GEOL 102: Historical Geology
Midterm Exam II Review

The Time Scale (for Exam 2: You are not responsible for the numbers):

Eon	Era	Period	Range (Ma)
Phanerozoic	Paleozoic	Permian	298.9-251.9
		Carboniferous	358.9-298.2
		Pennsylvanian	323.2-298.2
		Mississippian	358.9-323.2
		Devonian	419.2-358.9
		Silurian	443.8-419.2
		Ordovician	485.4-443.8
		Cambrian	541.0-485.4
Proterozoic	Neoproterozoic	Ediacaran	635-541
		Cryogenian	720-635
		Tonian	1000-720
	Mesoproterozoic	Stenian	1200-1000
		Ectasian	1400-1200
		Calymmian	1600-1400
	Paleoproterozoic	Statherian	1800-1600
		Orosirian	2050-1800
		Rhyacian	2300-2050
		Siderian	2500-2300
Archean	Neoarchean		2800-2500
	Mesoarchean		3200-2800
	Paleoarchean		3600-3200
	Eoarchean		c. 4030-3600
Hadean			4567-c. 4030

Hadean Eon

Precambrian definition Hadean definition

Craton = Platform + Shield; Orogen

Hadean events:

- Formation of proto-Earth (Tellus) by accretion of planetesimals (ices, organics, silicates, metals)
- The Iron Catastrophe: energy from collisions & radioactive decay & gravity differentiates proto-Earth into Core (metals), Mantle (silicates), and Atmosphere (gases)
    - Primordial atmosphere: H, He, limited amounts of water vapor & other gases; lost due to solar wind, low gravity, energy from impacts (especially Theia)
- Collision with Mars-sized Theia produces Earth & Moon
    - Earth's mantle melts into Magma Ocean
    - When cools below boiling point of water, actual water oceans form
    - Reducing Atmosphere: carbon dioxide, methane, ammonia, water vapor, nitrogen; formed from volatiles degassing out of mantle
- Crust forms from partial melting of mantle in presence of water. Originally all mafic, but continental-type lithologies from additional partial melting by 4.40 Ga
- High speed drip tectonics

Archean Eon

Late Heavy Bombardment: increased rate of impacts from 4.1-3.8 Ga

Archean geology: Granitoid-Greenstone complexes Komatiites
Banded Iron Formations Cratonic Complexes

Difference between Archean and post-Archean tectonics, atmosphere, etc.: detrital uraninite & pyrite

Possible presence of continent Ur by 4.2 Ga

Evidence for Archean life:

- Fractionated carbon ~3.8 Ga

- Microfossils in chert possible 3.5 Ga, definite 3.4 Ga
- Stromatolites 3.4 Ga: ?cyanobacteria, or maybe earlier non-aerobic phototrophs
- Abiogenesis by 3.4 (or 3.8) Ga
    - Simple building blocks → amino acids → biological polymers → competition for space/resources → accumulation of traits of simple cells
- Biofilms: dominant way of life from Archean through Proterozoic
- LUCA: Last Universal Common Ancestor, by 3.4 Ga
- Prokaryotes (archaeans & bacteria), many extremophiles

Oldest glaciers at 2.9 Ga
Sterols (compounds made by eukaryotes) by 2.7 Ga

<u>Proterozoic Eon</u>
Shift to modern tectonism and orogenic belts (2.95 Ga in southern Africa, later elsewhere)
Kenoran Orogeny (2.5 Ga) One of the oldest known, evidenced by granitic intrusions into Archean rocks, Superior Province in Canada
Wopmay (2.0 Ga) Oldest for which good structural & lithological evidence is known, Slave Province in Canada
Great Oxidation Event:

- Phase I: 2.7-2.4 Ga, increased level of oxygen due to cyanobacteria sucked up by iron in water, major BIF deposition
- Phase II: 2.4-2.0 Ga, oxygen levels climb in atmosphere; reducing atmosphere is oxidized (methane, ammonia, etc. broken down)
    - The Nitrogen-Oxygen Atmosphere
- First oxidized terrestrial redbeds
- Last detrital pyrite & uraninite ~2.3 Ga; last BIFs around 1.9-1.8 Ga
- Huronian Glaciations (at least 3 pulses between 2.45 & 2.2 Ga; loss of greenhouse methane cooled world)

