

Paleozoic Evolution of the Appalachians: *Tectonic Overview*

Three major tectonic episodes, all involving lateral accretion of terranes:

deformation, terrane migration, accretion, and continental convergence

1. **Ordovician Taconic Orogeny** (~470-440 Ma)

- collision of Laurentian margin with one or more magmatic arcs
Shelburne Falls arc (475-470 Ma) and Bronson Hill arc (454-442 Ma)
- or, continent-continent collision
between Laurentia and proto-Andean region of Gondwana
- slope & rise sediments thrust westward over shelf deposits

2. **Devonian Acadian Orogeny** (~420-360 Ma)

- accretion of Avalon terrane
southward continuation of Silurian Caledonian Orogeny (NW Europe)
*collision of Baltica with Laurentia to form **Laurussia***
- deformation of Bronson Hill arc and sedimentary basins seaward of BH arc
at least 3 pulses of deformation
- oblique accretion of Avalon and other terranes(?)
much strike-slip displacement but also subduction (coastal volcanics)
- large mountains
erosion creates thick clastic wedge (Catskills and Pocono Mtns.); thinned westward toward cratonic interior

3. **Pennsylvanian-Permian Alleghenian Orogeny** (~325-275 Ma)

- collision with Gondwanaland
*consolidation of supercontinent **Pangea***
- extensive zone of deformation
New England - Georgia & Alabama (Appalachian Mtns.)
- Oklahoma, Arkansas (Ouachita Mtns.) - Texas (Marathon Mtns.)
 - side-effects:
deep crustal shear in Mass., formation of Narragansett rift basin
basement block faulting in western interior, uplift of ancestral Rockies

"TECTONIC CYCLES"

- recorded by the creation of **foreland basins sedimentation** in eastern New York
- associated with **tectonic uplift and deformation** due to the accretion of island arcs to the east in Massachusetts (first the **Ordovician Taconic Orogeny** followed by the **Devonian Acadian Orogeny**):

Ordovician Taconic Orogeny (generalized succession in eastern NY)

<u>Age</u>	<u>Environment</u>	<u>Lithology</u>	<u>Formation</u>
<i>late Ordovician</i>	deltaic and foreland basin fill	molasse (sandstone, siltstone, mudstone)	<i>Queenston Fm.</i>
<i>middle Ordovician</i>	deep foreland basin	flysch (sandst. turbidites & black shale)	<i>Utica & Canojoharie Shales, Schenectady & Snake Hill Fms., Normanskill Fm.</i>
	buckling of crust (drowning of carb. platform)	interbedded limestone & black shale	<i>Dolgeville Fm.</i>
<i>middle Ordovician</i>	shallow water carbonate platform/ramp	limestone	<i>Black River & Trenton Groups (Lowville, Napanee, Kings Falls, Sugar River Ls. & Denley Ls.)</i>

End of one tectonic cycle and the beginning of another:

- Taconic highlands were subsequently eroded and the foreland basin filled
- Upper Ordovician molasse facies is overlain by Silurian - Lower Devonian shallow water carbonates (=base of the next tectonic cycle)

Devonian Acadian Orogeny (generalized succession in eastern NY)

<u>Age</u>	<u>Environment</u>	<u>Lithology</u>	<u>Formation</u>
<i>Middle to Late Devonian</i>	basin fill & thick alluvial fans, alluvial plains, & shallow marine	molasse (conglomerates, sandstones, siltstones, & mudstones)	<i>Catskill clastic wedge</i>
<i>Early to Middle Devonian</i>	marine foreland basin	flysch (limestones, shale, siltstone, sandstone)	<i>Tristates Group, Onondaga Ls. Hamilton Group</i>
<i>Early Devonian</i>	shallow marine	limestone, marlstone	<i>Helderberg Group (Manlius, Coeymans, Kalkberg, New Scotland, Becraft, Alsen, Port Ewen)</i>

EARLY PALEOZOIC ERA

Cambrian and Ordovician Periods

Laurentia in tropics

passive continental margins surround much of Laurentia

- thick, deep water slope & rise deposits
- thinner sequences of shelf deposits

Gondwana

- large continent
Africa + S. America + Antarctica + Australia + India + New Zealand
- remained intact throughout Paleozoic Era

High global sea level

- break-up of late Proterozoic supercontinent
increased length of spreading ridges
- little or no continental ice
- vast areas of the continents flooded by shallow seas
shallow water sandstones and carbonates cover much of Laurentia

Fluctuations in global sea level

- widespread **sandstone** □ **limestone sequences**
- separated by major **inter-regional unconformities**

Sauk Sequence (Cambrian-Early Ordovician)

