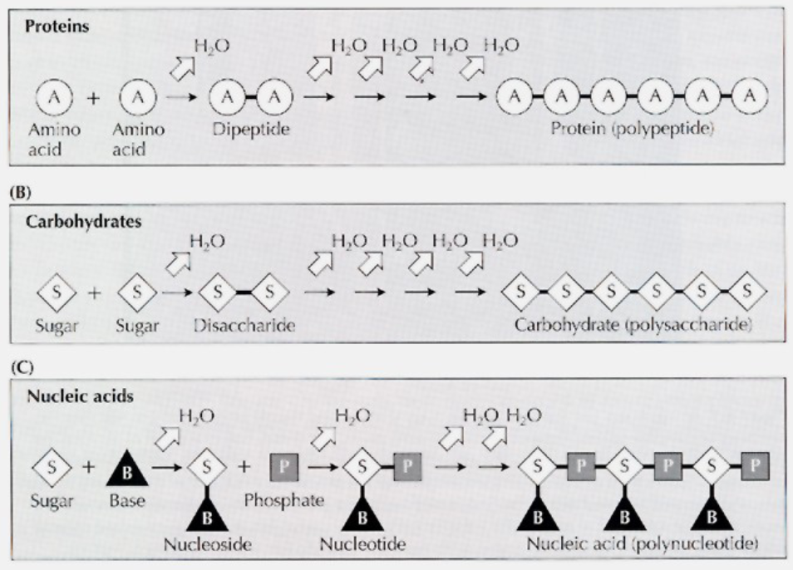
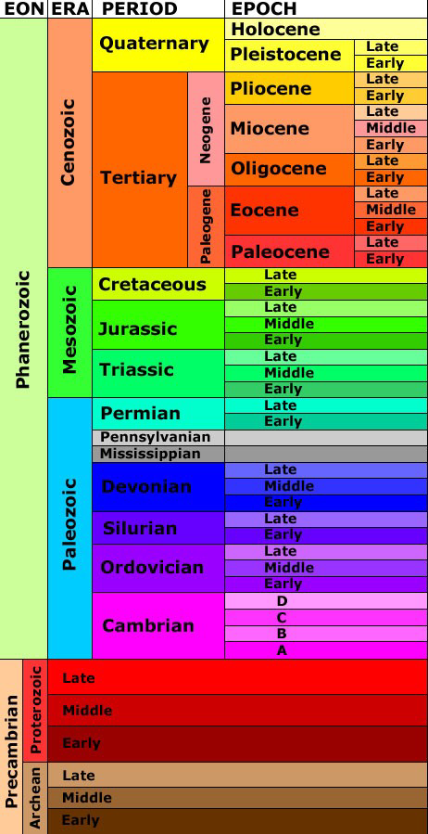
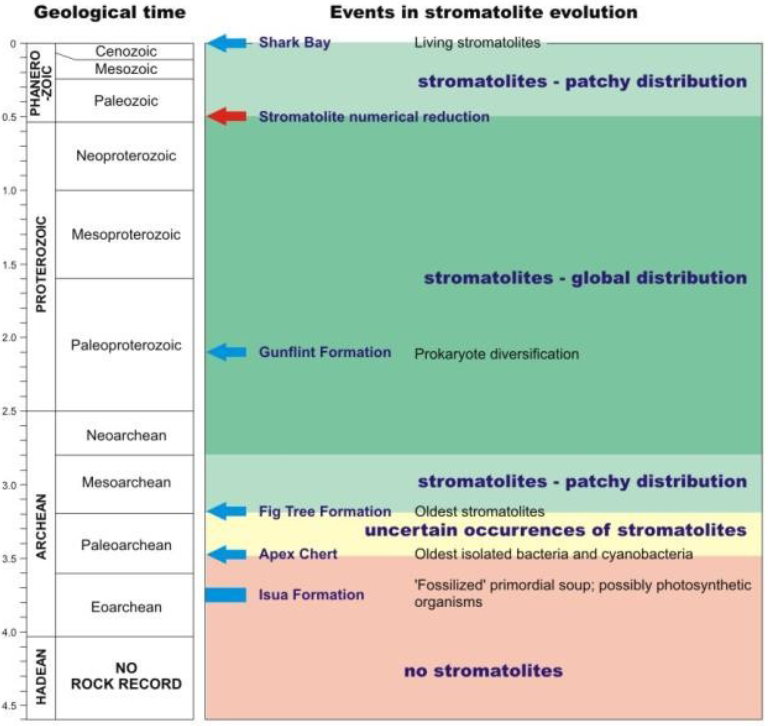
**Emergence of Life on Earth**

