MUHAMMAD IMRAN

Topic no 1 to 80 mid term and 81 to 165 final term syllabus

ZOO503 Zoogeography and Paleontology

1 Paleontology as a science: Paleontology in the modern world

Paleontology as a science

Paleontology in the modern world

What is Paleontology?

The branch of science concerned with fossil animals and plants. It is the study of fossils to determine organisms' evolution & ecology.

The Word Originates from Greek "palaios-old", "ontos-creature" "logos-study" and Paleontology lies on the border between Biology and Geology. The fossils are present in the layers of earth and on the different areas of the earth. This is why the geology is of great importance in studying paleontology.

Use of Paleontology

1. **Origin of life:**

In the modern world the paleontology is being used for studying origin of life. Paleontology is study of old creatures and we further go in the past we can infer how the life originated in the first place. People want to know where life came from, where humans came from, where the Earth and universe came from. These have been questions in philosophy, religion and science for thousands of years and paleontologists have a key role. Despite the spectacular progress of paleontology, earth sciences and astronomy over the last two centuries, many people with fundamentalist religious beliefs deny all natural explanations of origins – these debates are clearly seen as hugely important.

2. **Curiosity about different worlds**

How different environment give rise to different organisms. We can speculate about how a life form could evolve in a world which is different from our world. Science fiction and fantasy novels allow us to think about worlds that are different from what we see around us. Another way is to study paleontology – there were plants and animals in the past that were quite unlike any modern organism. Just imagine land animals 10 times the size of elephants, a world with higher oxygen levels than today and dragonflies the size of seagulls, a world with only microbes, or a time when two or three different species of humans lived in Africa!

3. **Climate and biodiversity change**

Thinking people, and now even politicians, are concerned about climate change and the future of life on Earth. Much can be learned by studying the modern world, but key evidence about likely future changes over hundreds or thousands of years comes from studies of what has happened in the past. For example, 250 million years ago, the Earth went through a phase of substantial global warming, a drop in oxygen levels and acid rain, and 95% of species died out might this be relevant to current debates about the future?

4. **The shape of evolution**

The tree of life is a powerful and all-embracing concept – the idea that all species living and extinct are related to each other and their relationships may be represented by a great branching tree that links us all back to a single species somewhere deep in the Precambrian.

Biologists want to know how many species there are on the Earth today, how life became so diverse, and the nature and rates of diversifications and extinctions. It is impossible to understand these great patterns of evolution from studies of living organisms alone.

5. Extinction

Fossils show us that extinction is a normal phenomenon: no species lasts forever. Without the fossil record, we might imagine that extinctions have been caused mainly by human interactions.

6. Dating rocks

Biostratigraphy, the use of fossils in dating rocks, is a powerful tool for understanding deep time, and it is widely used in scientific studies, as well as by commercial geologists who seek oil and mineral deposits. Radiometric dating provides precise dates in millions of years for rock samples, but this technological approach only works with certain kinds of rocks. Fossils are very much at the core of modern stratigraphy, both for economic and industrial applications and as the basis of our understanding of Earth's history at local and global scales.

2 Paleontology as a science: What is Science?

Science is a systematic enterprise that builds and organizes knowledge in the form of testable explanations and predictions about the universe. **From Latin scientia, meaning "knowledge"** Science is supposed to be about reality, about hard facts, calculations and proof. In mathematics, and many areas of physics, this might be true. In natural sciences, there have been two main approaches

1. **Induction**
2. **deduction**

Induction

- **Sir Francis Bacon**: **The enquirer might hope to see common patterns among the observations, and these common patterns would point to an explanation, or law of nature.**

Deduction

Aristotle : A series of observations point to an inevitable Outcome "All *men are mortal. Socrates is a man. Therefore*
Socrates is mortal."

Mathematics and in detective work.

Hypotheticodeductive method

- Karl Popper
- "Proof is impossible"
- Scientists set up the hypotheses
- hypothesis testing;
- They seek to refute, or disprove, hypotheses rather than to prove them.

A good Hypothesis

1. hypotheses should be sensible and testable
2. Speculation vs. "Informed deduction"
3. Should be based on observable facts, not the fantasy.

Paradigm shifts

Thomas Kuhn: science shuttles between so-called times of normal science and times of scientific revolution. Scientific revolutions, or paradigm shifts, are when a whole new idea invades an area of science.

An Example of Paradigm shift

The paper by Luis Alvarez and colleagues (1980). The Earth had been hit by a meteorite 65 million years ago, caused the extinction of the dinosaurs and other groups.

Paleontology rendition in Popular culture

- Jurassic Park and Walking with Dinosaurs
- The slow evolution of reconstructions of ancient life over the centuries reflects the growth of paleontology as a discipline.

3 Paleontology as a science: Steps to understanding

Steps to understanding

1. Earliest fossil finds
2. Fossils as magical stones.
3. Fossils as fossils
4. The idea of extinction
5. The vastness of geological time

Earliest fossil finds

- Prehistoric
- peoples picked up and used them as Ornaments
- Early Greeks, Xenophanes (576–480 bce) and Herodotus(484–426)

Fossils as magical stones

- Roman and medieval times
- Fossil sharks' teeth were known as *glossopetrae* worn as amulets
- The idea of *vis plastica*
- The work of Johann Beringer

Fossils as fossils

- The genius of Leonardo da Vinci
- Nicolaus Steno, true nature of *glossopetrae*
- Robert Hooke, descriptions of Fossils using a crude microscope
- Magical explanations of fossils were debunked

The idea of extinction

- Robert Hooke was one of the first to hint at the idea of extinction
- William Hunter (1768): "American incognitum"
- Reality of extinction: French natural scientist Georges Cuvier
- Cuvier : father of comparative anatomy

The vastness of geological time

- Sedimentary rocks and their contained fossils document the history of long spans of time.
- Naming of the geological periods and eras : 1820s and 1830s
- Stratigraphy is an understanding of geologic time
- Until the late 18th century, scientists accepted calculations from the Bible that the Earth was only 6000–8000 years old by dissecting the head of a huge modern shark.

4 Paleontology as a science: Fossils and evolution

Fossil & Evolution:

1. Progressionism and Evolution
2. Darwinian evolution

People want to know where life came from, where humans came from, where the Earth and universe came from. These have been questions in philosophy, religion and science for thousands of years and paleontologists have a key role (seepp. 117–20). Despite the spectacular progress of paleontology, earth sciences and astronomy over the last two centuries, many people with fundamentalist religious beliefs deny all natural explanations of origins – these debates are clearly seen as hugely important.

1. **Progressionism and Evolution**

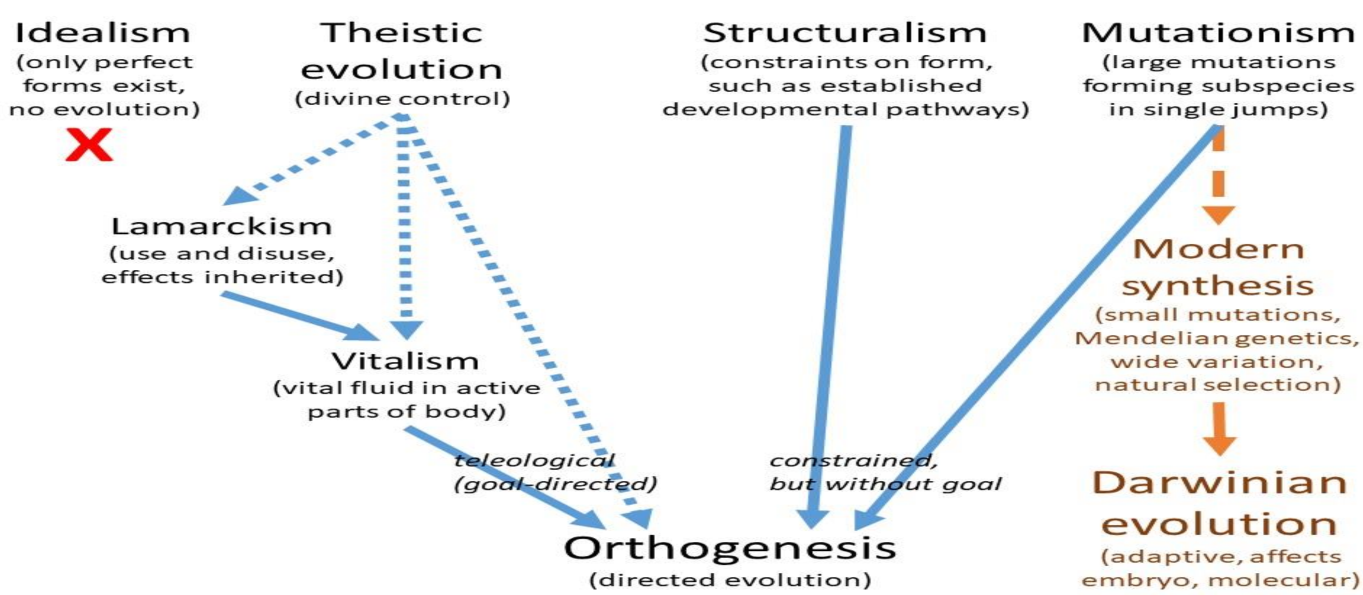
Limited Knowledge of the fossil record in the 1820s and 1830s. Paleontologists debated whether there was a progression from simple organisms in the most ancient rocks to more complex forms later. Charles Lyell (1797–1875), was an antiprogressionist. **Charles Lyell (1797–1875),** was an antiprogressionist. He believed that the fossil record showed no evidence of long-term, one way change, but rather cycles of change. He would not have been surprised to find evidence of human fossils in the Silurian, or for dinosaurs to come back at some time in the future if the conditions were right. **Progressionism (Orthogenesis)** was linked to the idea of evolution. The work of **Comte de Buffon** (1707–1788) and **JeanBaptiste Lamarck (1744–1829)**. Lamarck s' idea of "Great Chain of Being" or the *Scala naturae*. "All organisms were linked in time by a unidirectional ladder, from simplest at the bottom to most complex at the top"

1. **Darwinian evolution**

- Charles Darwin (1809–1882), developed the theory of evolution by natural selection in the 1830s. Abandoning the usual belief that species were fixed and unchanging. Idea of evolution by common descent, that all species today had evolved from other species in the past.

The problem: how the variation within species could be harnessed to produce evolutionary change?

- Ideas of Thomas Malthus (1766–1834). Survival of the fittest through adaptations, Book "On the Origin of Species
(1859)"
- **"Modern synthesis"** Modern genetics early in the 20th century. Amalgamation of Genetics with "natural history" (systematics, ecology, paleontology). Establishment of Darwinian evolution by natural selection.



5 Paleontology as a science: Paleontology today

Palenotology Today:

1. Dinosaurs and fossil humans
2. Evidence of earliest life
3. Macroevolution
4. Paleontological research

Dinosaurs and fossil humans:

19th century paleontology: "Archaeopteryx", true "missing link" predicted by Darwin only 2 years before. Incomplete remains of Neandertal man in 1856

- ***Archaeopteryx* lithographica, Specimen displayed at the Museum für Naturkunde in Berlin.**

Evidence of earliest life:

Older, simpler, forms of life were recognized after 1960 by the use of advanced microscopic techniques, and some aspects of the first 3000 million years of the history of life are now understood. Extraordinary progress in understanding the earliest stages in the evolution of life.

- Cambrian fossils
- Precambrian fossils
- In 1947, the first soft-bodied **Ediacaran fossils** were found in Australia .

Macroevolution:

Rates of evolution, the nature of speciation , the timing and extent of mass extinctions the diversification of life, other topics that involve long time scales.

Paleontological research:

Done by paid professionals, by amateur enthusiasts, amateurs are not paid to work as palaeontologists, collaborations between different sciences is the key. Most paleontological research is more mundane.

6 Fossils in time and space

Early paleontologists did not know these things, and so they tried to pack the whole of the history of life into a relatively short span of time, visualizing trilobites or dinosaurs inhabiting a world that was much as it is today. The Earth is old, and the distribution of continents and oceans has changed radically over time. **Past:** History of life into a relatively short span of time **Life on Earth:**

- Evolving for up to 4 billion years
- Complex story of fossil groups coming and going
- Continents moving from place to place

How to Study fossils in time and space:

Development of geographic and temporal frameworks. Accurate and reliable enough to chart the distributions of fossil organisms through time and space. Paleogeographers and Stratigraphers are equipped with a range of computer-based hightech methods. Models describing the distributions of the continents, oceans and their biotas throughout geological time.

Use of Fossils information:

Fossils information is also useful in Geology. Allows the tectonic history of mountain ranges to be reconstructed. Helps in identifying the levels of thermal maturity of rocks. The gas and oil windows in hydrocarbon exploration.

7 Fossils in time and space: Frameworks

Rock stratigraphy :

A rock stratigraphy is the essential framework that paleontologists use to accurately locate fossil collections in both temporal and spatial frameworks.

Leonardo's legacy:

The origin of modern stratigraphy: Leonardo da Vinci and his drawings. da Vinci portrayed a clear sequence of laterally continuous, horizontal strata showing the concept of superposition

Steno's Work:

- Nicolaus Steno: Established the simple fact that older rocks are overlain by younger rocks if the sequence has not been inverted law of superposition of strata (The **law of superposition** is an axiom that forms one of the bases of the sciences of geology, archaeology, and other fields dealing with geological stratigraphy. In its plainest form, it states that in undeformed stratigraphic sequences, the oldest **strata** will be at the bottom of the sequence).
- The principle of original horizontality: "Strata either perpendicular to the horizon or inclined to the horizon were at one time parallel to the horizon";
- The principle of lateral continuity: "Material forming any stratum were continuous over the surface of the Earth unless some other solid bodies stood in the way"
- The principle of cross-cutting relationships: "If a body or discontinuity cuts across a stratum, it must have formed after that stratum.

Types of Stratigraphy:

1. Lithology (Lithostratigraphy)
2. Fossils (Biostratigraphy)
3. Tectonic units, such as thrust sheets (Tectonostratigraphy)
4. Magnetic polarity (Magnetostratigraphy),
5. Chemical compositions (Chemostratigraphy)
6. Discontinuities (Allostratigraphy),
7. Seismic data (Seismic stratigraphy)
8. Depositional trends (Cyclo- and sequence stratigraphies)

8 Fossils in time and space: lithostratigraphy

Early geologists thought the Earth was very young. Scottish scientist James Hutton (1726–1797) chellenged . "no vestige of a beginning,– no prospect of an end". "ruins of an earlier world" **Gaia hypothesis and Modern Concept**:

- **Gaia hypothesis:** Earth as a living organism in equilibrium with its biosphere.
- **Modern Concept:** Earth as a dynamic and changing system, **Lithostratigraphy:**

All aspects of stratigraphy start from the rocks themselves. The order and succession of rocks is called lithostratigraphy. Building blocks for any study of biological and geological change through time. Successions of rock are often divided by gaps or unconformities. A stratigraphy is required to monitor biological and geological changes through time and underpins the whole basis of Earth history.

- The Permian through Jurassic strata of the Colorado Plateau area of southeastern Utah demonstrate the principles of stratigraphy.

Stratigraphic unit:

A stratigraphic unit is a volume of rock of identifiable origin and relative age range that is defined by the distinctive and dominant, paleontologic features. It is fundamental Unit of Lithostratigraphy. Lithostratigraphic units are bodies of rocks, bedded or unbedded.

Lithostratigraphic units:

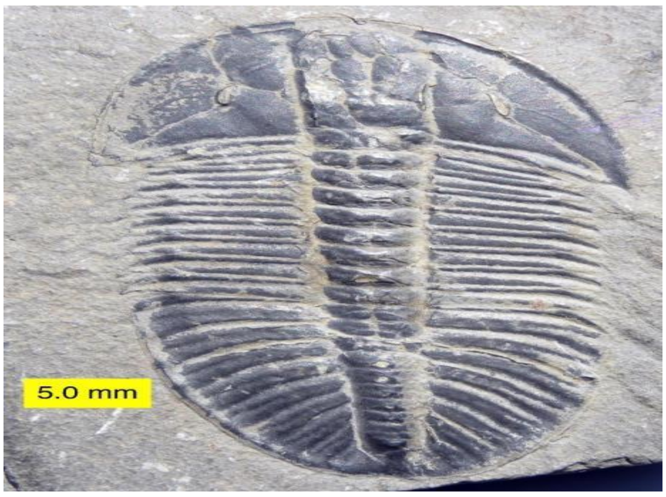
1. A bed, is a lithologically distinct layer within a member or formation and is the smallest recognizable stratigraphic unit.
2. A member is a more local lithologic development, usually part of a formation
3. The formation, a rock unit that can be mapped and recognized across country
4. A succession of contiguous formations with common characteristics is called a group
5. Groups themselves may comprise a supergroup

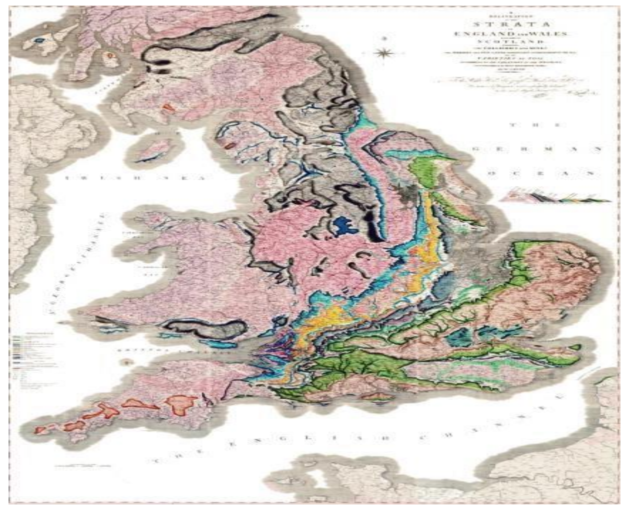
9 Fossils in time and space: Use of fossils: discovery of biostratigraphy (Part 1)

Early Palaeontologists:

- Work of William Smith in Britain "Assemblages of fossils in different layers". William Smith: Trilobite-Dominated assemblages in England and Wales area.

- Georges Cuvier (Anatomist) and Alexandre Brongniart in France (Mollusck expert). Cuvier and Brongniart: Comparison of different strata in Paris basin and supposed Biological catastrophs in between.





The Work of John Phillips:

Formally defined the three great eras separated by extinction events.

- Paleozoic (“ancient life”)
- Mesozoic (“middle life”) Cenozoic (“recent life”)

Precise biotic and morphological changes along phylogenetic lineages. Accurate correlation using a wide variety of fossil organisms

<u>Biostratigraphy: the means of correlation:</u>

- Biostratigraphy is the establishment of fossil based successions and their use in stratigraphic correlation. Measurements of the stratigraphic ranges of fossils, or assemblages of fossils, form the basis for the definition of biozones. **Biozones:** The main operational units of a biostratigraphy. The known range of a zone fossil is the time between its first and last appearances in a specific rock section,
  1. **First appearance datum (FAD)** 2. **Last appearance datum (LAD)**

Establishment of biozones. Quantitative techniques to understand the relationships between rock thickness and time, and to make links from locality to locality.