Tippecanoe Sequence (Late Ord.-Silurian)

Ordovician Taconian Orogeny

- warped crust of eastern craton
- created intra-cratonic basins and arches
e.g., Michigan Basin, Cincinnati Arch

"Cambrian Explosion"

rapid diversification of marine animals with hard-parts

change from largely autotroph-dominated ecosystems of Proterozoic & Neoproterozoic:

1. cyanobacterial mats (**stromatolites**)
2. eukaryotic phytoplankton (**acritarchs**)
3. multicellular red & green algae ("**seaweed**")
4. multicellular animals (**Ediacaran biota**)

rise of heterotrophs at Proterozoic/Phanerozoic transition

including scavengers and predators

why?

- innovations & evolutionary thresholds
biomineralization, circulatory & nervous systems
- hard parts provided tissue support & protection
- increased oxygen levels
- rising sea level, widespread shallow marine niches

several phases of radiation:

1. lowermost Cambrian
 - *tiny, simple, tube or vase-shaped skeletal fossils*
2. Tommotian Fauna
 - *oldest, diverse skeletonized fauna*
 - *3-4 m.y.*
3. typical "Cambrian Fauna"
 - *radiation of larger skeletonized fauna*

"Cambrian Fauna"

- **trilobites*** (calcium phosphate)
- **inarticulate brachiopods** (chitinophosphatic shells)
- sponge-like **archeocyathids** (bioherms)
- mid-Cambrian **Burgess Shale** (B.C.)
 - exceptional preservation of soft-bodied organisms*
 - = "Lagerstätten": rare windows to true animal diversity*

*index fossils (biostratigraphy and correlation)

Changes

- steady **decline of stromatolites**
grazing and burrowing by heterotrophs
- **extinction of archeocyathids** by mid-Cambrian
- several episodes of **trilobite extinctions**
evolution of better competitors or predators?

beginning in Ordovician, faunas are different:

calcium carbonate shells dominate:

- more rigid
- adaptations for anchoring to substrate
- muscle/organ support
- better protection

"Paleozoic Fauna" (Ordovician-Permian)

- **articulate brachiopods***
- **bryozoans**
- **crinoids** (attached echinoderms)
- **cephalopods*** (nautiloids □ ammonoids)
- rugose & tabulate **corals**
- **stromatoporoid sponges**
- **ostracodes**
- **conodonts***
- **graptolites***

*index fossils

Late Ordovician to Devonian reefs: *stromatoporoid sponges + tabulate corals*

Changes

- **glaciation** at end of Ordovician
lowering of sea level
- end-Ordovician **mass extinctions**
*2 pulses: 1) effects of cooling & glaciation, 2)
global warming*

MIDDLE PALEOZOIC ERA

Silurian and Devonian Periods

During Silurian, Taconic highlands eroded
molasse overlain by shallow water carbonates
(*Niagara Falls*)

Barrier reefs develop in Great Lakes region

Formation of large continent: **Laurussia**
"Old Red Sandstone Continent"

- Welding of Baltica (NW Europe) with NE Laurentia

Late Silurian Caledonian Orogeny
(*Scandinavia & Great Britian*)

- Accretion of microcontinent (Avalon Terrane) to N. Appalachians

Mid- to Late Devonian Acadian Orogeny

Thick **Catskill clastic wedge** shed westward across eastern U.S.

Catskill and Pocono Mtns.

Recall: 2 episodes of extinctions of marine invertebrates at end of Ordovician

Biotic recovery during Silurian:

- "Paleozoic fauna" rediversified
- tabulate coral-stromatoporoid reefs
- jawless fish (ostracoderms) diversified
marine & fresh water

Great diversification of fish during Devonian:

"Age of Fishes"

- jawed armored fish (placoderms; all extinct)
- sharks, skates, rays*
- true bony fishes*
includes lobe-finned fishes, gave rise to amphibians

*dominant fishes by end of Devonian

Important predators:

- **eurypterid** arthropods
marine & fresh water
- **ammonoid** cephalopods

TERRESTRIAL ENVIRONMENTS:

Silurian

- vascular plants invade land
spore-bearing plants (require moisture for reproduction)

Devonian

- rapid evolution of land plants
spore and seed-bearing plants
first trees, spread of forests
- earliest terrestrial arthropods
insects & scorpions
- bivalve molluscs invade fresh water

Vast terrestrial lowlands

alluvial plains, wetlands, & deltas

Reefs widespread and massive by early Late Devonian
important hydrocarbon reservoirs

Mass extinctions during Late Devonian

- tropical marine taxa hardest hit:
coral-stromatoporoid reefs completely wiped-out
pelagic & nektonic organisms hard hit:
 - placoderms
 - ammonoids
 - eurypterids
 - graptolites
 - conodonts
- terrestrial plants unaffected

Cause(s)?