Craton assembly throughout Paleoproterozoic
Increasing mineral diversity: addition of oxygenated atmosphere and life increases number of minerals found in the world
Mesoproterozoic: Development of passive margin sediments on edges of cratons (first large continental shelves)
Large scale igneous activity (Matachewan dike swarms 2.50-2.45 & Mackenzie dike swarms 1.269-1.267 Ga)
Grenville Orogeny (1.3-1.0 Ga) eastern North America, assembly of Rodinia
Keeweenawan Rift (1.108-1.086 Ga)
Break up of Rodinia (birth of Pacific Ocean)
Pan-African Orogeny (650-550 Ma) assembly of Pannotia
Snowball Earth cycles:

- Makganyene 2.2 Ga, Sturtian 717-711 Ma, Marinoan 663-636 Ma & Gaskiers 582 Ma
- Erosion → scrubs CO_2 → cools world → ice builds up → albedo increases → cools more → positive feedback loop until Earth is cooled
- During Snowball, most cycles shut down
- CO_2 and other greenhouse volatiles build up until hothouse world
- Record: glacial strata overlain by cap carbonates
- Snowball Earth: shut down by warming sun? Or by metabolism from animals?

Proterozoic Life:

- Oldest eukaryotes definitely by 1.6 Ga
    - Origin by endosymbiosis (mitochondria from bacteria; chloroplasts from cyanobacteria)
    - Acritarchs by 1.4 Ga
- Stromatolites common
- Rise of multicelluarity (~1200 Ma by red algae, ~600-580 Ma by animals)
    - Almost no bioturbation until late Ediacaran, and then only very shallow
    - Oldest animals in Ediacaran, post-Gaskiers: Doushantou embryos, sponges; Trace fossils; Garden of Ediacara (cnidarians, vendobionts, *Kimberella*, *Cloudina* & *Namacalathus*)

Breakup of Pannotia at Ediacaran/Cambrian boundary → Gondwana, Laurentia, Baltica, Siberia; formation of Iapetus, Paleo-Asian & Rheic Oceans

Paleozoic Era: Cambrian (Є)

Base of Cambrian (Fortunian): first appearance of *Trichophycus pedum*; some rare skeletonized fossils

2nd Stage of Cambrian ("Tommotian"): the Small Shelly Fauna and archaeocyathids

3rd Stage of Cambrian ("Atdabanian"): the Cambrian Explosion: biogeochemical rather than phylogenetic event [various subgroups extend back far into Ediacaran, so the "sudden" appearance of skeletons is independent of the phylogenetic branching]

Major Є fossil groups: Archaeocyathid sponges; arthropods, including trilobites; anomalocaridids; brachiopods (lingulates & articulates); proto-mollusks; primitive mollusk, including early gastropods & bivalves (& cephalopods at end of Є); primitive echinoderms; primitive chordates (including earliest vertebrates, esp. conodonts). Largest animals only 1-2 m long, and nearly all less than 30 cm (1').

Cambrian Substrate Revolution: loss of the matgrounds as burrowers & grazers diversify

Huge global transgressions

Paleozoic Era: Ordovician (Θ or O)

Separation of Avalonia from Gondwana

Taconic Orogeny [First part of Appalachian system] (Middle-Late O, Laurentia & Taconic Island Arc [& possibly Baltica & Avalonia in north??], huge volcanic eruption (Big Bentonite aka Millbrig Beds))

Great Ordovician Biodiversification Event (GOBE): diversification of many groups of marine invertebrates; more predators, more forms that burrow or stick well above sediment-water interface

Major new O fossil groups: Receptaculitids; stromatoporoid sponges; rugose and tabulate corals; bryozoans (including stony & lacy bryozoans); increased articulate brachiopod, bivalve & gastropod diversity; nautiloids; blastoids; crinoids; motile stalkless echinoderms (ophiuroids, asteroids, echinoids, holothuroids); graptolites; "ostracoderm" (bony armored jawless fish)

Possible colonization of land by Є, definitely by late O; possible land arthropods in O

First tabulate-stromatoporoid reefs in Late O

Massive Gondwanan glaciers in latest Ordovician; huge mass extinction

Paleozoic Era: Silurian (S)

Widespread tabulate-stromatoporoid reefs (largest amount of metazoan-generated carbonate in history)

Major new S fossil groups: Eurypterids diversify as top predators (already present since Є); "ostracoderms" diversify, add paired fins; first jawed fish (including "placoderms", "acanthodians"); first bony fish

Colonization of freshwater & land: difficulties faced in these environments; land plants (spore plants only in O & S); arthropods (millipedes, arachnids)

Caledonian Orogeny (S [& early D?]): beginning of closure of Iapetus; Baltica + Laurentia + eastern Avalonia → Euramerica; mountains form in northern Europe; molasse in Europe: Old Red Sandstone

Paleozoic Era: Devonian (D)