10 Fossils in time and space: Use of fossils: discovery of biostratigraphy (Part 2)

- The fossil record is rarely complete. Only a small percentage of potential fossils are ever preserved. Stratigraphic ranges can also be influenced by the Signor–Lipps effect. **Signor–Lipps effect “Since the fossil record of organisms is never complete, neither the first nor the last organism in a given taxon will be recorded as a fossil”**
- Many different animal and plants are used in biostratigraphic correlation. Graptolites (1 myr) and Ammonites (25 kyr) are the best known and most reliable zone macrofossils.
- **Microfossil groups:** conodonts, dinoflagellates, foraminiferans and plant spores used in petroleum exploration. Comprise of small samples, drill cores and chippings. Microfossil groups many groups are widespread and rapidly evolving.

  Drawback:
  Techniques used to extract them from rocks are specialized, like acid digestion and thin sections.

<u>Chronostratigraphy:</u>

“The branch of geology concerned with establishing the absolute ages of strata.”

Dividing up geological time. Chronostratigraphy or global standard stratigraphy. Most fundamental of all stratigraphic concepts

<u>Sequence stratigraphy</u>

"Sequence Stratigraphy is a branch of geology that attempts to subdivide and link sedimentary deposits into unconformity bound units on a variety of scales."

Cyclostratigraphy

Finding the rhythm. Cyclostratigraphy is the study of astronomically forced climate cycles within sedimentary successions.

Geologic time scale

System of chronological dating that relates geological strata (stratigraphy) to time. Used to describe the timing and relationships of events that have occurred during Earth's history.

11 Fossils in time and space : Paleobiogeography

All living organisms have a defined geographic range. The ranges may be large or small, and controlled by a variety of factors including climate and latitude.

Early Biogeographists:

Charles Darwin (Galápagos islands) and Alfred Russel Wallace (East Indies) . Recognized the reality of biogeographic provinces. **Philip Sclater and Alfred Russel Wallace**. The Earth today can be divided into six main provinces (**Nearctic, Palearctic, Neotropical, Ethiopian, Oriental and Australasian**). Early **1900s, the German scientist Alfred Wegener** suggested that the continents moved across the Earth's surface on a liquid core, suggesting that continents could in fact drift.

Computerized paleogeographic systems:

Our understanding of plate movements has been greatly advanced. Paleomap Project taking the Earth far into the future as well as deep into the past.

Faunal and floral barriers:

Barriers of various types have partitioned biogeographic provinces through time.

The work of Gaylord Simpson:

George G. Simpson Three passages

- Corridors (open at all times)
- Filters (allowed restricted Access)
- Sweepstake routes (opened only occasionally)

Barriers

- Continental settings: mountain ranges, inland seas or even rain forests.
- Marine faunas: wide expanses of deep ocean, swift ocean currents or land.

- **Isthmus of Panama**

- Barrier for some organisms may provide a corridor for others.
- The emergence of the Isthmus of Panama (3 Mya) Connected North and South America
- Separated the Atlantic and Pacific oceans.

12 Fossils in time and space : Island Paleobiogeography

Island biogeography

Modern oceans are littered with islands. The biogeography of modern islands is complex and it is hard to apply models based on modern islands to ancient examples. Island biogeography is the study of the species composition and species richness on islands. Island biogeography is a study aimed at establishing and explaining the factors that affect species diversity of a specific community. Most islands are isolated from the mainland, and they are important powerhouses of speciation.

Moving island complexes: the cross-latitude transfer of evolving animals and plants may have acted as "Noah's arks". **Example:** The transit of India from Gondwana to Asia

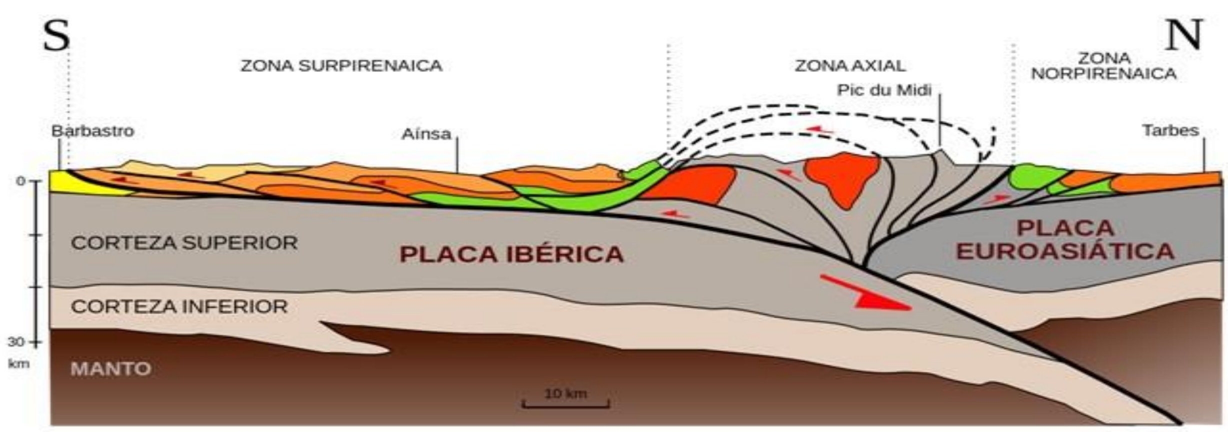
Island biotas (faunas and floras) are often diverse, with many endemic species and commonly with evidence that these species came originally from one or more source continents. **Galápagos, or Aldabra**, have become important sites for biologists to watch "**evolution in action**". It is difficult to understand the role of such islands through geological time By their very nature, being short lived and located in tectonically active areas. They are quickly lost and often destroyed.

13 Fossils in time and space : Fossils in fold belts

- **"One bad fossil is worth a good working hypothesis"**
- **Rudolf Trümpy, an eminent Alpine geologist.**

FOLD BELTS

A fold and thrust belt is a series of mountainous foothills adjacent to an orogenic belt, which forms due to contractional tectonics.



Profile through the Pyrenees. In the south a fold and thrust belt exists as sediments are folded and stacked (thrusted) on top of the other. WF

FOSSILS IN FOLD BELTS

Fossils from the deformed zones of mountain belts. They are usually poorly preserved. Metamorphosed and tectonized . We can reassemble ancient mountain belts and trace the origins of their jumbled structure using paleontological data. Fossils in fold belts can be of great value to structural geologists in understanding the rates and timing of tectonic events. A fossil that was originally symmetric, but now squeezed, or stretched. The precise evidence of the magnitude of the tectonic forces on it

- **Example** is the "**Delabole butterfly**" In fact, the wide-hinged fossils are "**Spiriferide brachiopods"**

Hughes and Jell (1992): Techniques to unstrain **Cambrian trilobites from Kashmir,** distorted by earth movements during the uplift of the **Himalayan mountain belt**

The investigation of thermal maturation is now a routine petroleum exploration technique. A number of groups of microfossils change color with changing paleotemperature.

14 Taphonomy and the quality of the fossil record

Taphonomy

"Taphonomy is the paleontological study includes all the processes that occur after the death of an organism and before its fossilization in the rock".

Plants and animals with hard tissues are most frequently preserved in the fossil record. Soft tissues usually decay rapidly, but rapid burial or early mineralization may prevent decay. Physical and chemical processes during transport and compaction damage hard tissues. Plants preserve as permineralized tissues, coalified compressions and cemented casts. Physical and chemical processes during transport and compaction damage hard tissues. Plants preserve as permineralized tissues, coalified compressions and cemented casts. Many of the analytic approaches used by taphonomists are also used by forensic scientists. Both observe the state of decay of remains. Measurement of the chemistry of the bone . Assessment of the rare earth elements (scandium, yttrium and the 15 lanthanides) to help pinpoint the time of death. Archeologist and Paleontologists both use these techniques

Fossil Record

- Quality of the fossil record?

Fidelity and quality of the fossil record.

- Can paleontologists trust their patchy fossil finds to understand large-scale patterns of evolution?

Paleontologists should be careful when they attempt to reconstruct a whole plant or animal, and try to understand its biomechanics, when they have just a few bones or bits of twigs. Care is required in seeking to understand patterns of diversity change and evolution when many fossil species are missing. Diverse opinions and arguments in favour and against the fossil records.

15 Taphonomy and the quality of the fossil record : Fossil preservation (Part 1)

Fossilization

Sometimes a plant or an animal dies ends up as a fossil. There are several stages that normally occur in the transition from a dead body to a fossil. In rare cases, soft parts may be preserved, and these examples of exceptional preservation are crucially important in reconstructing past life. "Lagerstätten"

Transition to fossil

1. Decay of the soft tissues of the plant or animal.
2. Transport and breakage of hard tissues.
3. Burial and modification of the hard tissues.

Two kinds of fossils

1. **Body fossils:** the partial or complete remains of plants or animals
2. **Trace fossils:** the remains of the activity of ancient organisms, such as burrows and tracks.

Decay

When large animals feed on dead plant or animal tissues, the process is termed scavenging. When microbes, such as fungi or bacteria, transform tissues of the dead organism, the process is termed decay

Factors controlling Decay

- **Oxygen** • **Microbial nutrients** • **Temperature** • **pH**

Example of Neolithic and younger "bog bodies" of northern Europe

Volatiles and Refractories

Soft parts of animals are made from volatiles, forms of carbon that break down readily. Refractories are the organic carbons much less liable to break down, such as cellulose.

Mineralization

Early mineralization of soft tissues depends on three factors:

1. **Rate of burial**
2. **Organic content**
3. **Salinity**

Physical and chemical effects occurring after burial, are termed as Diagenesis

Conservation traps

- **Obrution deposits**: sedimentation rates are so rapid that carcasses are buried virtually instantly
- **Amber**: fossilised resin

Mineralization Types

Mineralization of soft tissues occurs in three ways

1. Permineralization
2. Formation of mineral coats
3. Formation of tissue casts and shells

16 Taphonomy and the quality of the fossil record : Fossil preservation (Part 2)

Breakage and transport

Several processes of breakage

1. **Physical:** disarticulation, fragmentation, abrasion
2. **Chemical:** bioerosion, corrosion, dissolution
3. **Disarticulation:** Skeletons that are made from several parts may become disarticulated, separated into their component parts. After scavenging or decay of connective tissue
4. **Fragmentation:** Skeletons may also become fragmented. Individual shells, bones or pieces of woody tissue break up into smaller pieces usually along lines of weakness
5. **Abrasion:** Shells, bones and wood may be abraded by physical grinding and polishing against each other and against other sedimentary grains.
6. **Bioerosion:** The removal of skeletal materials by boring organisms such as sponges, algae and bivalves. Shells, bones and wood may undergo bioerosion
7. **Corrosion and Dissolution:** Before and after burial, skeletal materials are commonly corroded and dissolved by chemical action, i.e. by weak acidic waters

Burial and Modifications

- The remains are typically buried after scavenging, decay, breakage and transport.
- Sediment is washed or blown over the remains, and the specimen becomes deeply buried.
- During and after burial, the specimen may undergo physical and chemical change
- Addition of $CaCO_3$ is called Carbonate concretion
- Coprolites are phosphtised.

Plant Preservation:

Through petrification or cellular permineralization

1. Coal balls
2. Coalified compression
3. Cementation
4. Direct preservation of hard parts

17 Taphonomy and the quality of the fossil record : Quality of the fossil record

Incompleteness of the fossil record

- Charles Darwin "imperfection of the geological record"
- In 1972, David Raup explained all the factors that make the fossil record incomplete

Anatomic filters

Organisms are likely to be preserved only if they have hard parts, a skeleton of some kind. Entirely soft-bodied organisms, such as worms and jellyfish, are only preserved in rare cases

Biological filters

- Behavior and population size matter
- Common organisms such as rats are more likely to be fossilized than rare ones such as pandas
- Shorter life span of rats

Ecological filters

- Where an organism lives matters.
- Animals that live in shallow seas, or plants that live around lakes and rivers, are more likely to be buried under sediment
- Flying animals

Sedimentary filters

Some environments are typically sites of deposition, and organisms are more likely to be buried there. Mountainside or a beach VS a shallow lagoon or a lake

Preservation filters

Once the organism is buried in sediment, the chemical conditions must be right for the hard parts to survive. The destruction of bones or shells by acidic waters. worn and damaged by physical movement.

Diagenetic filters

- After a rock has formed, the rock may be transformed by the passage of mineralizing waters
- Either enhancing the fossils, by replacing biomolecules with mineral molecules, or destroying the fossil

Metamorphic filters

Over millions of years, the fossiliferous rock might be baked or subjected to high pressure. In these kinds of metamorphic fossils may survive these terrible indignities, or they may be destroyed.

Vertical movement filters

Burial means the rock has been covered by younger rock. Tectonic movements must subsequently raise the fossiliferous rock to the Earth's surface, or the fossil remains forever buried and unseen.

Human filters:

Fossils are seen and collected by a human being. The fossil has to be registered in a museum as part of collective human paleontological knowledge. Individual amateur collections wasted

Sampling and reality

The fossil record give us a good outline of the key events in the history of life. Understanding the history of life with the help of the fossils (small remnant of what once existed)is a big question

18 Paleoecology and paleoclimates

Fossil organisms provide fundamental evidence of evolution. They also allow the reconstruction of ancient animal and plant communities.

Paleoecologists

The functions of single fossil organisms (paleoautecology). The composition and structure of fossil communities (paleosynecology

The Paleoecology of fossil organisms

Described in terms of life strategies and trophic modes together with their habitats. All fossil organisms interacted with other fossil organisms. Described in terms of life strategies and trophic modes together with their habitats. All fossil organisms interacted with other fossil organisms.

The Paleoecology Analysis

Populations and paleocommunities may be analyzed with a range of statistical techniques.

Evolutionary Paleoecology

Charts the changing structure and composition of Paleocommunities through time.Ecological events can be ranked in importance.

Paleoclimates

Described on the basis of climatically-sensitive biotas and sediments together with stable isotopes. Climate has been an important factor in driving evolutionary change at a number of different levels.

Feedback loops and Gaia Hypothesis

Feedback loops between organisms and their environments indicate that the Gaia hypothesis is a useful model for some of geological time.

19 Paleoecology and paleoclimates : Paleoecology (Part 1)

Study of the life and times of fossil organisms, the lifestyles of individual animals and plants together with their relationships to each other and their surrounding environment.

Speculation

Element of speculation has prompted some paleontologists to exclude paleoecology from mainstream science

Solution

Emerging numerical and statistical techniques can help us frame and test hypotheses. Paleoecology is actually not very different from other sciences.

Two main areas

- **Paleoautecology** is the study of the ecology of a single organism • **Paleosynecology** looks at communities or associations of organisms.

Fidelity

The similarity of a death assemblage to its living counterpart, its fidelity. Measurements of biomass and taxonomic composition

Structure of Community

Numerical abundance and diversity are not the best estimates. Counts of stable adult populations are the most realistic monitors of community structure. A census of an extraordinarily preserved Lagerstätte deposit can help in the estimation of the Taphonomic loss. The degree of breakage with the attitude of fossils in sediments is useful to separate autochthonous (in place) from allochthonous (transported) assemblages.

The -Coenoses

The living assemblage, or biocoenosis, is transformed into a thanetocoenosis after death and decay. Taphocoenosis is the end product that is finally preserved

20 Paleoecology and paleoclimates : Paleoecology (Part 2)

Population

Populations are the building blocks of communities. A population is a naturally occurring assemblage of plants and animals that live in the same place at the same time and regularly interbreed.

Ecosystem

“All the populations of species living in association”

Keystone species help shape the ecosystem and that can trigger large-scale changes if they disappear. **E.g** A classic keystone species is the elephant **Incumbent Species**

Incumbent species can occupy the same ecological niche for many millions of years, adding stability to many ecosystems. **E.g** Dinosaurs and mammals

Habitat and Niche

Fossil organisms can be classified in terms of

- Habitat, where they live.(their address) • Niche, their lifestyle (their occupation).

Marine Sediments

- The majority of fossil animals have been found in marine sediments
- Occupy a wide range of depths and conditions.
- Photic zone is the depth of water penetrated by light

Marine Variety of Life

Marine environments host a variety of lifestyles. The upper surface waters are rich in floating plankton, and nektonic organisms swim at various levels in the water

Marine Sediments

- Benthos are the beasts that live in or on the seabed
- Mobile nektobenthos, scuttle across the seafloor
- the fixed or sessile benthos are fixed
- **Infaunal organisms** live beneath the sediment–water interface
- **Epifaunal organisms** live above it The sediment–water interface

Guilds

Guilds are groups of functionally similar organisms occurring together in a community.

Megaguild

Megaguilds are a range of adaptive strategies based on a combination of life position (e.g. shallow, active, infaunal burrower)

21 Paleoecology and paleoclimates : Paleoclimates

The study of changes in climate taken on the scale of the entire history of Earth. Uses the methods from the Earth and life sciences

Paleoclimatology

It obtains data from previously preserved things such as rocks, sediments, ice sheets, tree rings, corals, shells, and microfossils.

The Climate change in life history

Last 600 million years. Earth has oscillated at least five times between icehouse and greenhouse conditions. Spending most of the time in greenhouse climates

Five climate zones

1. Humid Tropical (no winters and average temperatures above 18°C)
2. Dry subtropical (evaporation exceeds precipitation)
3. Warm temperate (mild winters)
4. Cool temperate (severe winters)
5. Polar (no summers and temperatures below 10°C

Identification of climate zones

- A range of geological and paleontological criteria has helped identify climatic zones through time.
- **calcretes** (soils rich in calcium carbonate) and evaporites (evaporated salts) help identify dry, arid climates
- **Dropstones** (stones that plummet from the bottoms of melting icebergs into seabed sediments) and Tillites (rocks and sand left behind by an advancing glacier) indicate polar conditions.

Trends of climate change

- Short term trends
- Long term trends
- Consequences for evolution
- Biological Feedback and Gaia Hypothesis

22 Macroevolution and the tree of life

Evolution by natural selection

Evolution by natural selection is a core scientific model that was set out by Darwin. It has been confirmed again and again in every branch of Biology.

Intelligent design

Creationists attempts to promote their religious beliefs, such as “intelligent design” or belief in a flat Earth, are not testable and therefore are not science.

Speciation

Speciation often occurs by the establishment of a barrier, and the isolation of part of a previously interbreeding population. **Evolution**

- Evolution takes place both within
- Species lineages (phyletic gradualism)
- at the time of speciation (punctuated equilibrium)

Tree of Life

- The evolution of life may be represented by a single branching phylogenetic tree.
- Cladistics is a method of reconstructing phylogeny based on the identification of shared derived characters (homologies).

Evolution

- Molecular sequencing provides additional evidence for reconstructing and dating the tree of life.
- DNA has been extracted from fossils such as woolly mammoths, but not from truly ancient fossils

23 Macroevolution and the tree of life : Evolution by natural selection

Early Evolutionists

- Darwin laid the framework for Evolutionary Biology 150 years ago.
- No one has yet falsified Darwin’s theory of evolution by natural selection
- On The Origins of Species (1859)

Tree of Life

Darwin: life had diversified to millions of species by the continued splitting of species from a common stem. Explained for the first time the meaning of the natural hierarchy of life.

