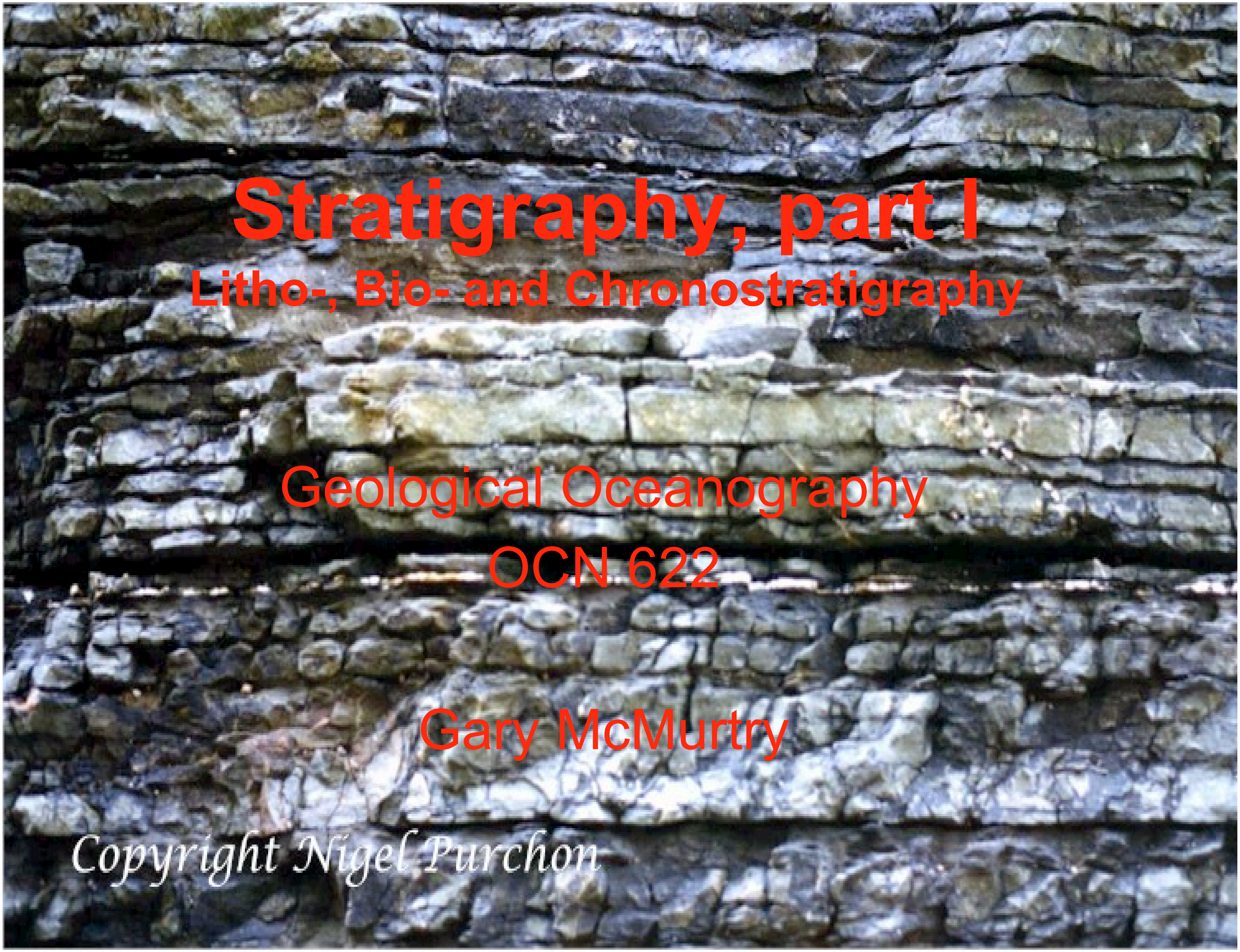
# Stratigraphy, part I

## Litho-, Bio- and Chronostratigraphy

Geological Oceanography
OCN 622

Gary McMurtry



# Outline

- Underlying principles, definition of terms

- Lithostratigraphy & sedimentary facies

- Ocean transgression-regression cycles & Phanerozoic global sea level curves

- Correlation & Biostratigraphy
  - Paleobiogeography
  - Biocorrelation

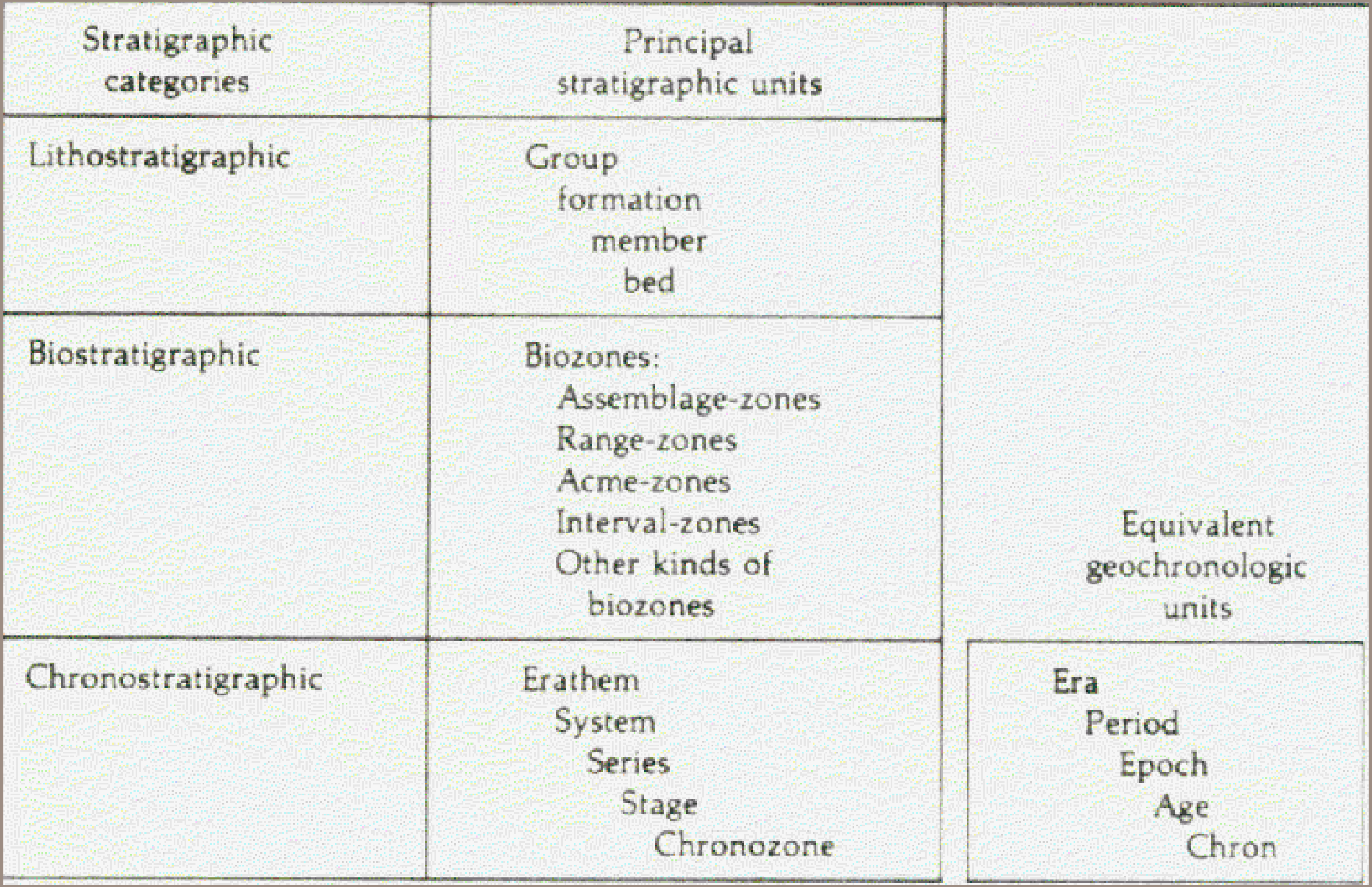
- Chronostratigraphy & Geologic Time Scales

# Underlying Principles of Stratigraphy

- Original horizontality (Nicolaus Steno, 1669)
- Superposition (N. Steno, violated by impact ejecta)
- Original continuity (N. Steno)
- Faunal succession (William Smith, 1796)

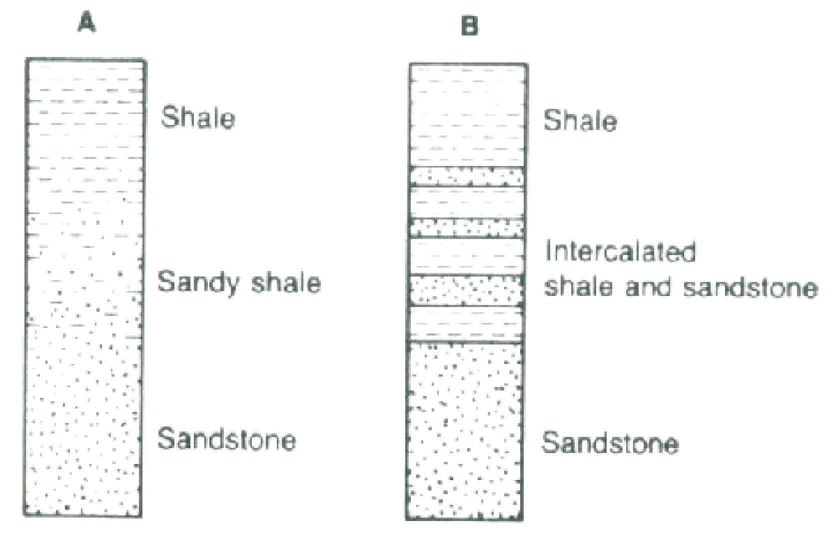
- Related fundamentals:
  - Uniformitarian Concept (James Hutton, 1785)
  - Catastrophism (Flood) Concept (Georges Cuvier, 1827)
  - Evolution Concept (Charles Darwin, 1859)

# Stratigraphic Terms

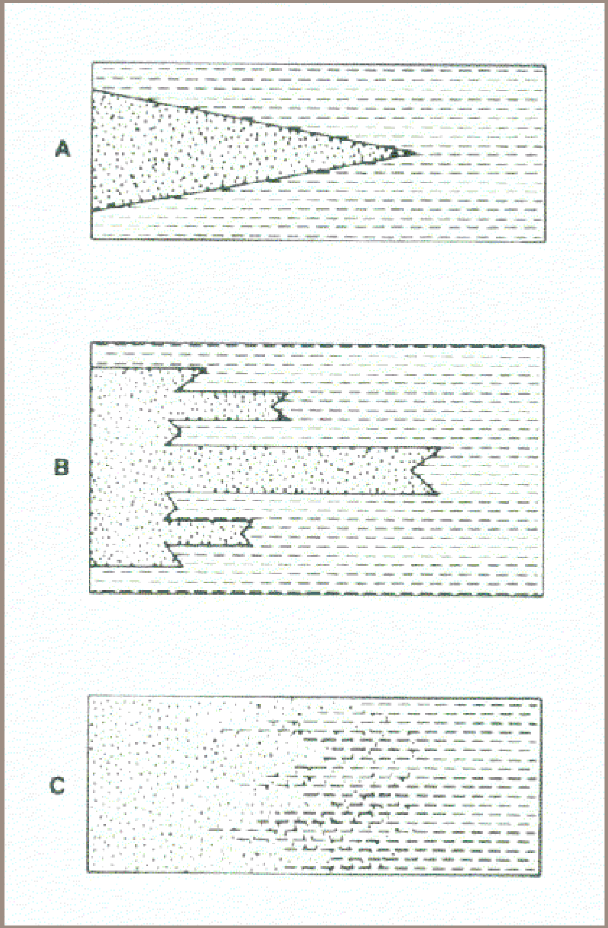


| Stratigraphic categories | Principal stratigraphic units | Equivalent geochronologic units |
|---|---|---|
| Lithostratigraphic | Group<br>formation<br>member<br>bed | |
| Biostratigraphic | Biozones:<br>Assemblage-zones<br>Range-zones<br>Acme-zones<br>Interval-zones<br>Other kinds of biozones | |
| Chronostratigraphic | Erathem<br>System<br>Series<br>Stage<br>Chronozone | Era<br>Period<br>Epoch<br>Age<br>Chron |