* **Dominant Elements**: Carbon, Oxygen, Hydrogen, Nitrogen, Sulphur, Phosphorus
* **Petroleum Composition:** Persistence of carbon-based life forms can be tested by studying composition of substances from organic decay, transformation  
   - Hydrocarbons: Natural Gas, Petroleum, Bitumen, Waxes, formed after death  
   - Large amounts of Carbon in these hydrocarbons, followed by H, S, O
* Living matter dominated by water, life evolved in aquatic environment
* **Monomers, Polymers:** - Oldest fossils are bacteria and cyanobacteria - CHON(SP) elements easily combine to form simple inorganic monomers  
   Carbon Dioxide, Methane, Ammonia, Water, etc  
   - Higher molecular masses compared to elements that dominate terrestrial planets primordial atmospheres  
   - Major problem in understanding early chemical reactions was chemical character of the atmosphere  
   - Modern atmosphere (nitrogen, large amounts of O2) could not favour formation of larger organic molecules (because oxidizing)
* **Primordial Soup:** Alekxandr Ivanovich Oparin (1894-1989)  
   - 1930: First model primordial atmosphere was reducing  
   - Organic molecules accumulate on surface, dissolve in water, electricity in atmosphere + UV radiation from space + heat from Earth all combine
* **Miller and Urey Experiment:** 1953, simple monomers react to form complex molecules  
   - Started with mixture of gases (H2, N2, NH3, CH4, H2O)  
   - Added electrical discharges, ultraviolet radiation  
   - Obtained 7 amino acids: Glycine, Alanine, Formaldehyde, Hydrogen Cyanide, Acetylene, Cyanoacetylene
* **Polymers:** - Simple organic monomers form larger molecules  
   - Some large molecules are polymers, repeating of monomeric unit  
    
   - Amino Acid: Dehydration Condensation (2 amino acid = dipeptide), form long chain known as protein (Polypeptide)  
   - Sugar: Two sugars form disaccharide, chain is polysaccharide (carbohydrates)  
   - Nucleic Acid: Sugar + Base = Nucleoside, add Phosphate = Nucleotide, chain of Nucleotides form a Polynucleotide = Nucleic Acid
* **Early Earth Events:**1. Early Crust Formation: Temperature difference between hot Earth and cold outer space, trapped heat inside, volcanoes common at surface  
  2. Early Atmosphere Formation: Gases from two sources: remnants of Solar System formation, new ones from volcanic phenomena  
  3. Ocean Formation: Early due to accumulation of water from vapour condensation.  
   Zircon minerals from Australia (4.4 bya, oldest minerals on Earth), require significant amounts of water (earliest oceans: 4.4 bya)  
  4. Catastrophic Meteorite Bombardment: Effects at surface of moon, Mercury, Mars. Not affected by tectonic plates, craters still visible unlike Earth  
   Infer this happened between 4.2 and 3.95 bya
* **Isua Formation:** 3.7-3.8 bya in southwestern Greenland  
   - Dark appearance: Deposited in reducing environment  
   - Small calcites: Molecular oxygen only existed in small amounts, layers of calcites could not form  
   - Formed in shallow marine environment  
   - Thin layers of graphite: Final process of organic matter, vestiges of primordial soup  
   - Living isolated organisms in primordial soup, created oxygen to form calcites  
   - Oldest Stromatolites found here, communities of prokaryotes, bacterias destroyed by fossilization
* **Earliest Isolated Bacteria, Cyanobacteria** - Cyanobacteria: slightly larger in fossil record, don’t differ much morphology  
   - Oldest fossils: Discovered in Apex Chert in Pilbara Craton of Western Australia  
   - **Apex Chert**: Rocks of conglomerates, transformed to chert through silification  
   - Earliest age of isolated cells: ~3.465 = 3.5 billion years  
   - Some cells = folded filament w/ cell-like C structures (modern iron bacteria)  
   - **Strelley Pool Chert**: Younger than Apex Chert by 10-15k years  
   Form chain-like structures, like modern purple bacteria  
   Prokaryotes in clustered form