Macroevolution

Paleontological aspects of evolution, such as the tree of life and studies of processes over thousands and millions of years, are sometimes called macroevolution (“big evolution”)

- **Microevolution ("small evolution") are all the smaller-scale and shorter-term processes studied by biologists and geneticists in the laboratory or in the field.**

Darwin's Quest of the Truth

- The **Voyage of *HMS Beagle***
  - Observation of Diversity of life
  - Evidence for relationship in time and space Awareness of Fossil record
  - Malthus' work

Principle of Natural Selection

"Only the organisms best adapted to their environment tend to survive and transmit their genetic characteristics in increasing numbers to succeeding generations while those less adapted tend to be eliminated."

Natural Selection

1. Nearly all species produce far more young than can survive to adulthood (Malthus'principle)
2. The young that survive tend to be those best adapted to survive.
3. Characters are inherited from parent to offspring, so the characters that ensure survival will tend to be passed on.
4. These survival characteristics will increase generation by generation.

24 Macroevolution and the tree of life : Evolution and the fossil record

Species:

Species consist of many highly variable individuals, often divided into geographically restricted populations and races. *Homo sapiens:* Single specie

Biological Species' Concept

"A species consists of all individuals that naturally breed together and that produce viable offspring"

- Humans
- Wolves and Dogs
- Birds and Frogs

Gene pool of Local populations

Local populations may be isolated from other populations of the same species, and with a subtly different gene pool, the overall array of genetic material in all the individuals within the population.

Gene flow

The cohesion of a species is maintained over its natural range by processes of gene flow.

The occasional wandering of individuals from one area to another, which interbreed with members of neighboring populations.

Gene flow: interbreeding with members of neighboring populations.

Speciation

- "The process of splitting of a population to form two species is speciation".
- The allopatric
- ("other homeland") model
- The geographic model (based on the establishment of geographic barriers)

The Reasons for Speciation

1. Each population, or set of populations, would start out with a different gene pool.
2. Selection pressures would be different, perhaps only subtly, on either side of the barrier.

Models of Speciation

1. **The Phyletic Gradualism Model:** Phyletic gradualism, where evolution takes place in the lineages, and speciation is a side effect of that evolution

2. **Punctuated Equilibrium Model:** Where most evolution is associated with speciation events, and lineages show little evolution (stasis).

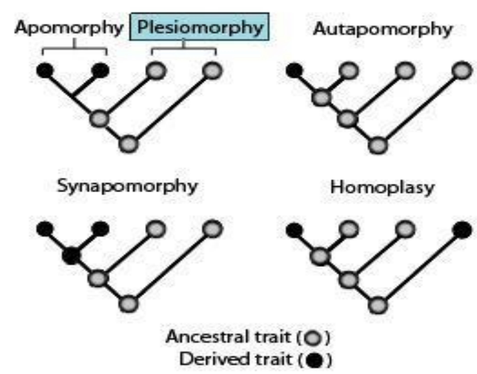
25 Macroevolution and the tree of life : The tree of life

Tree Thinking:

- ✓ Darwin was the first to picture evolution as a great branching tree.
- ✓ "Which species of ape is closest to humans – the gorilla or chimp?" ✓ Putting together complete trees of all species ✓ Scala Naturae: the ladder of life.
- ✓ Ladder go from lower to higher, simple to complex
- ✓ Tree of life: Splits and Branches
- ✓ Tree is a better analogy for life

Cladistics

- In Cladistics, we reconstruct the Life's Hierarchy.
- The true patterns of Relationship among the organisms.
- ▯ Similarities and Differences among organisms **Phylogenetically informative characters**



Good characters are phylogenetically informative, that is, indicative of the true phylogeny. These characters identify the clads. Phylogenetically uninformative characters fall into two main categories:

- Convergences
- Plesiomorphies

1. Convergence

Convergence in evolution is when features, or organisms, evolve to look the same perhaps because they live the same way.

2. Plesiomorphies

Plesiomorphies are characters that are shared by the organisms of interest, but also by other groups.

Monophyletic Groups

These are groups that had a single origin and include all the descendants of that common ancestor. Psittaciformes, the parrots, long been identified as real and distinct from all others by naturalists

Non Natural Groups

- Clades are distinguished from two kinds of non-natural groups:
- Paraphyletic groups
- Polyphyletic groups

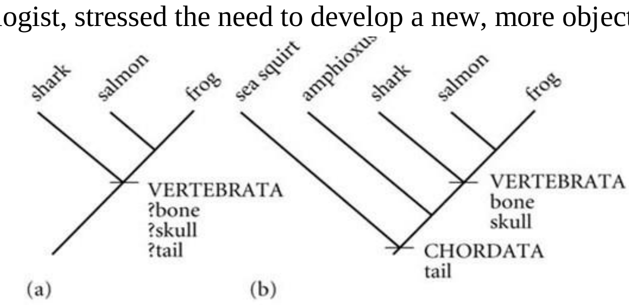
26 Macroevolution and the tree of life : Cladistics

Early Scientists

Willi Hennig (1913–1976), an eminent German entomologist, stressed the need to develop a new, more objective method in systematics, which has come to be called cladistics.

Cladistics

The fundamental aim of cladistics is to identify clades, and so to discover, or reconstruct, the tree of life. Patterns of relationships are shown as branching diagrams, or cladograms



Reconstructing the phylogeny of vertebrates by cladistic methods. (a) Are the defining features of vertebrates the possession of bone, a skull and a tail? (b) The tail is found in a wider group, termed the Chordata, but the skull and bone define the Vertebrata.

Nodes

The most closely related species are joined most closely. The branches in the cladogram join at branching points, or nodes, each of which marks the base of a clade

Apomorphies

Hennig called the phylogenetically informative characters "Apomorphies" or derived characters. Apomorphies are features that arose once only in evolution.

Synapomorphies

"Apomorphies" shared by two or more species are termed synapomorphies. Synapomorphies of **Order Psittaciformes** include the deep, hooked beak and the unusual foot.

Older distinctions

- "Homology" and "Analogy"
- Vertebrate Limbs
- Wing of bird, paddle of whale arm of human are the same. Homologs. ➢ Peddles of whales and seals

Molecular Revolution

Birth of Molecular Biology 1950s and 1960s. Comparisons of molecules allow analysts to do two things:

1. To draw up trees of relationships
2. To estimate time.

Dendrograms

Trees of relationships can be based on a comparison of the amount of difference between protein sequences, and a bestfitting dendrogram, or branching diagram, is drawn.

Molecular Clocks

Time estimation comes from the concept of the molecular clock. The amount of difference in the fine structure of a protein is proportional to the time since they last shared a common ancestor.

Nucleic Acids

The nucleic acid sequences must be aligned, that is matched, so that the code of a particular gene in one species is lined up with the same sequence in another species.

27 Fossil form and function

Fossil species

Fossil species are identified according to their external form; this is termed the morphological species concept. Variations in form include normal levels of individual variation The other types of variations in the forms of the fossils include

- ✓ Geographic distribution
- ✓ Sexual dimorphism
- ✓ Different growth stages
- ✓ ecophenotypic variation

Allometry

Fossil species may show allometry, or changes in relative proportions during growth; Specific organs may show positive (grow faster) or negative (grow slower) allometry.

Development and Phylogeny

The development of an organism may give some evidence about phylogeny. Changes in developmental rates and timing (heterochrony) may affect evolution.

The New "Evo-Devo" Perspective

Shows how certain developmental genes control fundamental aspects of form.

- ✓ Symmetry
- ✓ Front–back orientation
- ✓ Segmentation
- ✓ Limb form

Inferring function from ancient organisms:

Is difficult

- ✓ Various methods of doing this:
- ✓ Comparison with modern analogs
- ✓ Biomechanical testing
- ✓ Circumstantial evidence

Modern analogs

Modern analogs may provide exact parallels with some fossil organisms. More often they provide only principles or rules.

Biomechanical models

May be used to assess how the design of an ancient organism matches the hypothetical forces acting on it. May be used to assess how the design of an ancient organism matches the hypothetical forces acting on it. Models of locomotion are easy to produce.

Circumstantial evidence, such as

1. The enclosing rocks
2. Associated fossils
3. Trace fossils and
4. Close study of the fossils themselves can add considerable information on fossil function.

28 Fossil form and function : Growth and form (part 1)

Evolution and Form:

Darwin gave us an evolutionary view of form. He was astonished by the variety of external appearances, by their wonderful adaptations to life.

Forms:

The form, or external appearance, of any microbe, plant or animal is shaped by evolution.

- Wings for flight
- Longs beak and tongue of humming bird

Sexual selection

Sexual selection is the set of evolutionary processes that depend on interactions between the sexes.

Example: The astonishing tails and colors of male birds

Adaptations:

Plants and animals have adaptations that function in the context of both natural and sexual selection. An adaptation is an aspect of form that performs a physical or behavioral function.

Importance of Form:

The form of fossils is important for three reasons

1. Form is the only evidence we have in fossils for identifying species and wider relationships
2. Form can tell us about behavior and ecology
3. The study of changes in form through time informs us about evolution

Recognizing ancient species

Paleontologists use the morphological species concept. Statistical observations define the mean or average characteristics in specie.

29 Fossil form and function : Growth and form

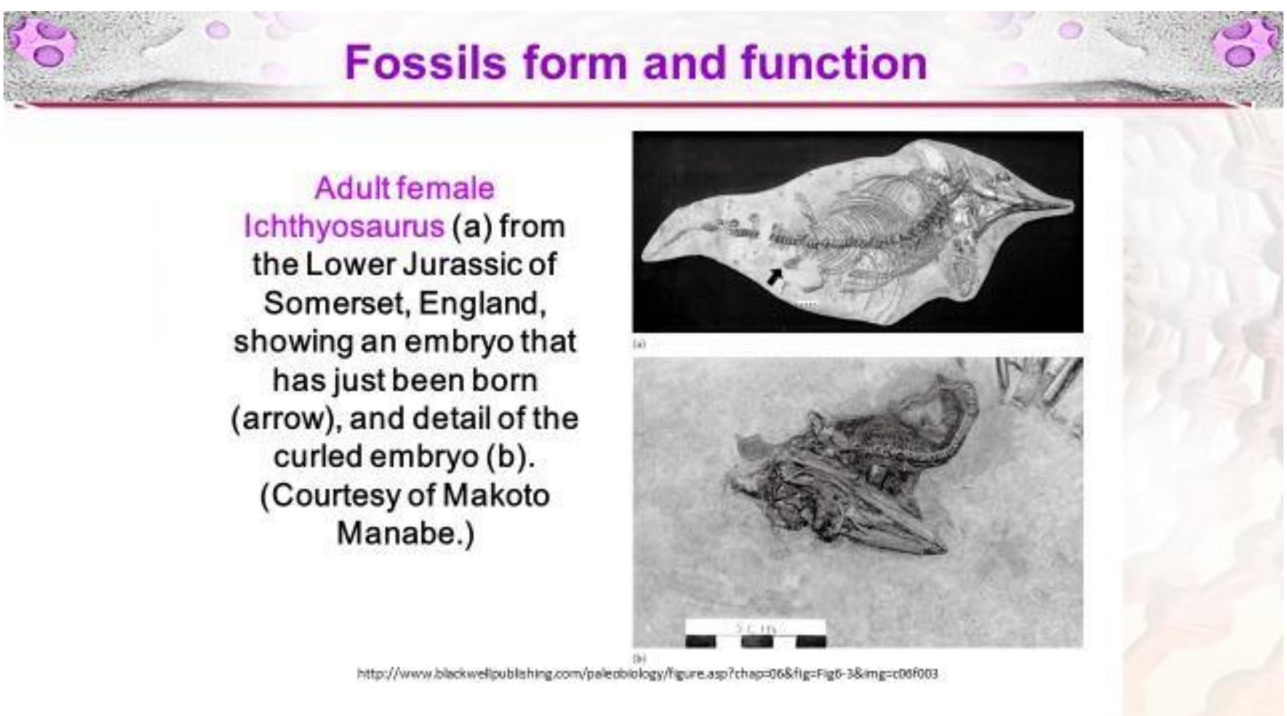
Variations Within the Species

Within a species, there may be a range of morphologies

- Individual variation
- The stuff of natural selection, as Darwin stressed.
- Geographic variation and physical differences between populations or subspecies in different parts of the overall species range.
- Sexual dimorphism, in which males and females may show different sizes, and different specialized features (horns, antlers, tail feathers). E.g Sexual dimorphism in ammonites, the Jurassic Kosmoceras. The larger shell was probably the female, the smaller the male. (Courtesy of Jim Kennedy and Peter Skelton.)
- Growth stages, where there may be quite different larval and adult stages, or where body form alters during growth
- Ecophenotypic effects, Where local ecological conditions affect the form of an organism during its lifetime

Allometry

- Changes in form during growth are common.
- Think of human growth: babies have relatively large heads and eyes, and small limbs.
- If measurements of the variable parts are scaled against a standard measure of the animal, it is evident that the proportions change as the animal grows older
- E.g: Adult female Ichthyosaurus from the Lower Jurassic of Somerset, England, showing an embryo that has just been born (arrow), and detail of the curled embryo. (Courtesy of Makoto Manabe.)



- **Allometric Growth**

The ratio of eye diameter to body length diminishes as the animal approaches adulthood. This is an example of allometric ("different measure") growth.

- **Isometric Growth**

If there is no change in proportions during growth, the feature is said to show isometric ("same measure") growth.

Biological Scaling Principle:

Some organs and functions relate to the mass of an animal (a three-dimensional measure) others relate to body length or body outline (one- and two-dimensional measures).

30 Fossil form and function : Evolution and development

Ontogeny and Phylogeny

Biologists have long sought a link between ontogeny (development) and phylogeny (evolutionary history).

Biogenetic Law

In 1866, Ernst Haeckel, a German evolutionist, announced his Biogenetic Law, that "ontogeny recapitulates phylogeny". Ernst Haeckel's idea was that the sequence of embryonic stages mimicked the past evolutionary history of an animal.

Von Baer's Law:

- A parallel between the sequence of development, and a cladogram.
- In human development embryo passes through the major nodes of the cladogram of vertebrates.
- The synapomorphies of vertebrates appear first, then those of tetrapods, then those of amniotes, then those of mammals, of primates, and of the species *Homo sapiens* last.

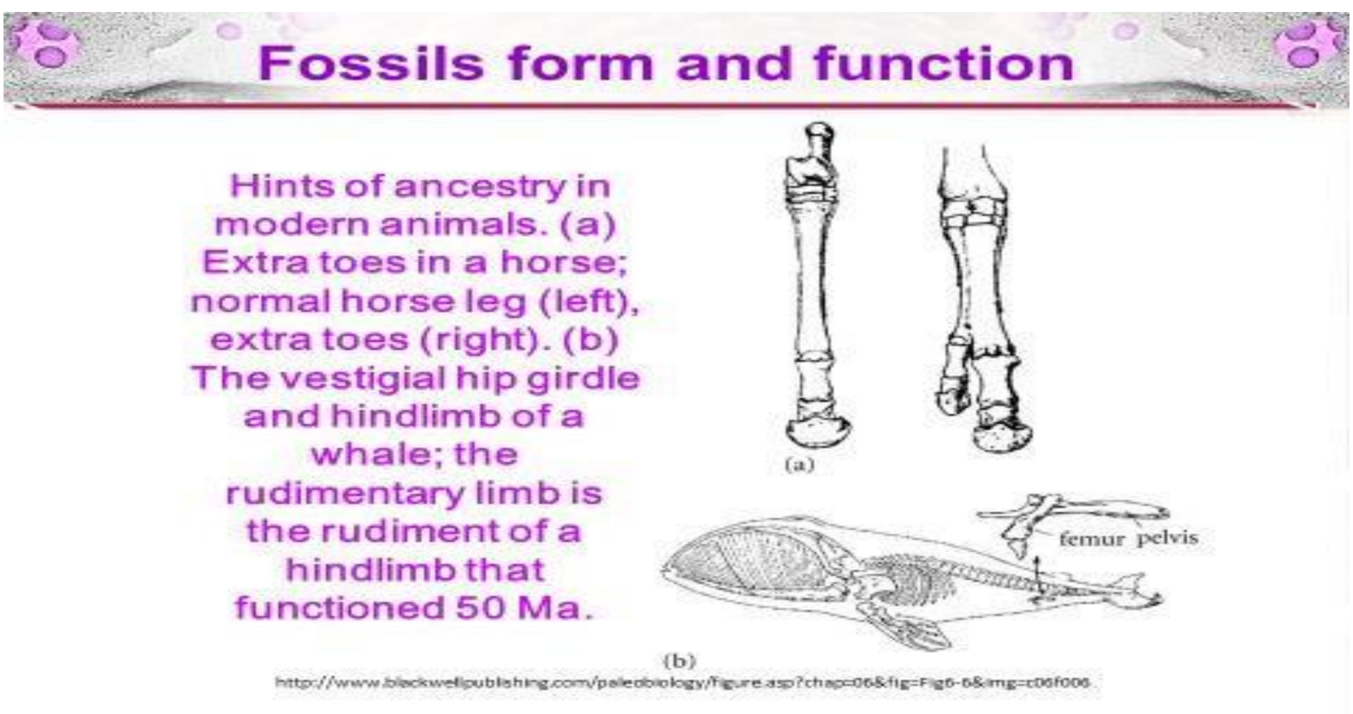
Development and Phylogeny :

Three other aspects of development throw light on phylogeny

- Atavisms
- Vestigial structures
- Patterns of Development

Atavisms:

Certain developmental abnormalities called atavisms, or throwbacks, show former stages of evolution, such as human babies with small tails or excessive hair



E.g: **Hints of ancestry in modern animals.**

- **Extra toes in a horse; normal horse leg (left), extra toes (right).**
- **The vestigial hip girdle and hindlimb of a whale; the rudimentary limb is the rudiment of a hindlimb that functioned 50 Ma.** **Developmental Genes** Widely shared among organisms. Since the 1980s a major new research field "evodevo" (short for evolution–development). Most famous developmental genes are the homeobox genes.

- **Determine aspects of form**
- Symmetry
- Anteroposterior orientation
- Limb differentiation

31 Mass extinctions and biodiversity loss

Introduction

Mass Extinctions

During mass extinctions, 20–90% of species were wiped out; these include a broad range of organisms, and the events appear to have happened rapidly. It is difficult to study mass extinctions in the Precambrian There have been a Neoproterozoic event between the Ediacaran and Early Cambrian faunas. The "big five" Phanerozoic mass extinctions occurred in the

- **End-Ordovician**
- **Late Devonian**
- **End-Permian**
- **End-Triassic**
- **End-Cretaceous**

The end-Permian mass extinction was the largest of all time
Probably caused massive volcanic eruptions, leading to acid rain and global anoxia.
The end-Cretaceous mass extinction has been most studied, and it was probably caused by a major impact on the Earth.
Smaller-scale extinction events include the loss of mammals at the end of the Pleistocene, perhaps the result of climate change and human hunting.

Recovery from Mass Extinctions

- **Takes a long time**
- **First, some unusual disaster taxa that cope well in harsh conditions**
- **Gives way to the longer-lived taxa that rebuild normal ecosystems**

Major Concern Today

Calculated species loss as high as during any mass extinction of the past.