# Definition of Beds, Contacts
## (a.k.a. Conformable Strata)

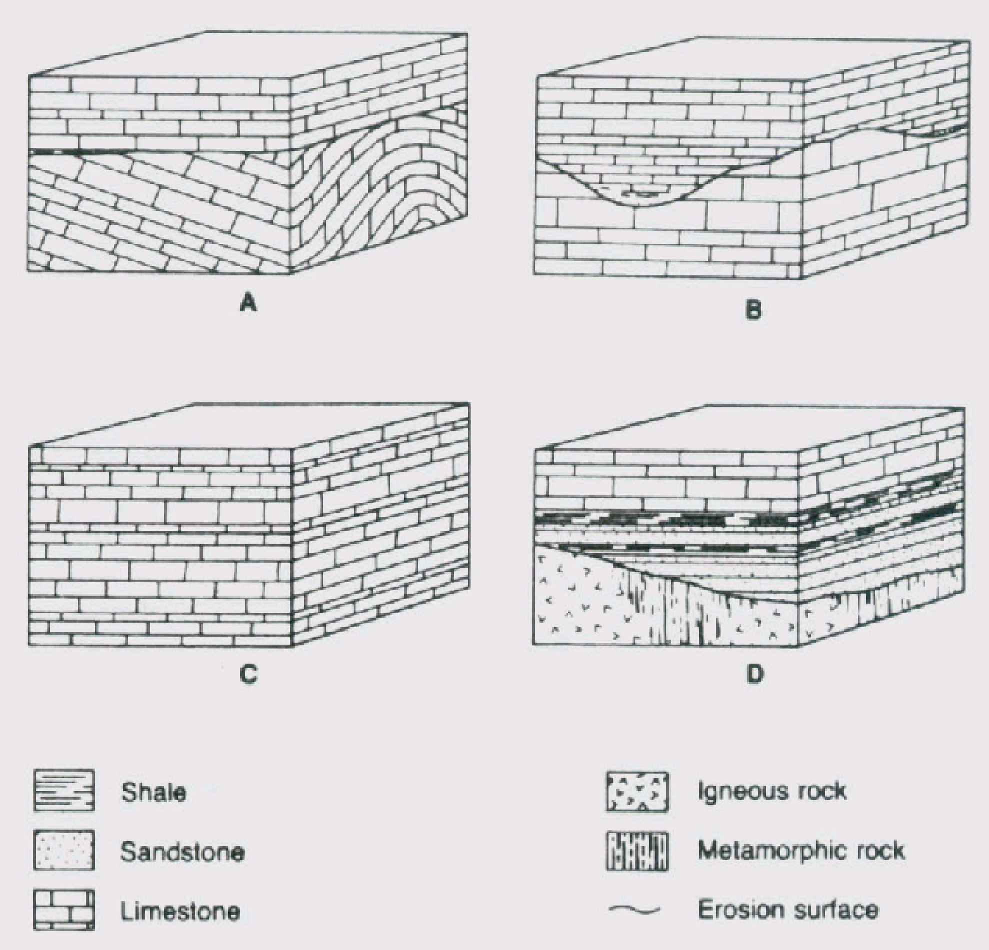


Vertical Contacts



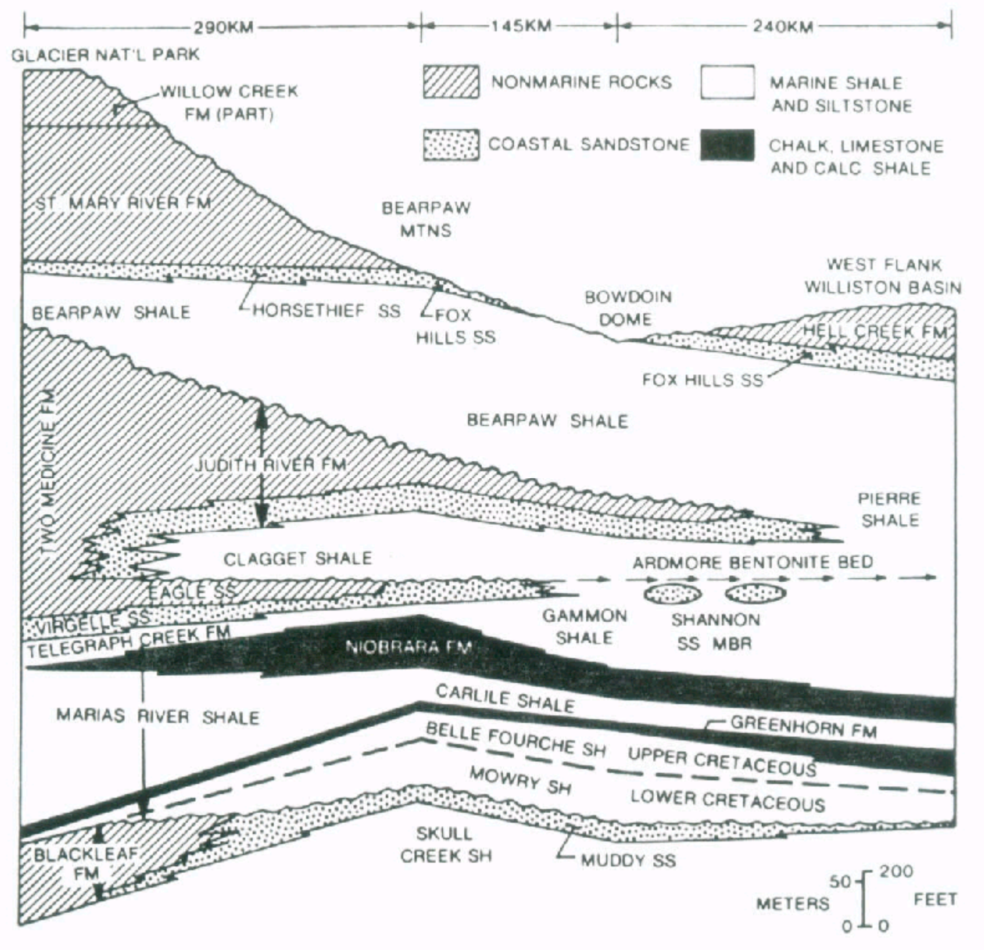
Horizontal Contacts

# Types of Unconformities



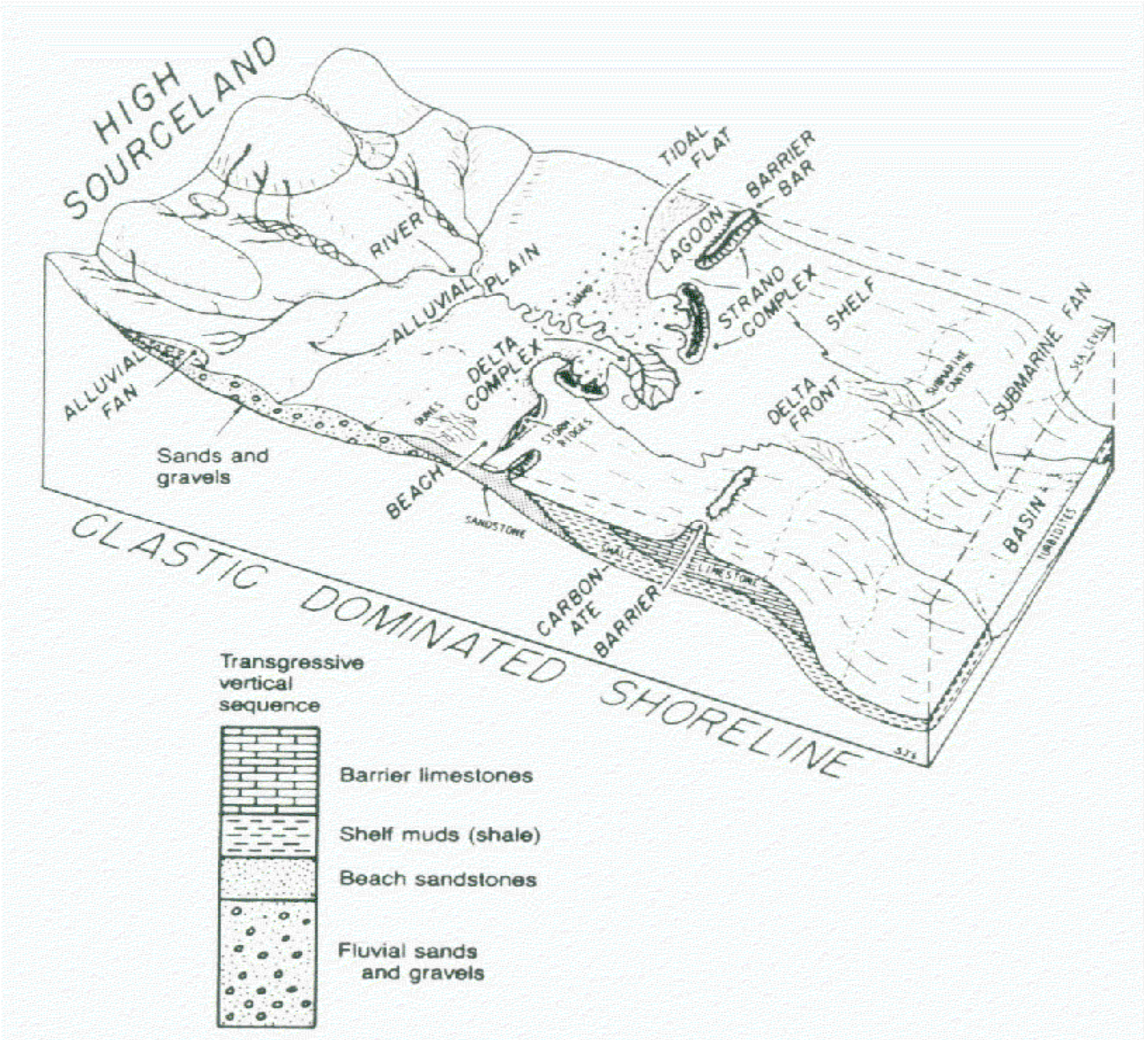
a. Angular Unconformity
b. Disconformity
c. Paraconformity (obscure)
d. Nonconformity

# Sedimentary Facies



Definition: “One or any two or more different sorts of deposits which are partly or wholly equivalent in age which occur side-by-side or in some-what close neighborhood”
-- Moore (1949)

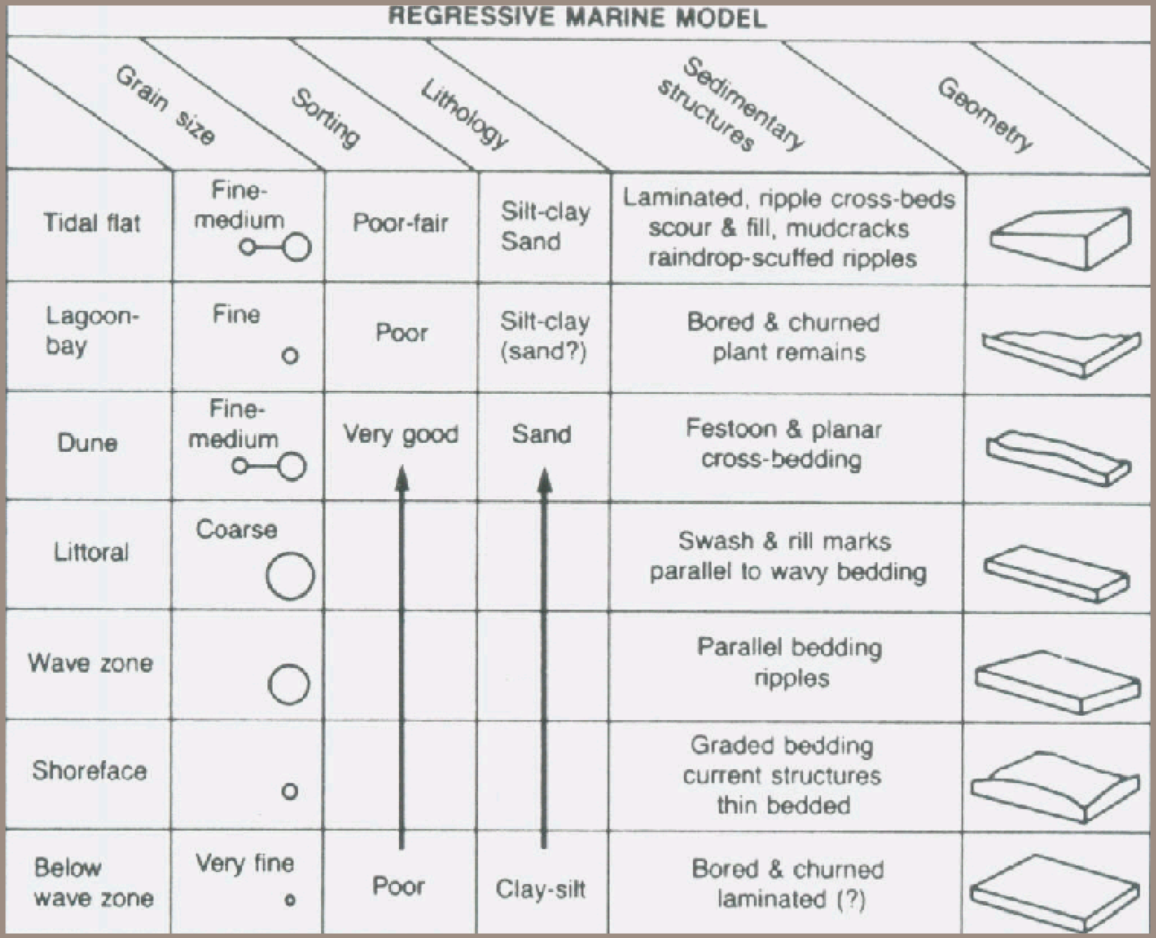
# Sedimentary Facies (Cont.)



**Walther's Law:**

"Those facies and facies-areas can be superimposed primarily which can be observed beside each other at the present time"
-- Walther (1884)

# Application of Facies Concept to Reconstruct Ancient Environment

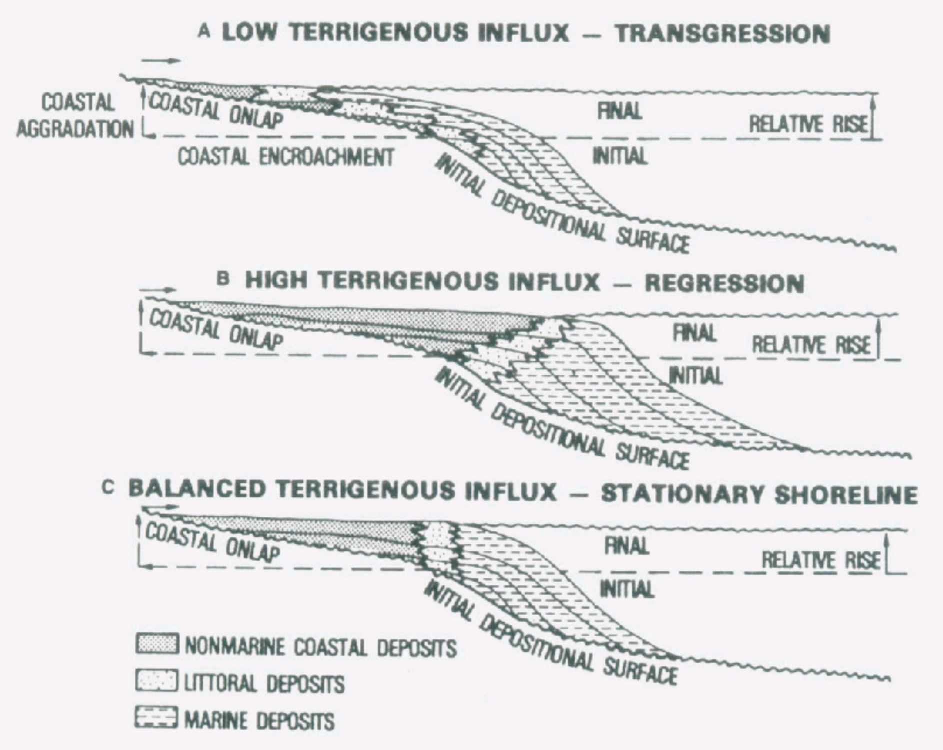


REGRESSIVE MARINE MODEL

| | Grain size | Sorting | Lithology | Sedimentary structures | Geometry |
|---|---|---|---|---|---|
| Tidal flat | Fine-medium | Poor-fair | Silt-clay<br>Sand | Laminated, ripple cross-beds scour & fill, mudcracks raindrop-scuffed ripples | |
| Lagoon-bay | Fine | Poor | Silt-clay (sand?) | Bored & churned plant remains | |
| Dune | Fine-medium | Very good | Sand | Festoon & planar cross-bedding | |
| Littoral | Coarse | | | Swash & rill marks parallel to wavy bedding | |
| Wave zone | | | | Parallel bedding ripples | |
| Shoreface | | | | Graded bedding current structures thin bedded | |
| Below wave zone | Very fine | Poor | Clay-silt | Bored & churned laminated (?) | |

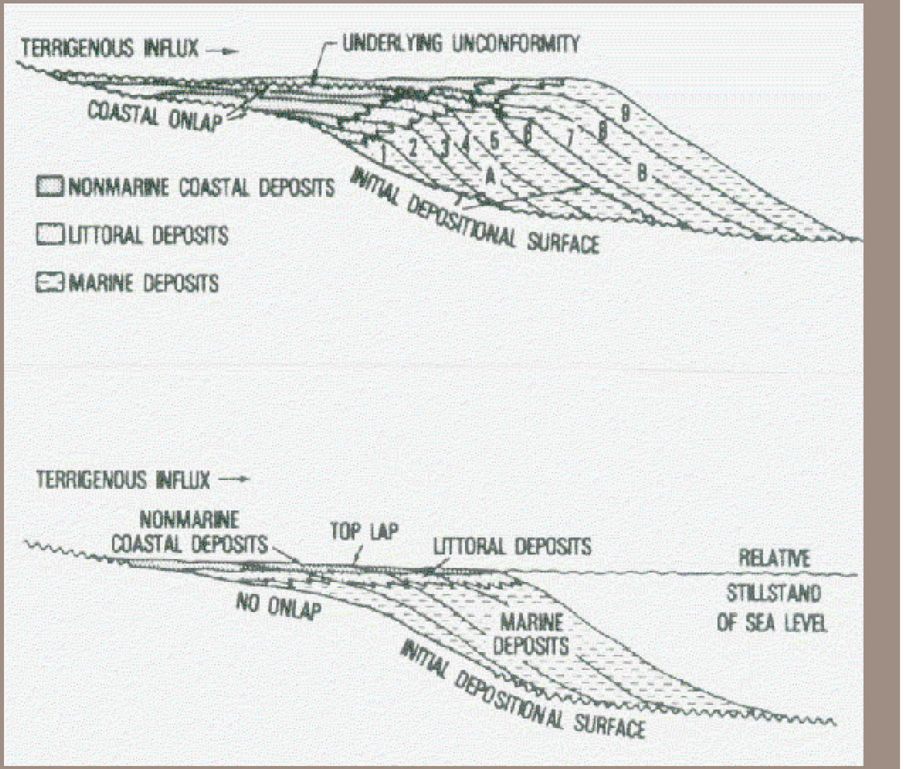
Example of sediments deposited during a regression (drawback) of the sea

# Transgression-Regression of the Sea Recorded in Coastal Sediments

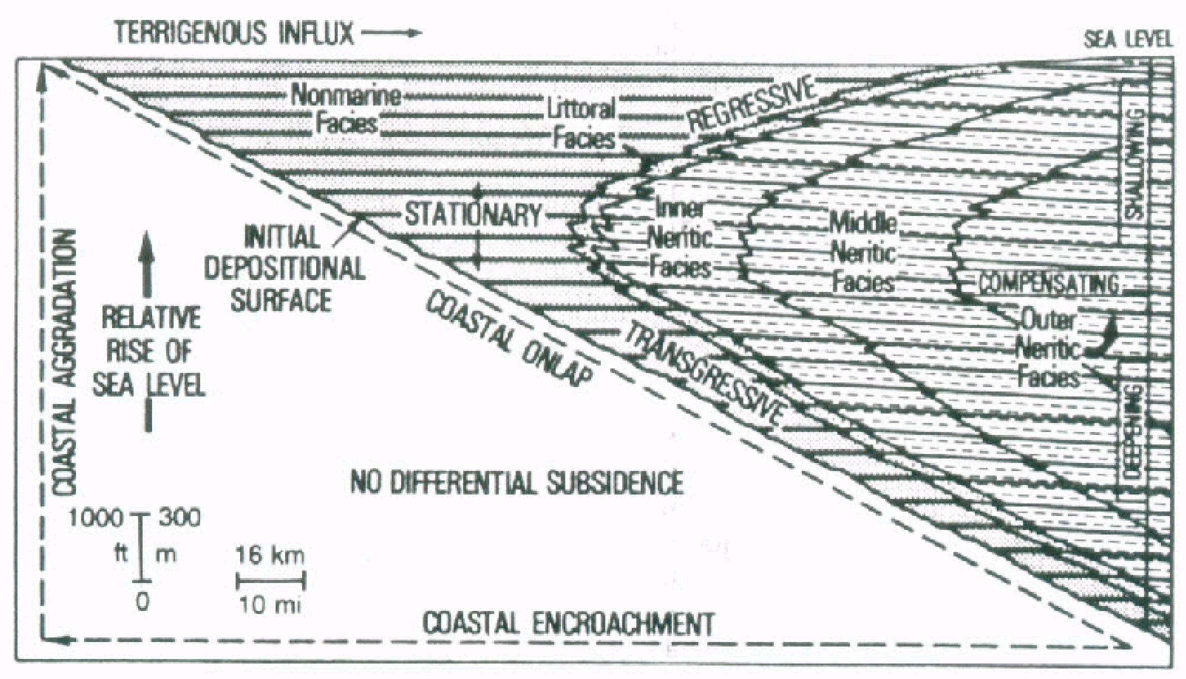


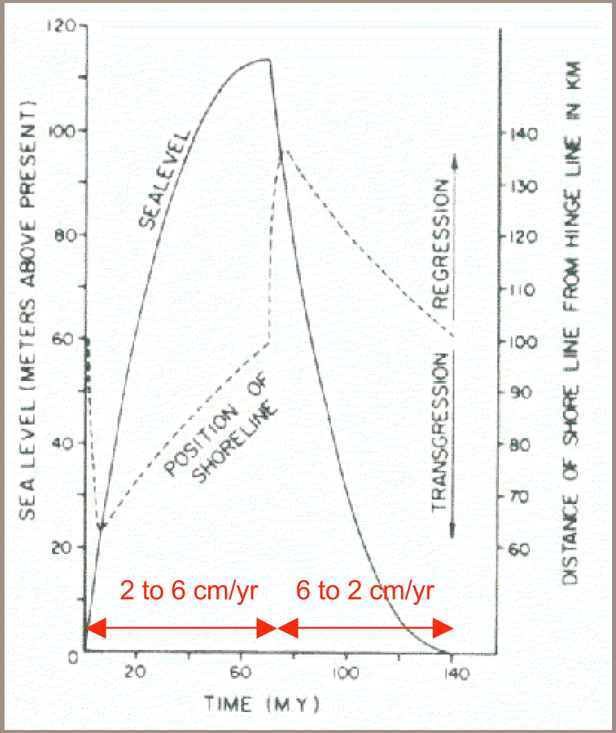
Transgression, regression & stationary shorelines--effects on coastal sediments & added complexity of variable river flux.

Coastal Onlap & Top Lap: rapid sea level fall & standstill examples.