****

**Evolution of Multicellularity**

* **Stromatolites**- Circular fossils, Cryptozoon (hidden organisms)  
  - Schreiber Beach, late 50s, first noticed prokaryotes, stromatolite structs 2.1bya  
  - Discovery documents prokaryote diversification  
  - First Precambrian fossils (transmitted light microscopy)  
  - Prefer warmer waters, column-like structures between tidal zones  
  - Living stromatolites in Shark Bay  
  - Photosynthetic, only alive in upper portion, rest is dead rock (very old)  
  - By Neoarchean, achieved global domination, previously slow growth  
  - Predator by Phanerozoic, sharp decline to patchy distribution (mostly in toxic lagoons, toxic for gastropod predators)
* **Stromatolite Structure**- Growth Surface: (1mm), highest diversity, produce oxygen, some photosynthetic, don't need oxygen to grow  
  - Undermat: (1mm) non-oxygen making photosynthetic bacteria, anaerobic bacteria can still use oxygen when needed, less bacteria than growth surface  
  - Oxygen-Depleted Zone: (1-2cm) Populated by rare anaerobic bacteria  
  - Stromatolite Mass: Rest of the stromatolite, calcium carbonate, no living organisms in this portion



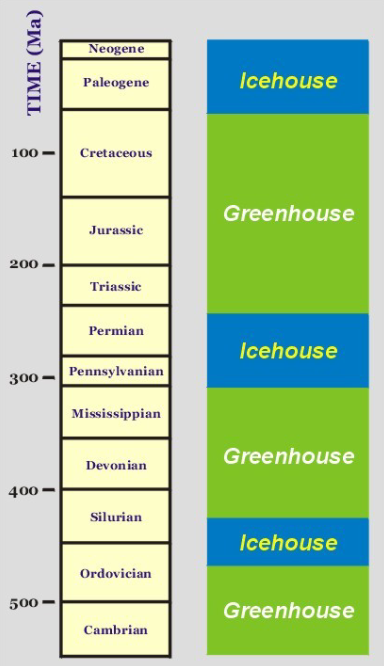
* **Banded Iron Formation (BIF)**- Another sediment in Isua formation  
  - Alternation of thin layers of iron oxides (hematite, magnetite, etc, Fe\_O\_)  
  - Formed during volcanic events, iron expelled and combined with dissolved oxygen from oceanic water, Archean-Proterozoic boundary  
  - Required free molecular oxygen  
  - Can tell Earth's atmosphere transformed from reducing to oxidizing (first mass extinction, organisms destroyed by their product)
* **Oldest Eukaryotes**- Biomarkers  
  - Toxic environment, prokaryotes clustered and formed larger organisms  
   Each Prokaryote to do one function (organelle)  
  - Evolved sexual reproduction, rapid evolution  
  - Fossils: Evolved 1.8 billion years ago  
  - Other records: Closer to 2.1 billion years ago
* **Bitter Springs Formation:** Australia  
  - First true eukaryote cells here, 1.0 bya  
  - Assigned to red algae (rhodophytes) and green algae (chlorophytes: Caryosphaeroides and Glenobotrydion)  
  - Some fossilized in process of cellular division, nucleus + membrane fossils  
  - Cell arrangement: Meiotic cell division  
  - Not found among the prokaryotes
* **Algal Multicellularity**- Bangiomorpha: Red algae, first multicellular organism  
   Filamentous thallus  
   Primitive holdfast attached to seafloor, rise up towards sunlight  
   1.2 bya (Proterozoic – Quaternary)  
  - Torridonophycus  
   Green algae, bag-like structure to help survive in dry climate  
   Creates protective structure in stress period  
   0.9 bya (Upper Preoterozoic – Quaternary)  
  - Melanocyrillium  
   Similar to modern testate amoebas (earliest animals)  
   Vase looking mf, open top, cytoplast to catch food from opening  
   Organic, sometimes with agglutinated particles  
   0.8-0.9 bya (Upper Proterozoic – Quaternary)  
  - Chuaria  
   Large size (1-2cm) plantic algae, green algae, multicellular
* **Grand Canyon Findings**- CD Walcott  
  - Small black coal disks in carbon-rich shales, assumed flattened shell  
  - Know large single-cell planktonic algae  
  - Increase size, instead of multicellularity they just became single big cell  
  - As it got big, Snowball Earth happened  
  - South Africa: Isolate calcitic cells covered in openings from the Cryogenian period  
   Animals achieved multicellularity here to survive the cold  
   Sponge **Otavia** evolved in cryogenian, became extinct by the end of it.

