- Earthworms, nematodes, springtails, woodlice
  - >200/m^2
  - 120 million nematodes per $metre^2$
- Contribute 10% to soil respiration
- Mainly physical effects
  - Increase surface area for attack
  - Mix materials
- Regulate microbial activity (grazing)

- **Can they go extinct?**
  - No true species
  - Can occupy tiny microhabitats
  - Extremely adaptable

        - Increase SA
- Dorsal blood vessel
    - Heart
- Collection of ganglia in cephalon
    - Brain
    - Near sensory organs
    - Ventral nerve cord
        - Ganglia per segment
- Genal caecae
    - Fine vessels just beneath exoskeleton
    - Respiration?

Eyes

- 3 types
- Some had none
- Holocroal
    - Most common
    - Biconvex
    - Continuous cornea across all lenses
    - Ancestral form
- Schizocroal
    - Fewer, larger lenses
    - Individual cornea
    - Separated by sclera
    - Paedomorphy of holocroal developmental form
- Abathocroal
    - Rarest
    - Lenses separated by shallow sclera
    - Largest lenses
    - Cornea each
- Variation by habitat
    - Stalks
    - Massive
    - Reduced
    - Lost

Ecdysis - Moulting

- Exoskeleton
    - Must shed in order to grow
- Facial sutures split allowing the animal to crawl out

        - Spines
        - Defence
        - Soft sediment stabilisation (filter feeders)
        - Swimming
    - Miniaturation
        - Fewer segments
        - Decreased size
        - Adaptation to new niche
        - Consequence of early development
            - Paedomorphosis
            - Early sexual maturity
    - Pelagic adaptation
        - Large eyes
        - Streamlining
        - Spines
    - Olenimorph
        - More thoracic segments
        - Flatter
        - Benthic, low O_2?
            - More segments = more legs = more gills
    - Pitted cephalon fringe
        - Perforated, wide fringe
            - Stabilisation
            - Water can pass through
        - Filter feeding

Extinction

- Declined from late Cambrian
- New forms evolving, but slower than extinctions
- Reasons:
    - Changes in sea level
    - Oceanic temperatures
    - Competition
        - Molluscs
        - Echinoderms (starfish)
    - Glaciation events around Gondwana margins at end of Ordovician
- Final extinction Permian-Triassic mass extinction (252mya)
    - 96% of marine life wiped out
    - Attributed to
        - Asteroid
        - Volcanic activity
        - Atmospheric change
        - Sea level fluctuations

Mass Extinctions

04 December 2014 13:30

Ediacaran Period

- Last period of proterozoic
  - 635-542mya
- All continents pushed together
  - Pannotia
- Varangian glaciation
  - Ended 595mya
  - Allowed radiation of multicellular animal life
- Fauna
  - Vendezoa
    - Quilted surface
    - Lacked gut
    - Fractal organisation
  - May have been ancestors of animals
  - May have been evolutionary dead end
- Mass extinction
  - 2 major groups
    - Soft-bodied vendians
    - Calcareous doudinids
  - Disappear from fossil record
  - Increase in black shale
    - Anoxia
- Survivors
  - Cydomedusa
    - Similar to jellyfish
    - Lack tentacles and radial symmetry
  - Spriggana
    - Segmented
    - Bilaterally symmetrical
    - Ancestral worm/trilobite?
    - Neither?
  -

Palaeozoic

542-251mya

Cambrian Period

- 542mya-488mya
- Pannotia broke up
  - Gondwana formed
  - Smaller tropical continental blocks
    - More warm, shallow seas
    - Allowed life to proliferate
- Cambrian Explosion
  - Invertebrates
    - Radiation
    - Hard- and soft-bodied
      - Trilobite and brachiopod ancestors
    - Many evolutionary dead-ends
  - Vertebrates
    - First chordates
      - Early, jawless vertebrates
      - *Pikaia*
      - Lancelets
        - Non-vertebrate chordates
        - Notachord
        - No true brain or skull

Ordovician Period

- 488-443mya
- Rapid plate movement and volcanism
- Extensive shallow seas
  - Barren land masses
- Sea level rises
- Erosion and deposition of sediment
- Fauna
  - Invertebrate
    - Diversity tripled
    - New ecosystems
  - Vertebrates
    - Jawless fish
      - Bones, teeth, scales
      - Lampreys
  - Most life in shallow seas
- Mass extinction
  - 2nd largest
  - Eliminated 60% of all terrestrial and marine genera
    - Brachiopods, bivalves, echinoderms, bryozoans, corals
  - Glaciation
    - CO_2 levels fell due to erosion
  - Gamma-ray burst?
    - Hypernova
    - Ozone stripped
    - Little evidence

Silurian Period

- 443.7-416mya
- Northern continents
- Ocean basins narrow
- Ice melted
  - Seas rose
- Shallow seas expanded
- Life
  - Plants
    - Invaded freshwater and land
  - Invertebrates
    - Invaded land
    - Extensive reefs
  - Vertebrates
    - Jawless fish radiate
      - Invertebrates still top predators
    - Armoured fish
      - placoderms
  - Living relatives
    - Brittle stars