- **The severity of the current extinction episode is still debated.**

32 Mass extinctions and biodiversity loss : Mass extinctions

Extinction

- **Extinction, is now a key theme in discussions about the future**
- **The dodo is perhaps the most iconic of icons**
- **An icon of human carelessness rather than of avian extinction.**
- **An image of a dodo from another era. Lewis Carroll introduced the dodo as a kindly and wise old gentleman in Alice Through the Looking Glass, although at the time most people probably regarded the dodo as rather foolish. Driven to extinction in the 17th century by overhunting, the dodo is now an image of human thoughtlessness.**

- **The most spectacular extinctions are known as mass extinctions**
- **Times when a large cross-section of species died out rather rapidly.**

Extinctions Events

- **There may have been only five or six mass extinctions throughout the known history of life, although there were many extinction events,**

Study of Mass Extinctions

- **From the 1980s**
- **Wide interdisciplinary links**
- **Stratigraphy**
- **Geochemistry**
- **Climate modeling**
- **Ecology**
- **Conservation**
- **Astronomy**
- **The study of mass extinctions involves careful hypothesis testing at all levels, from the broadest scale to the narrowest**

Back ground Extinctions

- **Extinction happens all the time**
- **Species have a natural duration of few million years and so they live for a time and then disappear**

Features of Mass Extinction

- **More than 30% of plants and animals of the time.**

- The extinct organisms spanned a broad range of ecologies
- The extinctions were worldwide covering most continents and ocean basins.

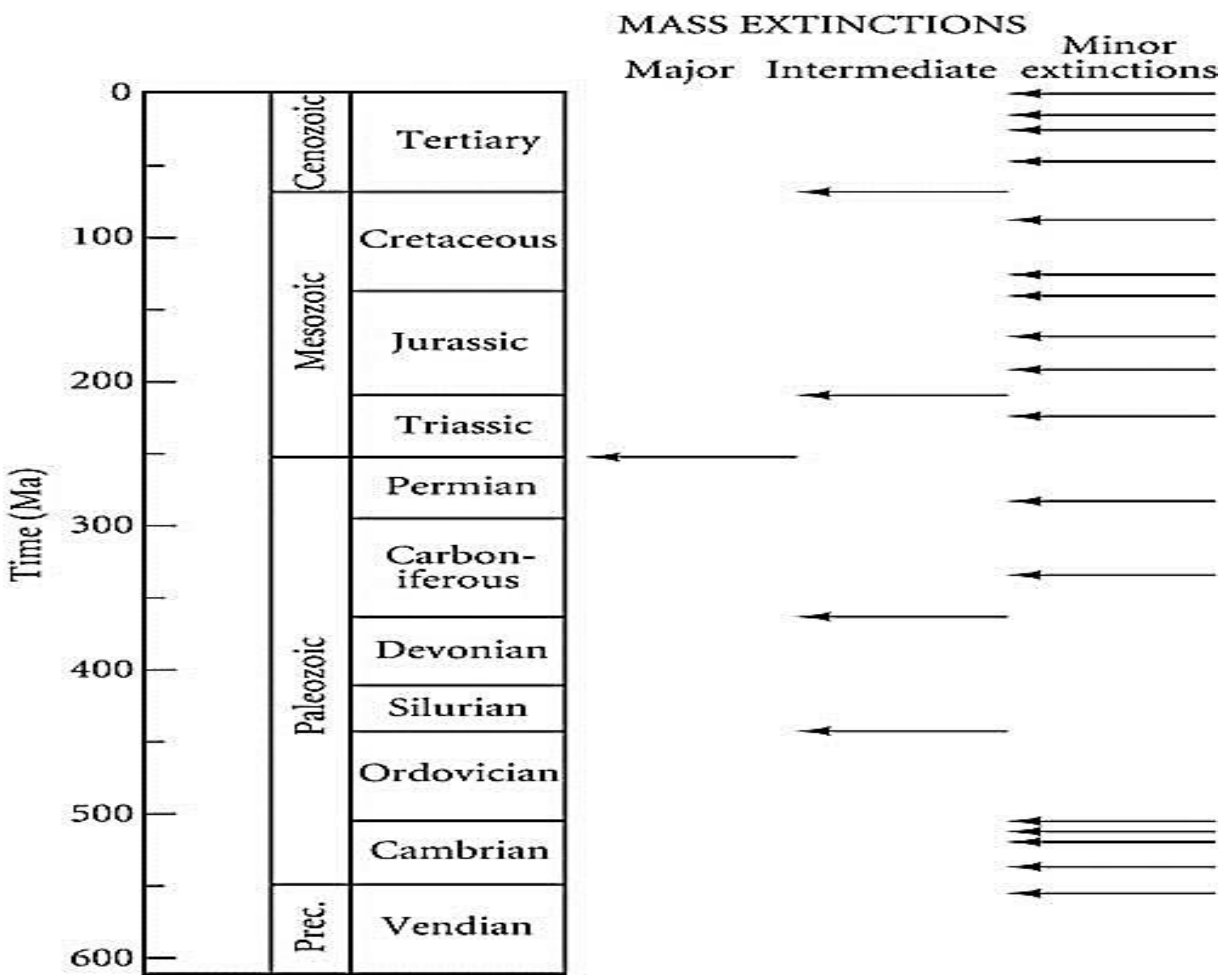
The extinctions all happened within a relatively short time

- The level of extinction stands out as considerably higher than the background extinction level.

33 Mass extinctions and biodiversity loss : Mass extinctions (continued)

Mass Extinctions

- **Paleontologists talk about the "big five" mass extinctions of the last 540 myr**
- **The Phanerozoic, and the current extinction crisis is sometimes called the "sixth extinction".**
- **Mass extinctions through the past 600 myr. Major: 50% of families and up to 96% of species**
- **Intermediate:**
- **global in extent, and involved losses of 20% of families and 75–85% of species. Minor mass extinctions:**
  causing losses of 10% of families and up to 50% of species



Patterns and Timings

- **Good-quality fossil records indicate a variety of patterns of extinction**
- **The rock record can be misleading**
- **Gradual extinctions might look catastrophic**

Signor–Lipps effect

- **Paleontologists will never find the very last fossil of a species.**
- **Signor and Lipps showed how this backward smearing now termed the Signor–Lipps effect**

Selectivity and mass extinctions

- **The second defining character of mass extinctions was that they should be ecologically catholic**
- **There should be little evidence of selectivity.**

Periodicity of mass extinctions

- **Fundamental debate has been whether each event had its own unique causes, or whether a unifying principle linking all mass extinctions might be found**

The idea of periodicity of impacts was reawakened by Rohde and Muller (2005) who argued for a 62 myr periodicity in mass extinction

34 Mass extinctions and biodiversity loss : The "big five" mass

The "big five" or the "big three"?

There is some debate about whether there were five or three mass extinctions. Key points about three of the five events .

1. *End-Ordovician* mass extinction

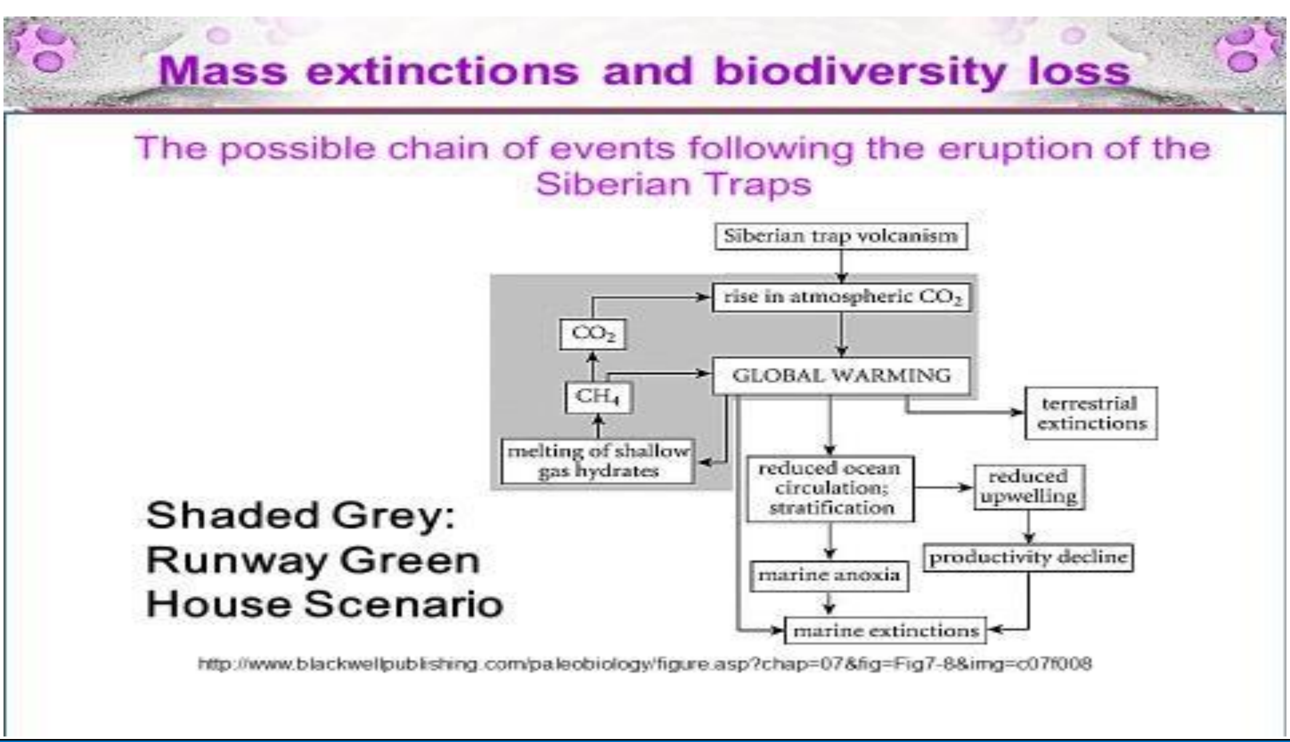
- 445 Ma
- Substantial turnovers occurred among marine faunas. Reef-building animals, brachiopods, echinoderms, ostracodes trilobites died out
- Major Climatic changes, Tropical-type reefs and their rich faunas lived around the shores of North America that then lay around the equator. Southern glaciation and lowering sea levels globally

2. *Late Devonian* mass extinction

- A succession of extinction pulses 380 to 360 Ma.
- The cephalopods were decimated.
- Causes: A major cooling phase associated with anoxia or an extraterrestrial impact

3. The End Permian/ Permo-Triassic (PT)

- The end-Permian, or Permo-Triassic, extinction was the most devastating of all time.
- Less understood than KT event.
- The peak of eruptions by the Siberian Traps was dated at 251 Ma, matching precisely the date of the PT boundary.
- Environmental changes studies of stable isotopes (oxygen, carbon) in those rock sections revealed a common story of environmental turmoil.



35 Mass extinctions and biodiversity loss : The Cretaceous-Tertiary event

4. ***The end-Triassic*** **mass extinction**

- The fourth of the big five mass extinctions
- A marine mass extinction event at, or close to, the Triassic- Jurassic boundary, 200 Ma
- Anoxia and global warming due to Volcanic eruptions

5. The End-Cretaceous/ Cretaceous-Tertiary (KT) events

<u>The KT event</u>

- Intense scrutiny since 1980: Reasonable theories (global climate change, change in plants, impact, plate tectonic movements, sealevel change)
- June 1980, paper in Science by Luis Alvarez and colleagues. 10 km meteorite (asteroid) had hit the Earth. The impact threw up a great cloud of dust that encircled the globe
- An unusual clay band right at the KT boundary, within a succession of marine limestones
- **Iridium spike:** where the iridium content shot up from normal background levels

- Alvarez Predictions: 150KM crater, 10 KM Diameter of Meteorite
- 1991, Crater was identified in Chicxulub in Mexico
- Catastrophic Extinction in plants, lower level of pollens, sudden loss of angiosperms and replacement with ferns. Progressive return to Microflora

Another Alternative

- **The gradualist model:** Extinctions occurred over long intervals of time as a result of climatic changes
- On land, subtropical lush habitats with dinosaurs gave way to strongly seasonal, temperate, conifer-dominated habitats with mammals

Third school of Thought

Volcanic activity: The Deccan Traps in India represent a vast outpouring of lava that occurred over the 2–3 myr spanning the KT boundary

36 The origin of life

RNA world:

By fusion of organic molecules in the first billion years after the formation of the Earth. Self-replicating RNA "RNA world"

The Origin of Life

Photosynthesis by a group of bacteria, called cyanobacteria, generated molecular oxygen (O2). The atmosphere became oxygenated

Three great domains

- By gene sequencing of modern organisms,
- Bacteria, Archaea and Eucarya
- The first two are prokaryotes, the last eukaryotes

The Earliest Fossils

Bacteria in rocks up to 3.2 Ga, indicated by stromatolites. Structures built by alternating algal mats and sediment layers **Cellular Organism**

Cellular fossils 3.5 Ga are highly controversial. The first widely accepted cellular fossils date from 2.5 Ga

Origin of Eukarya

Lipids Biomarkers, evidence for cyanobacteria and eukaryotes 2.7 Ga. The oldest eukaryotes, 1.9 Ga

Origin of Sexes

Red algae from 1.2 Ga show that sex had originated. They show mitosis, but also meiosis, which is unique to sexual reproduction

Origin of Multicellularity

Together with sex came multicellularity. The possession of many, often specialized, cells, first seen in 1.2 Ga red algae

37 The origin of life : Scientific Methods

Scientific models

Some of them now rejected by the evidence. Others still available as potentially valid hypotheses:

- Spontaneous generation
- Inorganic model
- Extraterrestrial origins
- Biochemical model
- Hydrothermal model

Spontaneous generation

- Medieval scholars
- Organisms sprang into life directly from nonliving matter
- Pasteur, 1861
- Meat in airtight containers: maggots did not appear

The inorganic model

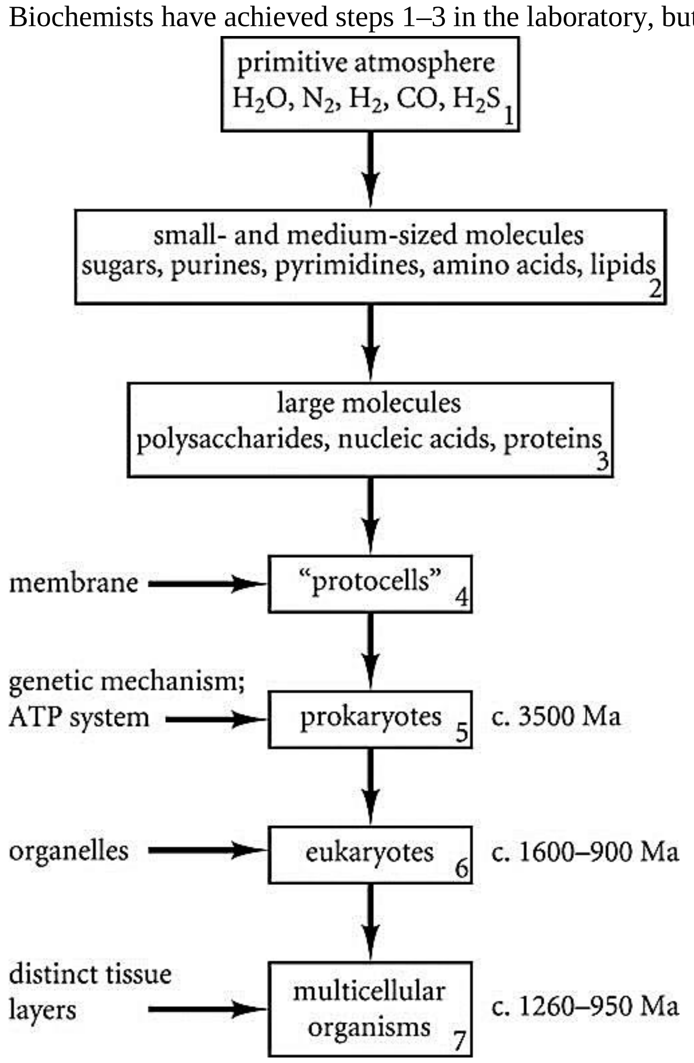
- Complex organic molecules arose gradually on a pre-existing, non-organic replication platform
- Silicate crystals
- Graham Cairns-Smith of Glasgow University, 2007
- not conclusive

Extraterrestrial Model:

- The building blocks for life were seeded on Earth from outer space
- Simple organic molecules in meteorites called carbonaceous chondrites
- Panspermia
- 1996, David McKay

Biochemical Model

- 1920s, independently
- Russian biochemist, A. I. Oparin
- British evolutionary biologist, J. B. S. Haldane
- Life could have arisen through a series of organic chemical reactions that produced ever more complex biochemical structures
- Biochemical theory of Origin of Life
- The biochemical theory for the origin of life, as proposed by Oparin and Haldane in the 1920s.
- Biochemists have achieved steps 1–3 in the laboratory, but scientists have so far failed to create life.



Hydrothermal Model

- Modification to the Oparin–Haldane biochemical model

- The last universal common ancestor of life (LUCA) was a hyperthermophile, a simple organism that lived in unusually hot conditions.
- Seawater mixes with molten magma and emerges as superheated steam, with the sulfur in it now concentrated as sulfide
- Emerging hot-water plume black
- Black smokers

38 The origin of life: Testing the Biochemical Method

Stanley Miller

In 1953, then a student at the University of Chicago, made a model of the Precambrian atmosphere and ocean in a laboratory glass vessel . Exposed a mixture of water, nitrogen, carbon monoxide and nitrogen to electric sparks, to mimic lightning, found a brownish sludge in the bottle after a few days.

Brownish Sludge

Contained sugars, amino acids and nucleotides. Researchers consider the mixture of gases that Miller used was strongly chemically reducing

Further Experiments

In 1950s and 1960s led to the production of polypeptides, polysaccharides and other larger organic molecules

Protocells of Sidney Fox

FSU, Succeeded in creating cell-like structures, in which a soup of organic molecules became enclosed in a membrane. Didn't survive for long

39 The origin of life: RNA World

Precellular Life

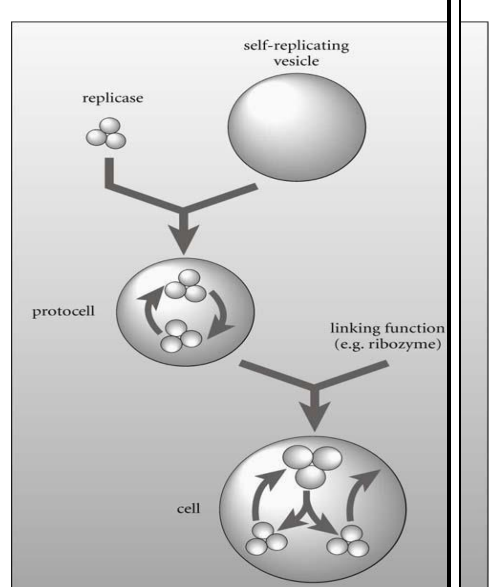
The transition from non-living to living. No a single Step. Widely accepted view "RNA World"

RNA

RNA, or ribonucleic acid, is one of the nucleic acids and it has key roles in protein synthesis. The genetic code. There are several different forms of RNA

RNA the Precursor

In 1968, Francis Crick suggested that RNA was the first genetic molecule. RNA has unique property of acting both as a gene and an enzyme. RNA could act as a precursor of life



RNA World

Walter Gilbert first used the term "RNA world" in 1986. The first evidence. Sidney Altman and Thomas Cech.

