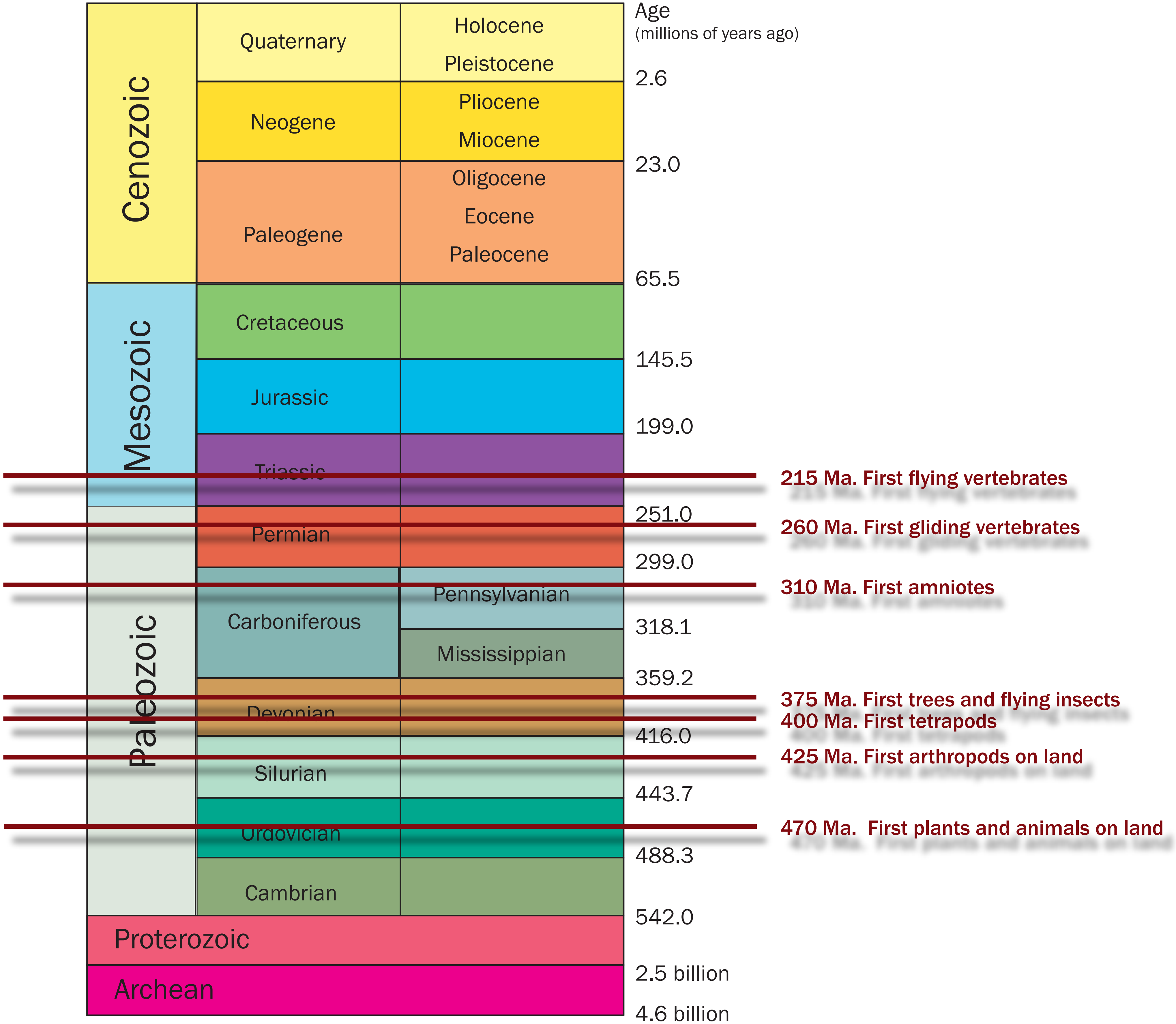


Photo credit



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Archean			4.6 billion

215 Ma. First flying vertebrates

260 Ma. First gliding vertebrates

310 Ma. First amniotes

375 Ma. First trees and flying insects

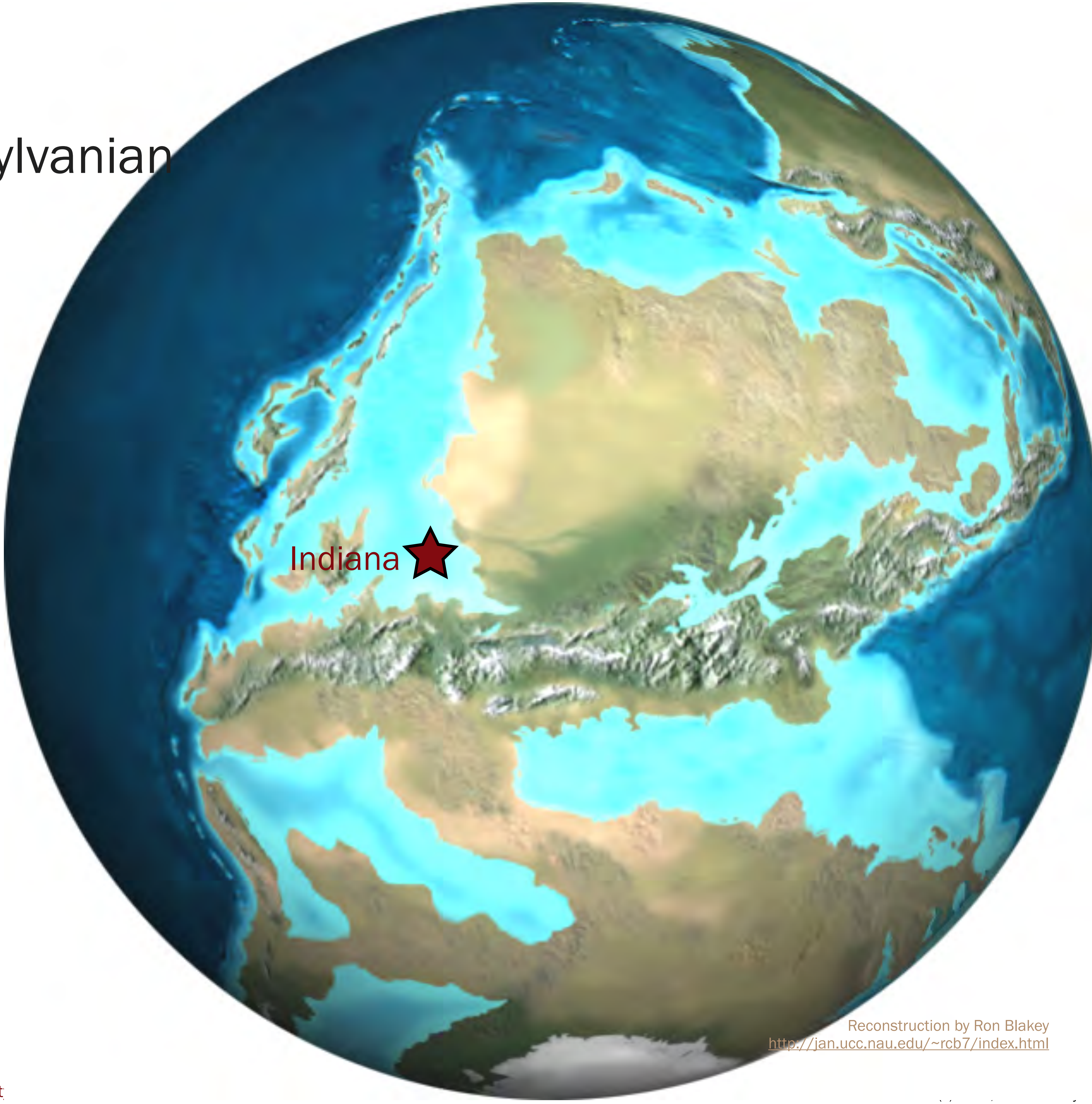
400 Ma. First tetrapods

425 Ma. First arthropods on land

470 Ma. First plants and animals on land

The Late Pennsylvanian

(300 mya)



Reconstruction by Ron Blakey
http://jan.ucc.nau.edu/~rcb7/index.html

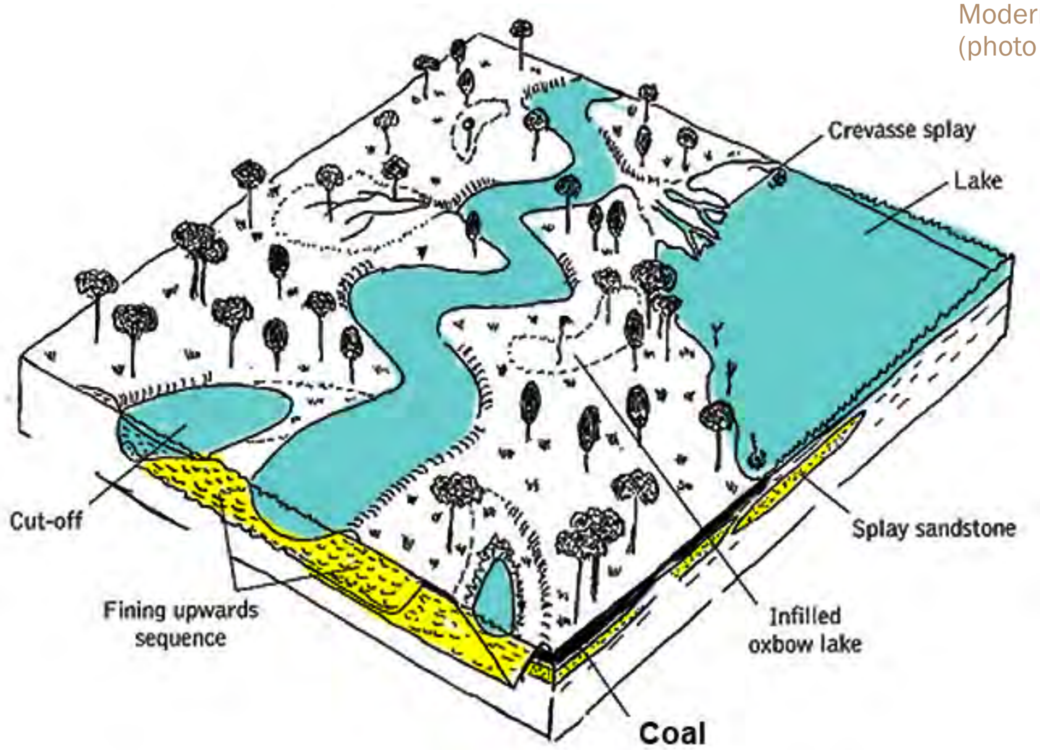
Carboniferous Rain Forests

Coal producing swamps on low-lying margins of the continents

Home of the the early radiation of tetrapods, the clade of vertebrates who colonized land and ancestrally had four limbs

Modern peat bog, Orono, Maine
(photo by D. Polly)