**Ediacaran Fauna** - Southern Australia, impressions in fine sediments, multicellular

* **Parvancorina**:   
  - Shield-shaped front end, central axis with weak segmentation, up to 10 pairs of appendages, head shield facing the direction of water current (for feeding?)
* **Tribrachidium:**- Originally interpreted as single organism, now as holdfast for another organism. Disk-shaped w/ three raised arms, borders. Triradial symmetry
* **Dickinsonia:**- 1-100cm, resembles a flatworm, segmented head + tail. No internal organs. Tail only occurs in mature specimens
* **Charnia:**- Enigmatic, strong similarities with modern sea-pens. Bilateral symmetry (stem with matching fronds), feather shaped fronds with series of side branches
* **Spriggina:** - Resembles large swimming worm. Elongated "spine" with V-shaped muscle clusters on each side  
   - Hardened head of organic tissue, vestige of cephalic shield (beginning of cephalisation, who were the predators?)  
   - Resembles the first vertebrates, those don’t appear for a long time
* **Kimberella:**- Complex structure, three peripheral layers full of cavities. Central part has a slightly inflated structure. Center structure fossilizes, harder organic tissue  
  - Always found very well defined at one end, other end no structure (horseshoe)  
  - Was a grazer, no structure at front as it was a siphon, need a muscle to do so  
  - Likely ancestor of molluscs, very rare
* **Vendia:  
  -** Bilateral symmetry. Head, lateral parts, tail, no eyes or mouths  
  - Impressions of internal cavity  
  - First ediacaran with internal cavities, invertebrates started here
* **Onega:**- Body architecture in 3 parts: Head, Body, Tail (similar to Trilobites)  
  - 50m years between Onega and Trilobites, maybe not an ancestor
* **General Symmetry:  
  -** Body cavities of oldest creatures form radial symmetries  
  - As we get closer to the present, body cavities form bilateral symmetries  
  - Arrange organisms stratigraphically, organisms start to coagulate into lineages

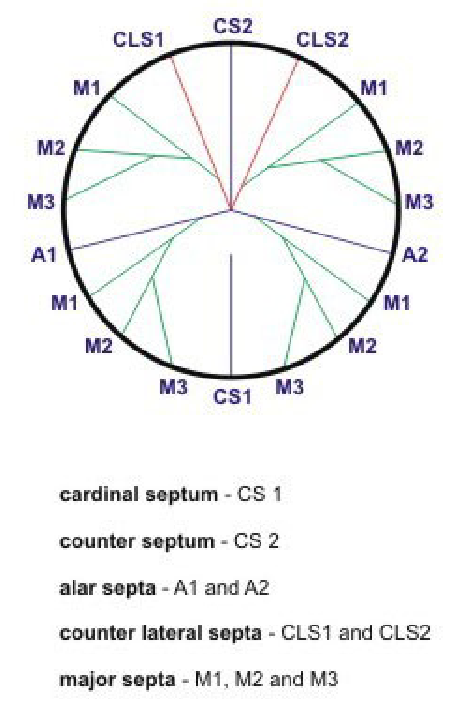
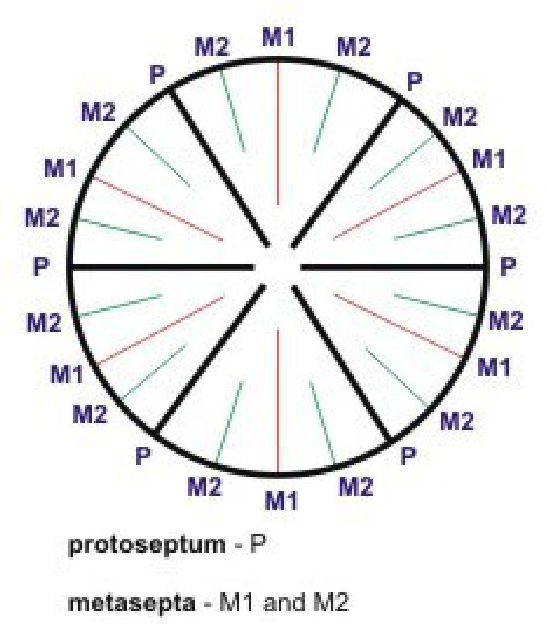
**Cambrian Life Diversification**