# Coastal "Sediment Wedge" from a Single T/R Cycle





Proposed long-term mechanism:
Spreading Rate Changes =>
Sea level Fluctuations (Pitman, 1968)

# Depositional Sequences

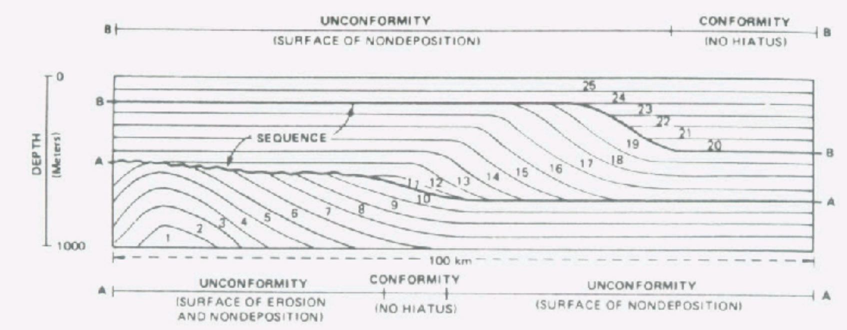
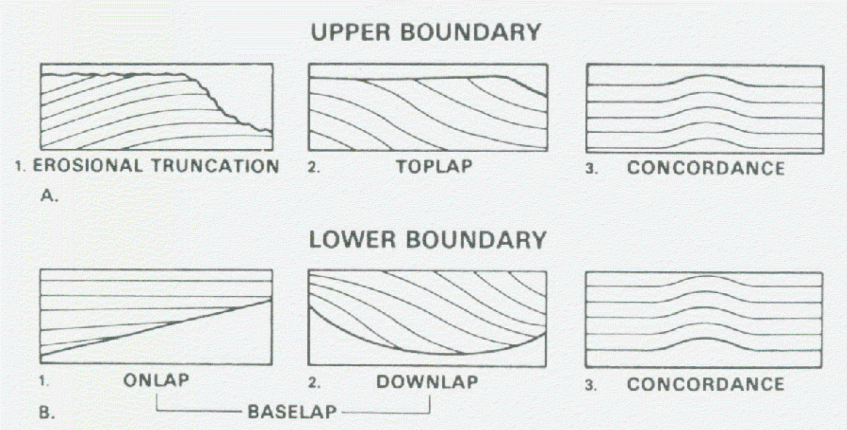


Illustration of concept, with beds numbered

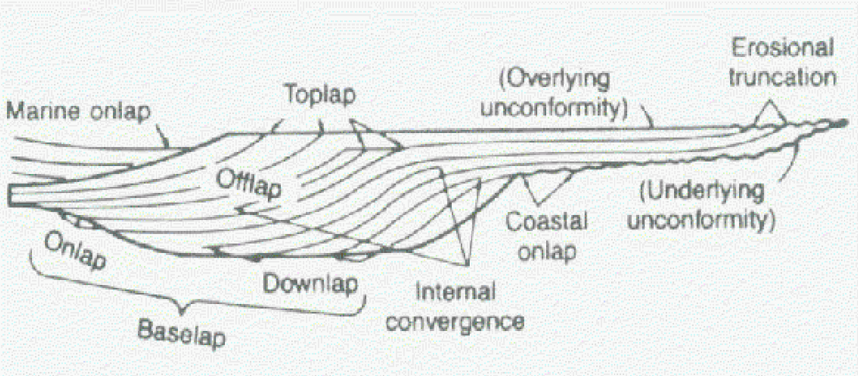
Large-scale coastal sediment sections defined by seismic stratigraphy



Relations of strata to upper (a) and lower (b) boundaries

Get Oil?

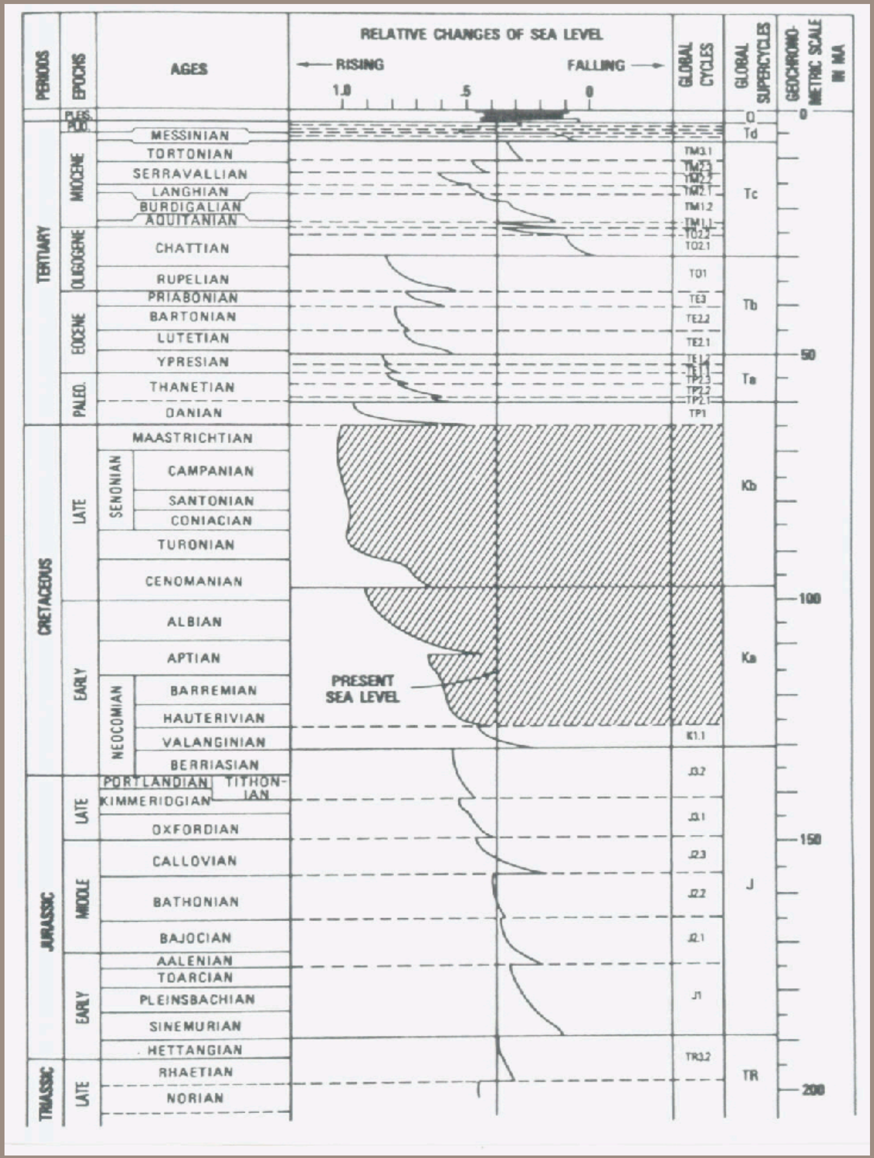
Terminology of unconformable boundaries that define sequence



From: Boggs (1987)

# Vail Sea level Curve

## based upon Seismic Stratigraphy

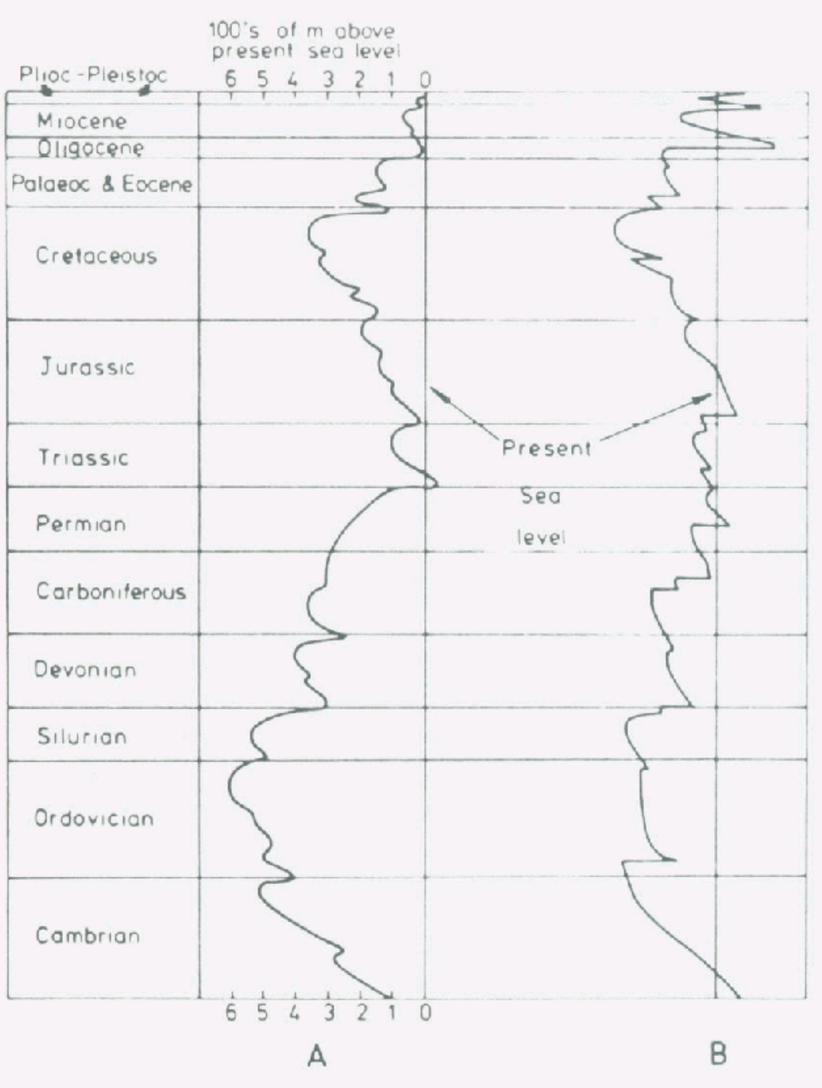


The interplay of sea level, subsidence & sediment supply determines the sediment layer configurations, and vice versa.

Thank you Chevron Research!

P. Vail et al. (1977)

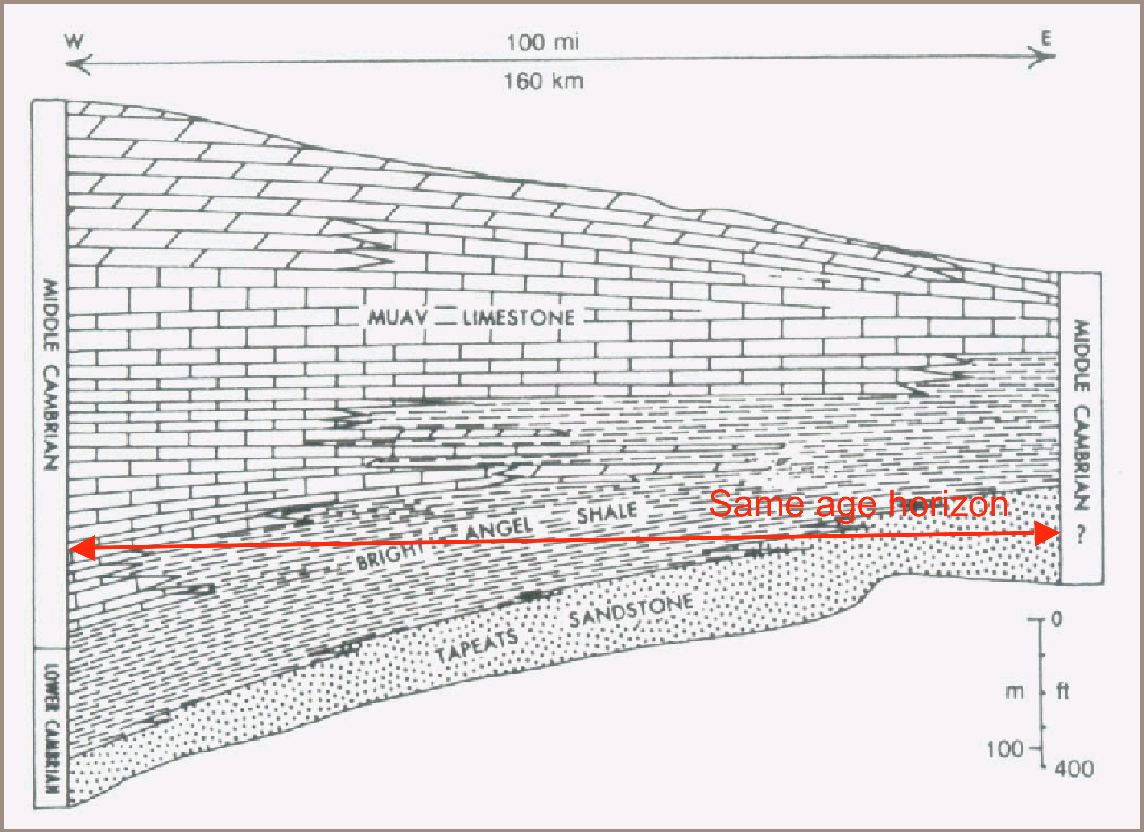
# Comparison of Vail et al. and Hallam Sea level Curves



A. Hallam (1984)
B. Vail et al. (1977)

Note Hallam's curve is much smoother than Vail et al. curve, which does not account for regressive sea erosion => unconformities.

# Lithostratigraphic Correlation

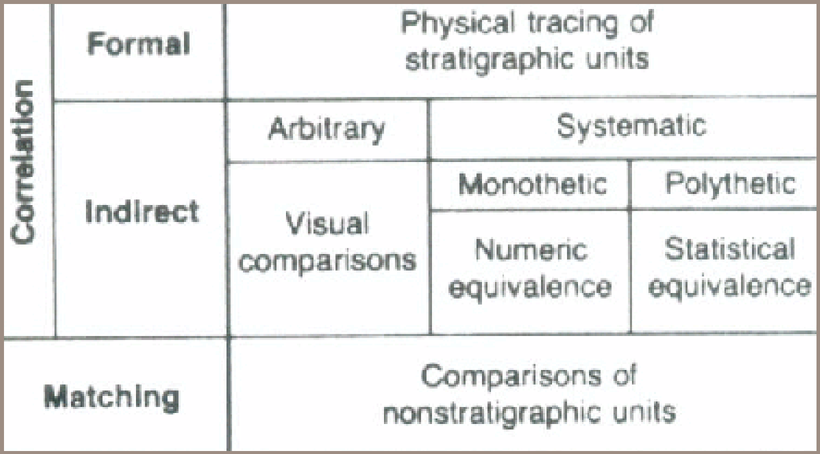


Changes in age of the Cambrian Tapeats Sandstone across the Grand Canyon, AZ (from: Boggs, 1987)

Definitions:

1. Lithocorrelation =
   similar lithology
2. Biocorrelation =
   similar fossil content
3. Chronocorrelation =
   same age

# Lithostratigraphic Correlation, cont.



| | | | | |
|---|---|---|---|---|
| Correlation | Formal | Physical tracing of stratigraphic units | | |
| | Indirect | Arbitrary | Systematic | |
| | | | Monothetic | Polythetic |
| | | Visual comparisons | Numeric equivalence | Statistical equivalence |
| Matching | | Comparisons of nonstratigraphic units | | |

Summary of Methods:
Formal is best, but not always achievable!

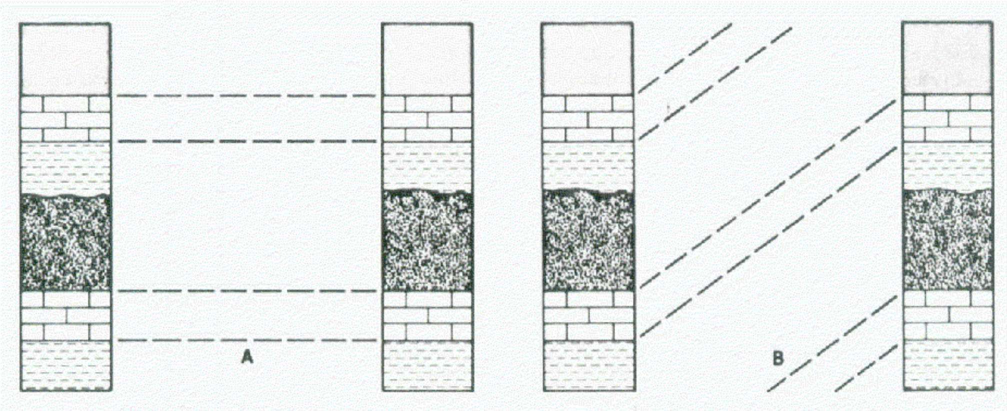
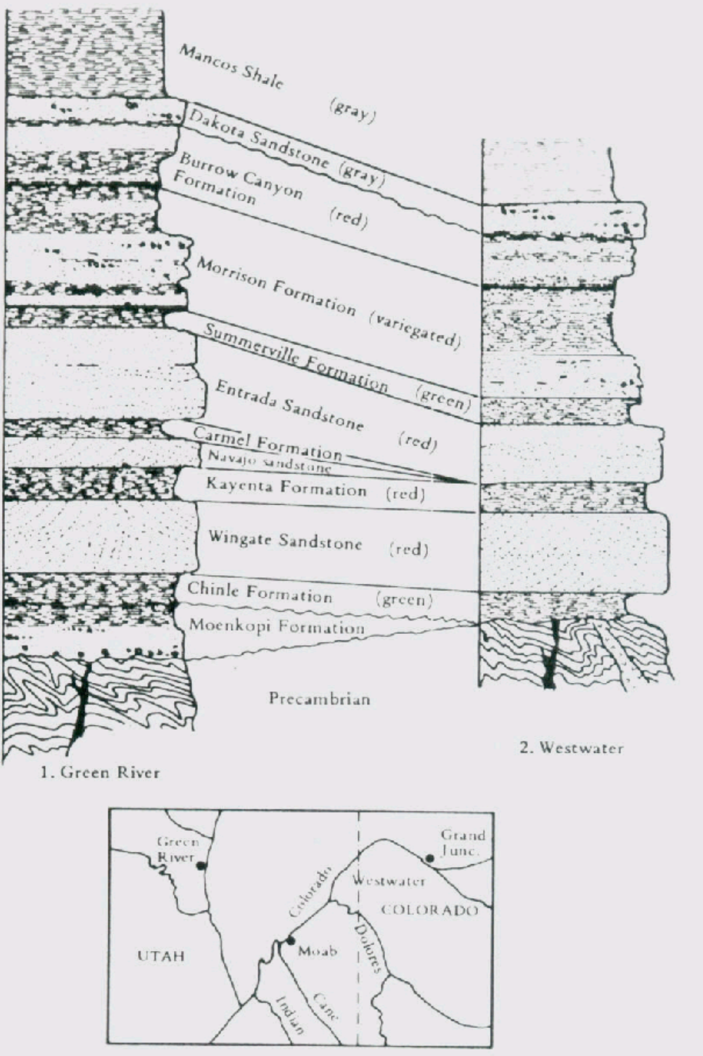


Illustration of difference between matching (a) versus correlation (b) of similar-appearing strata

# Lithostratigraphic Correlation, cont.

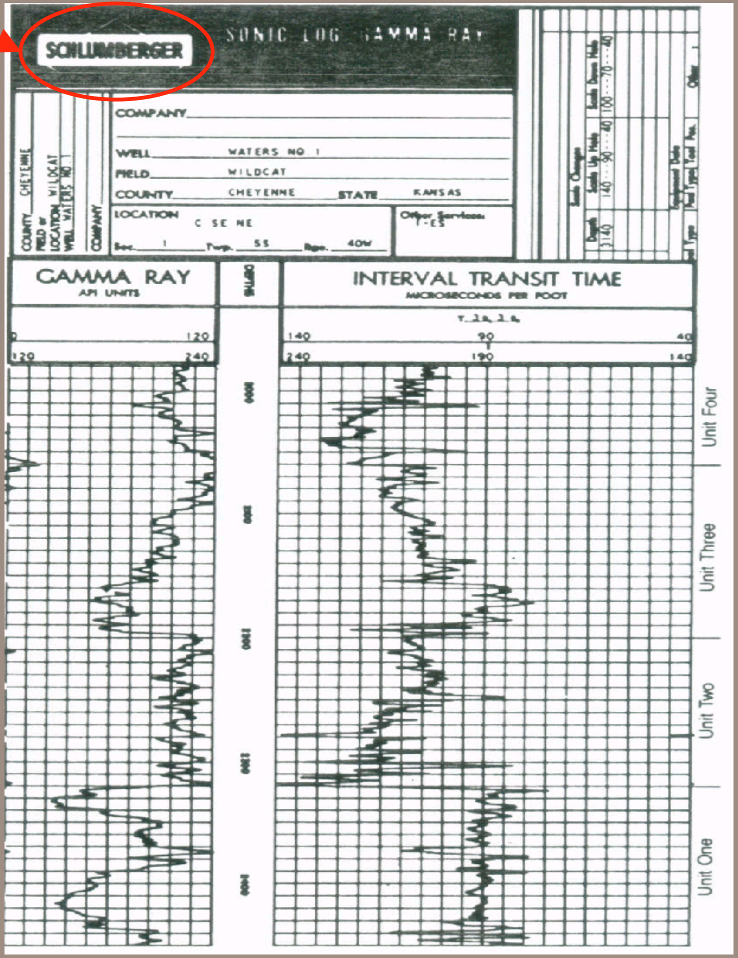


Example of strata correlation among distinctive rock "outcrop" units

Colorado Plateau, W. USA

# Lithostratigraphic Correlation (cont.)

Hot stock tip!