Devonian Period

- Warm, dry climate
- Northern continents divide
- Tropics
  - Dry land
    - Arid and humid
  - Warm shallow seas
- Seas
  - Geochemistry changes
  - Periods of hypoxia
- Life
  - Plants
    - More land plants
    - Evolve adaptation to keep water
    - Roots, seeds, transport systems, woody tissues
      - Trees
    - Cause creation of soils
  - Invertebrates
    - Arthropods colonise land
    - Massive reefs
  - Vertebrates
    - Freshwater fish
    - Placoderms
    - Sarcopterygians
    - Sharks
    - Aquatic tetrapods
- Mass extinctions
  - Multiple events
  - Over a large period
  - 22% marine animals
  - Black shale
    - Lack of oxygen in seas
  - Glaciation
    - Plants removing CO_2
  - Weathering
    - Plants
    - Nutrient input to seas leading to stagnation
    - Carbon sinks
  - Kellwasser Event
    - Warm, shallow water
      - Marine invertebrates
    - Eliminated reef builders
      - Brachiopods, ammonites
    - Survivors
      - Evolved smaller eyes and larger respiratory surfaces
      - Poor visibility and low O_2
  - Hangenberg Event
    - Sea and freshwater
    - Ammonites, trilobites, placoderms, sarcopterygians, tetrapods
    - Living relative

Mesozoic

251-65.5mya

Triassic

- Recovery period
  - From end-Permian mass extinction
- Extremely high temperatures
  - Ice-free poles
  - Humid and arid regions
- Supercontinent Pangaea
  - Persisted for most of the period
  - Began to disintegrate in late triassic
- Life
  - Plants
    - Radiation of seed plants
    - Radiation of ferns
  - Stromatolites
    - Re-emerged in early triassic
    - Few grazing invertebrates
  - Marine invertebrates
    - Bivalves replaced extinct brachiopods as dominant filter feeders
    - True corals
    - Ammonoids recovered
  - Terrestrial vertebrates
    - Many radiations
      - Archosaurs
        - Dinosaurs, crurotarsans, pterosaurs
        - "Mammal-like reptiles flourished. Walrus-like reptiles, placodonts, appeared in the shallow seas"
      - Icthyosaurs
      - Mammals
      - Frogs
  - Marine recovery
  - Living relatives
    - Norfolk island pine
      - Similar to triassic conifers
    - Tuatara
      - Only 2 species remain
      - Resembles triassic sphenodontians
        - Large, diverse group
- End-triassic mass extinction
  - Extinguished 76% of species
  - Marine invertebrates
    - Conodonts disappeared
      - Small fossil record
  - Terrestrial vertebrates
    - Large amphibians disappear
    - Large, non-dinosaurian reptiles disappeared
      - Except for crocodilians
      - Crurotarsans
      - Mammal-like reptiles etc.
  - Causes
    - Impact event
      - No conclusive evidence
    - Central Atlantic Magmatic Province (CAMP) flood basalt event
      - Massive volcanic outpourings

Jurassic Period

- Disintegration of Pangaea
- Ocean widened
  - Shallow water environments widespread
- Climate
  - Globally warm and humid
  - Cooling in mid-Jurassic
- Life
  - Plants
    - Ferns, conifers, cycads, gingkos
  - Marine invertebrates
    - Radiation of bivalves, corals, echinoderms, bryozoans, corals, lobsters
    - Growth of large sponge reefs
    - Adaptation of burrowing strategies
      - More successful predators
  - Vertebrates
    - Radiation of dinosaurs
      - Theropods, sauropods, Ornithischians
        - Massive and majestic
    - Radiation of crocodylomorphs
      - Only surviving crurotarsans
    - Radiation of large marine reptiles
    - Evolution of birds
  - Living relatives
    - *Selaginella*
      - Moss-like
      - Little change since Jurassic
    - Horsetails
      - Widespread
      - Larger in Jurassic
    - *Gingko*
      - Only one remaining species
      - Widespread and diverse in Jurassic
    - Giant dragonfly
      - *Petalura gigantea*
      - Similar to Jurassic *libellulium*

Cretaceous

- Pangaea continued to disintegrate
- High CO_2 levels
  - Hot climate
  - High sea levels
    - Huge, shallow seas
- Life
  - Plants
    - Evolution of flowering plants
      - Diversified through the cretaceous
  - Invertebrates
    - Evolution of pollinators
    - Marine invertebrates
      - Radiation of bivalves, ammonites, snails
  - Vertebrates
    - Radiation of dinosaurs, birds, sharks, bony fish
  - Living relatives
    - Plants
      - Magnolia
      - Water ferns
      - Quillwort
      - Dipteris
      - Monkey puzzle
      - *Welwitschia mirabilis*
      - Redwoods
    - Thorny oyster
    - Slender roughy
    - Gar pikes
    - Duck billed platypus