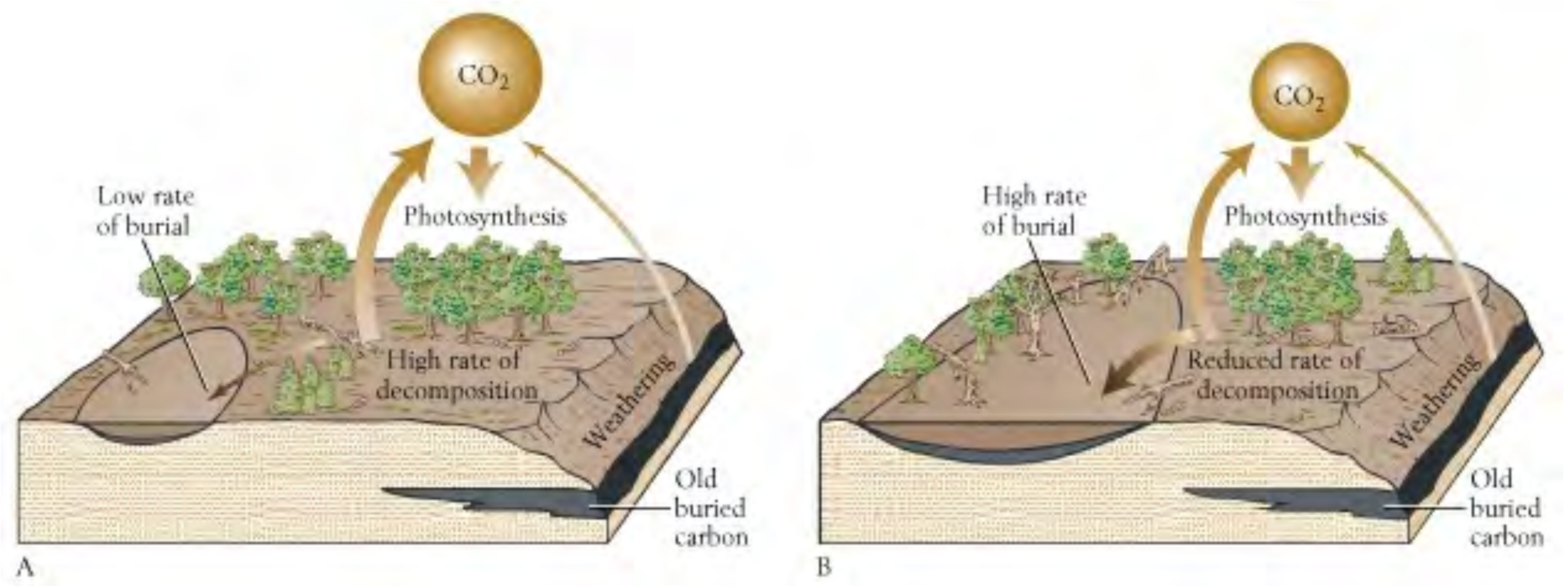
Carboniferous rain forest



(Hancock and Skinner, 2000. Oxford Companion to the Earth)

The Effects of Plant Burial on Carbon

Normally rate of burial of organically bound carbon is roughly equal to the rate at which it is released by weathering



Low rates of burial,
increase in atmospheric CO_2

High rates of burial,
decrease in atmospheric CO_2

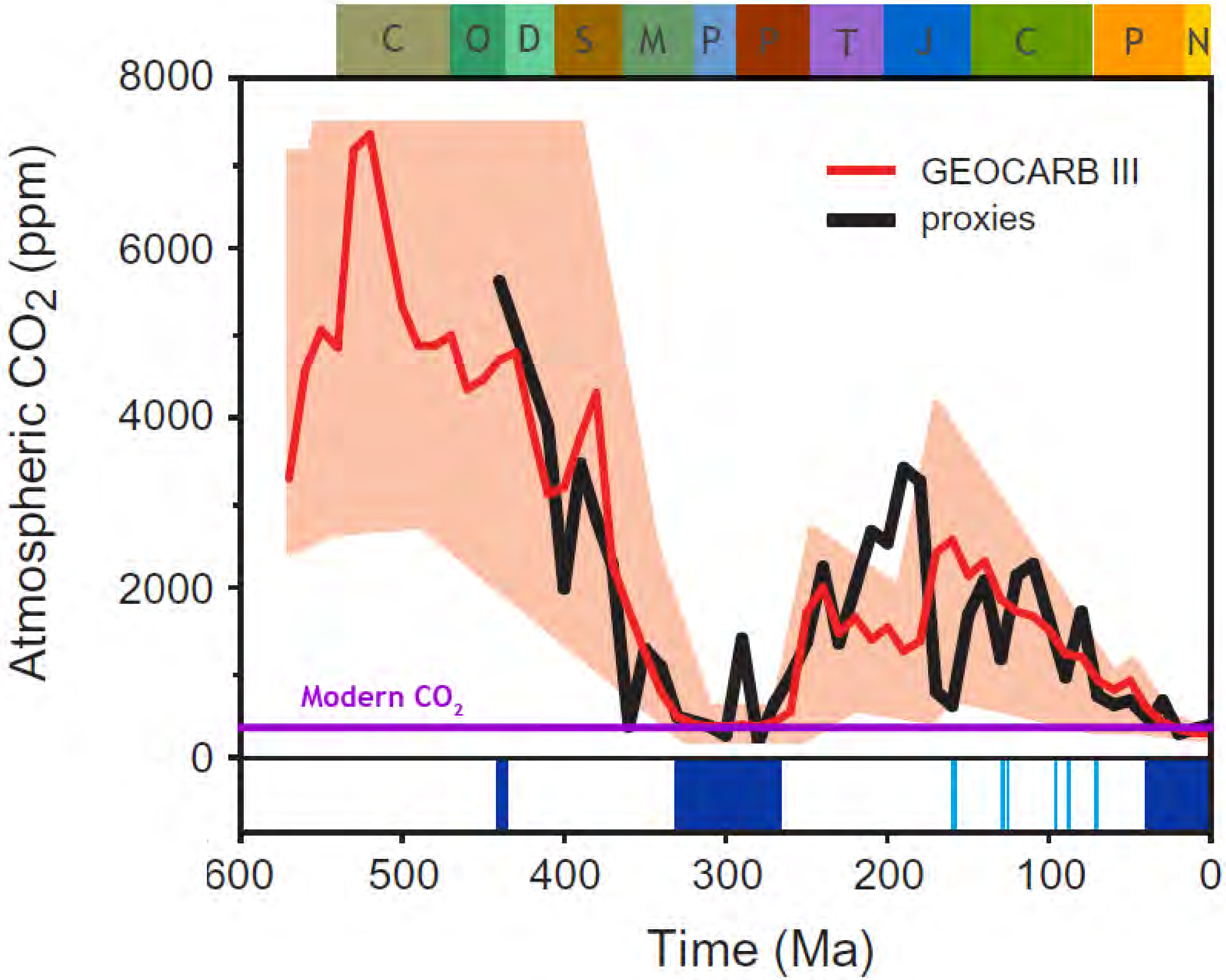
Weathering of carbonates also decreases atmospheric CO_2. Carbon dioxide in atmosphere prevents heat from radiating back into space.

Atmospheric carbon dioxide through

CO_2 crashed to one of its all time global lows in the Pennsylvanian and early Permian

Glacial ice covered most of the southern continent (Gondwana)

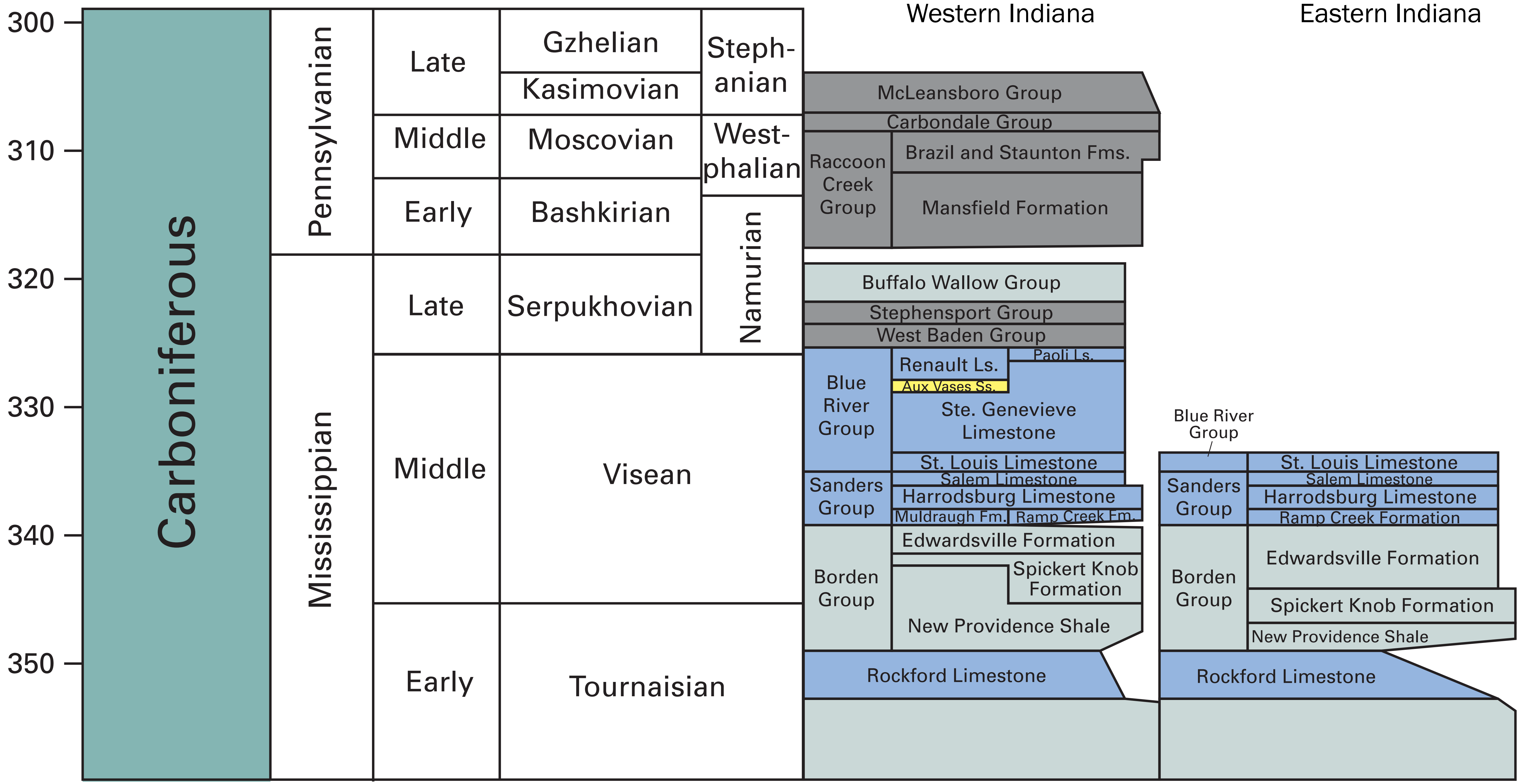
Extinction of plants and animals at 300 Ma, associated with increased aridity and collapse of the Carboniferous rain forest system



(Royer, Berner, Montañez, Tabor and Beerling, 2004. CO2 as a primary driver of Phanerozoic climate. GSA Today, 14: 4-10)