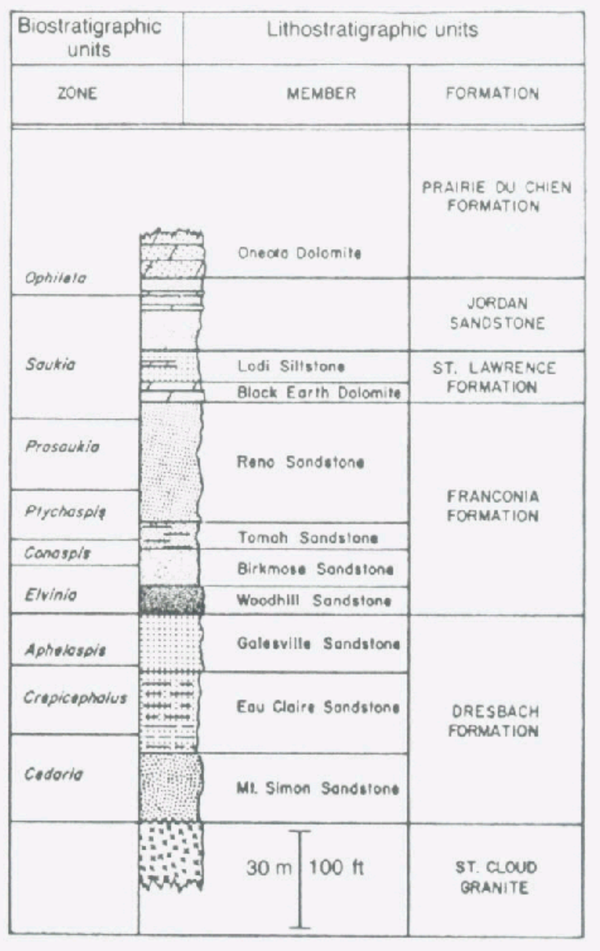


Example of <u>subsurface</u> strata correlation based on well logs

<u>Gamma ray</u> = radioisotope beam attenuation by $H_2O$ => porosity data

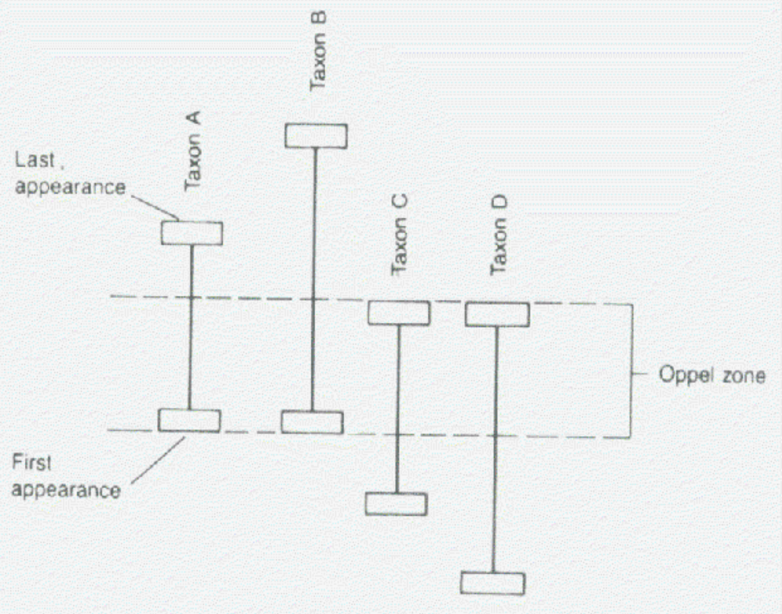
<u>Interval Transit Time</u> = sound attenuation => rock properties, e.g., density

# Biostratigraphy



Bio- and Litho-stratigraphic units are not necessarily the same!

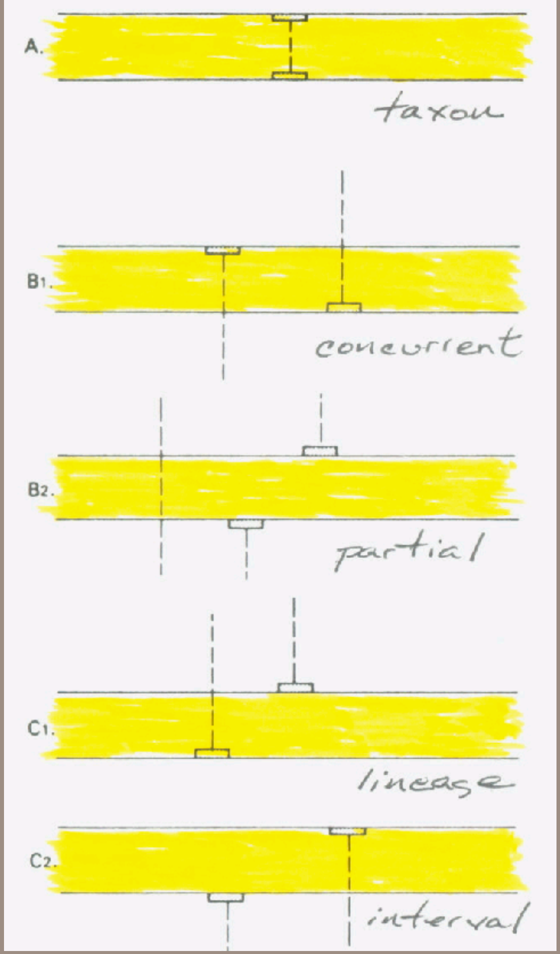
## Stage & Zone Concepts*



*based upon principle of faunal succession.

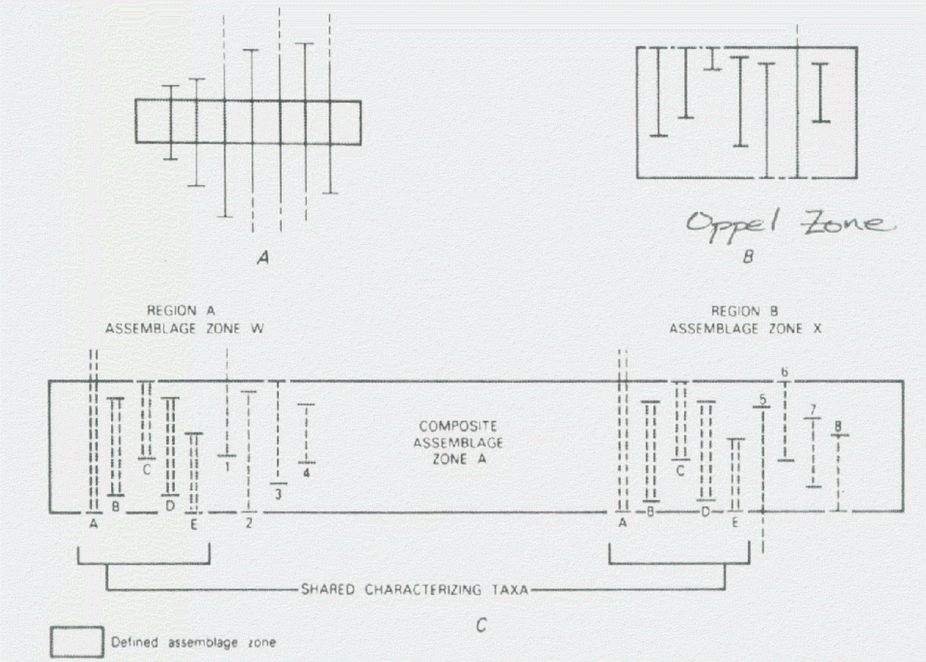
# Biostratigraphy (cont.)

Types of Interval or Range Zones



One or two taxa

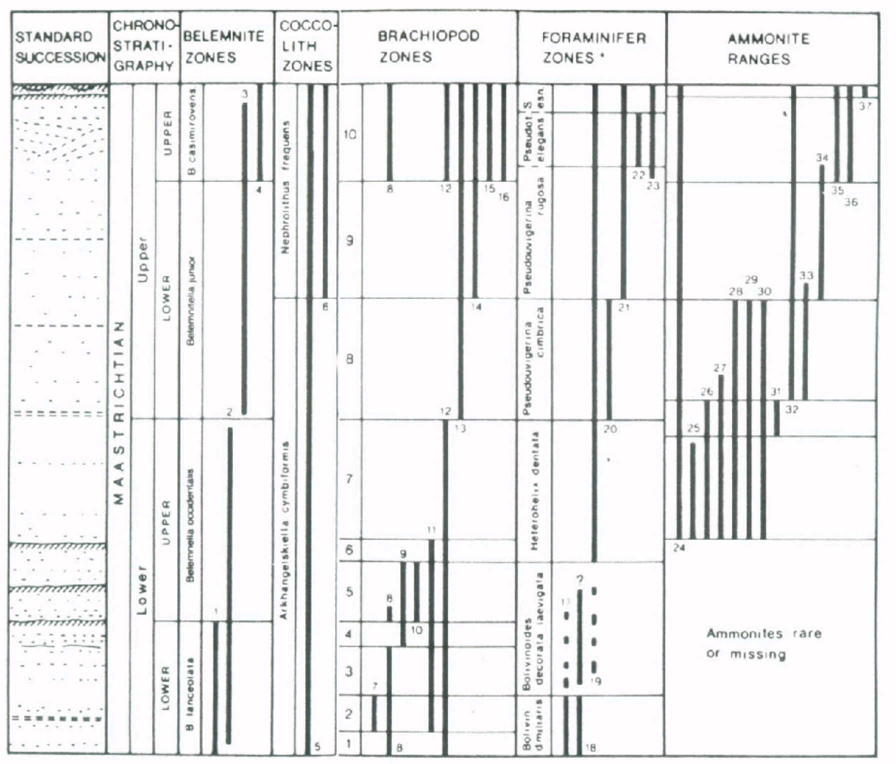
Assemblage Zones



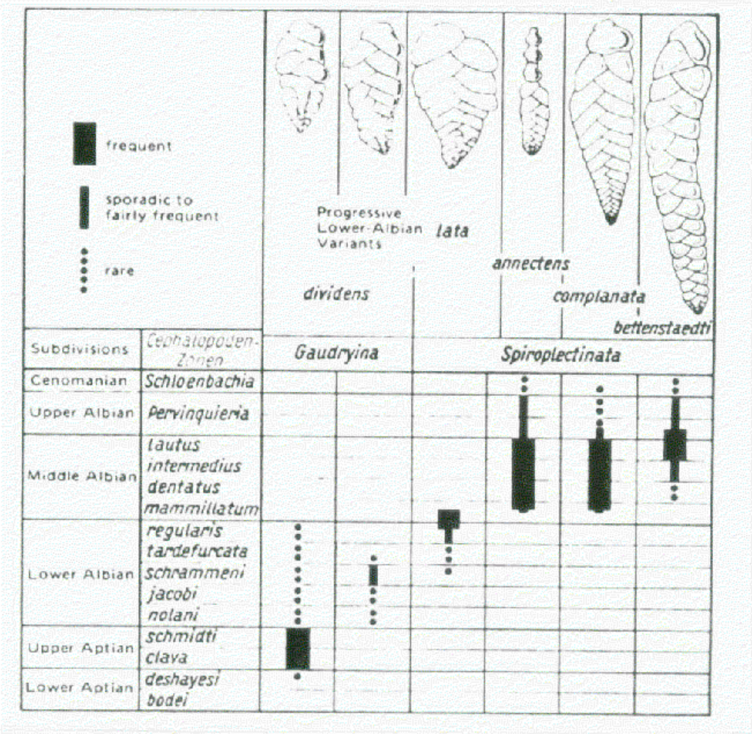
More is better…

# Biostratigraphy (cont.)

Subdivision example based upon
<u>Concurrent</u> range zones



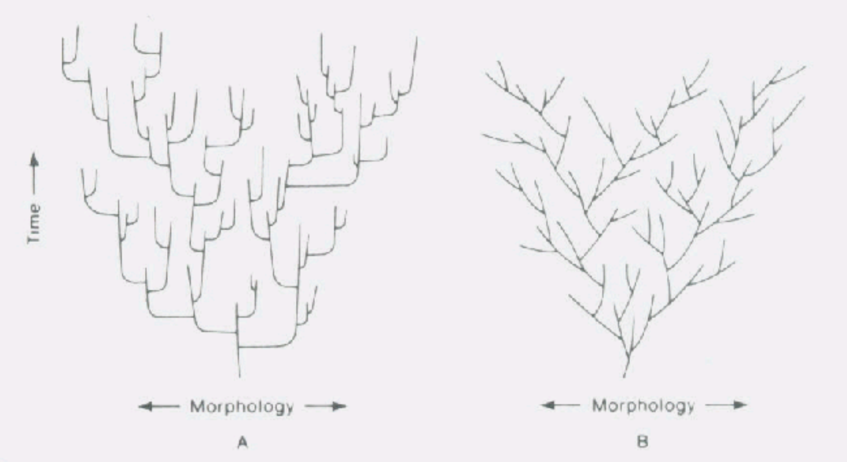
Subdivision example based upon
<u>Abundance</u> zones (range & frequency)



From: Boggs (1987)

# Biostratigraphy (cont.)

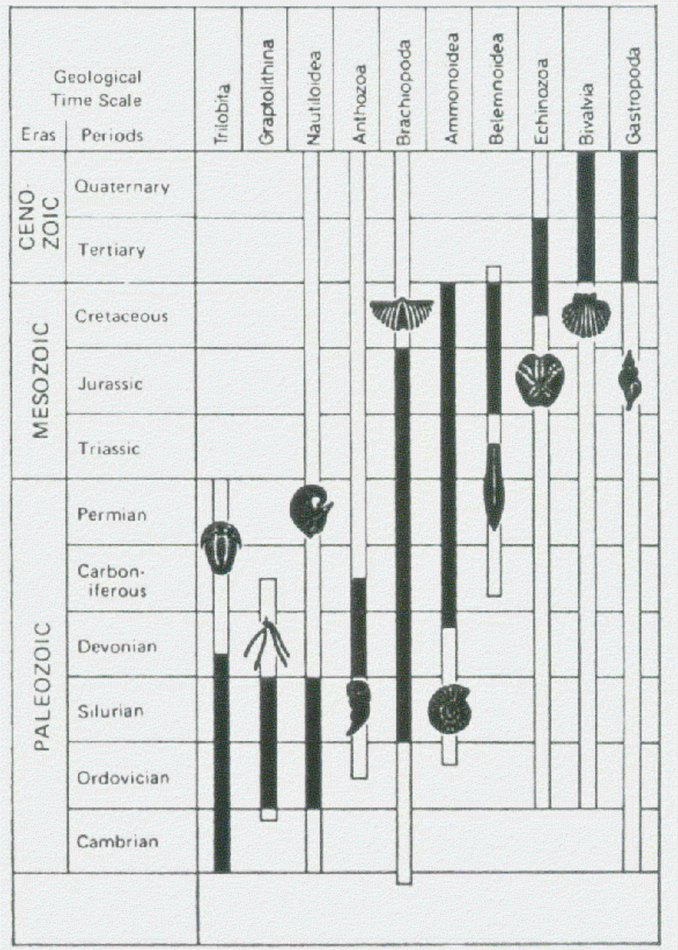
Evolution Theory as Basis for Biostratigraphic Zonation



Punctuated (a) vs. Gradual (b) Models

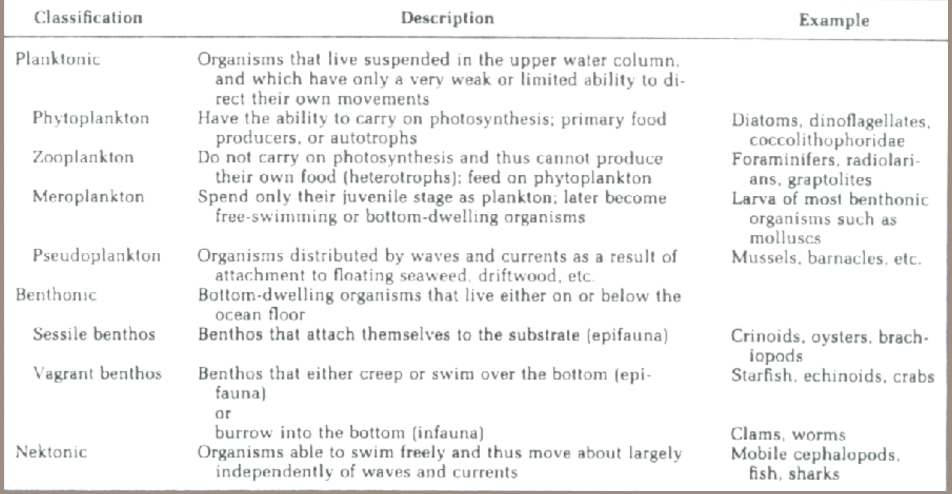
Species variations are one-directional & irreversible!