- Late Devonian glaciation in Gondwana

possible climatic feedbacks:

spread of forests, burial of carbon, lowering of atmospheric CO₂, & global cooling?

Middle Devonian-Early Mississippian **Antler Orogeny**

- first Cordilleran orogeny of the Paleozoic
- partial closure of basin between **Klamath island arc** and Laurussia
 - similar to Japan off of Asia*
- deepwater slope & rise sediments thrust eastward over shallow water carbonates
 - Roberts Mountain Thrust (Nevada)*

LATE PALEOZOIC ERA

Carboniferous and Permian Periods

Mississippian Period (Early Carboniferous)

- last widespread Paleozoic carbonate-rich epicontinental sea on N. Amer. craton
 - Kaskaskia Sequence*
- "Age of Crinoids"
- west & mid-continent: thick, shallow water carbonates
 - today: cliff & ridge-forming limestones*
- east: black shales interbedded with prograding clastics from Acadian highlands

Pennsylvanian Period (Late Carboniferous)

- collision of Laurussia & Gondwana
consolidation of supercontinent Pangea
- large areas of craton uplifted
east: Alleghenian Orogeny - last phase of Appalachian deformation
south: Ouachita and Marathon Mtns.
west: "ancestral Rocky Mtns."
- gradual draining of epicontinental seas

1. Alleghenian Orogeny

- collision of eastern N. Amer. with NW Africa (Gondwana)
- New England □ AL

2. Deformation of southern margin

- collision with northern S. Amer.
- OK & AR □ TX

3. Basement uplifts (mainly block faults)

- due to compression from E, S, & W
- uplift of Ancestral Rocky Mtns.
- alluvial fans & alluvial plains
thick deposits of conglomerate, arkosic ss & red mudstone

1-3: profound impact on sedimentation

- great volume of sediment supplied to mid-continent
- widespread terrestrial deposits:
alluvial plain
*flood plain**
*deltaic/marginal marine**
**coal-bearing strata*

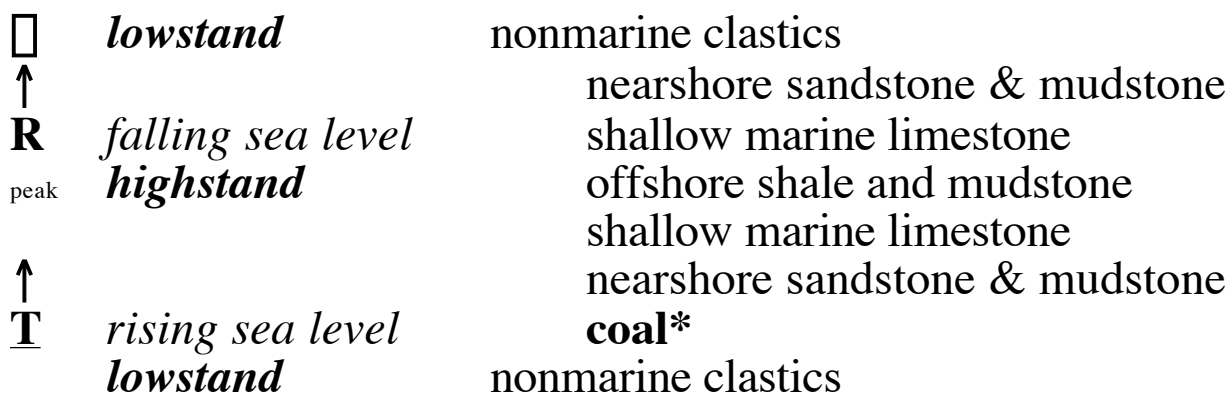
PENNSYLVANIAN COAL

1. flood plain coals (e.g., PA)
 - peat accumulated in lowland swamps/overbank areas of flood plain*
2. deltaic coals (e.g., IL)
 - prograding deltas with retreat of epicontinental seas*

*high frequency oscillations of sea level due to **glacial cycles on Gondwana**
 = **cyclic deposits** ("cyclothems") caused by both tectono- & glacioeustatic changes in sea level

idealized cyclothem:

transgressive-regressive sequence



***coal swamps** formed on nonmarine deposits as sea level began to rise

Pennsylvanian Fossils

TERRESTRIAL

- first reptiles during Penn., but terrestrial faunas **dominated by amphibians***
many were much larger than today's familiar amphibians