* **Earliest Shelly Animals**- Neoproterozoic of Namibia, SW Africa  
  - Cloudina: Calcitic, tubelike fossil. Discoveries were completely recrystallized.  
   Looks like a worm, but worms did not exist before the Precambrian.  
   Precipitated calcium carbonate like cnidarians, determined to be a coral first, but always has same morphology no matter where it is found, not a coral  
   Cloudina-like fossils in China, determined a sponge, extinct for long time, reappeared here
* **Precambrian/Cambrian Boundary**- Original: Boundary defined by animals with an exoskeleton, wrong idea  
  - Organisms began to dig in sediment, deeper in search of food, decomposing organic matter  
  **-** New group of organisms, new ecological niches, evolution took over  
  - Index Fossil: Trichophycuspedom (formerly Phycodespedum), boundary  
   between Proterozoic-Cambrian  
  - Russophycus: Frequent above boundary, bilaterally symmetrical trace fossils  
   Worldwide trace fossil to identify the Lower Cambrian
* **Tommotion Fauna Generalities**- Latouchella: Strange, gently coiled shell in 1 piece, probably ancient gastropod  
  - Yochelcinoella: As above, with siphon on shell, is mollusk- Above two are first snails/brachiopods, first predators of stromatolites  
  - Shells are tubular, spinose, conical, plates or sclerites also occur  
  - Microcystis: Flanked with sclerites and legs beneath. Scales and sclerites with horns defend for carnivorous warms, inefficient against being swallowed hole  
  - Evolution of Tommotion Fauna had major impact, associated with strong reduction in stromatolite occurrences
* **North America – Main Tectonic Structures**- Canadian Shield: Strongest stretch in North America  
  - North American Platform: Shallow waters, stable around Canadian Shield  
   Surrounded by shallow depression basins  
  - Mobile Belts: Permanent source of earthquakes, extremely unstable, 4 in NA
* **Earth's Climate**- Seven-fold oscillation history in Late Precambrian-Phanerozoic interval  
  - Greenhouse: Warm and Humid  
  - Icehouse: Dry, Cold, Arid