Important Macrofossil Groups



Ideal Index Fossil = abundant, widespread, short range

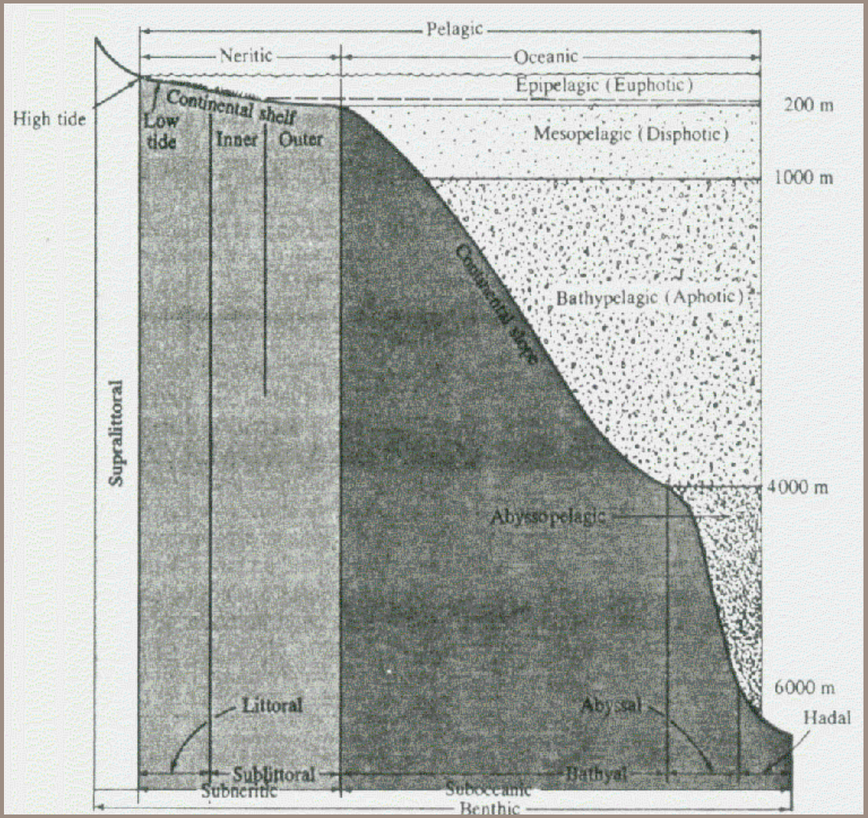
# Biogeography



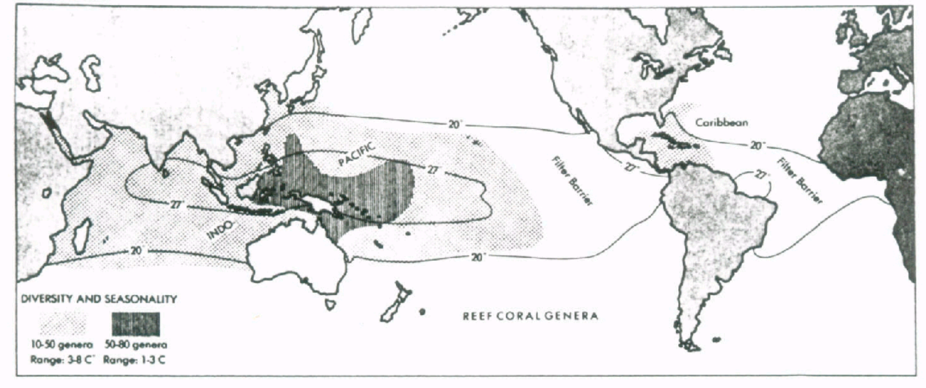
| Classification | Description | Example |
|---|---|---|
| Planktonic | Organisms that live suspended in the upper water column, and which have only a very weak or limited ability to direct their own movements | |
| Phytoplankton | Have the ability to carry on photosynthesis; primary food producers, or autotrophs | Diatoms, dinoflagellates, coccolithophoridae |
| Zooplankton | Do not carry on photosynthesis and thus cannot produce their own food (heterotrophs); feed on phytoplankton | Foraminifers, radiolarians, graptolites |
| Meroplankton | Spend only their juvenile stage as plankton; later become free-swimming or bottom-dwelling organisms | Larva of most benthonic organisms such as molluscs |
| Pseudoplankton | Organisms distributed by waves and currents as a result of attachment to floating seaweed, driftwood, etc. | Mussels, barnacles, etc. |
| Benthonic | Bottom-dwelling organisms that live either on or below the ocean floor | |
| Sessile benthos | Benthos that attach themselves to the substrate (epifauna) | Crinoids, oysters, brachiopods |
| Vagrant benthos | Benthos that either creep or swim over the bottom (epifauna)<br>or<br>burrow into the bottom (infauna) | Starfish, echinoids, crabs<br>Clams, worms |
| Nektonic | Organisms able to swim freely and thus move about largely independently of waves and currents | Mobile cephalopods, fish, sharks |

Present Habitats of Marine Organisms => Paleoceanographic Interpretations = Bonus Information!

(Uniformitarian application)



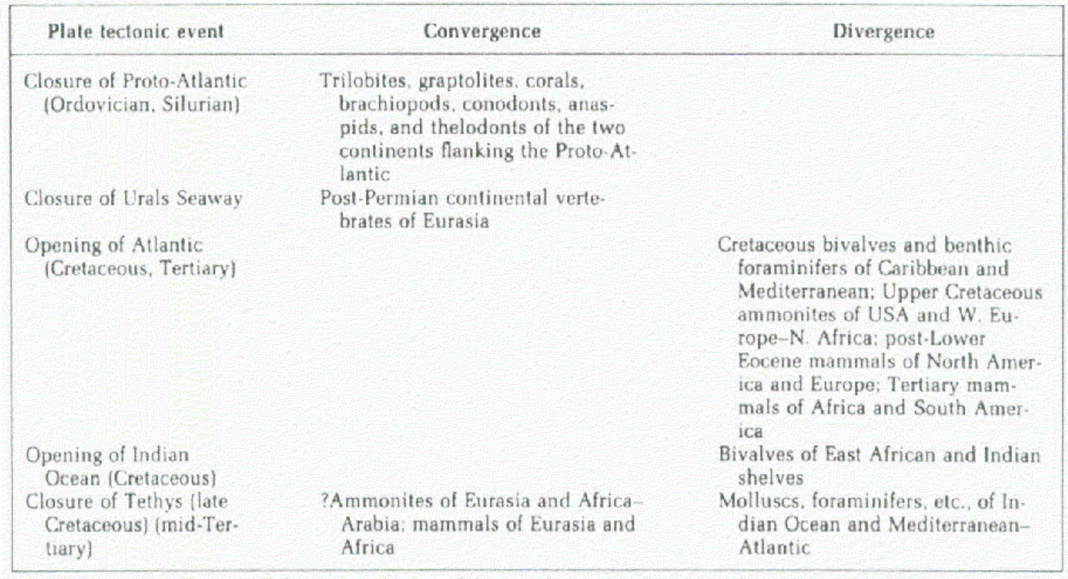
# Biogeography (cont.)



## Barriers to Dispersal

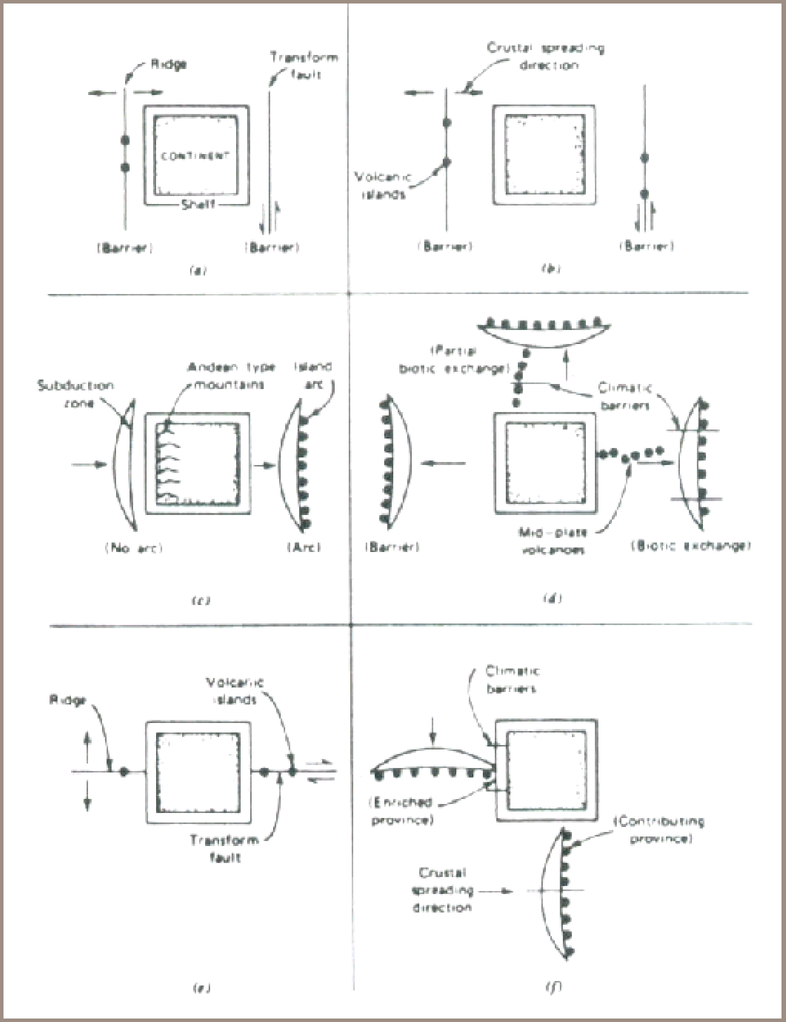
Example of temperature (latitude) and filter barriers on modern corals

Summary of Plate Tectonic Events & Changes in Faunal Distribution Patterns



| Plate tectonic event | Convergence | Divergence |
|---|---|---|
| Closure of Proto-Atlantic (Ordovician, Silurian) | Trilobites, graptolites, corals, brachiopods, conodonts, anaspids, and thelodonts of the two continents flanking the Proto-Atlantic | |
| Closure of Urals Seaway | Post-Permian continental vertebrates of Eurasia | |
| Opening of Atlantic (Cretaceous, Tertiary) | | Cretaceous bivalves and benthic foraminifers of Caribbean and Mediterranean; Upper Cretaceous ammonites of USA and W. Europe–N. Africa; post-Lower Eocene mammals of North America and Europe; Tertiary mammals of Africa and South America |
| Opening of Indian Ocean (Cretaceous) | | Bivalves of East African and Indian shelves |
| Closure of Tethys (late Cretaceous) (mid-Tertiary) | ?Ammonites of Eurasia and Africa–Arabia; mammals of Eurasia and Africa | Molluscs, foraminifers, etc., of Indian Ocean and Mediterranean–Atlantic |

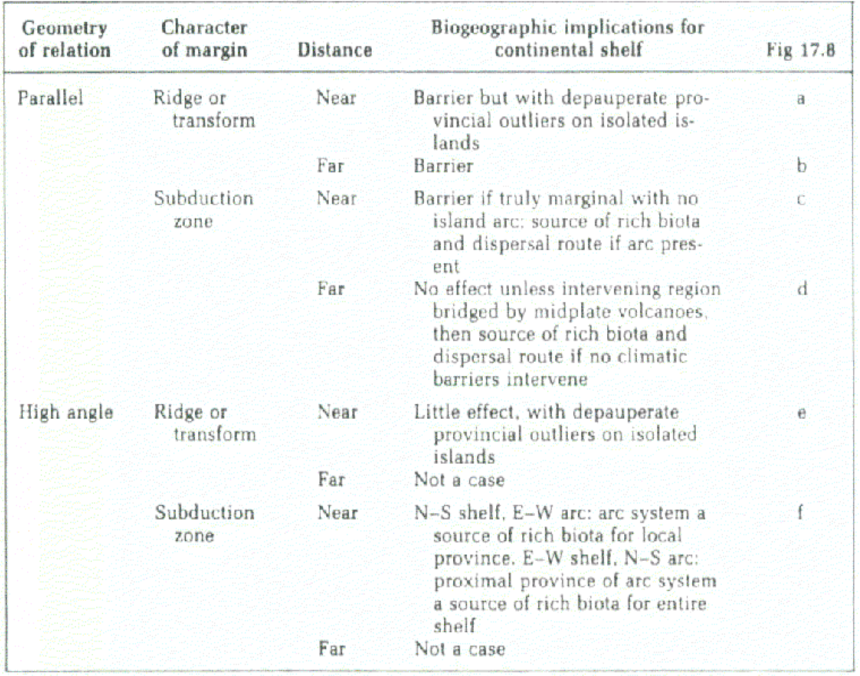
# Biogeography (cont.)



Let's add terrains...

Plate Tectonic Barrier & Dispersal Models (Valentine, 1971)

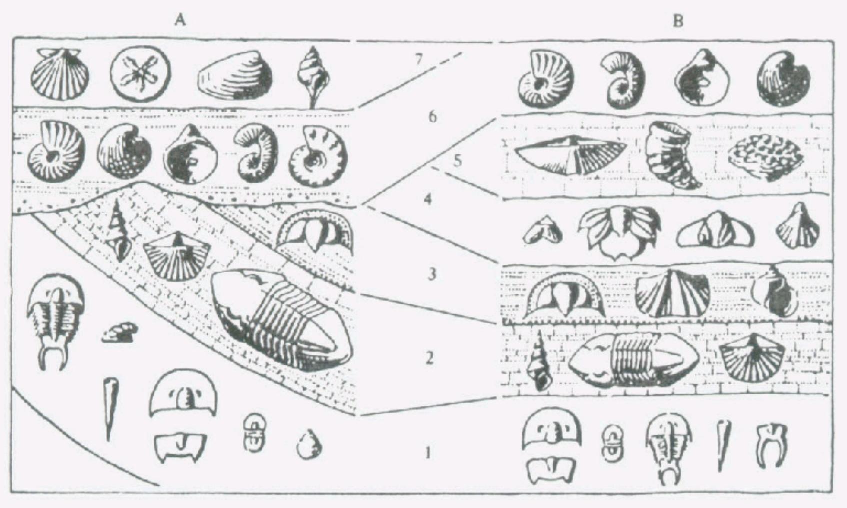
Includes migrating arcs, volcanic island chains, seamounts…



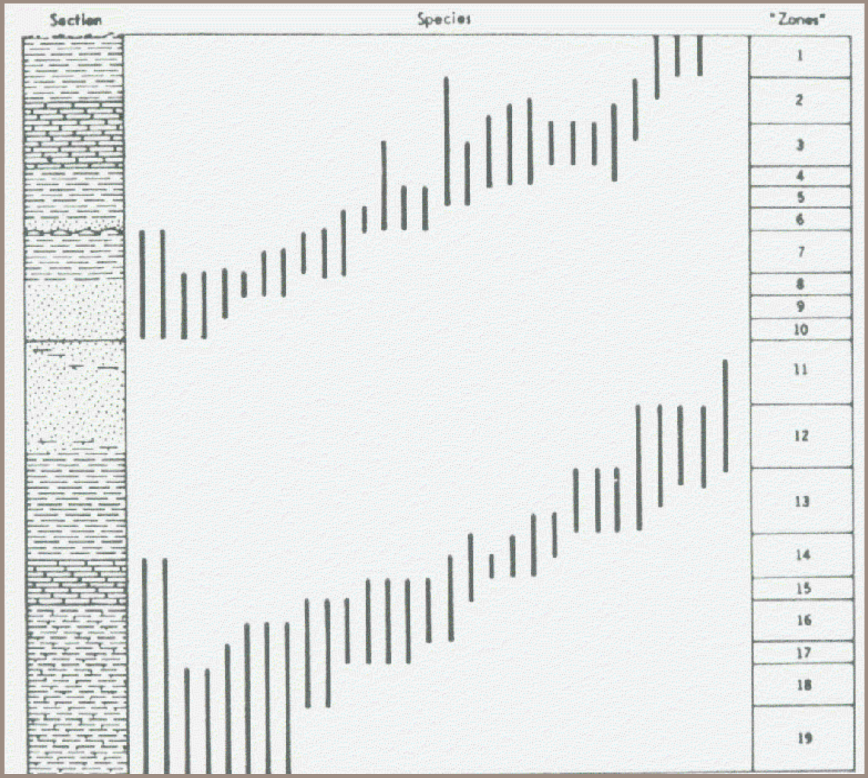
| Geometry of relation | Character of margin | Distance | Biogeographic implications for continental shelf | Fig 17.8 |
|---|---|---|---|---|
| Parallel | Ridge or transform | Near | Barrier but with depauperate provincial outliers on isolated islands | a |
| | | Far | Barrier | b |
| | Subduction zone | Near | Barrier if truly marginal with no island arc: source of rich biota and dispersal route if arc present | c |
| | | Far | No effect unless intervening region bridged by midplate volcanoes, then source of rich biota and dispersal route if no climatic barriers intervene | d |
| High angle | Ridge or transform | Near | Little effect, with depauperate provincial outliers on isolated islands | e |
| | | Far | Not a case | |
| | Subduction zone | Near | N–S shelf, E–W arc: arc system a source of rich biota for local province. E–W shelf, N–S arc: proximal province of arc system a source of rich biota for entire shelf | f |
| | | Far | Not a case | |