Global Time Scale

Rock Units



300
310
320
330
340
350

Carboniferous

Pennsylvanian
Mississippian

Late
Middle
Early
Late
Middle
Early

Gzhelian
Kasimovian
Moscovian
Bashkirian
Serpukhovian
Visean
Tournaisian

Steph-anian
West-phalian
Namurian

Western Indiana

McLeansboro Group
Carbondale Group
Raccoon Creek Group
Brazil and Staunton Fms.
Mansfield Formation
Buffalo Wallow Group
Stephensport Group
West Baden Group
Blue River Group
Renault Ls.
Paoli Ls.
Aux Vases Ss.
Ste. Genevieve Limestone
St. Louis Limestone
Sanders Group
Salem Limestone
Harrodsburg Limestone
Muldraugh Fm.
Ramp Creek Fm.
Borden Group
Edwardsville Formation
Spickert Knob Formation
New Providence Shale
Rockford Limestone

Eastern Indiana

Blue River Group
St. Louis Limestone
Sanders Group
Salem Limestone
Harrodsburg Limestone
Ramp Creek Formation
Borden Group
Edwardsville Formation
Spickert Knob Formation
New Providence Shale
Rockford Limestone

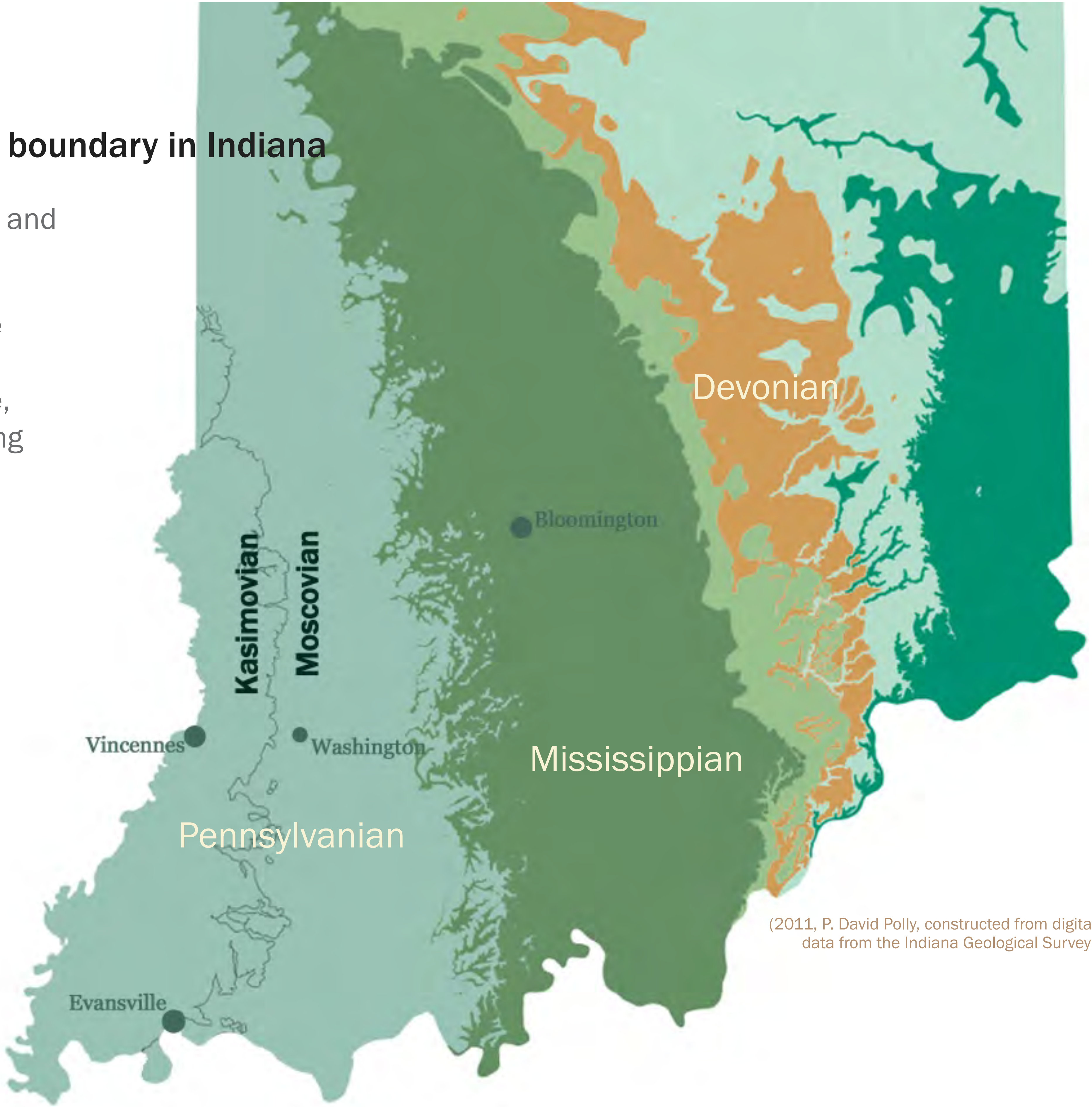
USGS
science for a changing world

REGIONAL STRATIGRAPHY AND PETROLEUM
SYSTEMS OF THE ILLINOIS BASIN, U.S.A.
By
Christopher S. Swezey
2009

The Moscovian-Kasimovian boundary in Indiana

Contact between the Carbondale and McLeansboro Groups

Rocks west of the boundary were deposited during the time of Carboniferous rainforest collapse, tetrapod extinction, and increasing endemism.

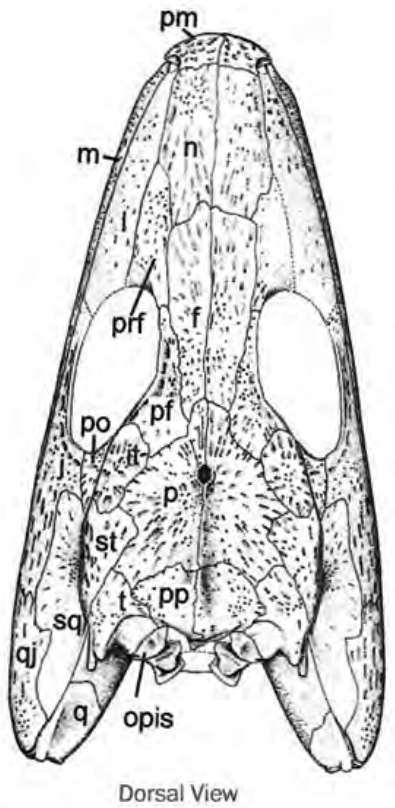


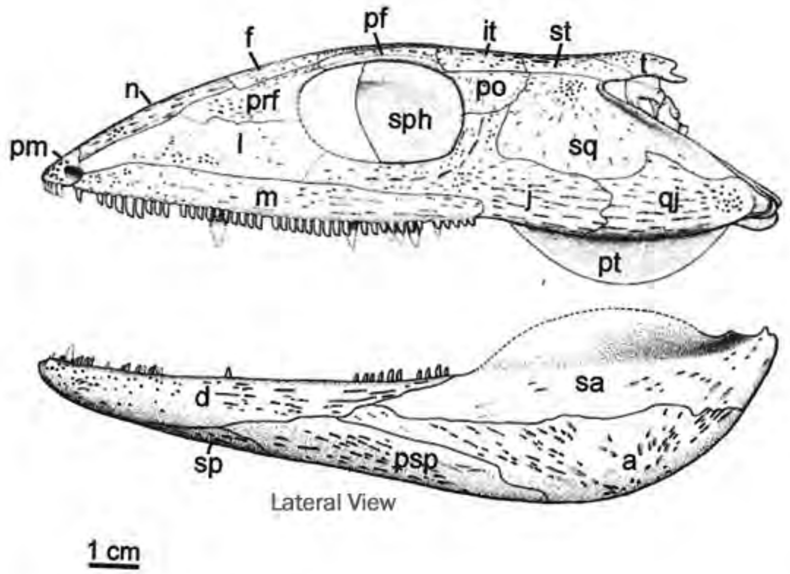
(2011, P. David Polly, constructed from digital data from the Indiana Geological Survey)

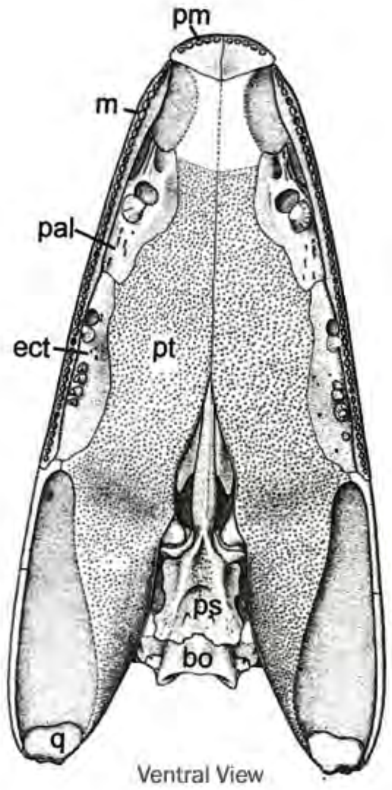
Proterogyrinus, a Carboniferous tetrapod

Medium sized, terrestrial insectivore

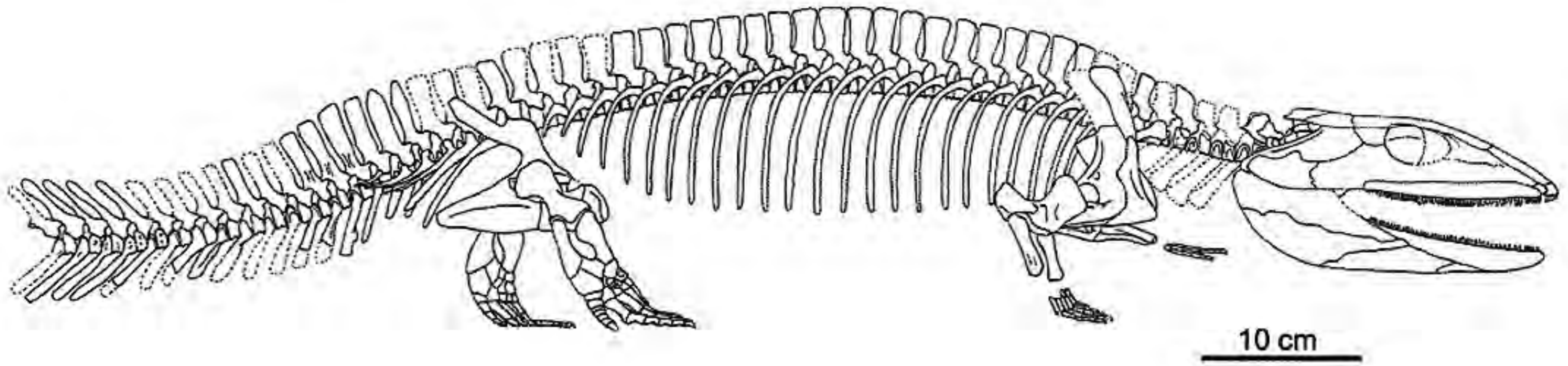
Predates the Kasimovian rainforest collapse







Proterogyrinus scheelei
Embolomere anthracosaur
Late Mississippian
Namurian A, (Serpukhovian)
Greer, West Virginia