Ribozyme

An RNA that could edit out unnecessary parts of the message it carried before delivering it to the ribosome. Cech called his discovery a ribozyme

Chasing Evidence

Since 1990, Jack Szostak and colleagues argued that the first RNA molecules on the prebiotic ("before life") Earth were assembled from nucleotides dissolved in rock pools

RNA Replicase

One RNA acted as a Template and another Enzyme. Combine as an RNA replicase. Szostak and colleagues proposed a second precellular structure, "A self-replicating vesicle"

Protocell

A membrane-bound structure composed mainly of lipids that self-replicates. The RNA replicase entered a self-replicating vesicle. RNA replicase to function efficiently

The model behind "RNA world", where an RNA replicase and a self-replicating membrane-bound vesicle combine to form a protocell

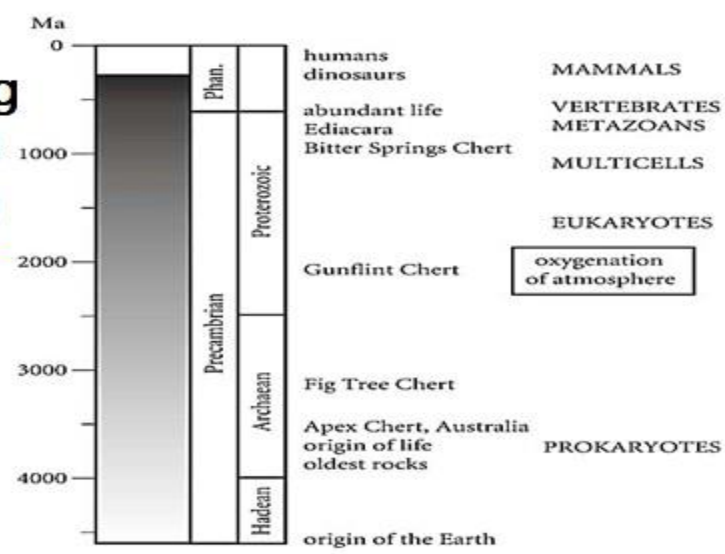
40 The origin of life : Evidence for the origin of life

The Early Precambrian world The Precambrian is divided into

- Hadean eon
- Archaean eon
- Proterozoic eon

Hadean Eon spans from the origin of the Earth, 4.57 to about 4 Ga

Time scale showing major events in the history of the Earth and of life. Most of the time scale is occupied by the Precambrian



Precambrian world

Beginning of the Hadean. Temperatures on surface were too high. The crust was too unstable for any form of carbonbased life to exist

Cooling of Earth

As the Earth's surface cooled, the lithosphere, its rocky crust, began to differentiate as a cooler upper layer above the underlying asthenosphere.

Oldest Rocks

The oldest rocks are from Canada and are dated at 3.8–4 Ga, and some mineral grains from Australia have even been dated to 4.4 Ga

The Archaean Eon

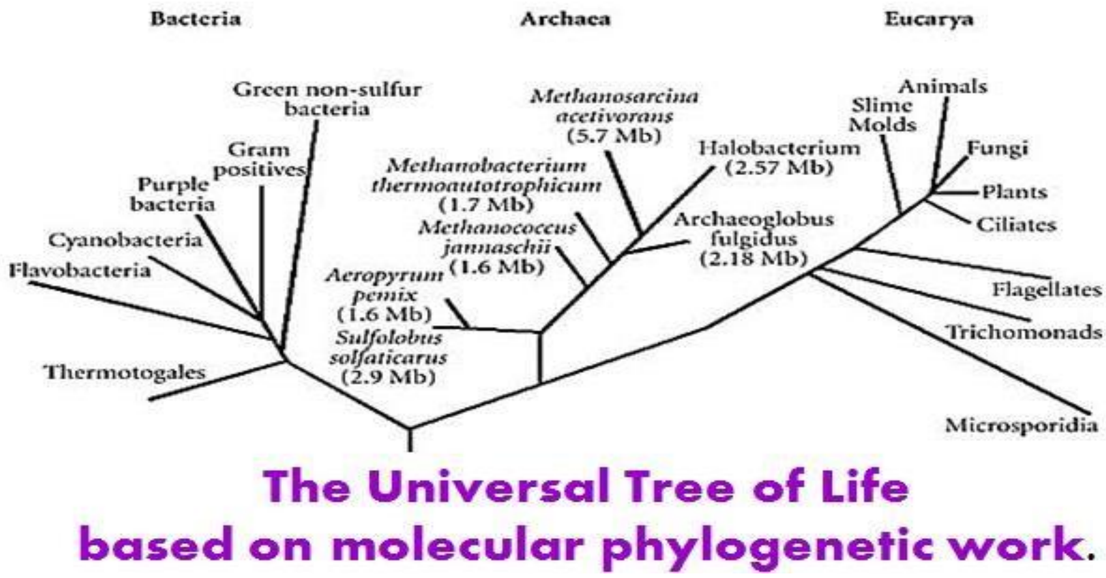
Lasted from about 4 to 2.5 Ga. The oldest sedimentary rocks from the Isua Group in Greenland, dated at 3.8–3.7 Ga. Rosing and Frei (2004), Reported values of δ13C in organic matter from the Isua Group rocks that match those of modern living organic matter.

The Great Oxygenation Event

The Proterozoic Eon, from 2.5 Ga to 542 Ma. 2.4 Ga, atm oxygen levels rose to one-hundredth or one-tenth of modern levels

A Second Rise of Oxygen

Around 0.8–0.6 Ga is indicated by increased levels of marine sulfate. The two rises in oxygen levels, at the beginning and end of the Proterozoic



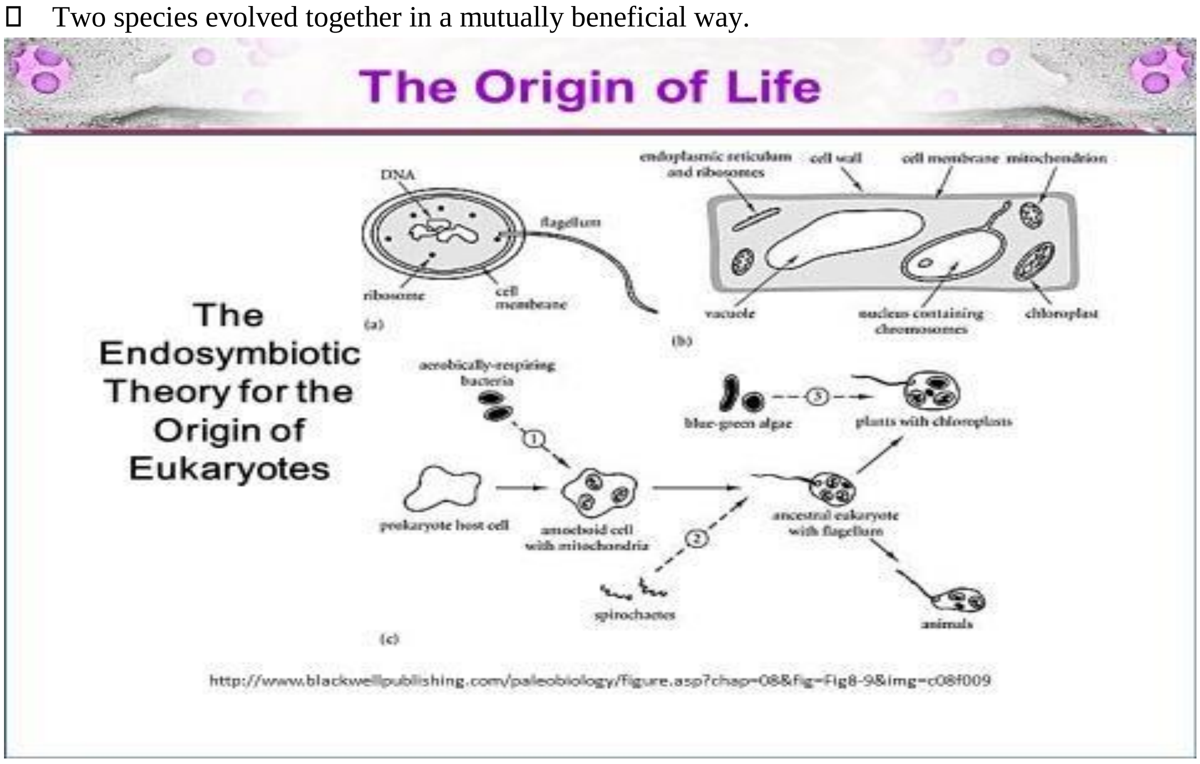
41 The origin of life: Life diversifies: eukaryotes

Eukaryote Characters

- Evidence about the earliest evolution of the three domains is scant
- Nucleus: DNA in chromosomes
- Cell organelles

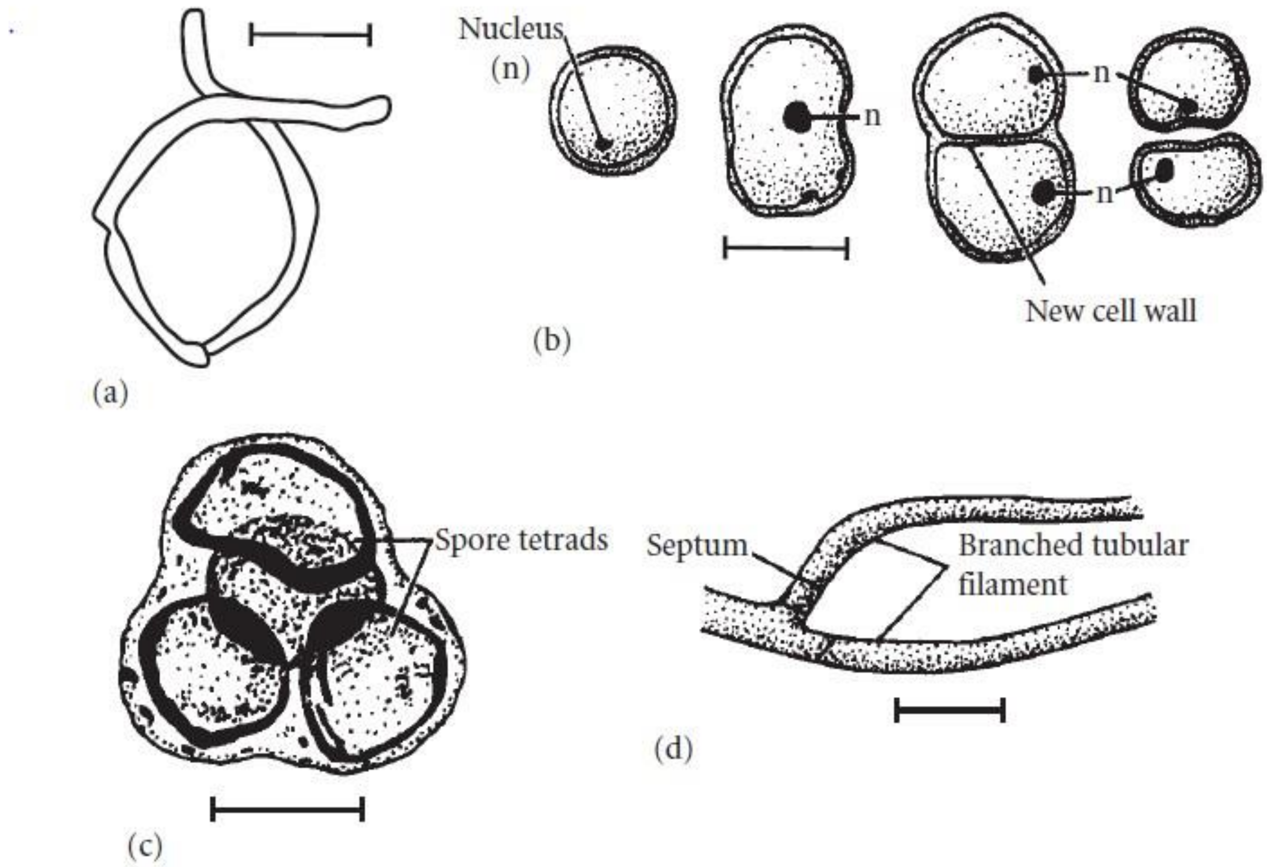
Endosymbiotic Theory

- Margulis: 1970s.
- Prokaryote consumed, or was invaded by, prokaryotes .
- Two species evolved together in a mutually beneficial way.



Basal Eukaryotes

- The oldest eukaryote is controversial Lipid biomarkers indicate that eukaryotes were around at least by 2.7 Ga
- The oldest eukaryote fossil may be Grypania, a coiled, spaghetti-like organism that has been reported from rocks as old as 1.85 Ga



•

Multicellularity and sex

True multicellular organisms arose only among the eukaryotes. Allowed plants and animals to become large (kelp, reach lengths of tens of meters). Sexual reproduction involves the exchange of gametes (sperms and eggs) between organisms **Bangiomorpha**

One of the oldest multicellular organisms/eukaryote is Bangiomorpha 1.2 Ga. Multicellular and a member of a modern group that engages in sex.

42 Protists : Protista: introduction

Micropaleontology

- **A multidisciplinary science, focused on the study of microorganisms or the microscopic parts of larger organisms.**

Prokaryotes

- **Unicellular microbes lacking nuclei and organelles, include the carbonate producing cyanobacteria • Promoted an oxygen-rich atmosphere**

Protists

- **Unicellular organisms with nuclei, a variety of organisms with external protective coverings (tests and cysts) • Kingdoms Protozoa and Chromista**

Fossilized Protists

- **Split into**
- **Organic (acritarchs, dinoflagellates, chitinozoans),**
- **Calcareous (coccolithophores, foraminiferans)**
- **Siliceous (diatoms, radiolarians)**

Foraminifera

- **Single-celled animal-like protozoans**
- **Contain both benthic and planktonic form**
- **With chitinous, agglutinated tests throughout the Phanerozoic**

Rock Formers

- **Radiolarians: animal-like protozoans with siliceous tests,**
- **Diatoms: plant-like protozoans with silicic skeletons**
- **Both important rock formers.**

43 Protists: Kingdom Protista

Kingdom Protista

- **Single-celled organisms with nuclei and organelles • Autotrophs • Heterotrophs •**
- **The Protista is a convenient grouping but it is not well defined • Subdividing the diversity of protists is equally problematic • On the basis of Trophism • Phylogenetic • Mode of locomotion**
- **Flagellates and Amoebans**

The First Protists

- **Heterotrophs, but chloroplasts were acquired separately in at least six lineages, producing autotrophs, • Lost secondarily even more often • Groups with microfossil records are widely scattered across the diversity of protists • Modern molecular genetic and cytologic research**

44 Protists : Protozoa

<u>Protozoa</u>

Neither animal nor plant, but single-celled eukaryotes that show animal characteristics such as motility and heterotrophy. Able to form cysts.

<u>Foraminifera</u>

Foraminifera are shelled & heterotrophic, Phanerozoic sedimentary rocks, Considerable bio stratigraphic and paleoenvironment-al value.

<u>Radiolaria</u>

The radiolarians are marine, unicellular, planktonic protists with delicate skeletons. Usually composed of a framework of opaline silica. Origin in the Mid Cambrian or earlier, became common in the Ordovician. Often found in deep-sea cherts associated with major subduction zones. Radiolarian cherts commonly occur in oceanic facies preserved in mountain belts, associated with ophiolites, origins and destruction of ancient ocean systems

<u>Acritarchs</u>

A mixed bag of entirely fossil, hollow, organic-walled microfossils that are impossible to classify. The acritarchs are probably polyphyletic

<u>Dinoflagellates</u>

The dinoflagellates, or “whirling whips”, comprise a group of microscopic algae with organic-walled cysts. Dinoflagellate biomarkers have been identified in Upper Proterozoic and Cambrian rocks. A number of Paleozoic acritarch taxa may in fact be dinoflagellates

<u>Ciliophora</u>

Consist of some 8000 species of single-celled organisms that swim by beating cilia. Tithonian (Upper Jurassic) to the Albian (Middle Cretaceous)

45 Protists : Chromista

Chromistans

A paraphyletic group of eukaryotes that usually contains chloroplasts with chlorophyll c. Chlorophyll c is absent from all known plant groups. The group includes various algae, the coccolithophores and the diatoms. Primary producers, functioning as part of the phytoplankton

Nannoplankton

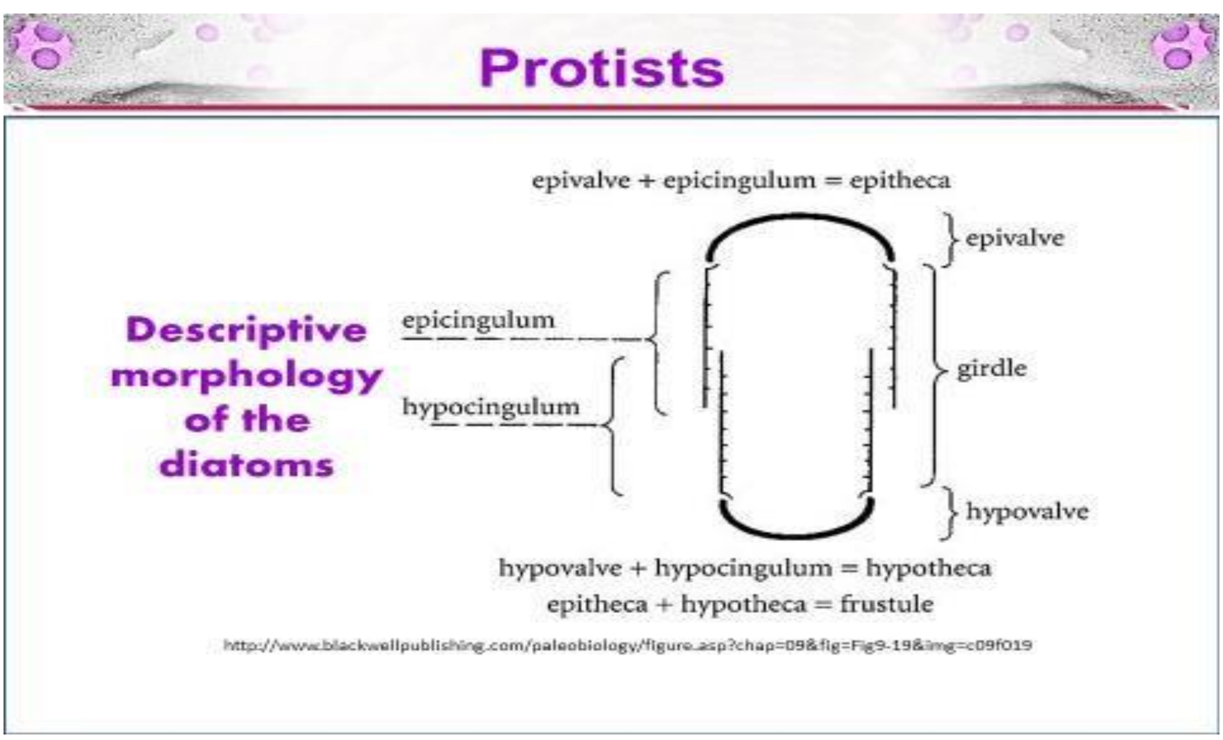
Defined as plankton less than 63 µm across, the smallest standard mesh size for sieves. Includes organic-walled and siliceous forms

Coccolithophores

- Dominant members of the fossil calcareous nannoplankton, and calcareous plates, Coccoliths.
- Dominate nannofossil assemblages, Calcareous nannoplankton.
- Appeared: Late Triassic
- Increased: Jurassic and Cretaceous
- Reaching an acme of diversity: Late Cretaceous
- Severely affected: KT mass extinction
- Radiated: Early Paleogene and throughout the Cenozoic
- Extremely abundant: Modern oceans

46 Protists : Chromista Diatoms

Diatoms

- Unicellular autotrophs that are included among the Chrysophyte algae characterized by large green-brown chloroplasts. Both individuals and loosely integrated colonies. Saline to freshwater.
- **The Centrales –** prefer marine environments;
- **The Pennales –**more common in freshwater lakes
- Diatom frustules, Endospores: preserved in fossil record
- 

Range of temperatures. Common: **Antarctic plankton**.