J. W. Valentine (1971)

# Biocorrelation

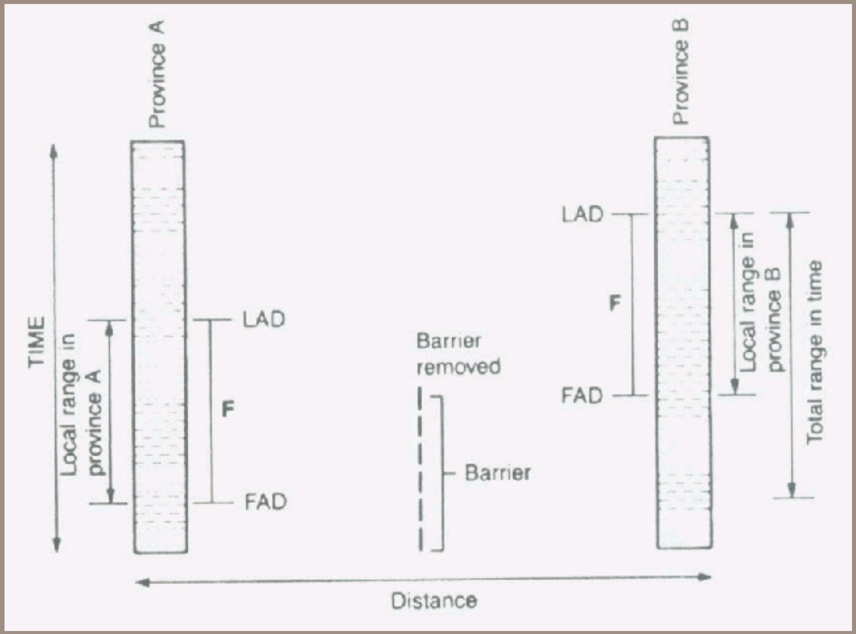


Simple visual correlation of macrofossils



Multiple fossil taxa requiring statistical correlation techniques

# Biocorrelation (cont.)



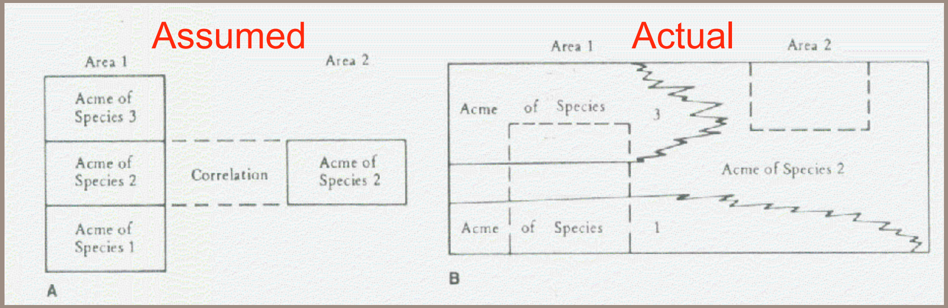
Pitfalls to avoid in correlation

Left: Biogeographic migration

Bottom: Acme (abundance) zone pitfalls

**FADs and LADs:**

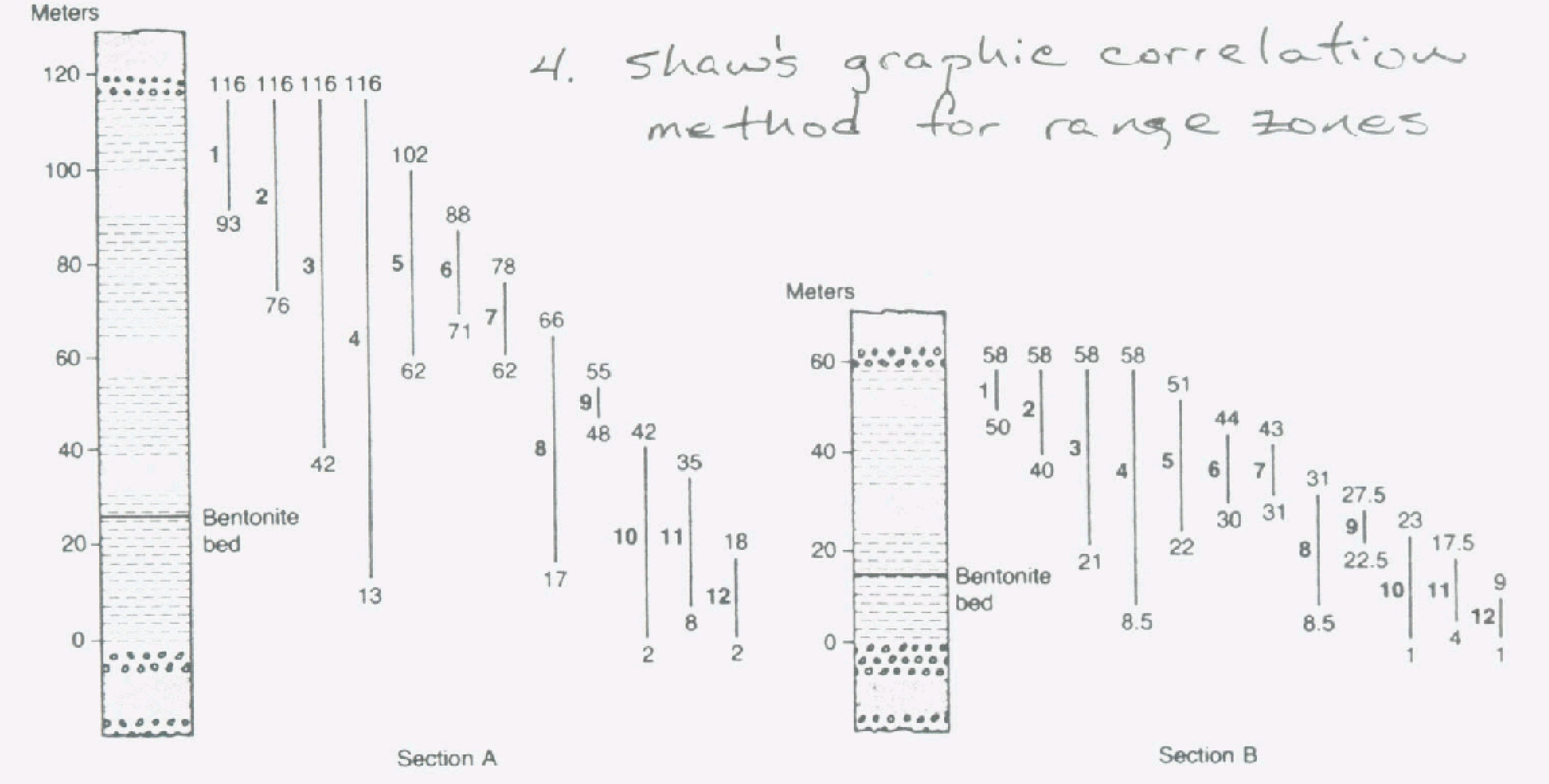
**FAD = First Appearance Datum**
**LAD = Last Appearance Datum**



Also: abundance => favorable environment
=> suddenly unfavorable
=> mechanical concentration

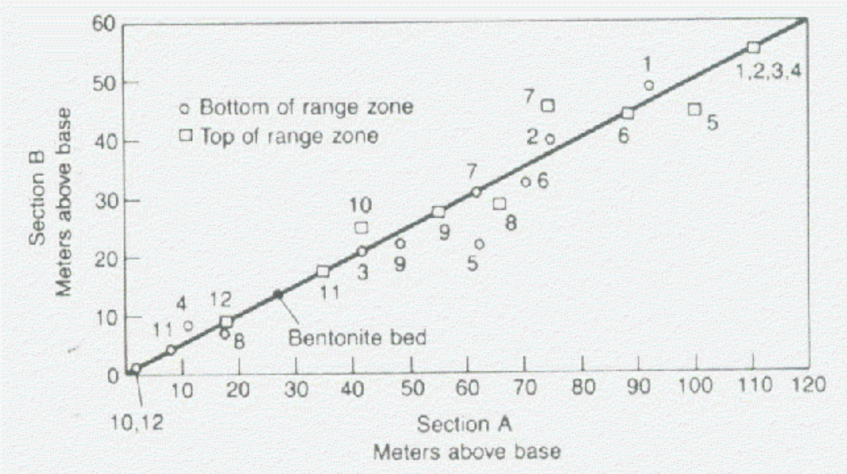
# Biocorrelation (cont.)

Shaw's graphic correlation => relative sedimentation rates



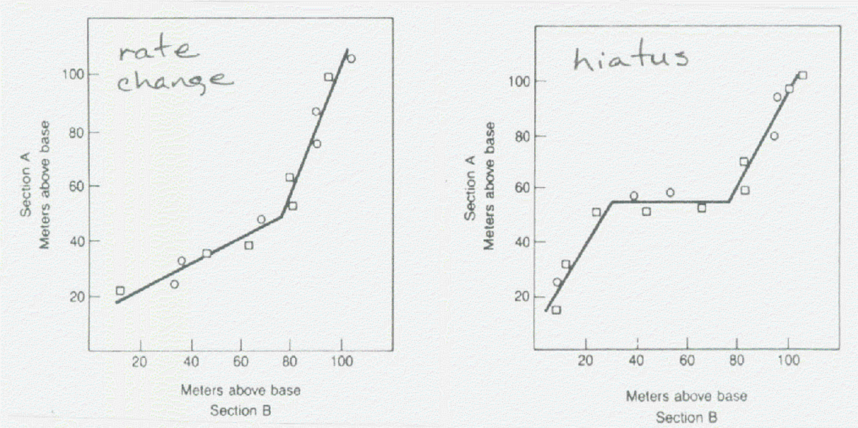
Note: numbers at FADs and LADs are heights in sections in meters above base

# Biocorrelation (cont.)

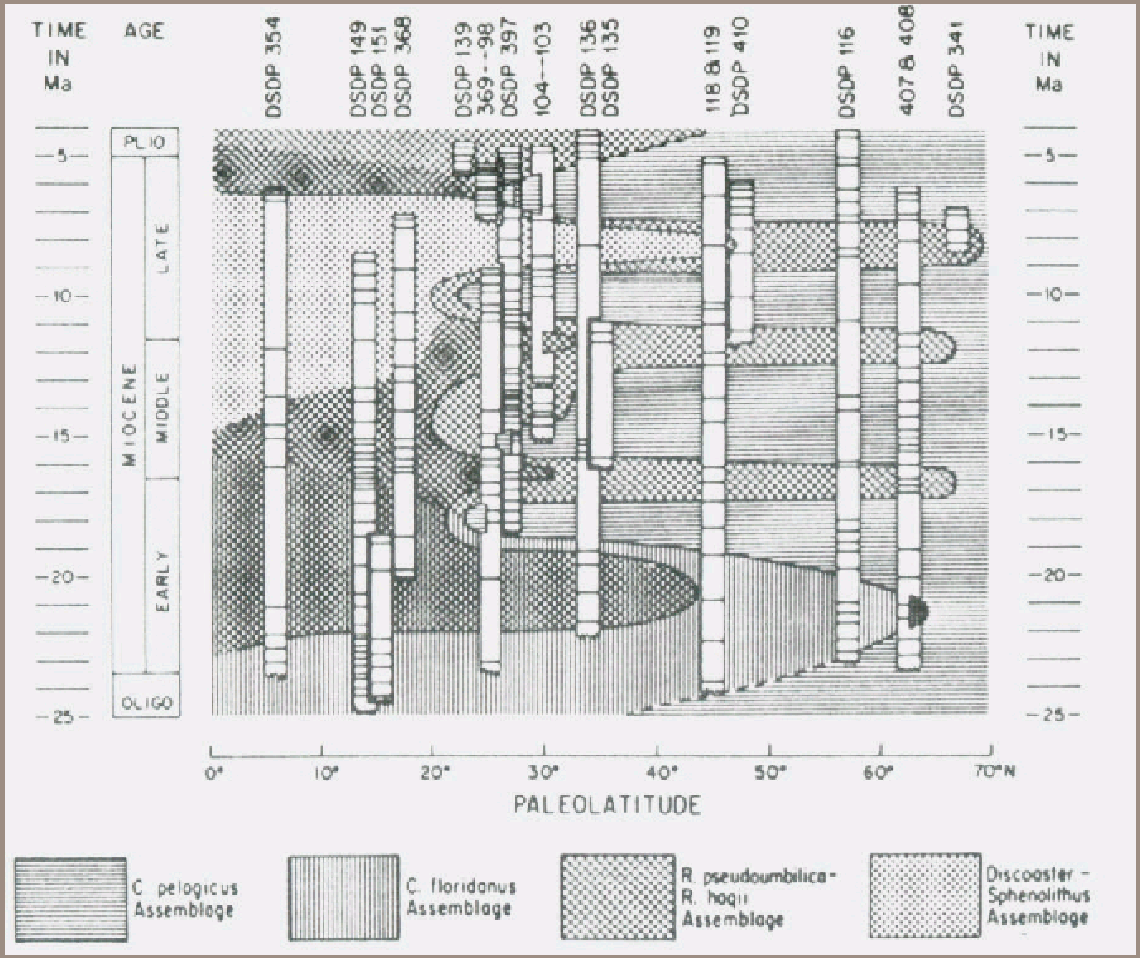


Relative sedimentation between Sections A & B (previous slide) are linear, A > B

Shaw's method sensitive to rate changes & hiatuses in sedimentation

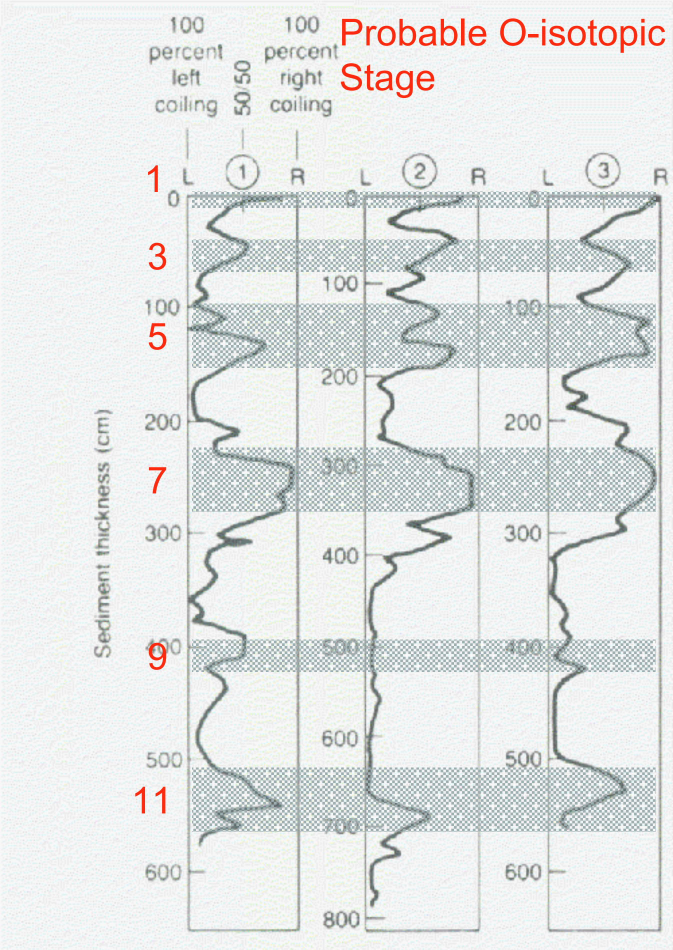


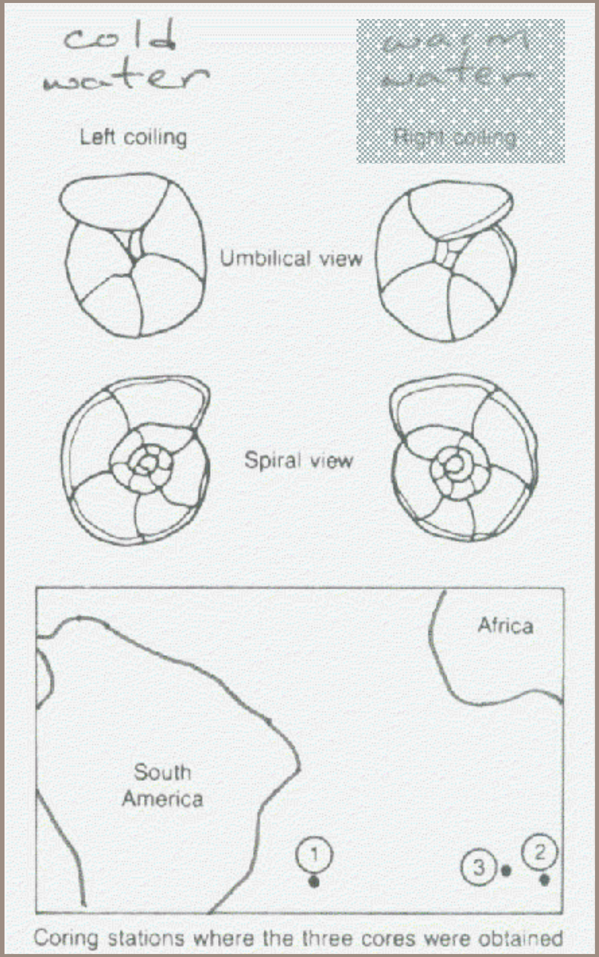
# Paleoclimate Data



Example of major fluctuations in climate in Miocene of North Atlantic Basin as revealed by acme zones