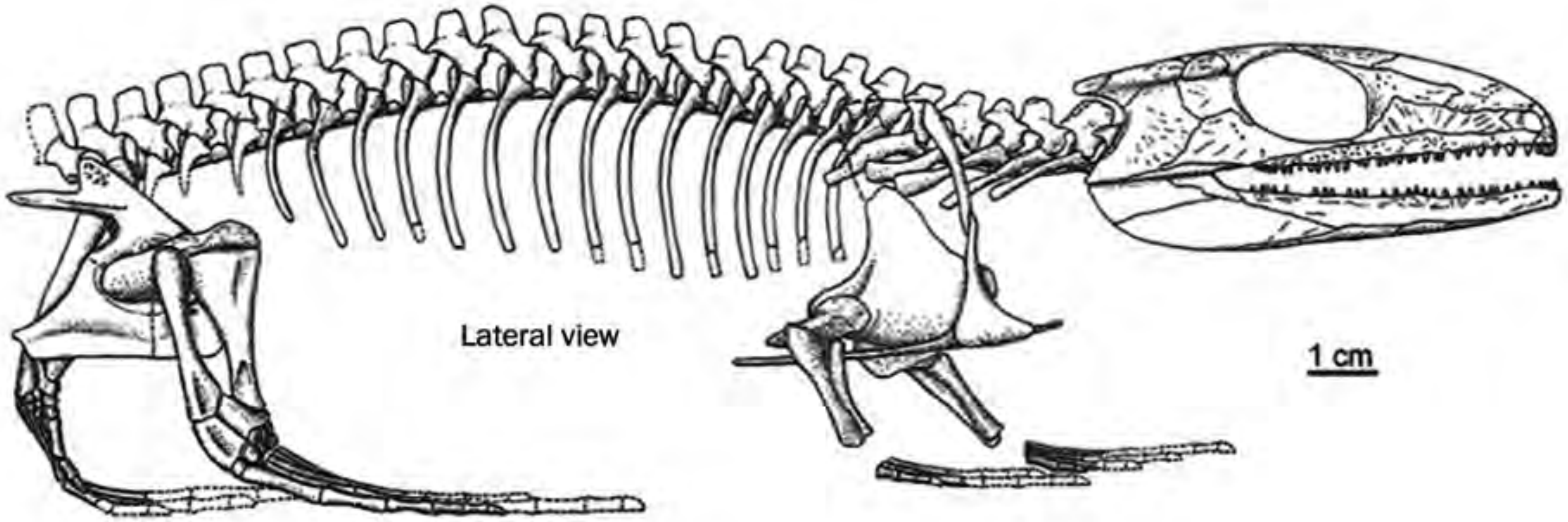


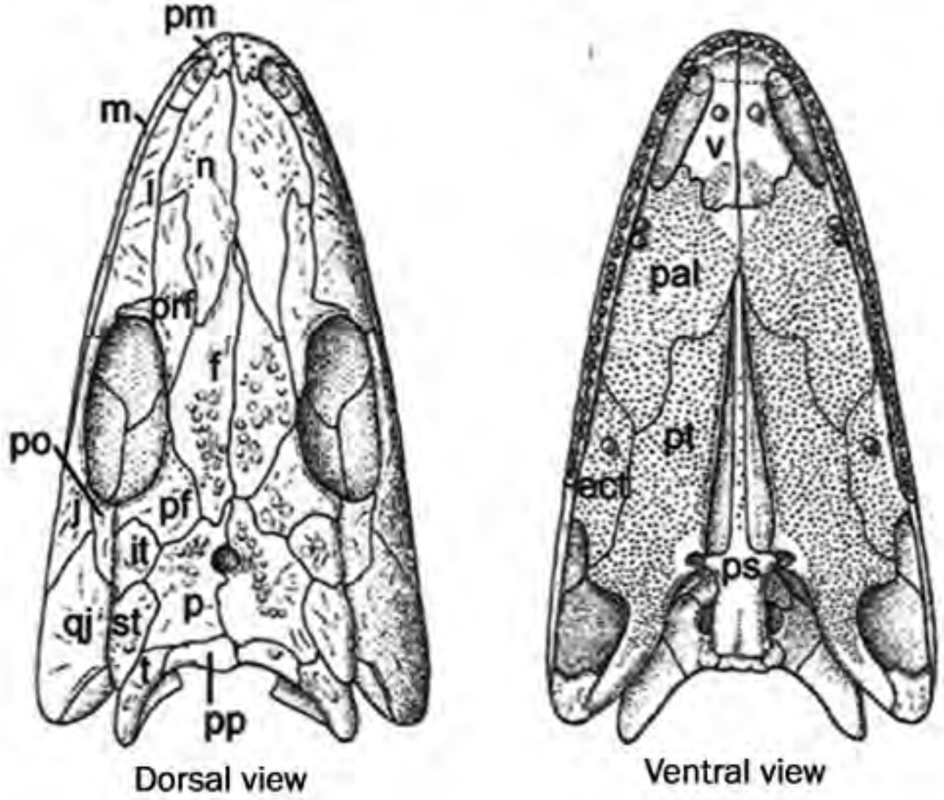
from Carroll, 2009. *The Rise of Amphibians*

Gephyrostegus, a Carboniferous

Small, terrestrial insectivore

Predates the Kasimovian rainforest collapse





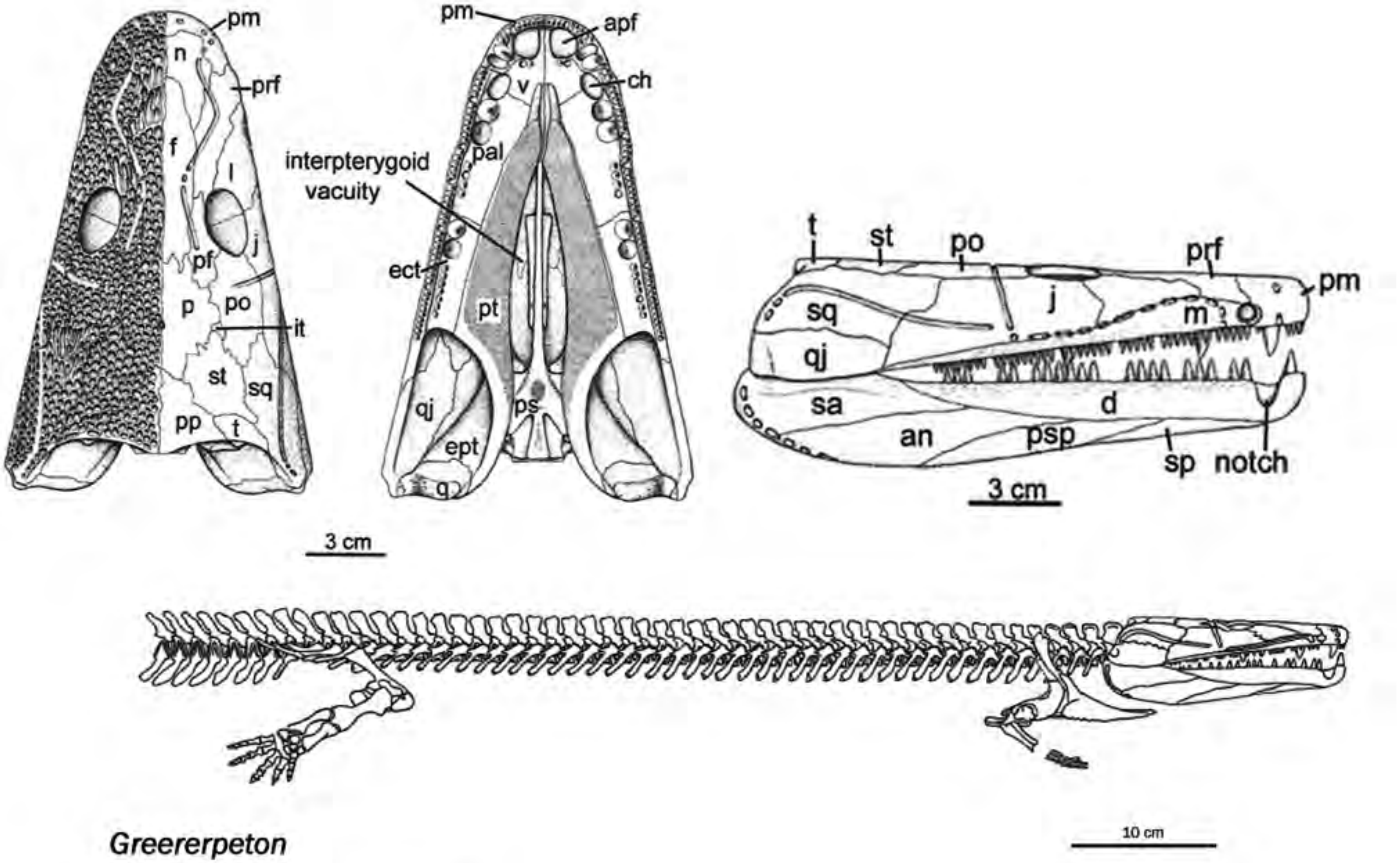
Gephyrostegus bohemicus
Anthracosauridae
Nyrany, Czech Republic
Westphalian D (Moscovian)
Middle Pennsylvanian

from Carroll, 2009. *The Rise of Amphibians*

Greererpeton, a Carboniferous tetrapod

Medium,
aquatic
piscivore

Extinct with the
Kasimovian
rainforest
collapse



Greererpeton
Colosteidae
Namurian A (Serpukhovian)
Late Mississippian

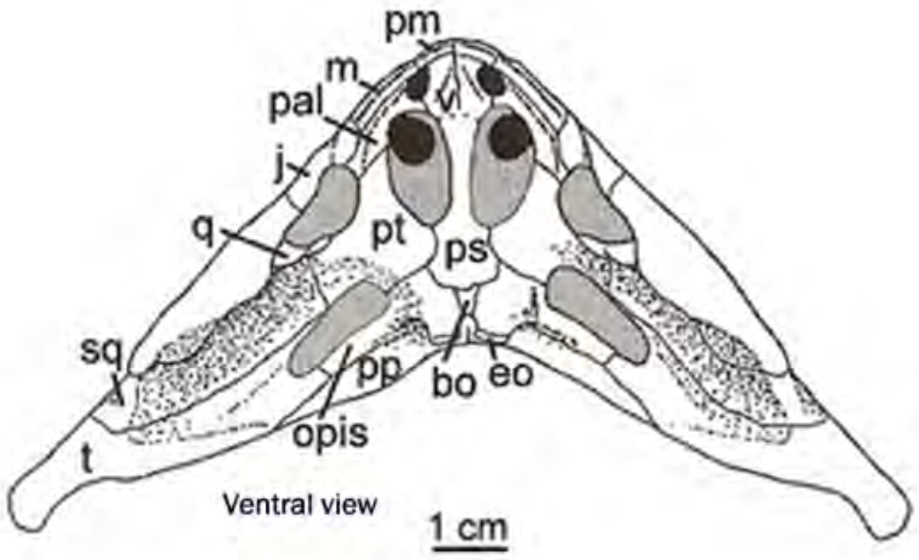
from Carroll, 2009. *The Rise of Amphibians*