First diverse floras: mid-Cretaceous,10 families from Aptian rocks. 100 genera of centric diatoms: the Upper Cretaceous. The first pennate diatoms appeared during Paleogene colonizing freshwater for the first time. The group reached an acme during the Miocene.

47 Origin of the metazoans

Fossil evidence

Few basic body plans have appeared in the fossil record, most animals have triploblastic architecture. Three fundamental body layers.

Molecular Data

Show three main groupings of animals:

- Deuterostomes
- Spiralians
- Ecdysozoans

Spiralians and Ecdysozoans:

the protostomes. **Three Groups**

- The deuterostomes (echinoderm–hemichordate–chordate group)
- The Spiralians (mollusk–annelid–brachiopod–bryozoans group)
- The ecdysozoans (arthropod–nematode–priapulid plus other taxa group)

Five lines of evidence

- Body fossils
- Trace fossils
- fossil embryos
- The mol. Clock
- Biomarkers

Suggest metazoans originated before Ediacaran 600 Ma

Coincidence or Design

Snowball Earth by coincidence or design was a pivotal event in metazoan history; bilaterians evolved after the Marinoan glaciation.

The First Metazoans

Probably similar to the demosponges, occurring first before the

Ediacaran **The Ediacaran Biota**

- A soft-bodied assemblage of uncertain affinities
- Reaching its acme: the Late Proterozoic
- Earliest ecosystem having large, multicellular organisms

Cambrian Explosion

The Cambrian explosion generated a range of new body plans during a relatively short time interval.

Ordovician Radiation

Marked by accelerations in diversification at the family, genus and species levels along with complexity in marine communities.

48 Origin of the metazoans : Origins

Precambrian life

Evidence of metazoan body and trace fossils. The investigation of minute fossil embryos. Carefully calibrated molecular clocks. Biomarkers

Metazoan Life

Molecular data suggest metazoans have been around for at least 600 myr. During which time as many as 35 separate phyla have evolved. Recalibrated molecular clocks. Animal origins be tracked back only to the Ediacaran, when there was also a sudden rise in oxygen levels in the deep ocean

Body Fossil Evidence

Earliest metazoans occur in Ediacara biota 600–550 Ma. Significant Proterozoic record for the cnidarians and sponges **Trace Fossil Evidence**

The oldest locomotory trace fossils are from about 550 Ma northwest Russia. Fecal strings from rocks some 600 Ma suggesting. Digestive system

Embryo Fossil Evidence

Best studied example: Doushantuo Formation, South China 580 Ma. Earliest body fossil evidence for metazoan life

Molecular Evidence

Molecular clock, the metazoan clade excluding the sponges and cnidarians, has been placed at anywhere between 900 and 570 Ma

Biomarker Evidenc

Biomarkers, essentially the biochemical fingerprints of life. BMs associated with metazoan demosponges from rocks older than the Ediacaran

49 Origin of the metazoans : Invertebrate body and skeletal plans

Invertebrate Body & Skeletal Plans

Body plans are usually defined by the number and type of enveloping walls of tissue together with the presence or absence of a **Celom**. The first metazoans were multicellular with one main cell type & **peripheral collar cells or choanocytes**, with a whip or **flagellum**.

The Parazoan Body Plan

Seen in **sponges**, characterized by cells organized in two layers separated by jelly-like material punctuated by so-called wandering cells or amoebocytes

The Diploblastic Body Plan

Cnidarians and the ctenophorans. Two layers are separated by acellular mesogloea

- an outer ectoderm
- an inner endoderm

The Triploblastic Body Plan

Seen in most other animal. Has three layers of tissues from the outside in: the ectoderm, mesoderm and endoderm.

Bilateral Symmetry

Defines the bilaterians. The development of the celom or body cavity characterizes Most of the animal groups found as fossils

Skeleton

The skeleton is an integral part of the body plan of an animal, providing support, protection and attachment for muscles **Hydraulic Skeleton**

Many animals such as the soft-bodied mollusks (slugs) possess a hydraulic skeleton in which the movement of fluid provides support

Rigid Skeletons

Mineralized material

- may be external (exoskeleton) in the case of most invertebrates
- Internal (endoskeleton) structures, in the case of a few mollusks

Skeleton Growth

Growth is accommodated in a number of ways. Most invertebrate skeletons grow by the addition of new material, a process termed accretion. Arthropods, however, grow by periodic bursts between intervals of ecdysis or molting

50 Origin of the metazoans : Classifications and Relationships

Classification

Based on purely morphological data and embryology has problems. Difficulties in establishing homologous characters and homoplasy

Basal Eumetazoans

The demosponges and calcisponges are the simplest animals. The cnidarians are the most basal eumetazoans

Three Groups

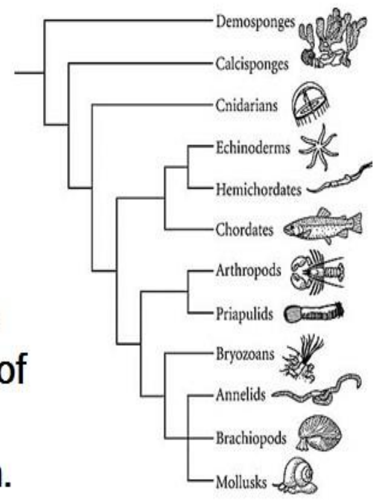
Three robust bilaterian groupings are recognized mainly on molecular data

- Ecdysozoans,
- Spiralians
- Deuterostomes

Protostomes

Ecdysozoans, spiralians comprise the protostomes. "First mouth" mouth develops directly from the blastopore. By cell growth and migration` **Deuterostomes** "Second mouth" however, have a mouth arising from a secondary opening. True blastopore develops as anus. Echinoderm–Hemichordate-Chordate

The locator tree outlines some of the main features of animal evolution.



Larval Types

Invertebrate larvae are occasionally identified in the fossil record. More advanced preparatory and high-tech investigative techniques

- Nauplius larva: crustaceans
- Planula: cnidarians
- Trochophore larva: mollusks and the polychaetes
- Shelled veliger: mollusks

Evolutionary Faunas

51 Origin of the metazoans : Four key faunas

The three great evolutionary faunas of **Phanerozoic, Cambrian, Paleozoic** modern Developed during last 550 myr. The **Ediacara biota**, Faunas during **Cambrian** explosion & **Ordovician** radiation set the scene for life on our planet.

Ediacara Biota

The Ediacaran biota consisted of enigmatic tubular and frond-shaped, mostly sessile organisms that lived during the Ediacaran Period (ca. 635–542 Mya)

- First impressions of soft-bodied organisms
- Upper Proterozoic rocks of Namibia
- In the Pound Quartzite
- In the Ediacara Hills, north of Adelaide
- Shallow-water siliciclastic sediments
- Soft-bodied, with high SA/V ratios
- Radial or bilateral symmetries
- Extinct about 550 Ma

Cambrian Explosion

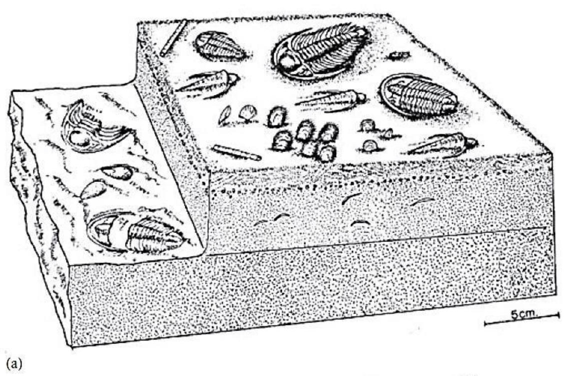
- Cambrian radiation
- Relatively short span event 20my
- 541 million years ago
- Most major animal phyla appeared

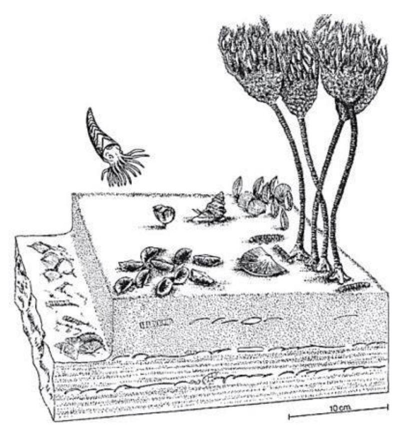
Generated many entirely new and spectacular body plans. Sequential appearance of successively more complex metazoans. Phylogenetic analysis shows metazoans evolved monophyletically from flagellated colonial protists similar to modern choanoflagellates.

52 Origin of the metazoans : Ordovician Radiation

Ordovician Radiation

- Great Ordovician biodiversification event (GOBE),
- Evolutionary radiation of animal life during the Ordovician Period, 40 my after the CE.
- Followed a series of Cambrian–Ordovician Extinction events
- Fauna went on to dominate the Palaeozoic
- Marine diversity increased
- The majority of "Paleozoic" taxa were derived from Cambrian stocks
- Interplay of many geological and ecological factors likely produced the diversification



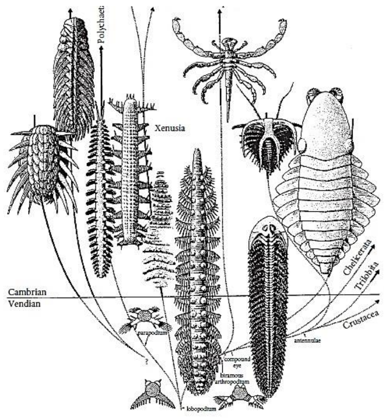


- Ordovician diversification generated witnessed a staggering increase in biodiversity at the family, genus and species levels.
- E.g. **The Ordovician Seafloor, The Cambrian Seafloor**

53 Origin of the metazoans : Soft-bodied invertebrates

Inadequate Fossil Record

- Out of 25 or so commonly recognized animal phyla fewer than nine (35%) have an adequate fossil record
- A number of larger soft-bodied phyla lack a preservable skeleton
- Soft-bodied forms are preserved in fossil Lagerstätten
- Significance of the diverse worm-like animals at the Precambrian–Cambrian boundary and the postulated origins of some major clades



Burgess Shale

Burgess Shale and other exceptionally preserved faunas suggests that many of these soft-bodied groups dominated certain marine paleocommunities

Platydendron

The platyhelminths or the flatworms are bilateral animals. *Platydendron* from the Middle Cambrian Burgess Shale has been ascribed to the platyhelminthes

Polychaetes

A diverse polychaete fauna has been described from the Burgess Shale. Even contains *Canada spinosa* . Similar to some living polychaetes. Paddle worms: most complete fossil record. Record is enhanced by the relatively common preservation of elements of the phosphatic jaw: scolecodonts

54 The basal metazoans: sponges and corals

Parazoa

Parazoans are metazoans composed of multicellular complexes with few cell types and lack variation in tissue or organs.
I.e. The sponges (Phylum Porifera). Two groups, the Porifera and the Cnidaria, form the basal parts of the metazoan tree, diverging during Neoproterozoic. Important parts of the planet's reef ecosystems

Sponges

Sponges are filter-feeding members of the sessile benthos. Contains a variety of grades of functional organization. Sponge reefs dominated: Phanerozoic. Calcareous grades. Siliceous sponges were important reef builders: Mesozoic **Stromatoporoids**

A grade of organization within the Porifera with a secondary calcareous skeleton. Important in reefs during the midPaleozoic and mid-Mesozoic

Archaeocyaths

- Cambrian organisms of sponge grade
- Mainly solitary
- Developed branching, modular growth
- Successfully built reefs in unstable environments

Cnidarians

The simplest of the higher metazoans with a radial diploblastic body plan and stinging cells or cnidoblasts. Sea anemones, jellyfish and hydra along with Corals

Reef-Type Structures

Reef-type structures were already present in the Late Precambrian hosting large, robust, colonial organisms. Reef development through time has waxed and waned. Dominated at different times by different groups of reef-building organisms

Coloniality

Evolved many times. One hypothesis suggests that a Precambrian colonial organism may have been a source for the bilaterians

55 The basal metazoans: sponges and corals : Porifera

Porifera:

Dr Robert Grant "Porifera is a unique group in its own right". Unique porous structure and cellular body plan, lack true tissues . Most lack symmetry, true differentiated tissues, and organs, although their cells, like those of the protists, can switch function

Skeleton

Sponges are skeletal organisms. Skeletons are composed of a colloidal jelly or spongin

Chamber Organization

Three levels

1. Ascon: Sacs with a single chamber lined by flagellate cells
2. Sycon: a number of simple chambers with a single central paragaster.
3. Leucon: most common where a series of sycon chambers access a large central paragaster

Stromatoporoidea

Common in the fossil record from the Ordovician through the Devonian. Especially abundant in the Silurian and Devonian. These invertebrates were important reef-formers throughout the Paleozoic and the Late Mesozoic

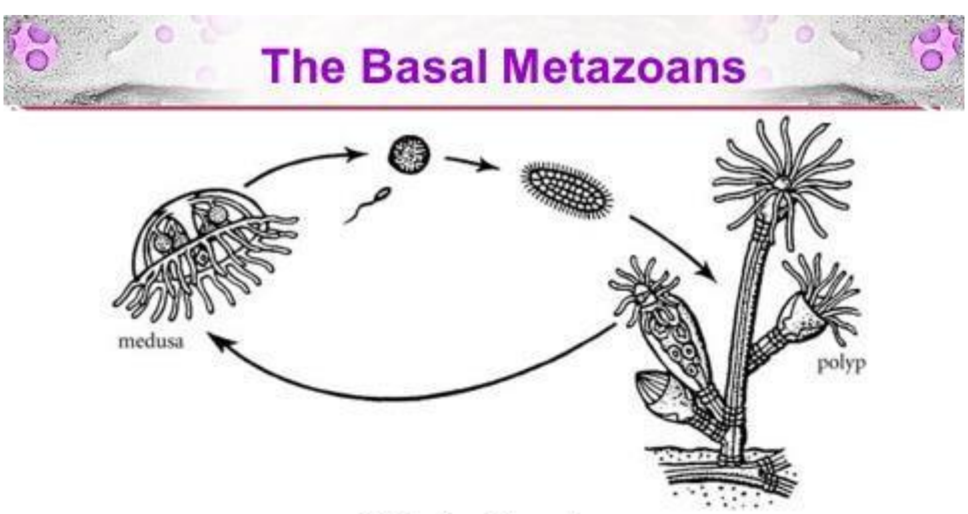
Archaeocyatha

"Ancient cups" are one of only a few major animal groups that are entirely extinct. Reef-building marine organisms of warm tropical and subtropical waters . Lived during the early (lower) Cambrian Period. It is believed that the center of the Archaeocyatha origin are now located in East Siberia

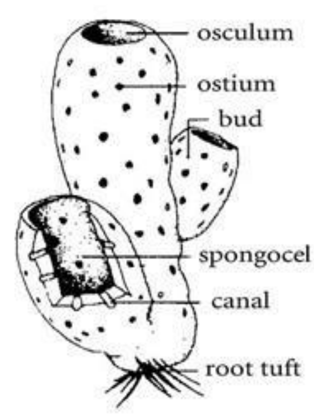
56 The basal metazoans: sponges and corals : Cnidaria

The Cnidarians

"Nettle-bearers". Include the Sea anemones, jelly fish, corals. The least complex of the true metazoans (eumetazoans). Few tissue types in a radial plan. Although there are no specialized organs and only a few tissue types, they are more complex than the parazoans . Two basic life strategies



Cnidarian life cycles
generalized view of the life of the hydrozoan Obelia, alternating between the conspicuous polyp and medusa stages
http://www.blackwellpublishing.com/paleobiology/figure.asp?chap=11&fig=Fig11-17&img=c11f017



Basic Sponge Morphology

- **Polyps**: sessile
- **Medusae**: swim,

Medusoids and polyps appear different, they are essentially same inverted structures. Cnidarian life cycles generalized view of the life of the hydrozoan Obelia, alternating between the conspicuous polyp and medusa stages

Class Hydrozoa

Polymorphic forms. Undivided enteron, solid tentacles, colonies. Chondrophora oldest cnidarians. Ediacaran to Recent **Class Scyphozoa**

Jellyfish, Lagerstätten. The extinct Conulata. Appeared in Cambrian. Extinct in Mid Triassic. Ediacaran to Recent

Class Anthozoa

Marine, sessile, colonial forms. Mobile planula larvae. Octocorallia class includes corals, sea anemones. Produce spicules microfossils. Ediacaran to Recent

Class Cubozoa

The sea wasps and box jellyfish. Both medusae and polyps. Restricted to tropical and subtropical latitudes. Carboniferous to Recent

Corals

Most diverse and most threatened ecosystems. The coral reef. Shallow-water coral reefs in zone extending 30° north and south of equator. 30m or 18 °C

57 Spiralians 1: lophophorates

The Spiralians

Morphologically diverse clade of protostome animals

- Molluscs
- Annelids
- Platyhelminths and other taxa

Lophophores

Lophophores, a filamentous feeding organ. Three spiralian invertebrate groups

- Brachiopods
- Bryozoans
- Phoronids

Brachiopods

- Twin-valved shellfish,
- Lophophore and a pedicle,
- Linguliformeans: organophosphatic shells
- Craniiformeans & rhynchonelliformeans: calcareous shells

Paleozoic Communities

Orthides and Strophomenides. Rhynchonellides and Terebratulides were in Lower-diversity post-Paleozoic brachiopod assemblages. Brachiopods dominated the filter-feeding benthos of the Paleozoic. Never fully recovered during the endPermian mass extinction

Living Brachiopods

Living brachiopods are relatively rare, occupying mostly cryptic and deep-water habitats.