# Paleoclimate Data (cont.)

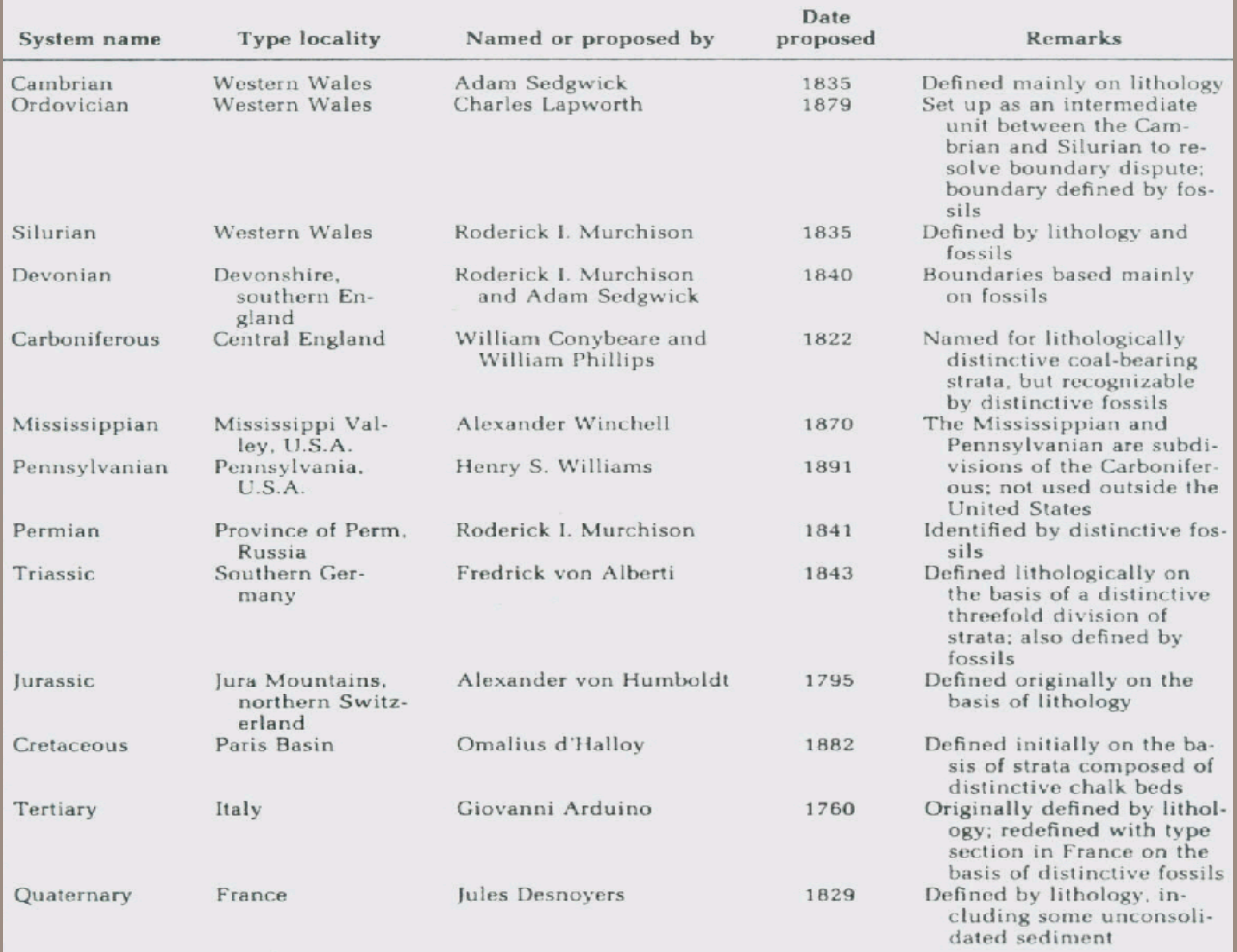




Biogeographical acme zone correlation based upon coiling ratios of foraminifers in three South Atlantic Basin sediment cores (original data of Ericson & Woolin, 1968)

# Chronostratigraphy & Geologic Time Scale

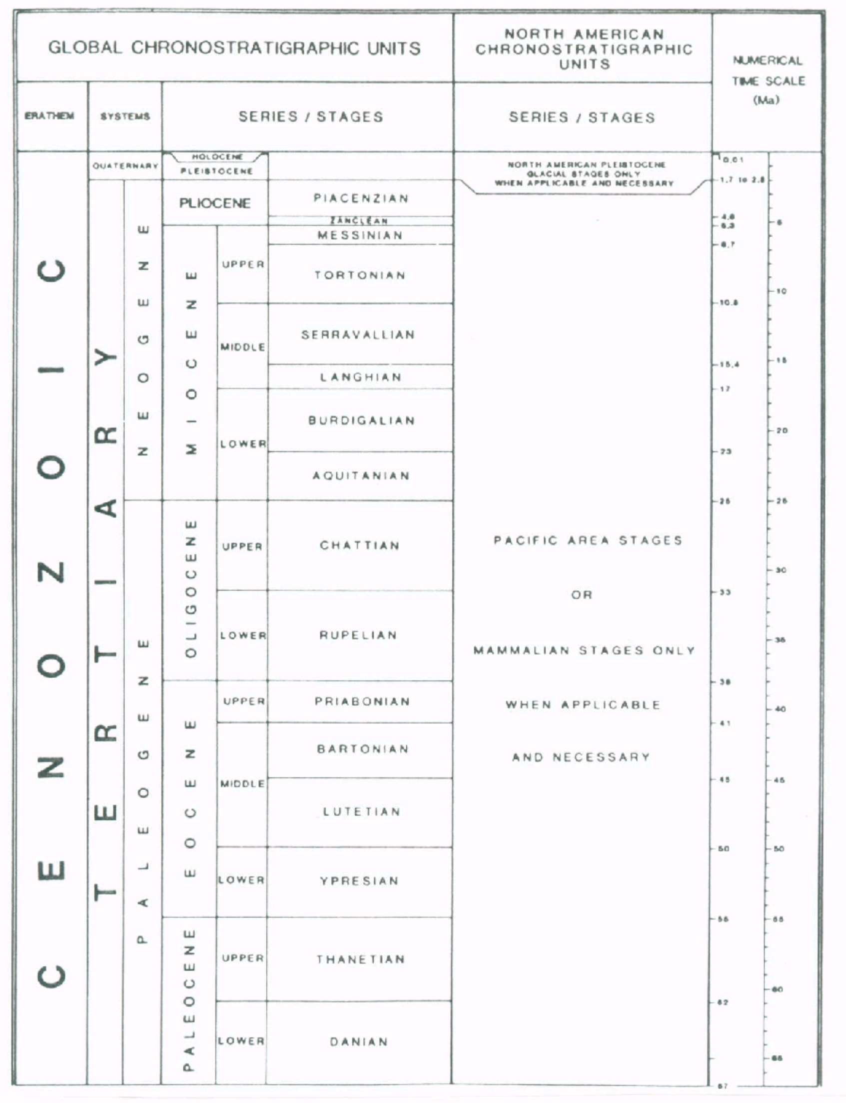
## The Geologic Systems and their Type Localities



| System name | Type locality | Named or proposed by | Date proposed | Remarks |
|---|---|---|---|---|
| Cambrian | Western Wales | Adam Sedgwick | 1835 | Defined mainly on lithology |
| Ordovician | Western Wales | Charles Lapworth | 1879 | Set up as an intermediate unit between the Cambrian and Silurian to resolve boundary dispute; boundary defined by fossils |
| Silurian | Western Wales | Roderick I. Murchison | 1835 | Defined by lithology and fossils |
| Devonian | Devonshire, southern England | Roderick I. Murchison and Adam Sedgwick | 1840 | Boundaries based mainly on fossils |
| Carboniferous | Central England | William Conybeare and William Phillips | 1822 | Named for lithologically distinctive coal-bearing strata, but recognizable by distinctive fossils |
| Mississippian | Mississippi Valley, U.S.A. | Alexander Winchell | 1870 | The Mississippian and Pennsylvanian are subdivisions of the Carboniferous; not used outside the United States |
| Pennsylvanian | Pennsylvania, U.S.A. | Henry S. Williams | 1891 | |
| Permian | Province of Perm, Russia | Roderick I. Murchison | 1841 | Identified by distinctive fossils |
| Triassic | Southern Germany | Fredrick von Alberti | 1843 | Defined lithologically on the basis of a distinctive threefold division of strata; also defined by fossils |
| Jurassic | Jura Mountains, northern Switzerland | Alexander von Humboldt | 1795 | Defined originally on the basis of lithology |
| Cretaceous | Paris Basin | Omalius d'Halloy | 1882 | Defined initially on the basis of strata composed of distinctive chalk beds |
| Tertiary | Italy | Giovanni Arduino | 1760 | Originally defined by lithology; redefined with type section in France on the basis of distinctive fossils |
| Quaternary | France | Jules Desnoyers | 1829 | Defined by lithology, including some unconsolidated sediment |

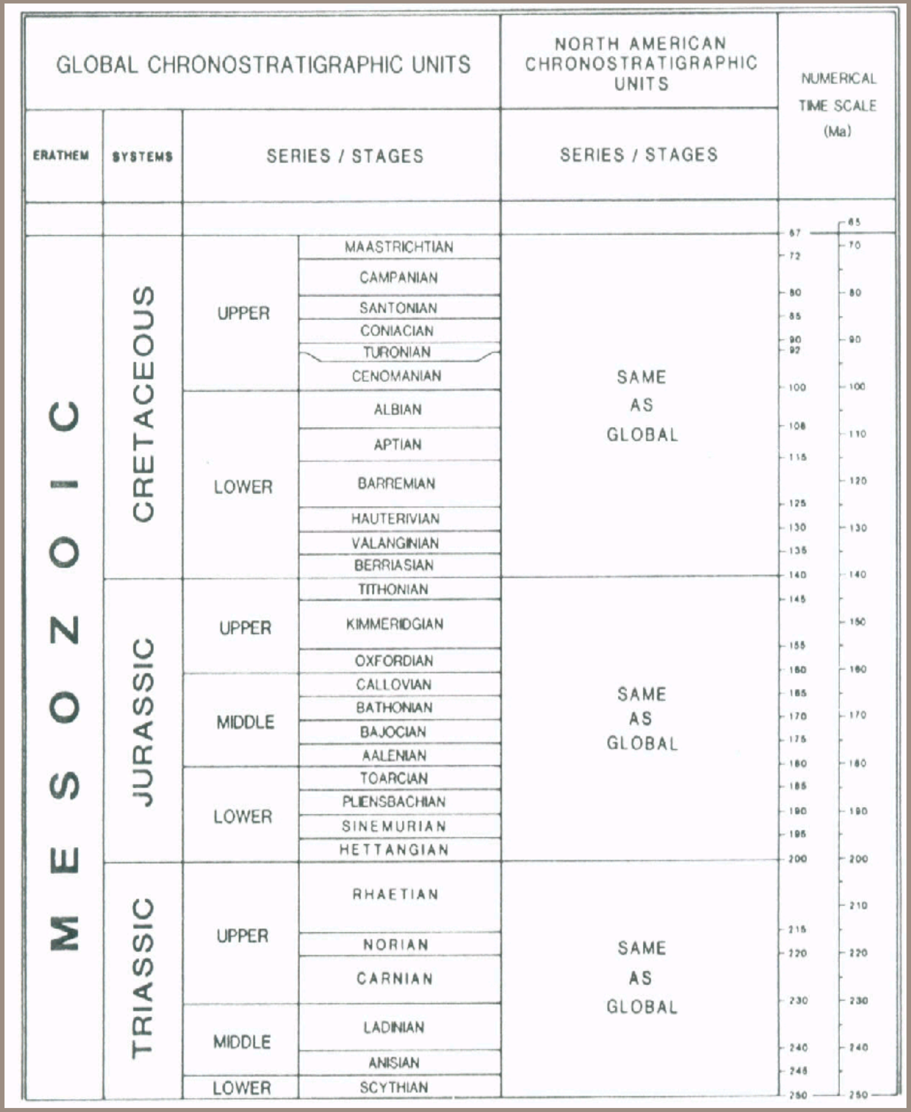
From: Boggs (1987)

# The Cenozoic Era



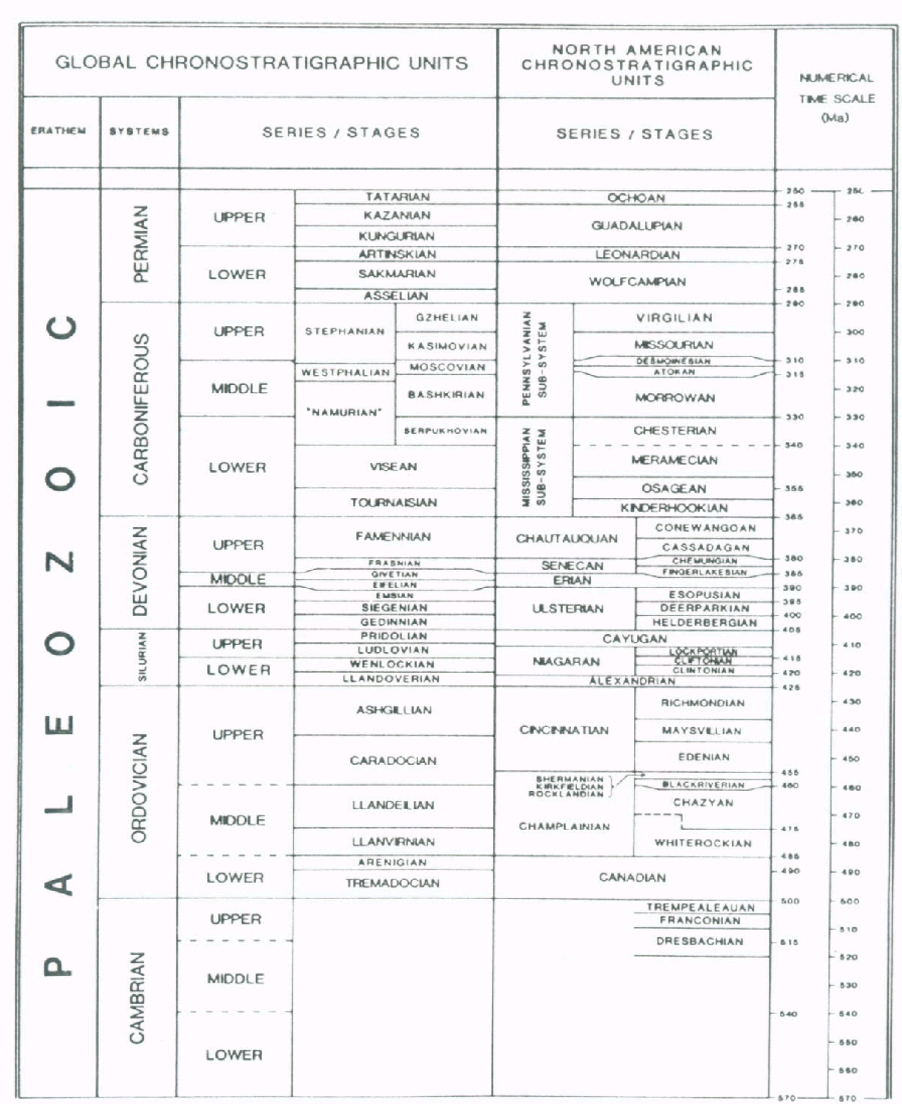
| GLOBAL CHRONOSTRATIGRAPHIC UNITS | | | | | | NORTH AMERICAN CHRONOSTRATIGRAPHIC UNITS | NUMERICAL TIME SCALE (Ma) | |
|---|---|---|---|---|---|---|---|---|
| ERATHEM | SYSTEMS | | SERIES / STAGES | | | SERIES / STAGES | | |
| CENOZOIC | QUATERNARY | | HOLOCENE | | | NORTH AMERICAN PLEISTOCENE GLACIAL STAGES ONLY WHEN APPLICABLE AND NECESSARY | 0.01 | |
| | | | PLEISTOCENE | | | | 1,7 to 2,8 | |
| | TERTIARY | NEOGENE | PLIOCENE | | PIACENZIAN | PACIFIC AREA STAGES<br>OR<br>MAMMALIAN STAGES ONLY<br>WHEN APPLICABLE<br>AND NECESSARY | 4,8 | |
| | | | | | ZANCLEAN | | 5,3 | 5 |
| | | | MIOCENE | UPPER | MESSINIAN | | 6,7 | |
| | | | | | TORTONIAN | | 10,8 | 10 |
| | | | | MIDDLE | SERRAVALLIAN | | 15,4 | 15 |
| | | | | | LANGHIAN | | 17 | |
| | | | | LOWER | BURDIGALIAN | | 23 | 20 |
| | | | | | AQUITANIAN | | 25 | 25 |
| | | PALEOGENE | OLIGOCENE | UPPER | CHATTIAN | | 33 | 30 |
| | | | | LOWER | RUPELIAN | | 38 | 35 |
| | | | EOCENE | UPPER | PRIABONIAN | | 41 | 40 |
| | | | | MIDDLE | BARTONIAN | | 45 | 45 |
| | | | | | LUTETIAN | | 50 | 50 |
| | | | | LOWER | YPRESIAN | | 56 | 55 |
| | | | PALEOCENE | UPPER | THANETIAN | | 62 | 60 |
| | | | | LOWER | DANIAN | | 67 | 65 |