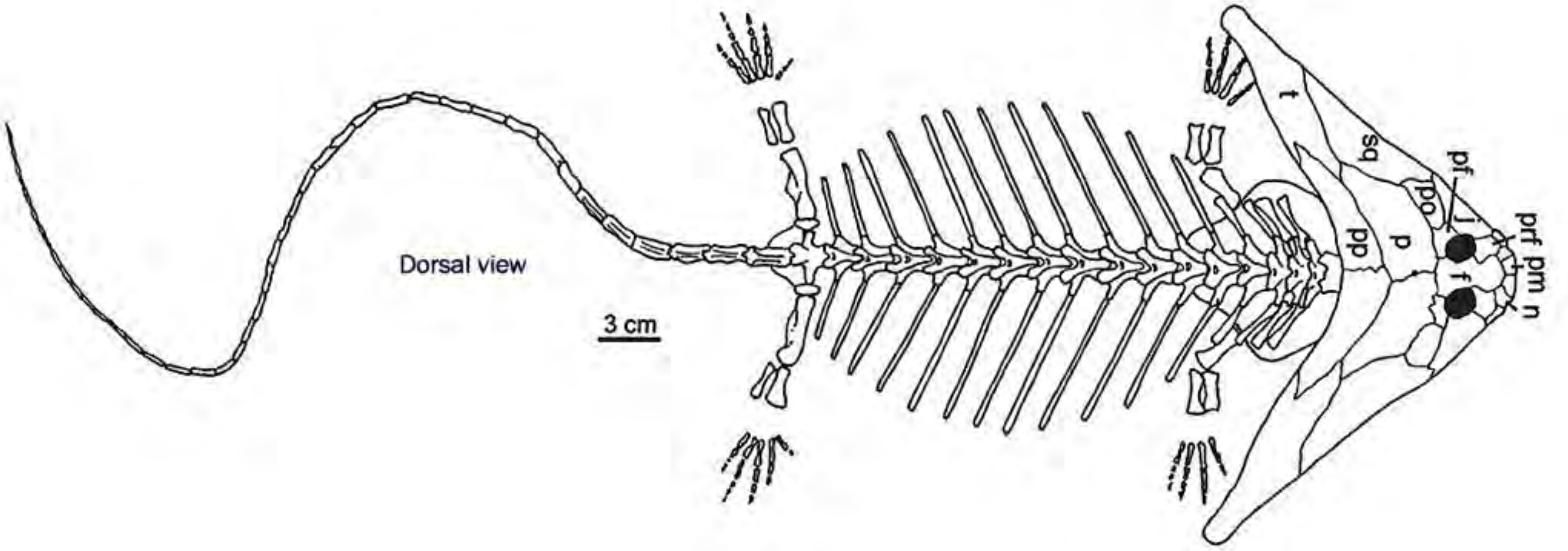
Diplocaulus, a Carboniferous and Permian tetrapod

Medium sized,
aquatic
piscivore

Lived after the
Kasimovian
rainforest
collapse

Diplocaulus magnicornus
Nectridean lepospondyl
Early Permian, Texas

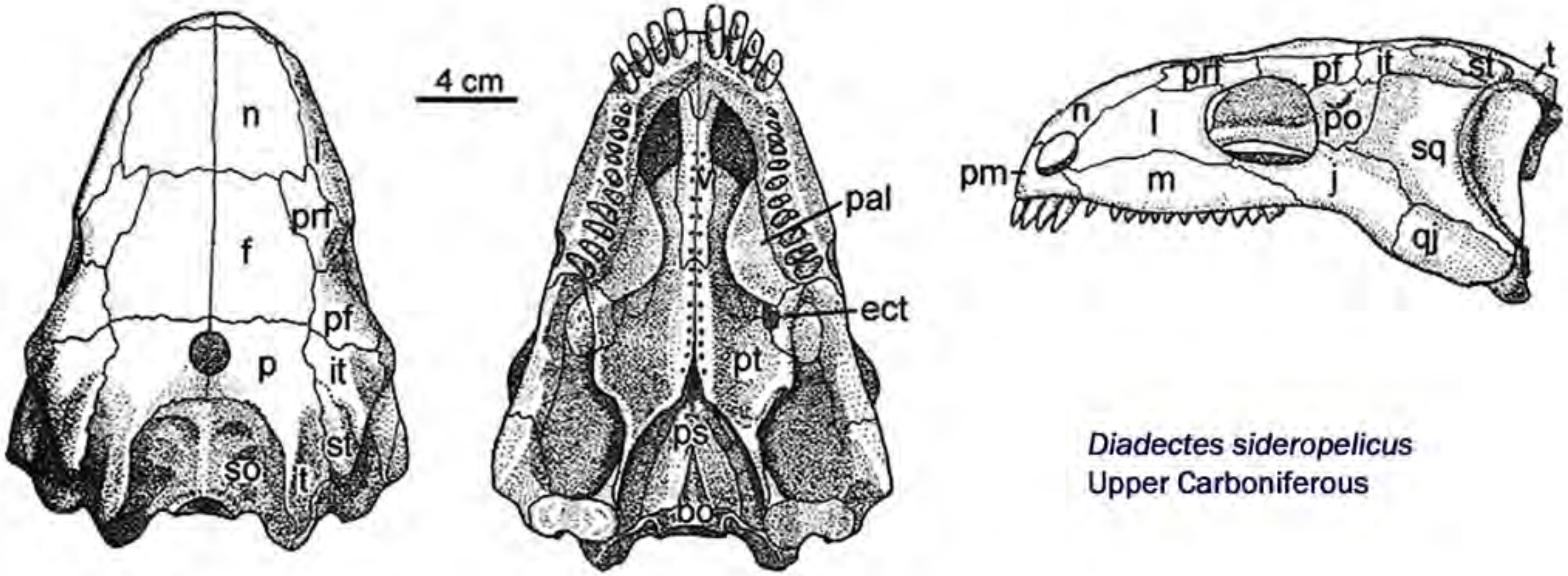




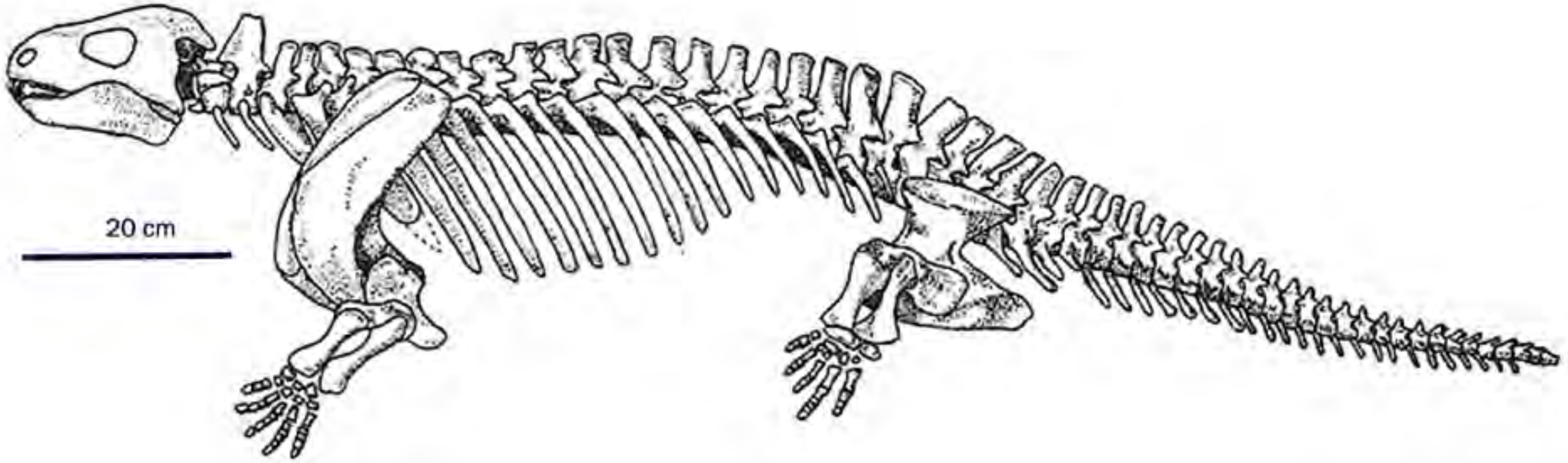
Diadectes, a Carboniferous and Permian tetrapod

Large, terrestrial herbivore

Lived after the Kasimovian rainforest collapse

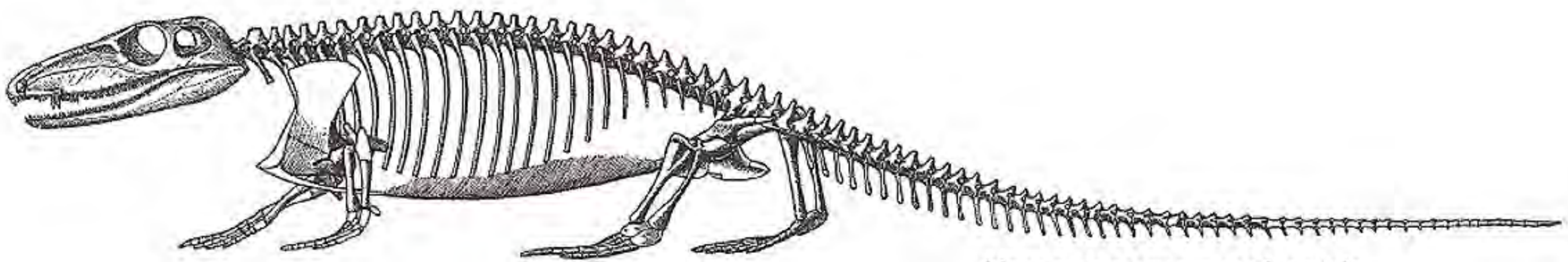


Diadectes sideropelicus
Upper Carboniferous



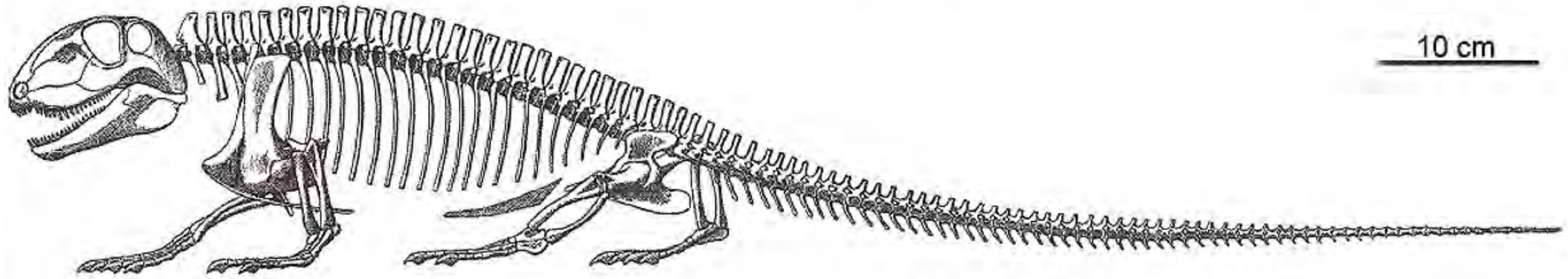
Synapsids, Carboniferous and Permian tetrapods