- terrestrial flora **dominated by spore-bearing plants & trees***
e.g., fern-like plants and trees
widespread coal swamps with Lycopod trees
Sphenopsid trees (Calamites) on floodplains

*dominant fauna & flora required **moist conditions** for life cycle

other important plant firsts:

- first **seed ferns** (oldest seed plants) appeared during Late Devonian
- first **gymnosperms** ("naked seed plants") appeared during Late Carboniferous
Cordaite trees formed upland forests

MARINE:

- typical "Paleozoic fauna"

- ammonoids & fusulinids (larger forams)
important for biostratigraphy

Permian Period

- continued consolidation of Pangea
- continued glaciation on Gondwanaland
- major regression of epicontinental seas
- drying-out of continental interior climate
 - widespread terrestrial red beds (with anhydrite)*
 - coastal dune fields*
 - salt deposition (more than during any other time)*
- marine conditions restricted to western U.S. & Canada
 - "Kaibab Sea"*

Permian basins of W. Texas

barrier reefs and oil

1. deep basins (grabens) adjacent to reefs
accumulate organic matter
= *petroleum source rocks*
2. reef carbonates are fairly porous
= *good reservoir rocks*
3. later, evaporites accumulated across entire area
(impermeable layers)
= *good cap rocks (seal)*

Permian fossils

TERRESTRIAL

- coal swamp floras replaced by **seed-bearing gymnosperms** (conifers)
in seed plants, spores not released to environment,
□ *reproduce without moist conditions*
- amphibians replaced by radiation of **reptiles**
evolution of shelled egg (= amniote egg, "self-contained pond")
□ *reproduce away from water*
more advanced jaws & teeth, greater speed & agility than amphibians
- evolution of **therapsids** = mammal-like reptiles
legs beneath bodies
probably endothermic metabolism (warm-blooded; endurance)
advanced & powerful jaws & teeth

MARINE:

- typical "Paleozoic fauna"
- ammonoids & fusulinids (larger forams)
important for biostratigraphy

END-PERMIAN MASS EXTINCTION

"mother of all extinctions"

2 pulses of extinction

- ~90% of all marine species,
~50% of invertebrate families:
all trilobites
all rugose & tabulate corals
all fusulinid forams
most brachiopods, ammonites, lacy bryozoans,
& crinoids
many characteristic elements of the "Paleozoic
Fauna"
- ~70% of terrestrial vertebrate families
~75% amphibian, ~80% reptile families
- fungal spore spike

Possible Causes?

1. **global regression**, draining of epicontinental seas
consequences?
 - loss of marine niches & greater competition
 - increased aridity & seasonality on continents*specialist organisms unable to cope*
2. drop in **atmospheric O₂**?
this following Pennsylvanian build-up
 - weathering & oxidation of organic matter
 - reduction in global productivity*perturbation in carbon cycle*
3. **volcanism**: eruption of **Siberian flood basalts**, explosive volcanism in S. China
 - CO₂ + sulfate aerosols
 - short-term cooling, long-term warming*climatic instability*
4. **anoxia** in deep ocean
5. reduction of **oceanic salinity** due to deposition of evaporites?

Summary of Paleozoic First-Order Tectonic "SuperCycle"

1. LATEST PROTEROZOIC AND CAMBRIAN

- **continental dispersal** & end of major glaciation
- **rising global sea level** & flooding of continental areas
Sauk Sequence
- **adaptive radiation** of shelly marine animals
"Cambrian explosion"
- **"Cambrian Fauna"**
radiations & extinctions

2. ORDOVICIAN TO MISSISSIPPIAN

- widespread shallow carbonate-dominated **epicontinental seas**
- **transgressive-regressive** sedimentary sequences deposited across N. Amer.
Tippecanoe & Kaskaskia Sequences
- **tectonic pulses** & growth of North America
Taconian, Acadian, & Antler Orogenies
- radiation of marine **"Paleozoic Fauna"**
+/- stable lineages
- **biotic occupation** of the land
parallel evolution of plants & animals
- 2 episodes of **mass extinction**
end-Ordovician, Late Devonian

3. PENNSYLVANIAN TO PERMIAN

- **continental aggregation** & creation of **Pangea** Supercontinent
- major **tectonic activity**
Alleghenian Orogeny & uplift of Ouachitas & Ancestral Rockies
- **lowering of global sea level** & draining of epicontinental seas
Absaroka Sequence
- major **coal accumulation**, followed by **drying-out of climate**
- **faunal/floral evolution & turnover** tracks sea level & climate
from moist, humid climate to drier, more seasonable climate
- End-Permian **mass extinction**
regression, volcanism, climatic instability, perturbations of atmosphere & carbon cycle