# The Mesozoic Era



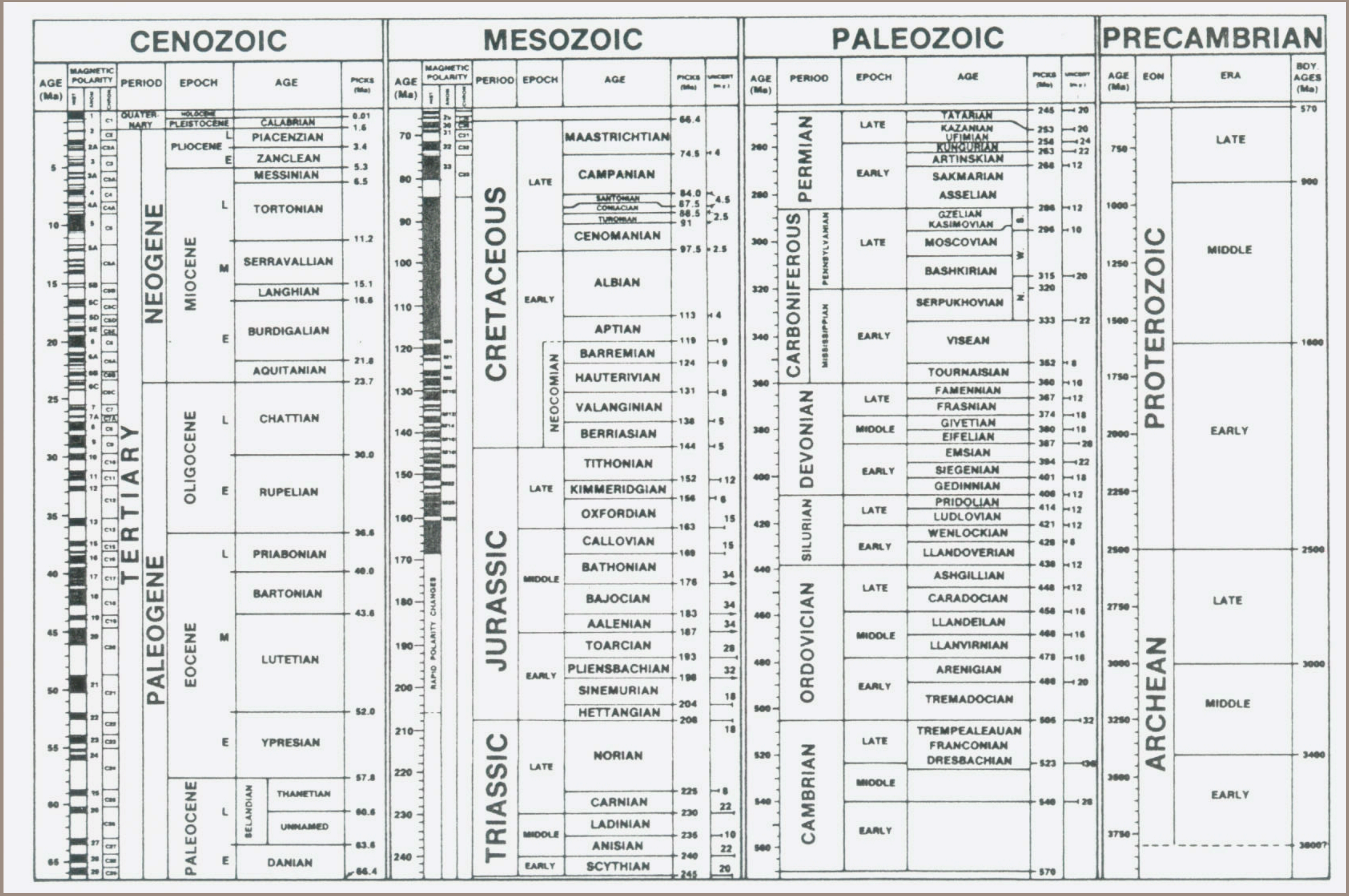
| GLOBAL CHRONOSTRATIGRAPHIC UNITS | | | | NORTH AMERICAN CHRONOSTRATIGRAPHIC UNITS | NUMERICAL TIME SCALE (Ma) |
|---|---|---|---|---|---|
| ERATHEM | SYSTEMS | SERIES / STAGES | | SERIES / STAGES | |
| | | | | | 67 |
| MESOZOIC | CRETACEOUS | UPPER | MAASTRICHTIAN | SAME AS GLOBAL | 72 |
| | | | CAMPANIAN | | 80 |
| | | | SANTONIAN | | 85 |
| | | | CONIACIAN | | 90 |
| | | | TURONIAN | | 92 |
| | | | CENOMANIAN | | 100 |
| | | LOWER | ALBIAN | | 108 |
| | | | APTIAN | | 115 |
| | | | BARREMIAN | | 125 |
| | | | HAUTERIVIAN | | 130 |
| | | | VALANGINIAN | | 135 |
| | | | BERRIASIAN | | 140 |
| | JURASSIC | UPPER | TITHONIAN | SAME AS GLOBAL | 145 |
| | | | KIMMERIDGIAN | | 155 |
| | | | OXFORDIAN | | 160 |
| | | MIDDLE | CALLOVIAN | | 165 |
| | | | BATHONIAN | | 170 |
| | | | BAJOCIAN | | 175 |
| | | | AALENIAN | | 180 |
| | | LOWER | TOARCIAN | | 185 |
| | | | PLIENSBACHIAN | | 190 |
| | | | SINEMURIAN | | 195 |
| | | | HETTANGIAN | | 200 |
| | TRIASSIC | UPPER | RHAETIAN | SAME AS GLOBAL | 215 |
| | | | NORIAN | | 220 |
| | | | CARNIAN | | 230 |
| | | MIDDLE | LADINIAN | | 240 |
| | | | ANISIAN | | 245 |
| | | LOWER | SCYTHIAN | | 250 |

# The Paleozoic Era



| GLOBAL CHRONOSTRATIGRAPHIC UNITS | | | | | NORTH AMERICAN CHRONOSTRATIGRAPHIC UNITS | | NUMERICAL TIME SCALE (Ma) | |
|---|---|---|---|---|---|---|---|---|
| ERATHEM | SYSTEMS | SERIES / STAGES | | | SERIES / STAGES | | | |
| PALEOZOIC | PERMIAN | UPPER | TATARIAN | | OCHOAN | | 250 | 250 |
| | | | KAZANIAN | | GUADALUPIAN | | 255 | 260 |
| | | | KUNGURIAN | | | | | |
| | | LOWER | ARTINSKIAN | | LEONARDIAN | | 270 | 270 |
| | | | SAKMARIAN | | WOLFCAMPIAN | | 275 | 280 |
| | | | ASSELIAN | | | | 285 | |
| | CARBONIFEROUS | UPPER | STEPHANIAN | GZHELIAN | PENNSYLVANIAN SUB-SYSTEM | VIRGILIAN | 290 | 290 |
| | | | | KASIMOVIAN | | MISSOURIAN | | 300 |
| | | MIDDLE | WESTPHALIAN | MOSCOVIAN | | DESMOINESIAN | 310 | 310 |
| | | | | | | ATOKAN | 315 | |
| | | | "NAMURIAN" | BASHKIRIAN | | MORROWAN | | 320 |
| | | | | SERPUKHOVIAN | MISSISSIPPIAN SUB-SYSTEM | CHESTERIAN | 330 | 330 |
| | | LOWER | VISEAN | | | MERAMECIAN | 340 | 340 |
| | | | | | | OSAGEAN | 355 | 350 |
| | | | TOURNAISIAN | | | KINDERHOOKIAN | | 360 |
| | DEVONIAN | UPPER | FAMENNIAN | | CHAUTAUQUAN | CONEWANGOAN | 365 | 370 |
| | | | | | | CASSADAGAN | | |
| | | | FRASNIAN | | SENECAN | CHEMUNGIAN | 380 | 380 |
| | | | | | | FINGERLAKESIAN | 385 | |
| | | MIDDLE | GIVETIAN | | ERIAN | | | |
| | | | EIFELIAN | | | | | |
| | | LOWER | EMSIAN | | ULSTERIAN | ESOPUSIAN | 390 | 390 |
| | | | SIEGENIAN | | | DEERPARKIAN | 395 | |
| | | | GEDINNIAN | | | HELDERBERGIAN | 400 | 400 |
| | SILURIAN | UPPER | PRIDOLIAN | | CAYUGAN | | 405 | |
| | | | LUDLOVIAN | | NIAGARAN | LOCKPORTIAN | | 410 |
| | | LOWER | WENLOCKIAN | | | CLIFTONIAN | 415 | |
| | | | | | | CLINTONIAN | 420 | 420 |
| | | | LLANDOVERIAN | | ALEXANDRIAN | | 425 | |
| | ORDOVICIAN | UPPER | ASHGILLIAN | | CINCINNATIAN | RICHMONDIAN | | 430 |
| | | | | | | MAYSVILLIAN | | 440 |
| | | | CARADOCIAN | | | EDENIAN | | 450 |
| | | | | | SHERMANIAN<br>KIRKFIELDIAN<br>ROCKLANDIAN | BLACKRIVERIAN | 455 | |
| | | MIDDLE | LLANDEILIAN | | CHAMPLAINIAN | CHAZYAN | 460 | 460 |
| | | | | | | | | 470 |
| | | | LLANVIRNIAN | | | WHITEROCKIAN | 475 | 480 |
| | | LOWER | ARENIGIAN | | CANADIAN | | 485 | |
| | | | TREMADOCIAN | | | | 490 | 490 |
| | CAMBRIAN | UPPER | | | | TREMPEALEAUAN | 500 | 500 |
| | | | | | | FRANCONIAN | | 510 |
| | | | | | | DRESBACHIAN | 515 | 520 |
| | | MIDDLE | | | | | | 530 |
| | | | | | | | 540 | 540 |
| | | LOWER | | | | | | 550 |
| | | | | | | | | 560 |
| | | | | | | | 570 | 570 |

# Geologic Time Table with Absolute & Polarity Ages



## CENOZOIC

| PERIOD | | EPOCH | | AGE | PICKS (Ma) |
|---|---|---|---|---|---|
| QUATERNARY | | HOLOCENE | | | 0.01 |
| | | PLEISTOCENE | | CALABRIAN | 1.6 |
| TERTIARY | NEOGENE | PLIOCENE | L | PIACENZIAN | 3.4 |
| | | | E | ZANCLEAN | 5.3 |
| | | MIOCENE | L | MESSINIAN | 6.5 |
| | | | | TORTONIAN | 11.2 |
| | | | M | SERRAVALLIAN | 15.1 |
| | | | | LANGHIAN | 16.6 |
| | | | E | BURDIGALIAN | 21.8 |
| | | | | AQUITANIAN | 23.7 |
| | PALEOGENE | OLIGOCENE | L | CHATTIAN | 30.0 |
| | | | E | RUPELIAN | 36.6 |
| | | EOCENE | L | PRIABONIAN | 40.0 |
| | | | M | BARTONIAN | 43.6 |
| | | | | LUTETIAN | 52.0 |
| | | | E | YPRESIAN | 57.8 |
| | | PALEOCENE | L | SELANDIAN: THANETIAN | 60.6 |
| | | | | SELANDIAN: UNNAMED | 63.6 |
| | | | E | DANIAN | 66.4 |

## MESOZOIC

| PERIOD | EPOCH | | AGE | PICKS (Ma) | UNCERT (m.y.) |
|---|---|---|---|---|---|
| | | | | 66.4 | |
| CRETACEOUS | LATE | | MAASTRICHTIAN | 74.5 | 4 |
| | | | CAMPANIAN | 84.0 | |
| | | | SANTONIAN | 87.5 | 4.5 |
| | | | CONIACIAN | 88.5 | |
| | | | TURONIAN | 91 | 2.5 |
| | | | CENOMANIAN | 97.5 | 2.5 |
| | EARLY | | ALBIAN | 113 | 4 |
| | | | APTIAN | 119 | 9 |
| | | NEOCOMIAN | BARREMIAN | 124 | 9 |
| | | | HAUTERIVIAN | 131 | 8 |
| | | | VALANGINIAN | 138 | 5 |
| | | | BERRIASIAN | 144 | 5 |
| JURASSIC | LATE | | TITHONIAN | 152 | 12 |
| | | | KIMMERIDGIAN | 156 | 6 |
| | | | OXFORDIAN | 163 | 15 |
| | MIDDLE | | CALLOVIAN | 169 | 15 |
| | | | BATHONIAN | 176 | 34 |
| | | | BAJOCIAN | 183 | 34 |
| | | | AALENIAN | 187 | 34 |
| | EARLY | | TOARCIAN | 193 | 28 |
| | | | PLIENSBACHIAN | 198 | 32 |
| | | | SINEMURIAN | 204 | 18 |
| | | | HETTANGIAN | 208 | |
| TRIASSIC | LATE | | NORIAN | 225 | 18<br>8 |
| | | | CARNIAN | 230 | 22 |
| | MIDDLE | | LADINIAN | 235 | 10 |
| | | | ANISIAN | 240 | 22 |
| | EARLY | | SCYTHIAN | 245 | 20 |

RAPID POLARITY CHANGES

## PALEOZOIC

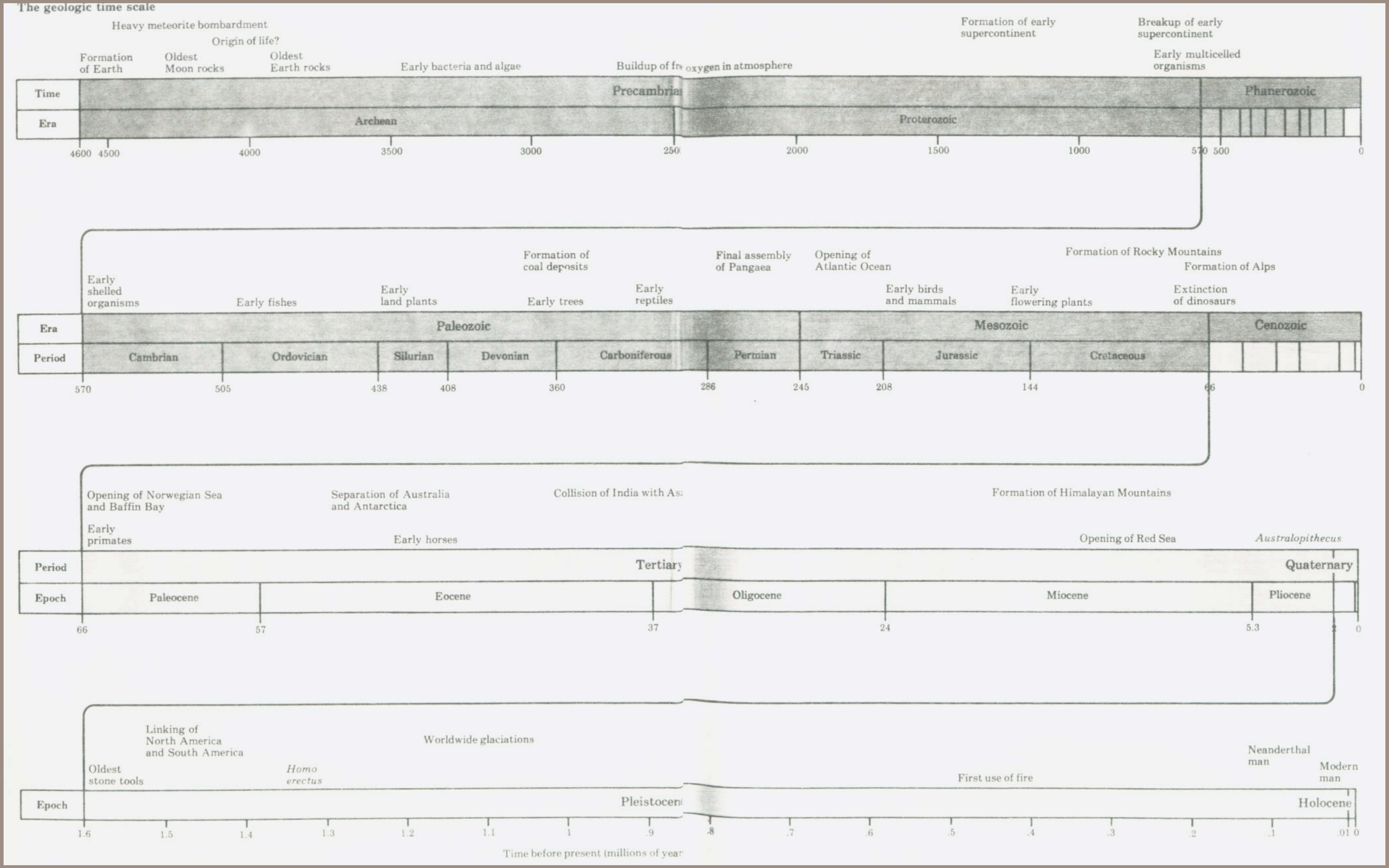
| PERIOD | | EPOCH | AGE | | PICKS (Ma) | UNCERT (m.y.) |
|---|---|---|---|---|---|---|
| | | | | | 245 | 20 |
| PERMIAN | | LATE | TATARIAN | | 253 | 20 |
| | | | KAZANIAN<br>UFIMIAN | | 256 | 24 |
| | | EARLY | KUNGURIAN | | 263 | 22 |
| | | | ARTINSKIAN | | 268 | 12 |
| | | | SAKMARIAN<br>ASSELIAN | | 286 | 12 |
| CARBONIFEROUS | PENNSYLVANIAN | LATE | GZELIAN<br>KASIMOVIAN | G. | 296 | 10 |
| | | | MOSCOVIAN | W. | | |
| | | | BASHKIRIAN | | 315 | 20 |
| | MISSISSIPPIAN | | | | 320 | |
| | | EARLY | SERPUKHOVIAN | N. | 333 | 22 |
| | | | VISEAN | | 352 | 8 |
| | | | TOURNAISIAN | | 360 | 10 |
| DEVONIAN | | LATE | FAMENNIAN | | 367 | 12 |
| | | | FRASNIAN | | 374 | 18 |
| | | MIDDLE | GIVETIAN | | 380 | 18 |
| | | | EIFELIAN | | 387 | 28 |
| | | EARLY | EMSIAN | | 394 | 22 |
| | | | SIEGENIAN | | 401 | 18 |
| | | | GEDINNIAN | | 408 | 12 |
| SILURIAN | | LATE | PRIDOLIAN | | 414 | 12 |
| | | | LUDLOVIAN | | 421 | 12 |
| | | EARLY | WENLOCKIAN | | 428 | 6 |
| | | | LLANDOVERIAN | | 438 | 12 |
| ORDOVICIAN | | LATE | ASHGILLIAN | | 448 | 12 |
| | | | CARADOCIAN | | 458 | 16 |
| | | MIDDLE | LLANDEILAN | | 468 | 16 |
| | | | LLANVIRNIAN | | 478 | 16 |
| | | EARLY | ARENIGIAN | | 488 | 20 |
| | | | TREMADOCIAN | | 505 | 32 |
| CAMBRIAN | | LATE | TREMPEALEAUAN<br>FRANCONIAN<br>DRESBACHIAN | | 523 | [illegible] |
| | | MIDDLE | | | 540 | 26 |
| | | EARLY | | | 570 | |

## PRECAMBRIAN

| EON | ERA | BDY. AGES (Ma) |
|---|---|---|
| | | 570 |
| PROTEROZOIC | LATE | 900 |
| | MIDDLE | 1600 |
| | EARLY | 2500 |
| ARCHEAN | LATE | 3000 |
| | MIDDLE | 3400 |
| | EARLY | 3800? |

From: Palmer (1983)

# Expanded Geologic Time Scale



From: Press & Siever (1984)