Large, terrestrial predator



Varanosaurus acutirostris
Ophiacodontidae, Synapsida
Early Permian

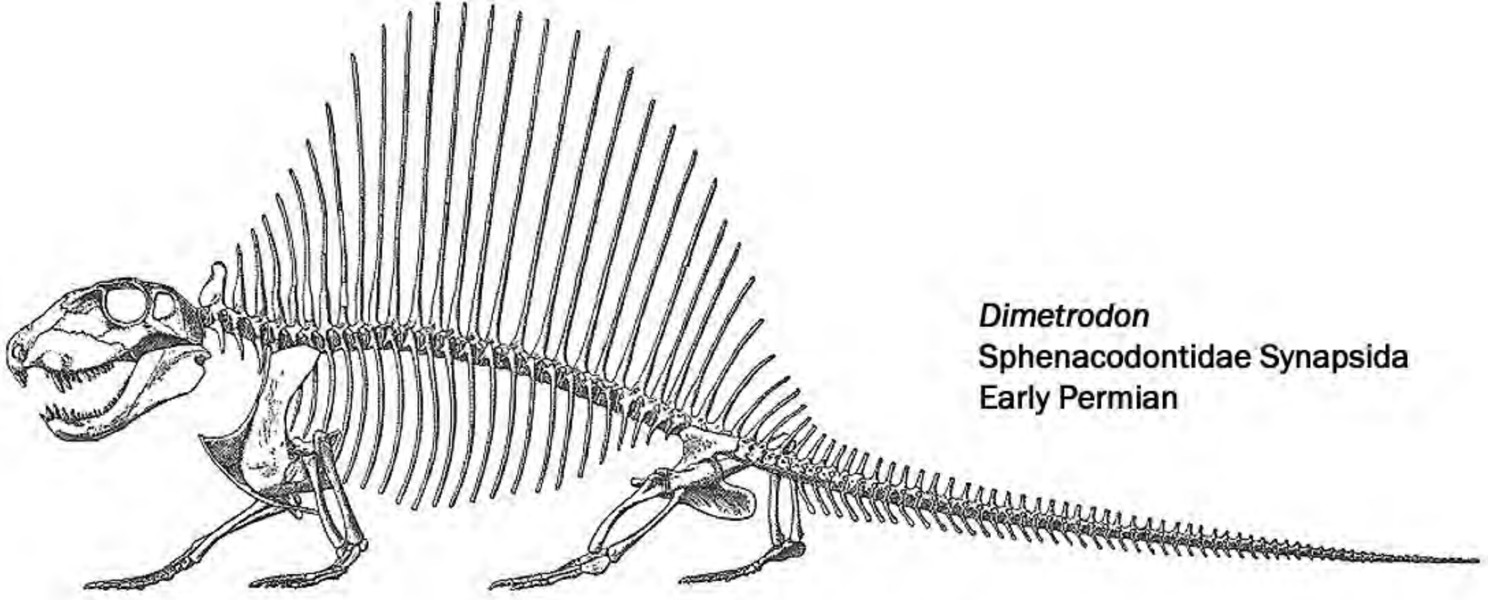
10 cm



Lived after the Kasimovian rainforest collapse

10 cm

Haptodus baylei
Sphenacodontidae, Synapsida
Late Carboniferous-Early Permian



Dimetrodon
Sphenacodontidae Synapsida
Early Permian

10 cm

The paleobiological diversity of early tetrapods

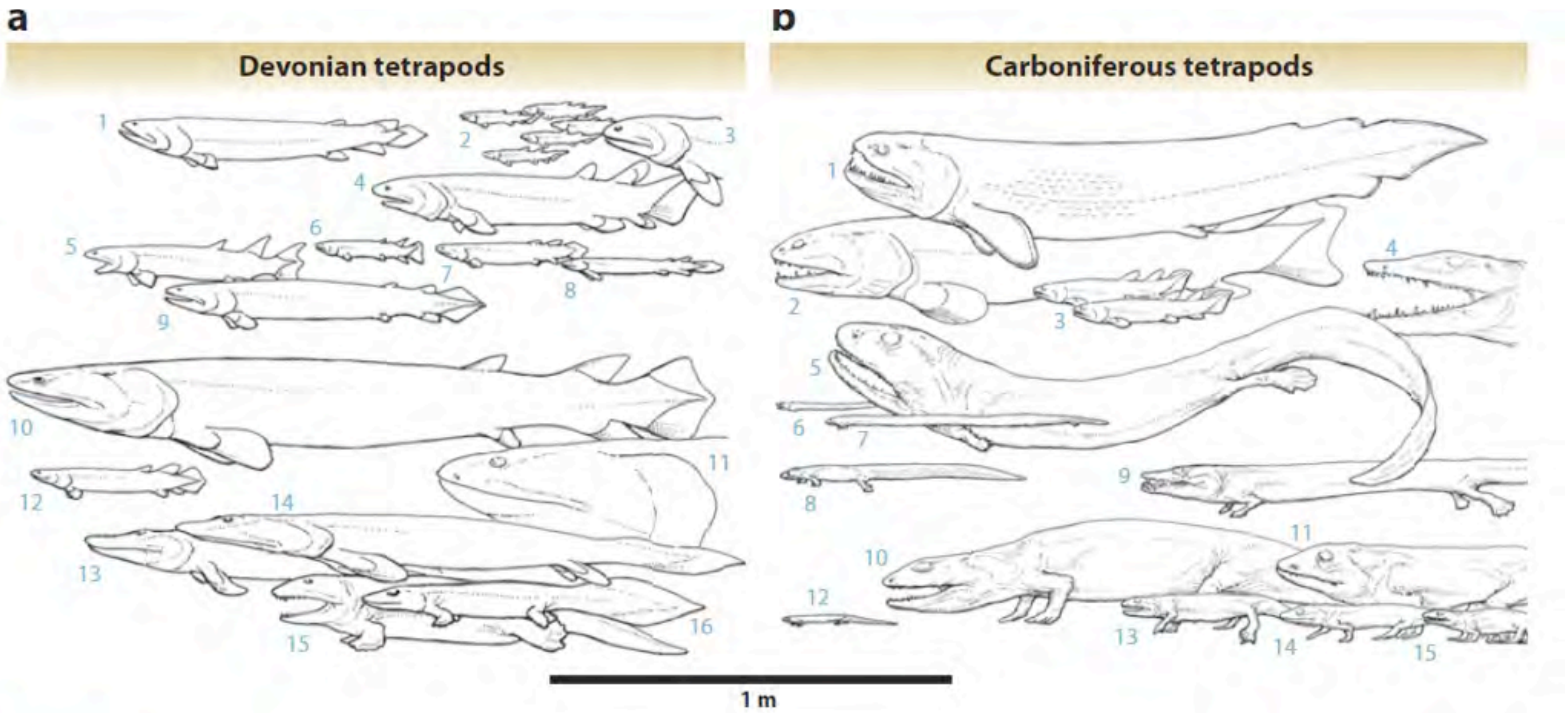


Figure 2

(*a*) Devonian tetrapods drawn to scale, illustrating anatomical diversity; all taxa are stem members. 1. *Gooloogongia*, a rhizodont; 2. *Osteolepis*, an osteolepidid; 3. *Koharalepis*, an osteolepidid; 4. *Canowindra*, an osteolepidid; 5. *Eusthenopteron*, a tristichopterid; 6. *Tristichopterus*, a tristichopterid; 7. *Gyroptychius agassizi*, an osteolepidid; 8. *Gyroptychius dolichotatus*, an osteolepidid; 9. *Cabonnichthys*, a tristichopterid; 10. *Mandageria*, a tristichopterid; 11. *Eusthenodon*, a tristichopterid; 12. *Glyptopomus*, an osteolepidid; 13. *Tiktaalik*, an elpistostegalid; 14. *Panderichthys*, an elpistostegalid; 15. *Ichthyostega*, a limbed stem tetrapod; 16. *Acanthostega*, a limbed stem tetrapod. (*b*) Carboniferous tetrapods drawn to scale, illustrating anatomical diversity. Taxa shown include stem (1–5, 9, 11) and crown group (6–8, 10, 12–15) members. 1. *Strepsodus*, a rhizodont; 2. *Megalichthys*, a megalichthyid; 3. *Rhizodopsis*, a megalichthyid; 4. *Megalocephalus*, a baphetid (stem tetrapod); 5. *Crassigyrinus*, a stem tetrapod; 6. *Palaeomolgophis*, an adelospondyl (stem amniote or stem tetrapod); 7. *Brachydectes*, a lysorophid (stem amniote); 8. *Urocordylus*, a nectridean (stem amniote); 9. *Greererpeton*, a colosteid (stem tetrapod); 10. *Proterogyrinus*, an embolomere (stem amniote); 11. *Pederpes*, a whatcheeriid (stem tetrapod); 12. *Westlothiana*, a stem amniote; 13. *Silvanerpeton*, an embolomere (stem amniote); 14. *Dendrerpeton*, a temnospondyl (stem lissamphibian); 15. *Gephyrostegus*, a gephyrostegid (stem amniote).

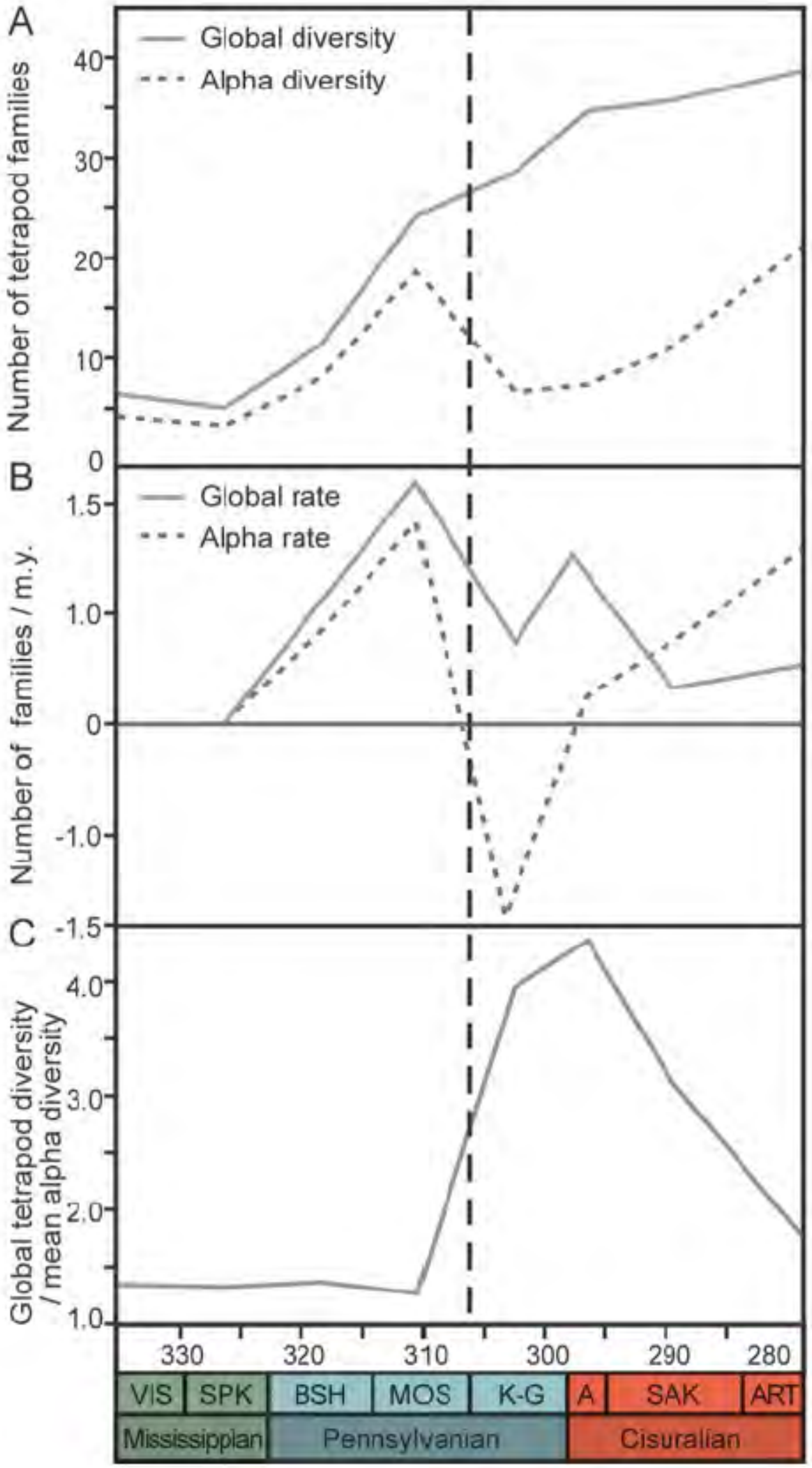
Coates, M. I., M. Ruta, and M. Friedman. 2008. Ever since Owen: changing perspectives on the early evolutio of tetrapods. Annual Review of Ecology, Evolution, and Systematics, 39: 571-592.