Bryozoans

Colonial invertebrates with Lophophores. Displaying marked non-genetic variation across a wide range of environments **Stenolaemata**

Dominated Paleozoic bryozoan faunas. Only the cyclostomes surviving the combined effects of the end-Permian and endTriassic mass extinctions. Stenolaemata are a class of marine bryozoans. This class originated in the Ordovician, and members still live today. All extant species are in the order Cyclostomatida

Cyclostomes

Cyclostomes continued to decline after the end-Cretaceous extinction event. Cheilostomes radiated to dominate Cenozoic assemblages

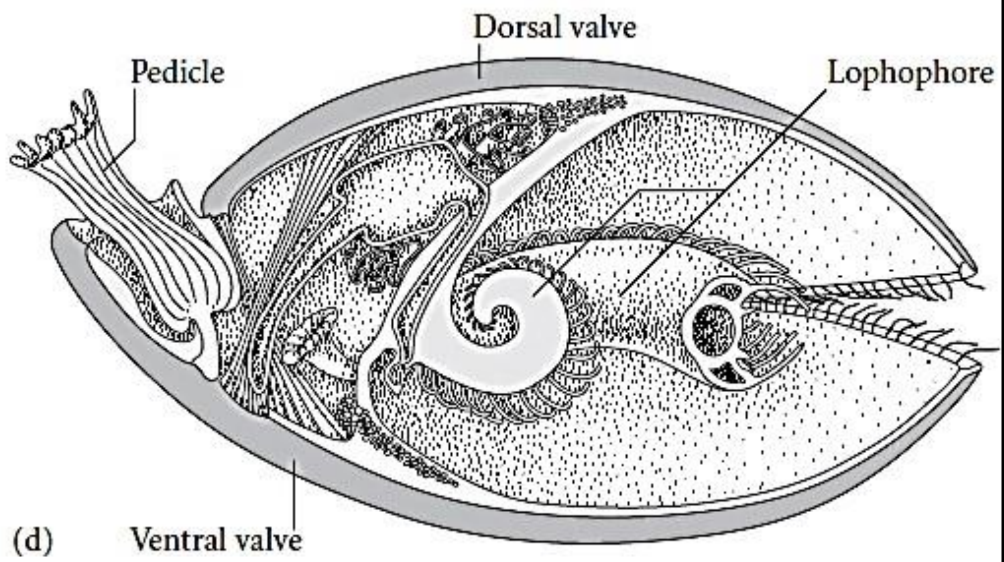
58 Spiralians 1: lophophorates : Brachiopoda

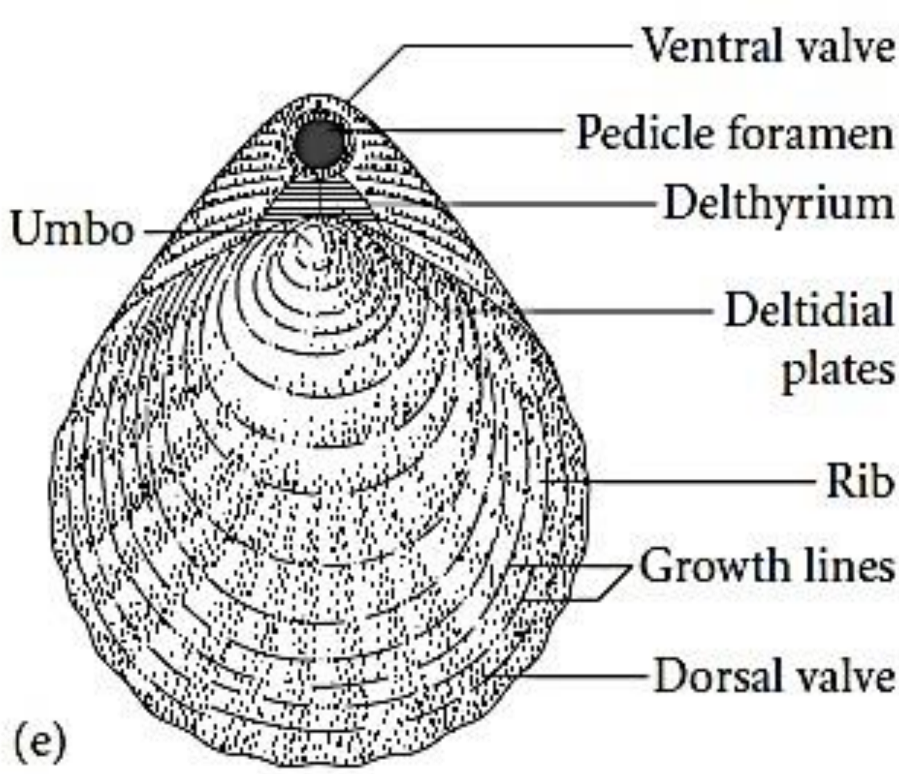
Brachiopoda

- Most successful invertebrate phyla
- Appeared: Early Cambrian
- Diversified: Paleozoic
- Dominate the low-level, suspension feeding benthos

Morphology

The brachiopod soft parts are enclosed by two morphologically different shells or valves with variety of muscles. The ventral or pedicle valve is larger





Distribution in time

- Cambrian

- Paleozoic

Modern brachiopod faunas, Fundamentally different. A dominance of different orders

Cambrian Faunas

Dominated by a range of non-articulated groups with groups of disparate articulated taxa

- Chileides
- Naukatides
- Obolellides etc

Ordovician Radiation

- Deltidiodont, Orthides and Strophomenides
- First evolved: Early Ordovician island complexes
- Dominated the shelf benthos & basis of the Paleozoic brachiopod fauna.

59 Spiralians 1: lophophorates : Brachiopoda — Five extinction events

Five Main Extinctions

The brachiopods experienced five main extinction events. Followed by recoveries and radiations of varying magnitudes

The End-Ordovician Event

Occurred in two phases, glaciation & loss of almost 80% of brachiopod families. Decline of deltidiodont groups. Dominance of the spiriferides pentamerides

Late Devonian events

Climate change. Removed the Atrypides & Pentamerides. Severely affected Orthides & Strophomenides. Spiriferides & Rhynchonellides survived in deeper-water environment

Carboniferous Era

Intervals of spectacular experimentation. Mimicked corals or developed extravagant clusters of spines. Reduced shells, presenting soft tissues to outside environment.

End-Permian Mass Extinction

Demise of over 90% of brachiopod species, disaster taxa including lingulids, later diversified within a few clades dominated by the rhynchonellides and terebratulides

End-Triassic Event

Removed the majority of the remaining spiriferides and the last strophomenides. Dominance of Rhynchonellide and terebratulide groups

Modern Brachiopods

Exhibit a remarkable range of adaptations based on a simple body plan and a well defined role in the fixed, low-level benthos.

60 Spiralians 1: lophophorates : Bryozoa

Bryozoans

All species are colonial. Skeletons fragment easily after death, least well-known invertebrates, 6000 living & 16,000 fossil species, marine. Superficially resembling the corals and hydroids, "Moss animals", Filter feeders, Sieve food particles using a retractable lophophore. The genus *Bowerbankia* is a relatively simple Bryozoan. Useful for illustrating the general anatomy of bryozoan zooids. E.g A Gymnolaemate.

Morphology

Each living zooid is enclosed by a body wall/cystid . The lophophore, with its beating cilia, A ring of 10 tentacles direct food to mouth leading into a U shaped gut. Egestion: anus

Oldest Bryozoans

Occur in the Tremadocian Stage of the Lower Ordovician. Primitive, soft-bodied bryozoans existed during the Cambrian but have not been fossilized. **Stenolaemata** dominated Paleozoic bryozoan faunas. Genera such as Monticulipora, Prasopora and Parvohallopora are typical of Ordovician assemblages. **Cheilostomes**, Polymorphic zooids, appeared during the Late Jurassic; Common in the Late Cretaceous and Paleogene of the Baltic and Denmark.

Brachiopods and Bryozoans

Members of the filter-feeding Paleozoic evolutionary fauna. Brachiopods a minor part of the Recent marine fauna but bryozoans continue to flourish

61 Spiralians 2: mollusks

Mollusks

- **The Phylum Mollusca can be traced back to at least the Late Precambrian, when *Kimberella* probably fed on algae in Ediacaran communities**

Early Mollusks

- **Characterized by some short-lived, unusual forms**
- **Molluskan features: mantle, mineralized shell and radula**
- **Members of the small shelly fauna**

Bivalves

- **Characterized by a huge variety of shell shapes, dentitions and muscle scars**
- **Adapted for a wide range of life strategies in marine and some freshwater environments**

Gastropods

- **Most gastropods undergo torsion in early life; they have a single shell, often coiled.**
- **The group adapted to a wide range of environments from marine to terrestrial.**

Cephalopods

- **The most advanced mollusks, with a head, senses and a nervous system**
- **Nautiloids, Ammonoids and the Coleoids**
- **Carnivorous**

Mollusks

- **During the Mesozoic developed a number of protective strategies**
- **Robust armor**
- **Deep infaunal life**
- **Multiformity of shape and color**

Annelid worms

- **Annelid worms were a sister group to the mollusks**
- **Their jaws, the scolecodonts, are relatively common in Paleozoic faunas**

62 Spiralians 2: mollusks : Mollusks: introduction

Phylum Mollusca

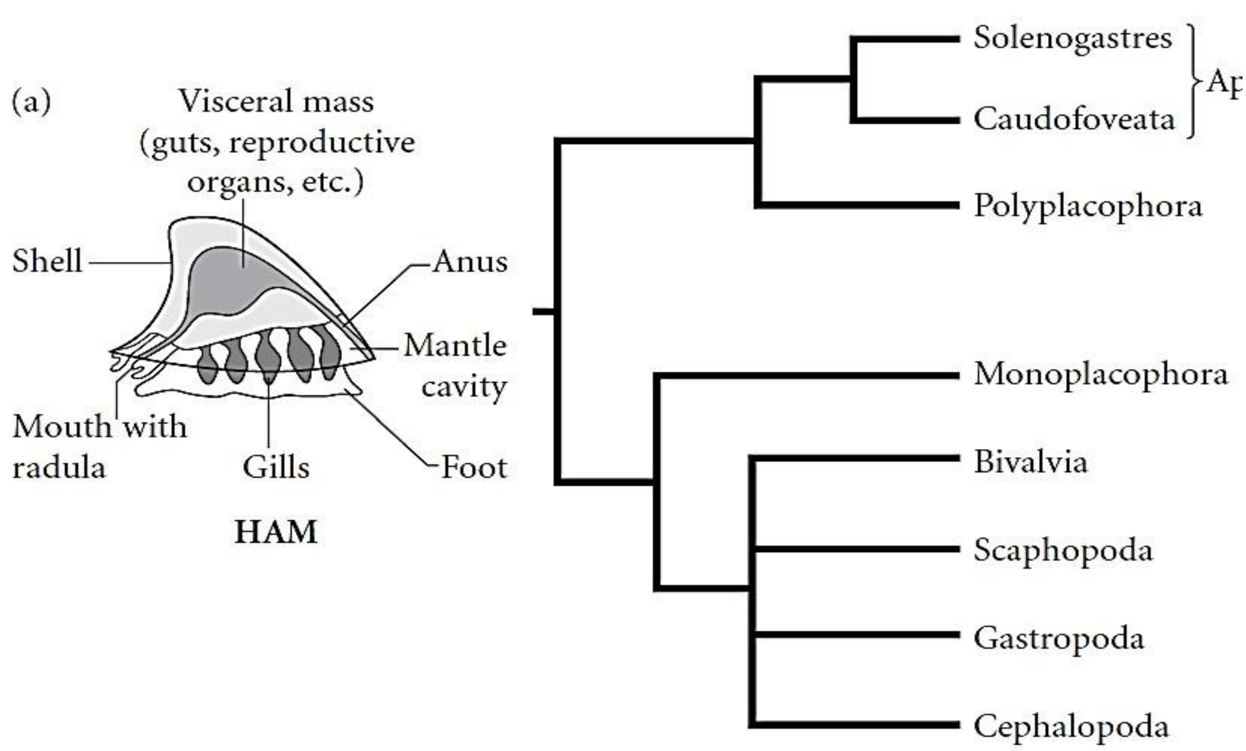
- **The Phylum Mollusca includes**
- **The slugs, snails, squids, cuttlefish and octopuses**
- **All manner of marine shellfish such as clams, mussels and oysters**
- **The most common marine animals today,**
- **Occupy wide range of habitats**
- **Abyssal depths of the oceans and intertidal mudflats**
- **Forests, lakes and rivers.**
- **Mollusks are usually**
- **Unsegmented**
- **Soft-bodied animals**
- **With a body plan based on four features**

Four Features

1. **The head contains the sensory organs, and a rasping feeding organ, the radula Composed of chitin and designed to scrape and in some cases drill.**
2. **The foot is primitively a sole-like structure on which the animal crawls, but is considerably modified in many mollusks.**
3. **The visceral mass of the digestive, excretory, reproductive and circulatory organs is enclosed in the celomic cavity.**
4. **The mantle is a sheet of tissue lying dorsally over the visceral mass that is responsible for secreting the shell.**

Molluskan shells

- **Secreted as calcium carbonate, mainly aragonite, with an organic matrix and an outer organic layer.**
- **Visualizing molluskan evolution**
- **Hypothetical ancestor Archemollusk,**
- **Merged with a recent cladogram for the phylum**



63 Spiralians 2: mollusks : Early mollusks

Early Mollusks

Early Cambrian: A time of experimentation. A variety of short-lived, often bizarre molluskan groups. Dominating many faunas. First mollusks descended from forms like living flatworms. Spiculate animals. Radula and gills on the posterior. Similar to modern soft-bodied Aplacophorans

Characters/Features

- Characterized by some short-lived, unusual forms.
- Molluskan features: mantle, mineralized shell and radula. Members of the small shelly fauna
- Characterized by some short-lived, unusual forms
- Molluskan features: mantle, mineralized shell and radula
- Members of the small shelly fauna

Aplacophorans

A group of shell-less mollusks. Aplacophorans and shelled mollusks shared a common ancestor probably during the Late Precambrian. **E.g Kimberella** . The body fossils and trace fossils place Kimberella near the base of the Molluskan clade and suggest a deep origin for the phylum. **Odontogriphus** possesses a radula, a broad foot and a stiffened dorsum, so placing it firmly within the mollusks, close to Kimberella

Halkieria

Cambrian rocks of the Danish island of Bornholm. Articulated specimens from the Early Cambrian Sirius Passet fauna from North Greenland. Halkieria is a mollusk, possessing most of the features that define the phylum, but a number of characters (such as the shells at the anterior and posterior of the animal) have formed the basis for a new class of mollusk, the Diplacophora .

Origins

- Halkieriid mollusks
- Lower Cambrian
- The hyoliths – long, conical, calcareous shells with an operculum-covered aperture
- Cambrian to Permian

64 Spiralians 2: mollusks : Class Bivalvia

Bivalves

Among the commonest shelly components of beach sands. Many taxa are farmed and harvested for human consumption. Pearls: a valuable by-product. Spectacular variety of shell shapes and life strategies.

Spanning the entire Phanerozoic. All based on a simple bilaterally symmetric exoskeleton.

Morphology

Bivalves are twin-valved shellfish superficially resembling the brachiopods. Common in modern seas. Bivalve shells: calcium carbonate, usually aragonite. Two valves are virtually mirror images of each other. Termed lamellibranchs or pelecypods, but they were first named Bivalvia by Linnaeus in 1758

Evolution

Basal Cambrian. Two Early Cambrian genera

1. Pojetaia from Australia and China
2. Fordilla from Denmark, North America and Siberia

Evolved from Rostroconchs. The class evolved rapidly in the Early Ordovician to include basal forms of all bivalve infrasubclasses. Tremadocian and Floian radiation. Major diversification: Paleozoic evolved extensive siphons helping deep-burrowing life modes. Early Mesozoic radiation featured siphonate forms

65 Spiralians 2: mollusks : Class Gastropoda

The Gastropods

The "belly-footed" mollusks. Most varied and abundant of the molluskan classes today. Snails and slugs. Forms both with and without a calcareous shell

- Entire Phanerozoic, evolved
- Swimming strategies: creeping, floating and • Trophic styles: razing, predatory and parasitic.

Torsion

Mantle cavity containing gills and anus, excretory and reproductive openings comes to lie above head. Seems to be disadvantageous loss of one of the gills

Evolution

No general agreement. Derived from a monoplacophoran- type ancestor by torsion and development of an exogastric condition. Shell is coiled away from the head. An origin from among coiled forms such as ***Pelagiella*** may link the monoplacophoran grade through the Tommotian ***Aldanella*** to the gastropods. Most Paleozoic gastropods are herbivores or detritus feeders. Classic study of Late Tertiary snails from Lake Turkana, Kenya, Williamson (1981): punctuated changes in 14 separate lineages

66 Spiralians 2: mollusks : Class Cephalopoda

Cephalopods

Most highly organized of the mollusks. The greatest complexity of any of the spiralians. Well-defined head with the foot modified into tentacles, "Head-footed. High metabolic and mobility rates.

Developed nervous system, sharp eyesight & an advanced brain. Adaptations for a carnivorous predatory life mode.

A tripartite division. Three subclasses include

1. **Nautiloidea**, with straight or coiled external shells with simple sutures (Late Cambrian to Recent)
2. **Ammonoidea**, with coiled, commonly ribbed external shells with complex sutures (Early Devonian to latest Cretaceous, possibly earliest Paleogene)
3. **Coleoidea**, with straight or coiled internal skeletons (Carboniferous To Recent). Belemnites (extinct), the squids and cuttlefish . The octopods: lost their skeleton.

67 Spiralians 2: mollusks : Class Scaphopoda

Scaphopods

Are generally rare as fossils. The Scaphopoda, or elephant-tusk shells, have a single, slightly curved high conical shell, open at both ends. They lack gills and eyes, have a mouth equipped with a radula. A foot, surrounded by tentacles similar to that of the bivalves, adapted for burrowing. Carnivorous, feeding on small organisms, foraminiferans. Spend life in quasiinfaunal positions within soft sediment in deeper-water environments. The first scaphopods appeared during the Devonian and apparently had similar lifestyles to living forms such as **Dentalium**.

68 Spiralians 2: mollusks : Class Rostroconcha

Rostroconchs

Relatively recently a small class of mollusks. Superficially resembling bivalves but lacking a functional hinge, documented from the Paleozoic. Over 35 genera. Originally described as bivalved arthropods, had a foot that emerged through the anterior gape between the shells. The two shells are fused along the middorsal line. Posteriorly the shells are extended as a platform or rostrum.

Evolution

Appeared first in Early Cambrian. Heraultipegma and Watsonella dominated faunas of the Tommotian. Diversified during Ordovician. Reach an acme: **Katian**. Similar to bivalves ecological niches, decline in abundance and diversity. Final extinction in end of the Permian, except Conocardiodes (*Arceodomus*). The Rostroconchs occupy a pivotal position in molluskan evolution. Developed from within the monoplacophoran plexus with a loss of segmentation. Generated both the bivalves and the scaphopods. The gastropods and cephalopods were probably derived independently from a separate monoplacophoran ancestor. Missing link between the univalved and bivalved molluskan lineages. Their unlikely morphology may have contributed towards their late discovery.