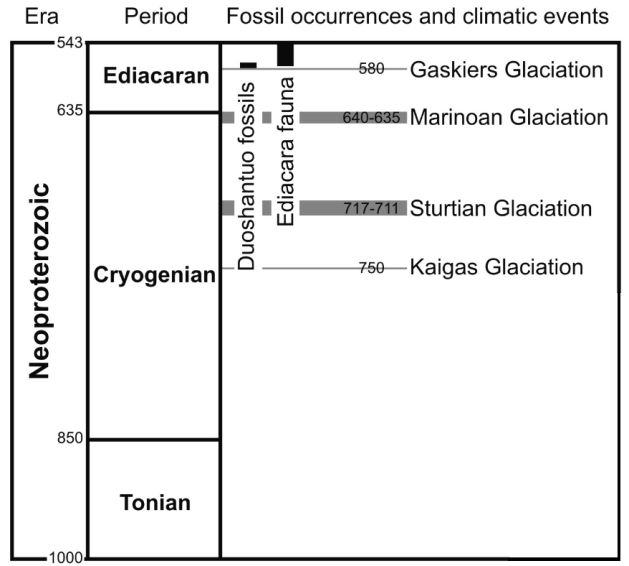
****

* **Sea Level Fluctuations  
  -** Not constant  
  - Major transgression initiated late Proterozoic after major Marinoan Glaciation  
  - Precambrian to Ordovician: Sauk Transgression, sea level increase  
  - Evolution needed to be fast
* **Intertidal Sedimentation**- Stromatolites were widespread in carbonate facies on both sides of the craton  
  - Insane tides and currents, every day would rise and recede across most of NA
* **Archaeocyathids** – First Reef Builders  
  - Calcareous sponges  
  - Cup-like structure, small size, two walls defining central cavity  
  - Walls contain intervalve (intervalum), full of septum (calcitic walls connecting the inner + outer walls), attach to seafloor with rootlike structures  
  - Calcitic, not flexible, totally covered in pores  
  - Needed resistance to currents  
  - Lived in new reefs, water energy carries small-size particles through pores, would eat and develop  
  - Very small reefs (2m in diameter, 50cm in height)
* **Trilobites**- Cambrian Explosion: massive life diversification  
  - Body can be divided into three obvious parts  
  - Originally very successful, new defensive strategy: Large size populations (cockroaches of paleozoic), two well-developed eyes to spot predators, first molting species with inflexible carapace  
  - Diverse through Cambrian and Ordovician  
   Cambropallus: Very large, 1 foot in length, dissuades predators by being big  
  - Died out when predators were too large and diverse (trilobites are primitive)  
  - At first, benthic at bottom of oceans, eventually planktic  
   Head and tail are almost equal to rotate body for water currents, thorax reduced to 2-3 segments, blind due to turbulent waters couldn’t see anyways
* **Burgess Shale**- Middle Cambrian  
  - Discovered by Walcott at beginning of 19th century in BC  
  - Fossils buried along continental slope, mobile belts surrounding NA, frequent earthquakes, underwater landslides, very rapid burial in anoxic conditions  
  - Chordate – Pikaia: Cephalocordate, like modern lancelet, small antennae on head with tapered tail for swimming. Full of V-Shaped muscles  
  - Opabinia: 5 eyes from head, irregular hole in head for proboscis mouth, predator to eat burrowers  
  - Anomalocaris: Most important predator, one meter in length, body covered in thick tissues, large eyes to spot prey, extremely efficient predator, global range and first major predator of Cambrian times (T-Rex of Cambrian)  
   So efficient at hunting ate everything, resorted to cannibalism  
  - Wiwaxia: 3-5 cm in length, headless body covered by protective armor plates, long spines  
  - Hallucigenia:: Long wormlike organism with appendages on both top and bottom. First thought in turbulent waters, legs on back to flip upright, realized they were just spines  
  - Ayisheaia: Missing link to Onychophorids (segmented worms w/out other fossil records), mixed features between segmented worms and arthropods

**Coral Evolution Events and Patterns**

* **Phylum Cnidaria**- Metazoans (multicellular organisms) organised in tissue-grade, no organs  
  - Characteristic feature: Nematocysts   
   Cells discharge poisonous substance, paralyze or kill prey
* **Body Architecture  
  -** Polyp Stage:  
   Sessile (fixed to sea bottom with root-like structure)  
   Asexual reproduction by budding  
   Frequent in reef environments  
  - Medusa Stage:  
   Jellyfish-like (free-dweller in the oceanic water column)  
   Sexual reproduction strategy
* **Classifications:** Hydrozoa, Scyphozoa, Anthozoa
* **Hydrozoa:** Marine and freshwater, hydroids/hydra exist, mostly polyp stage  
  - Hydrozoans lack a mineralized skeleton, rare in fossil record  
  - Evolutionary occurrence in Carboniferous
* **Scyphozoa:** Marine, mostly medusa  
  - Rare in fossil record, lack hard body parts, mostly water  
  - Evolutionary occurrence in Cambrian
* **Anthozoa:** Most of the fossil and living cnidarians (sea-pens, soft/stony corals)  
  - Evolved in the Cambrian, possibly late Proterozoic  
  - Exist only in the polyp stage, 2300 genera, over 6k species in fossil record
* **Subclass Zoantaria**- Stony corals, corallites  
  - 3 Major Orders: Tabulata, Rugosa, Scleractinia  
  - Tabulata, Rugosa: Ordovician-Permian  
  - Scleractinia: Triassic-Recent  
  - Between these orders: The Great Dying
* **Order Tabulata (Tabulates)**- Individuals (corallites) usually have no septa  
  - Horizontal plates (tabulae) occur within corallites as result of growth process  
  - Each hexagonal corallite groups together, grows to be very long  
  - No corallite today has their interior separated by horizontal plates
* **Order Rugosa (Tetracorals)**- Both solitary and colonial, name from wrinkled (rugose) aspect of corallites  
  - Tetracorals due to general arrangement of the septae  
  - Tabulae still exist in lower portion of corallite, can hardly be seen unless specimen is sectioned  
  - Mix both tabulae with longitudinal septae  
  ****  
  - Cardinal Septum: No attached septa, move vertically  
  - Counter Septum: Few lower order septae attached, angled from cardinal  
  - Most lower order septae attached to alar and counter laterals  
  - Resulting thickened calcareous structure in central portion of corallite is a columella
* **Order Scleractinia (Hexacorals)**- Evolved after the Great Dying  
  - Colonial and solitary  
  - No corals in sediments just above the Permian/Triassic boundary  
  - All corals of the Mesozoic and Cenozoic belong to this order  
  - Clearly separated between hermatypic and ahermatypic scleractinias function of the symbiosis with the photosynthetic algae zooxanthelae  
  - Septae are added successively and in sets at 60 degrees, 6 septae in a set  
  - Oldest set of septae are known as protoseptae, others metaseptae  
  ****

**Snowball Earth**

****