Tetrapod diversity through the rainforest collapse

Sahney *et al.* 2010 argued that the environmental fragmentation associated with rainforest collapse led to increased global diversity by isolating local communities and diversifying landscapes to open new niches

Global diversity - number of tetrapod families in the world

Alpha diversity - number of tetrapod families in local paleocommunities



Sahney et al., 2010. Rainforest collapse triggered Carboniferous tetrapod diversification in Eurameria. Geology, 38: 1079-1082.

Faunal and ecological turnover at the Moscovian-Kasimovian boundary

turnover - replacement of one organism or group of organisms by another, usually after an extinction event

faunal turnover - replacement of one taxonomic group of organisms by another

ecological turnover - replacement of a group of organisms adapted to one environment by one adapted to a different environment.

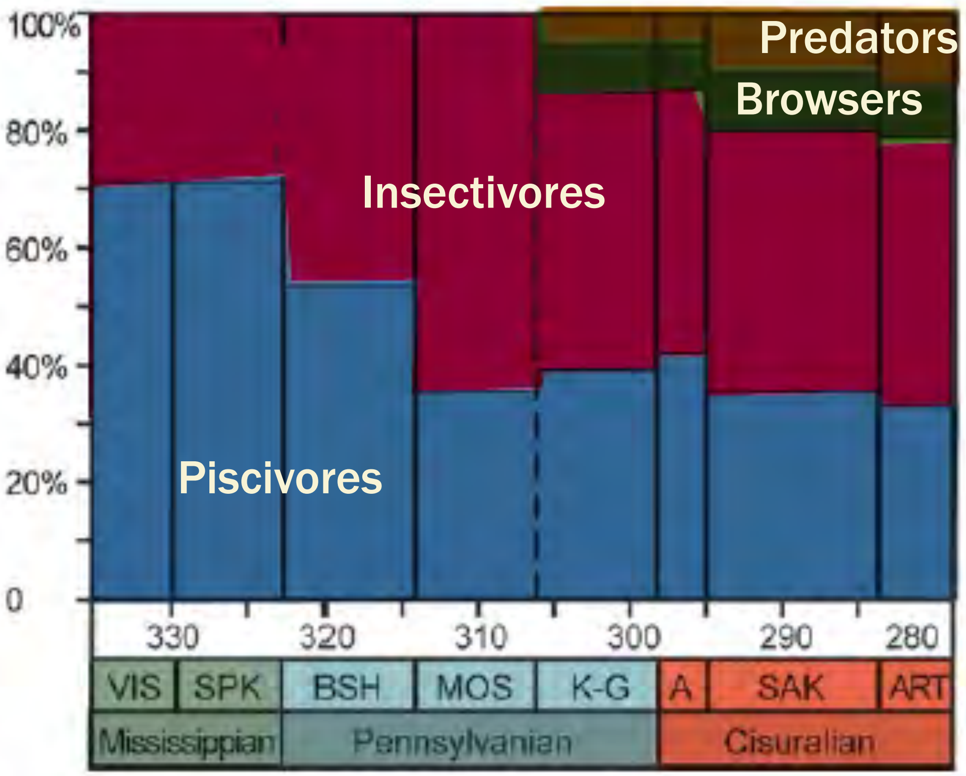


Figure 3. Global ecological diversity of tetrapods from Visean (346 Ma) to Artinskian (270 Ma). Time scale after Davydov et al. (2010). Abbreviations as in Figure 1.

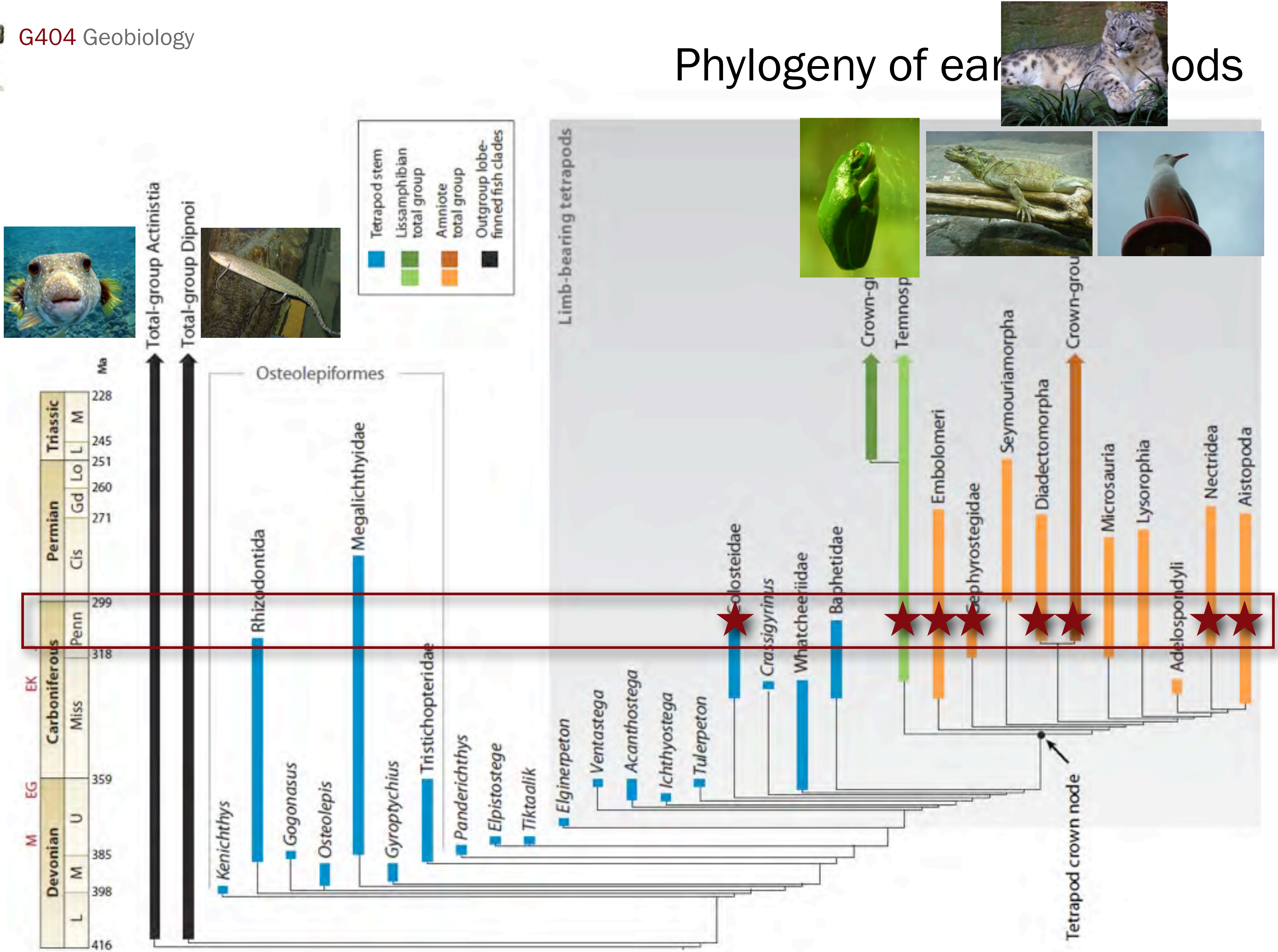
TABLE 1. NICHES, A COMBINATION OF DIET AND BODY SIZE OCCUPIED BY AMPHIBIANS AND "REPTILES" BEFORE AND AFTER THE ALPHA IMPLOSION

	Piscivores			Insectivores			Browsers			Predators			Total niches	Total families
	S	M	L	S	M	L	S	M	L	S	M	L		
BAS-MOS amphibians	Y	Y	Y	Y	Y								5	23
K-G amphibians	Y	Y	Y	Y	Y							Y	6	24
BAS-MOS reptiles	Y												1	2
K-G reptiles	Y	Y			Y		Y	Y	Y		Y	Y	8	5

Note: S—small; M—medium; L—large; BAS-MOS—Bashkirian-Moscovian; K-G—Kasimovian-Gzhelian.

Photo credit

Phylogeny of ear ods



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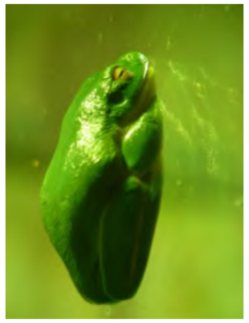
The diversity of living vertebrates