Yet more tabulate-stromatoporoid reefs

Acadian Orogeny [Second part of Appalachian system] (Late D): Euramerica + western Avalonia; final closure of Iapetus Ocean; molasse in U.S. Catskill Clastic Wedge

Major new D fossil groups: Ammonoids; placoderms as top predators & giant planktonivores, peak of diversity; chondrichthyians (sharks); bony fish diversify, including ray-fins (actinopterygians) and lobe-fins (sarcopterygians)

Devonian Nekton Revolution: great increase in diversity of open water swimmers (ammonoids, fish, etc.). Not merely swimmers just above the sea floor, but in the water column

New land life: lycophytes (clubmosses); ferns; first trees, including *Archaeopteris* (oldest woody plant); "seed ferns" (first seed plants); fungus "trees"; freshwater colonized by plants, arthropods, fish; first hexapods, stegocephalians

First trees and increased land plants leads to meandering streams, increased oxygen levels, first soils (lowered carbon dioxide leads to climate change)

Major mass extinction destroys tabulate-stromatoporoid reef community; extinction of stromatoporoids, "ostracoderms" & "placoderms"; loss of most tabulates, rugosans, primitive echinoderms, "acanthodians", "acritarchs", brachiopods, conodonts, ammonoids (latter three all rebound!)

Paleozoic Era: Carboniferous (C) (Mississippian (M) & Pennsylvanian (|P))

Shift from calcite to aragonite seas; Reefs rare, but crinoid meadows common. Encrinite.

Major new M fossil groups: fusulinid forams; sharks & ray-fins diversify
Antler Orogeny [First part of Cordilleran system] (M): collision of Antler Island Arc & western North America
Variscan Orogeny (Late M): Beginning of closure of Rheic Ocean, Iberia (then part of Gondwana) collides with French part of Euramerica; sometimes called "Hercynian Orogeny"
Alleghanian Orogeny [Third and final part of Appalachian system] (M-|P): Gondwana collides with eastern North America
Ouachitan Orogeny (|P): Collision between American Gulf Coast & Gondwana
Ancestral Rockies Orogeny [Second part of Cordilleran system] (|P): vertical displacement in response to Ouachitan
Uralian Orogeny (|P-P): Siberia + Euramerica = Laurussia
"Romer's Gap": low levels of diversification of tetrapods and terrestrial arthropods in M, possibly because of low oxygen levels
Coal Swamps in Northern Hemisphere; Cyclothems/coal measures driven by glacioeustatic transgression-regression cycles (very rapid), only in north because of shallower topography
Coal Swamp vegetation: scale trees (lycopods, giant clubmosses; in wet lands); segmented trees (*Calamites*, giant horsetail ferns), shoots allow them to propagate into drier land; "gymnosperms" (primitive seed plants) successful in very dry land, including seed ferns, cordaites, conifers. Scale trees die off at end of C, segmented trees in early P, cordaites until P/Tr extinction.
Continued drop in CO_2 (down to similar levels to pre-industrial modern) and all-time high of O_2 due to coal deposits; peak of Gondwanan glaciation
Major new terrestrial animals: Arthropleurids (top herbivores); insects (fixed wings in early |P, folded wing by late |P); giant arthropods in general; tetrapods (fully terrestrial as adults) (including first amniotes in late |P)

<u>Paleozoic Era: Permian (P)</u>
Assembly of Pangaea; Panthalassa Ocean & Paleotethys & Tethys Oceans
Development of continental climates, widespread deserts, draining of coal swamps
Permian reefs (brachiopods, bryozoans, sponges, algae)
Glossopteris flora around Gondwanan glacial region
Major P land animals: Amphibian-grade tetrapods diversify; amniotes (originated in |P) diverged into synapsids and reptiles; synapsids (incl. therapsids) dominant terrestrial vertebrates;
Sonoman Orogeny [Third part of Cordilleran system] (latest P-early Tr) Sonomia collides with western North America
Siberian Traps volcanism
Permian/Triassic Mass Extinctions:

- Greatest in Phanerozoic (two phases (Guadalupian & P/Tr), together killing off 95% of marine species)
- Total extinction of trilobites, rugose & tabulate corals, lacy (& most stony) bryozoans, blastoids, graptolites, fusulinids, eurypterids
- Extinction of all but a few genera each of brachiopods, crinoids, ammonoids, conodonts, therapsids
- Extinction of many insect groups
- Associated with Siberian Traps, massive carbon isotope shifts, severe anoxia and hypercapnia (high CO_2) in sea and atmosphere, sulfidic conditions, extreme global warming