Cenozoic

65.5mya - 0

Palaeogene period

- Pangaea continued to break up
  - Oceans widened
  - Established oceanic currents
- Climate cooled
  - Temperature cycled
- Life
  - Plants
    - Most survived K/T
    - Flowering plants diversified
    - First closed-canopy forests
    - Co-evolved with animal pollinators and dispersers
      - Large flowers and fruit
  - Invertebrates
    - True coral reefs
    - Diversification of gastropods, bivalves, echinoids (urchin), crustaceans
    - Diversification of pollinating insects
  - Vertebrates
    - Diversification of birds
    - Massive adaptive radiation of mammals
      - Evolution of large specialised teeth and limbs
        - Large carnivores and herbivores
      - Evolution of bats
      - Evolution of whales

respiratory surfaces
- Poor visibility and low O_2
- Hangenberg Event
  - Sea and freshwater
  - Ammonites, trilobites, placoderms, sarcopterygians, tetrapods
  - Living relative
    - Lycophytes
      - Mosses
    - Glass sponges
      - Silica based

Carboniferous Period

- 359-299mya
- Pangaea
- Climatic extremes
  - Tropical forests
  - Ice ages
- High O_2
  - Loss of development of life
- Life
  - Plants
    - Greater diversity
      - Trees, herbs, climbers
    - Complex ecosystems
  - Invertebrates
    - Radiation of terrestrial arthropods
    - Marine ecosystems
      - Reef-formers
  - Vertebrates
    - Radiation of jawed fish
    - Tetrapods
      - Terrestrial
      - Amniotic egg
        - Full terrestrial tetrapods/reptiles

Permian Period

- End of proterozoic
- Glaciation
- Drier
  - Swamps lost
  - Deserts
    - Reptile radiation
- Upland forests
  - Plants continued to diversify
- Sea level
  - Dropped
  - Continental shelves exposed
- Life
  - Plants
    - Extinction of ancient plant groups
    - Radiation of conifers and cycads
      - Drier climates
  - Invertebrates
    - Algal reefs
      - Brachiopods and bryozoans
        - Disappeared as seas lowered
  - Vertebrates
    - Synapsid reptiles radiated
      - Mammalian ancestors
    - Ray-finned fish radiated
- End-Permian Mass Extinction
  - Greatest extinction
  - Wiped out
    - 90% of marine species
      - Marine invertebrates worst effected
        - Survivors:
          - Small
          - Motile
          - Active [illegible]
          - Efficient gas exchange calcification
    - 70% of terrestrial vertebrates
      - 2/3 of families extinguished
        - Many therapsid
        - Many therapsid
        - Archosaurs including mammals
      - Most surviving families lost the majority of their species
      - Survivors:
        - *Lystrosaurus*
          - Herbivorous dicynodont therapsid (two teeth)
        - Cynodont and archosaurs
          - Ancestors of bird and mammals
  - Only known insect mass extinction
    - Terrestrial invertebrates
      - Most insect orders extinguished
        - Larges insects ever
      - Survivors
        - More similar to modern groups
  - Terrestrial plants
    - Few extinctions
      - Major ecosystem response
        - Cyclical decline and expansion of gymnosperm forests
          - Severe ecosystem stress
  - May have occurred in up to 3 pulses
    - Over several million years
  - 10 million year recovery
  - Causes
    - Impact event
      - No conclusive evidence
    - 2 flood basalt events
      - Emeishan and siberian traps
      - Massive volcanic eruptions
        - Blocked sunlight, acid rain, warming
    - Gasification of methane hydrates
      - Accumulate beneath sea-floor
      - Triggered to release methane by volcanism
      - Massive global warming
    - Anoxic event
      - Oxygen depletion of sea water
        - CO_2 release by volcanic eruption
      - Release of hydrogen sulphide by anaerobic bacteria
        - Kills terrestrial plants
      - Monkey puzzle
      - *Welwitschia mirabilis*
      - Redwoods
    - Thorny oyster
    - Slender roughy
    - Gar pikes
    - Duck billed platypus
      - Similar to cretaceous *Teinolophus*
- Cretaceous/Tertiary (K/T) extinction
  - Plants and marine primary producers
    - Severely reduced in numbers
    - Some extinctions
  - Marine invertebrates
    - Almost total extinction of colonial corals
      - Depend on algal symbiosis
    - Extinction of many cephalopod groups
      - e.g. ammonoids
  - Vertebrates
    - Extinction of dinosaurs, archaic birds, pterosaurs, large marine reptiles
  - Impact event (almost certainly
    - Layer of iridium rocks
      - Rare on Earth
      - Common in asteroids
    - Chicxulub crater
      - In Central America
      - Most likely site of impacts
    - Effects
      - Dust cloud
        - More than one year of darkness
      - Sulphuric acid aerosols
        - 20% sunlight blocked for more than a decade
          - Killed photosynthesisers
      - Infrared pulse and global firestorm
        - Killed exposed organisms
        - Reduced oxygen and increased carbon dioxide
  - Other causes
    - Volcanism
    - Drop on sea level
      - Reduction in shallow seas
      - Expanded freshwater