Class Agnatha
Lampreys and hagfish

Class Chondrichthyes
Sharks, rays and chimaeras

Class “Osteichthyes”
Ray-finned and lobe-finned fish

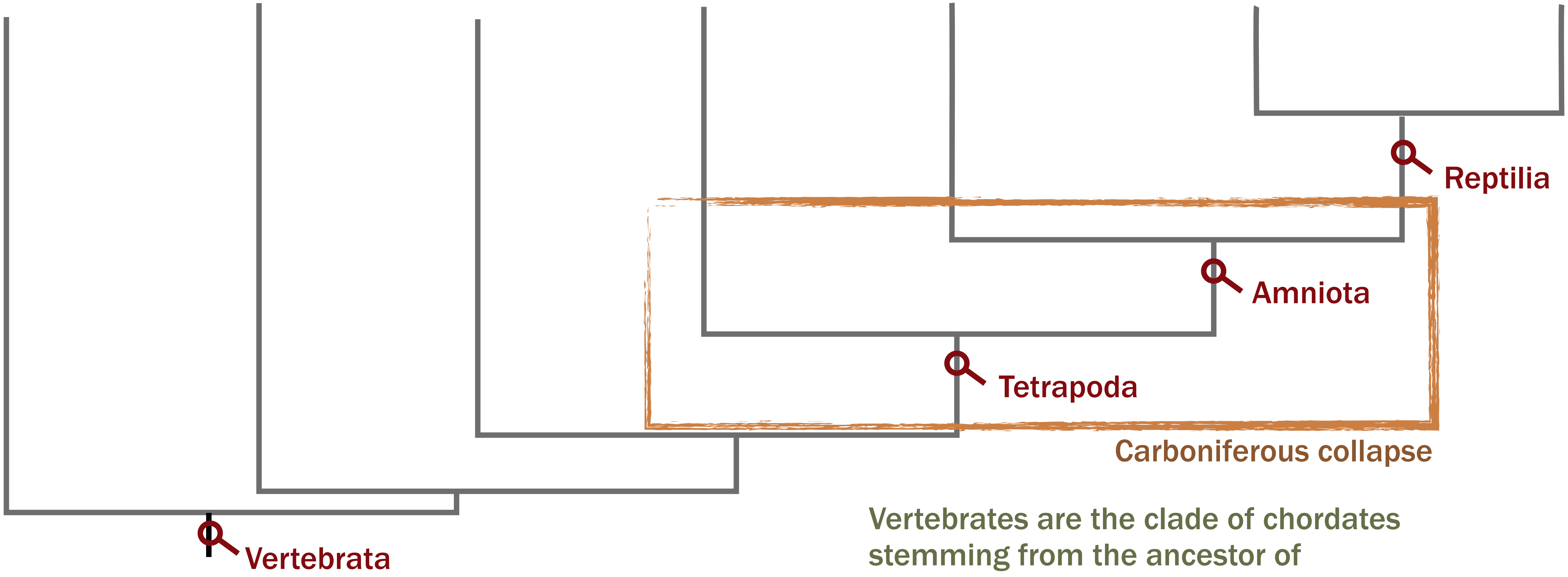
Class Amphibia
Frogs, salamanders and gymnophonians



Class Mammalia
Mammals

Class “Reptilia”
Lizards, snakes, crocodilians

Class Aves
Birds



The phylogeny of living vertebrates

Vertebrates are the clade of chordates stemming from the ancestor of lampreys, sharks, bony fish, amphibians, mammals, and reptiles that first evolved a mineralized skeleton

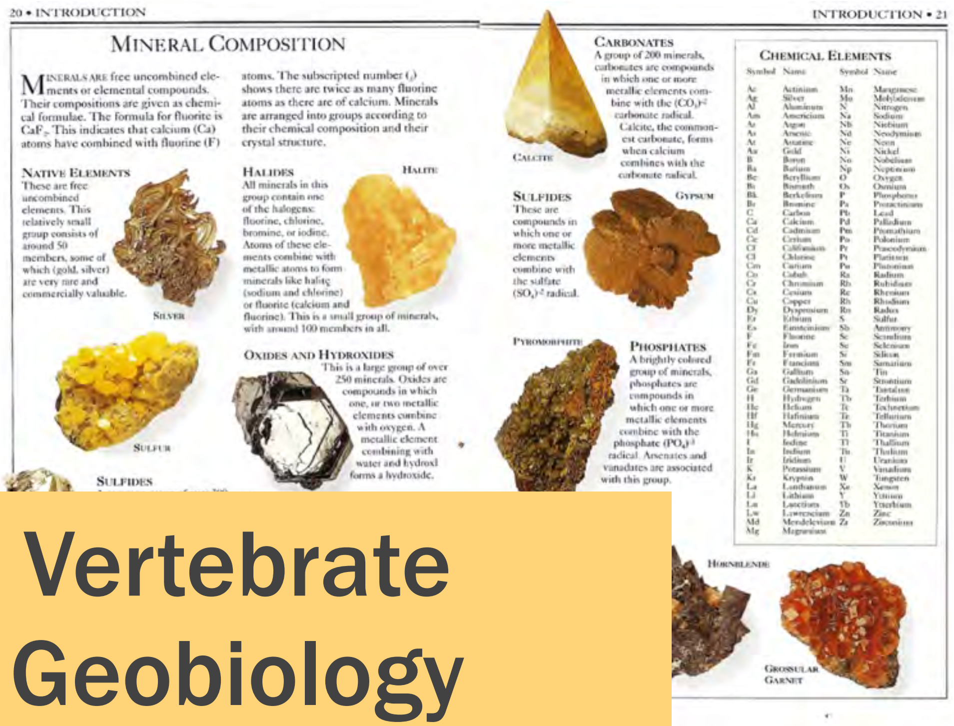
Principles of Geobiology

Geobiology is the application of biological principles and fossils to the study of earth history.

Geobiology involves:

1. evolution (including homology, adaptation, systematics, phylogeny, and taxonomy)
2. paleoenvironment (including paleoclimate, paleoecology)
3. functional morphology (including biomechanics, structural analysis)
4. biogeography and
5. geological time (including biostratigraphy, stratigraphy, dating methods)

Comparative subjects



20 • INTRODUCTION

MINERAL COMPOSITION

MINERALS ARE free uncombined elements or elemental compounds. Their compositions are given as chemical formulae. The formula for fluorite is CaF$_2$. This indicates that calcium (Ca) atoms have combined with fluorine (F) atoms. The subscripted number ($_2$) shows there are twice as many fluorine atoms as there are of calcium. Minerals are arranged into groups according to their chemical composition and their crystal structure.

NATIVE ELEMENTS

These are free uncombined elements. This relatively small group consists of around 50 members, some of which (gold, silver) are very rare and commercially valuable.

SILVER

HALIDES

All minerals in this group contain one of the halogens: fluorine, chlorine, bromine, or iodine. Atoms of these elements combine with metallic atoms to form minerals like halite (sodium and chlorine) or fluorite (calcium and fluorine). This is a small group of minerals, with around 100 members in all.

HALITE

SULFUR

OXIDES AND HYDROXIDES

This is a large group of over 250 minerals. Oxides are compounds in which one, or two metallic elements combine with oxygen. A metallic element combining with water and hydroxl forms a hydroxide.

SULFIDES

INTRODUCTION • 21

CARBONATES

A group of 200 minerals, carbonates are compounds in which one or more metallic elements combine with the (CO$_3$)$^{-2}$ carbonate radical. Calcite, the commonest carbonate, forms when calcium combines with the carbonate radical.

CALCITE

SULFIDES

These are compounds in which one or more metallic elements combine with the sulfate (SO$_4$)$^{-2}$ radical.

GYPSUM

PYROMORPHITE

PHOSPHATES

A brightly colored group of minerals, phosphates are compounds in which one or more metallic elements combine with the phosphate (PO$_4$)$^{-3}$ radical. Arsenates and vanadates are associated with this group.

CHEMICAL ELEMENTS

Symbol	Name	Symbol	Name
Ac	Actinium	Mn	Manganese
Ag	Silver	Mo	Molybdenum
Al	Aluminum	N	Nitrogen
Am	Americium	Na	Sodium
Ar	Argon	Nb	Niobium
As	Arsenic	Nd	Neodymium
At	Astatine	Ne	Neon
Au	Gold	Ni	Nickel
B	Boron	No	Nobelium
Ba	Barium	Np	Neptunium
Be	Beryllium	O	Oxygen
Bi	Bismuth	Os	Osmium
Bk	Berkelium	P	Phosphorus
Br	Bromine	Pa	Protactinium
C	Carbon	Pb	Lead
Ca	Calcium	Pd	Palladium
Cd	Cadmium	Pm	Promethium
Ce	Cerium	Po	Polonium
Cf	Californium	Pr	Praseodymium
Cl	Chlorine	Pt	Platinum
Cm	Curium	Pu	Plutonium
Co	Cobalt	Ra	Radium
Cr	Chromium	Rb	Rubidium
Cs	Cesium	Re	Rhenium
Cu	Copper	Rh	Rhodium
Dy	Dysprosium	Rn	Radon
Er	Erbium	S	Sulfur
Es	Einsteinium	Sb	Antimony
F	Fluorine	Sc	Scandium
Fe	Iron	Se	Selenium
Fm	Fermium	Si	Silicon
Fr	Francium	Sm	Samarium
Ga	Gallium	Sn	Tin
Gd	Gadolinium	Sr	Strontium
Ge	Germanium	Ta	Tantalum
H	Hydrogen	Tb	Terbium
He	Helium	Tc	Technetium
Hf	Hafnium	Te	Tellurium
Hg	Mercury	Th	Thorium
Ho	Holmium	Ti	Titanium
I	Iodine	Tl	Thallium
In	Indium	Tm	Thulium
Ir	Iridium	U	Uranium
K	Potassium	V	Vanadium
Kr	Krypton	W	Tungsten
La	Lanthanum	Xe	Xenon
Li	Lithium	Y	Yttrium
Lu	Lutetium	Yb	Ytterbium
Lw	Lawrencium	Zn	Zinc
Md	Mendelevium	Zr	Zirconium
Mg	Magnesium		

HORNBLENDE

GROSSULAR GARNET

	Mineralogy	**Vertebrate Geobiology**
Number of species	3,500	58,000 (living)
Historical?	No (species are "classes")	Yes (species are "individuals")
Governing processes	Chemistry, crystallography, weathering	Evolution, ecology
Elemental composition	Virtually all elements and many crystal structures	One mineral (hydroxyapatite) and only a few elements (O, C, H, N, P K, S, Cl, Na, Mg, Fe)
Methods for identification and analysis	Physical properties, petrography, mass spec, x-ray diffraction	Anatomy, molecular biology, biochemistry, histology, phylogenetic analysis, biomechanical principles

Overall structure of the course

1. Vertebrate diversity, morphology and functional analysis
2. Vertebrate phylogeny and classification
3. Phylogenetic reconstruction methods
4. Vertebrate stratigraphic record and biostratigraphy
5. History of vertebrate life and its earth systems context
6. Analysis of diversity, disparity, biogeography and climate
7. Recent history of vertebrate life on earth, human evolution, current environmental change and vertebrate life

Kinds of details to learn and memorize

1. Morphological and anatomical structures
2. Taxonomic names, especially “higher taxa”
3. Geological time periods and dates
4. Scientific terminology

Zooarchaeology lab

Wednesday labs will meet in the William R. Adams Zooarchaeology lab (4-6 pm)

Lab is located in the basement of the Student Building (Room 025)

A 1,400 square foot facility run by the Anthropology Department that includes over 10,000 modern comparative faunal remains.

Directed by Dr. Laura Scheiber, an Associate Professor in the Anthropology department, and managed by archaeology graduate student Matthew Rowe.

It is a privilege for G404 to be able to use the Zooarchaeology Lab facilities and specimens – please be careful with the skeletons and please leave the Lab as clean and orderly as you found it.

Photo credit

Scientific papers for further reading

Benton, M. J. 2010. The origins of modern biodiversity on land. *Philosophical Transactions of the Royal Society*, *B*, 365: 3667-3679.

Coates, M. I., M. Ruta, and M. Friedman. 2008. Ever since Owen: changing perspectives on the early evolutio of tetrapods. *Annual Review of Ecology, Evolution, and Systematics*, 39: 571-592.

DiMichele, W. A., I. P. Montanez, C. J. Poulsen, and N. Tabor. 2009. Climate and vegetational regime shifts in the late Paleozoic ice age earth. *Geobiology*, 7: 200-226.

Sahney, S., M. J. Benton, and H. J. Falcon-Lang. 2010. Rainforest collapse triggered Carboniferous tetrapod diversification in Eurameria. *Geology*, 38: 1079-1082.

Google scholar

GeoRef

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