69 Spiralians 2: mollusks : Evolutionary trends within the Mollusca

Phanerozoic

A spectacular variety of mollusk morphotypes and life modes evolved during the

Phanerozoic, from the simple body plan of the archemollusk

Cambrian

Despite the diversity of early mollusks in the Cambrian, the phylum was not notably conspicuous in the tiered suspensionfeeding

Paleozoic Bivalves

Common in nearshore environments, associated with *lingulide brachiopods*. Inhabited deeper-water clastic environments

- Late Paleozoic: a variety of carbonate environments
- End of the Paleozoic: shallow-water belts displaced the Paleozoic associations seaward.

Mesozoic and Cenozoic Bivalves

Late Mesozoic and Cenozoic: The significant radiation of infaunal taxa. A response to increased predation

Paleozoic Gastropods

The majority were Eogastropoda. Dominated shallow-water marine environments and some carbonate reef settings

Mesozoic Gastropods

Mesogastropoda, grazed on algal-coated hard substrates. The Cenozoic: the acme of the group with the radiation of the siphonal carnivorous neogastropods

Cephalopods

Radiation: during the Mesozoic. The development of a chambered shell with a siphuncle, which gave them considerable control over attitude and buoyancy.
Siphuncle: In shelled cephalopods such as nautiloids and ammonoids) a calcareous tube containing living tissue running through all the shell chambers, serving to pump fluid out of vacant chambers in order to adjust buoyancy.

70 Ecdysozoa: arthropods : Arthropods: introduction

Such as lobsters, spiders, beetles and trilobites. Have legs, a segmented body plan with jointed appendages and the ability to molt. From ek- 'out, off' + duein 'put' . The first major faunas: Early Cambrian. Appear bizarre, Probably were no more morphologically different to each other than living faunas.Arthropod-like animals in the Ediacara biota: Ancient origins.

Trilobites appeared in Early Cambrian and during the Paleozoic. Arthropods are spectacularly diverse group of legged invertebrates. Accounting for about three-quarters of all species living on the planet today

Trilobites

Evolved advanced visual systems. Enrolment structures. In Order to pursue a variety of benthic and pelagic life styles

The Largest Arthropods

Chelicerates and included the giant *eurypterids*. Patrolled marine marginal environments during the Silurian and Devonian.

Myriapods

Earliest terrestrial body fossils in the Mid Ordovician. Trackways of euthycarcinoids (i.e. stem-group mandibulates) show that these moved onto land even earlier (Late Cambrian).

Insects

Insects first appeared during the Early Devonian and diversified rapidly. There are probably **10 million** species of living insects

Flight in Insects

Insects had probably already evolved flight before the Mid Carboniferous, when giant dragonflies patrolled the forests.

The Crustaceans

Include many familiar groups such as crabs, lobsters and shrimps. Together with the barnacles and ostracodes.

History of Phylum

Exceptionally preserved fossils from the faunas of

1. Cambrian Burgess Shale
2. Chengjiang
3. Sirius Passet

71 Ecdysozoa: arthropods : Arthropods

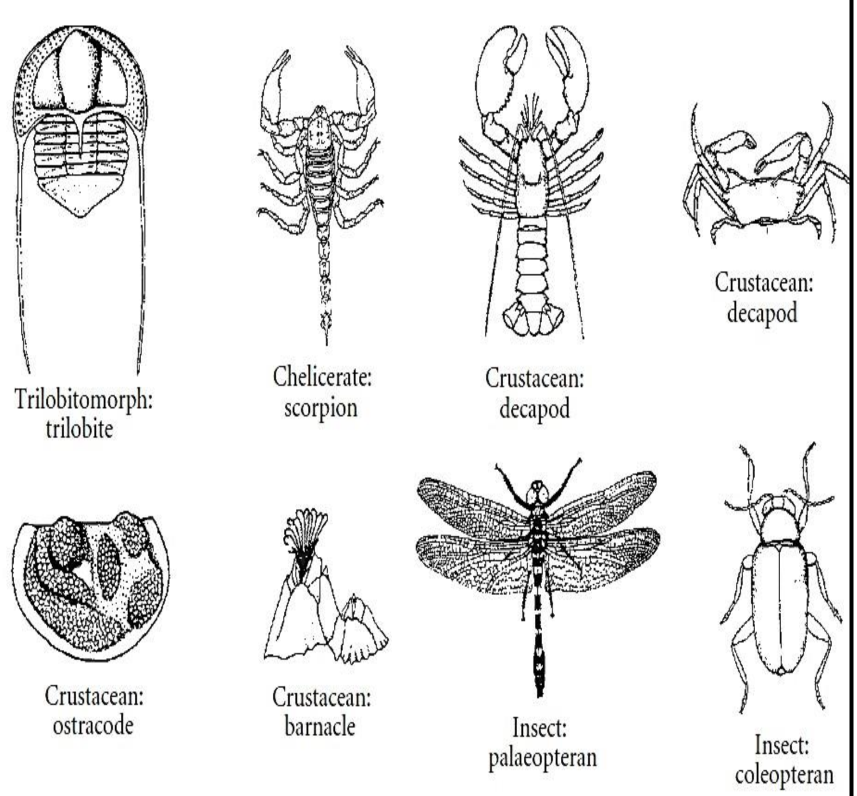
Basic Body Plan

Segmented, with jointed appendages. Adapted for feeding, locomotion and respiration. Exoskeleton appeared during the Early Cambrian. Differentiated into a head, thorax and abdomen. Often the head and thorax fused: Cephalothorax. Hard mouthparts, mandibles: Ability to process wide variety of foods

Arthropod Exoskeleton

Organic substance, chitin. Hardened or sclerotized by $CaCO_3$ or $Ca_3(PO_4)_2$. Potential for preservation: Excellent

- **Acts as a base for the attachment of locomotory muscles**
- **Permitting rapid movement**
- **Not usually mineralized**
- **Metamorphosis: Many arthropods**
- **Molting or Ecdysis: All the main groups**
- **Exuviae, or cast-off coverings: previous skeleton or cuticle of the animal**



Five Subphyla

- **During a geological history of at least 540 million years, the five subphyla of arthropod have adapted to life in marine, freshwater and terrestrial environments**

1. **Trilobitomorpha: Cambrian to Permian**
2. **Chelicerata: Cambrian to Recent**

3. **Myriapoda: Ordovician, Silurian to Recent**
4. **Hexapoda: Devonian to Recent**
5. **Crustacea: Cambrian to Recent**

72 Ecdysozoa: arthropods : Subphylum Trilobitomorpha

Trilobitomorphs

Highly derived arthropods, lack specialized mouthparts. Tagmata comprising the cephalon, thorax and pygidium. Trilobitomorph appendages. Mainly the trilobites and over 15,000 species are known. Common throughout the Paleozoic. Extinction in end of the Permian

Earliest Arthropods

Earliest arthropods were trilobites. Marine Cambrian strata are usually correlated on the basis of trilobite assemblages **Morphology**

Trilobite ("three-lobed"). Exoskeleton is divided into three lobes. The axial lobe protects digestive system, whereas the two pleural lobes cover appendages.

Evolution

Trilobite faunas: basis for many paleogeographic reconstructions of the Cambrian and Ordovician world. The Cambrian, complex biogeographic patterns. Some Early Paleozoic trilobite communities may also be interpreted as showing an onshore–offshore spectrum. Trilobites (such as Choubertella and Schmidtiellus) first appeared in the Early Cambrian. Survived until the end of the Permian. Last genera, such as Pseudophillipsia, disappeared: end of the Permian. History of 350 million years, the basic body plan was essentially unchanged

Macroevolution Studies

Trilobites have provided key evidence in studies of macroevolution. Controversy over punctuated equilibrium and phyletic gradualism

73 Ecdysozoa: arthropods : Subphylum Chelicerata

Chelicerates

Diverse and heterogeneous. Mites, scorpions and spiders. The familiar horseshoe crab Limulus, together with the extinct sea scorpions, the eurypterids. Prosoma (head and thorax) with 6 segments with appendages. An opisthosoma (abdomen) with 12 segments, pair of chelicerae (pincers) on the first segment of the prosoma.

Chelicerate Groups

Traditionally two main groups

1. The merostomes, including the aquatic horseshoe crab *Limulus* and the giant sea scorpions or *eurypterids*
2. The arachnids: mainly comprise the terrestrial spiders and scorpions. This split of the subphylum into marine and non-marine has been challenged.

Evolution

The bizarre Sanctacaris from the Middle Cambrian Burgess Shale may be a basal outgroup to the clade Chelicerata. Xiphosure (Horse Shoe crab) –like taxa, such as Eolimulus, have been described from the Lower Cambrian. A trend towards larger size and a shorter fused abdomen. 50 genera of eurypterids have been described. The group was most abundant during the Silurian and Devonian. Arachnids, Book lungs or tracheae or both.

74 Ecdysozoa: arthropods : Subphylum Myriapoda

Myriapods

A varied group comprising the millipedes, centipedes, symphylans and pauropods . First appeared during the Mid Silurian

Invasion of land

- The first animals to colonize the land. Heather Wilson and Lyall Anderson (2004) have described the few Silurian and Devonian taxa from Scotland. Fossil footprints of Arthropleura, Laggan Harbour, Isle of Arran, Scotland.
- The giant *Arthropleura*, nearly 2 m long, hoovered their way through the lush, green vegetation of the Late Carboniferous forests.
- Trackways from Middle Ordovician rocks in the English Lake District (Johnson et al. 1994) suggests that arthropods were on land about 50 myr earlier.
- Trace fossils from Cambrian rocks in Ontario push arthropod life on land back (MacNaughton et al. 2002) suggesting the presence then of large, amphibious Euthycarcinoids
- **The Millipedes:** Archidesmus (Lower Devonian), Cowiedesmus(Middle Silurian) and Pneumodesmus (Middle Silurian), from Scotland

Euthycarcinoids

An enigmatic group of arthropods with antennae and mandibles. In phylogeny somewhere near the origin of myriapods and insects

75 Ecdysozoa: arthropods : Subphylum Hexapoda

Hexapoda

- Can be divided into pterygotes (with wings) and apterygotes (without wings)
- Include the springtails, dragonflies, cockroaches and locusts
- The group may prove to have as many as 10 million living species when the rich faunas of the tropics have been completely described.
- Unbranched appendages, a simple gut, a single pair of antennae and a pair of mandibles, together with a toughened head capsule.
- Insects: six limbs

The Oldest Insect

Probably the springtail Rhyniella praecursor from the Lower Devonian Rhynie Chert of the Orcadian Basin of northeast Scotland

Insects Diversified

Had been earlier than had been thought (Labandeira 2006). The group probably originated in freshwater during the Late Silurian. Fresh water origin may account for the poor fossil record of the group before the Devonian (Glenner et al. 2006). Early and Mid Devonian faunas are known from Rhynie, Gaspé, Québec and Gilboa, New York State. Coincided with the diversification of land plants.

Insects Flight

By the Late Carboniferous a very diverse insect fauna had evolved, with forms such as the dragonflies and mayflies capable of powered flight

Insects & Plants

End of the Permian: familiar insect orders had appeared. Late Mesozoic and Cenozoic: significant coevolutionary relationships between plants and insects

Insects & Mammals

Miocene: Fossil hair trapped in amber together with the sand fly *Lutzomyia*. These blood suckers were already feeding on mammals (Peñalver & Grimaldi 2006).

76 Ecdysozoa: arthropods : Subphylum Crustacea

Crustaceans

A hard, crusty carapace. First appeared in the Cambrian. Aquatic, mainly marine, with gills, mandibles, two pairs of antennae and stalked compound eyes. The heavily armored crabs and lobsters typify this diverse subphylum. The barnacles and ostracodes are crustaceans with a notable geological record. **8** main classes. Ostracodes are considered part of the microfauna. Only **2** groups, the Cirripedia and the Malacostraca have significant geological records. The First Crustaceans:*Canadaspis* from the Burgess Shale.

Cirripedes

Or barnacles have shells, or capitula (singular, capitulum), consisting of several plates and these animals are adapted to an encrusting lifestyle. Acorn barnacles and goose barnacles. Contrasting life strategies. Acorn barnacles during the Late Cretaceous. Goose barnacles: Pseudoplankton

Malacostracans

Include two subclasses, Phyllocarids and Eumalacostracans. The phyllocarids have large bivalved carapaces, seven abdominal somites and a telson with a pair of furcae

Ostracodes

Ostracodes are crustacean arthropods, abundant and widespread in aquatic environments. Appeared first during the Early Cambrian

77 Deuterostomes: echinoderms and hemichordates

Deuterostomes

The first opening to develop in the embryo is the anus and a second forms the mouth. A dipleurula larva & body cavity that developed from an extension of the embryonic gut

Echinoderms

- Sea urchins starfish & sea cucumbers
- Water vascular system
- A mesodermal skeleton of calcitic plates
- Pentameral symmetry and tube feet.
- During the Cambrian radiation many bizarre forms evolved. The spindle-shaped *Helicoplacus* may be part of the stem group for the entire phylum
- **Pelmatozoans**: fixed echinoderms. The blastoids, crinoids and cystoids. The crinoids; four classes, the Inadunata, Flexibilia, Camerata and Articulata .
- The echinoids were part of the mobile benthos. During the Mesozoic irregular groups, adapted for burrowing, evolved from the more regular forms that characterized the Paleozoic.

Asteroids

Asteroids (starfish) were more important in post-Paleozoic rocks; their Triassic radiation may have inhibited the reradiation of some key groups of brachiopod

Carpoids

Traditionally classed with the echinoderms. Some have argued they were ancestral to chordates.

They were probably stem-group echinoderm

Hemichordates

Graptolites are hemichordates closely related to the living rhabdopleurids with similarly constructed rhabdosomes and ultrastructure. Graptolites probably pursued benthic (dendroids), planktic (dendroids and graptoloids) and automobile
(graptoloids) lifestyles. Graptoloids evolved rapidly and were widespread. The ideal zone fossils in rocks of OrdovicianSilurian and Early Devonian age.

78 Deuterostomes: echinoderms and hemichordates : Echinoderms

One of the most abundant marine animal groups. As fossils they can sometimes be rather robust an unusual five-fold symmetry & Water Vascular System

Water Vascular System

Water is forced around the plumbing by muscular action. Tube feet: are often modified for food processing, locomotion and respiration

Echinoderms

The 6000 or so living echinoderm species include familiar forms such as sea lilies, sea urchins, sand dollars, starfish and sea cucumbers. One of the most remarkable Lagerstätte occurs in the Upper Ordovician succession of the Craighead inlier, north of the Girvan valley, southwest Scotland. During the Early Cambrian radiation: bizarre forms appeared suddenly with very different morphologies. One non-pentameral group The helicoplacoids. E.g **Helicoplacus from the Lower Cambrian (×10).**

Classification

- Class Eocrinoide Cambrian to Silurian
- Class Paracrinoidea Ordovician
- Class Blastoidea Ordovician to Permian
- Class Diploporita Cambrian to Devonian
- Class Rhombifera Cambrian to Devonian
- Class crinoidea Ordovician to recent
- Class Asteroidea Ordovician to Recent
- Class Echinoidea Ordovician to Recent

79 Deuterostomes: echinoderms and hemichordates : Hemichordates

Form a small phylum of only a few hundred species. Common fossil representatives, the graptolites in ancient seas of the Early Paleozoic

Graptolites

- Extinct
- life styles are difficult to interpret
- small, soft-bodied animals with bilateral symmetry and a lack of segmentation

Hemichord

ata Two

classes

- First, the tiny, mainly colonial, pterobranchs in sessile benthos
- Second, the larger infaunal acorn or tongue worms, the enteropneusts

Closely related to cephalochordates and urochordates or tunicates. Molecular data suggest that the latter two groups are more closely related to the chordates. Graptolites probably pursued benthic (dendroids), planktic (dendroids and graptoloids) and automobile (graptoloids) lifestyles. Graptoloids evolved rapidly and were widespread. The ideal zone fossils in rocks of Ordovician-Silurian and Early Devonian age. **Classification**

- Class Graptolithina
- Order Dendroidea Cambrian to Carboniferous
- Order Tuboidea Ordovician to Silurian
- Order Camaroidea Ordovician
- Order Crustoidea Ordovician
- Order Dithecoidea Cambrian to Silurian
- Order Graptoloidea Ordovicianto Devonian

80 Fishes and basal tetrapods: Introduction

Vertebrates

Subgroup of the Phylum Chordata, a major deuterostome clade. The evolution of fishes from the Cambrian to the present day, and the Paleozoic tetrapods. Characterized by a skeleton made from bone (apatite). (Apatite is a group of phosphate minerals, usually referring to hydroxylapatite, fluorapatite and chlorapatite, with high concentrations of OH^-, F^- and Cl^- ions, respectively, in the crystal.) The oldest vertebrates are small fish-like creatures from the Early Cambrian of China.

Ancient Fishes

Armored fishes were abundant in Devonian seas and lakes. After the Devonian, the cartilaginous and bony fishes radiated in several phases.

Conodonts

Conodonts commonly occur as tooth-like elements that are useful in biostratigraphy, as are some other fish teeth and scales (ichthyoliths). **Tetrapods**

Arose during the Devonian from lobe-finned fish ancestors, and fish-eating amphibians.

Diversified in the Carboniferous.

Reptiles

The first reptiles were small insect eaters. Synapsids dominated ecosystems on land during the Permian and Triassic.The non-mammalian members are described as mammal-like reptiles in classical systematics; they can also be called stem mammals or proto-mammals. **Synapsids** evolved from basal amniotes and are one of the two major groups of the later amniotes; the other is the sauropsids, a group that includes modern reptiles and birds. These groups were heavily hit by the end-Permian mass extinction event, and diapsid reptiles, most notably the dinosaurs, were key forms through the Mesozoic. Diapsids ("two arches") are a group of amniote tetrapods that developed two holes (temporal fenestra) in each side of their skulls about 300 million years ago during the late Carboniferous period. The diapsids are extremely diverse, and include all crocodiles, lizards, snakes, tuatara, turtles, and dinosaurs

Importance of Vertebrates

Humans are such a successful species. The huge diversity and abundance of species of bony fishes, birds and mammals. Insects and microbes, arealso abundant and diverse. Vertebrates include the largest animals on land, in the sea and in the air.

Final term 81 to 165

ZOO503 - Zoogeography and Paleontology

81 Fishes and basal tetrapod's: Origin of the vertebrates

The Skeleton

Bone and cartilage

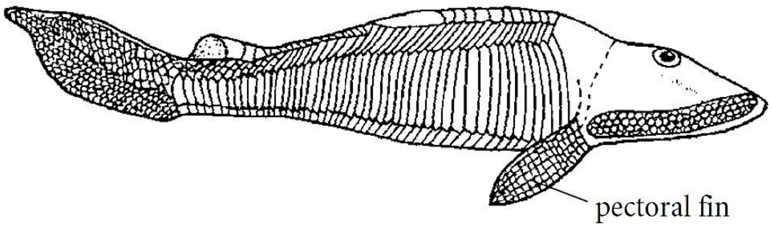
- **Bone:** A network of collagen fibers on which needle-like crystals of hydroxyapatite (a form of apatite, CaPO4) accumulate
- **Cartilage**: Flexible tissue, usually unmineralized, contains collagen and elastic tissues.

In humans; early skeleton, cartilage, progressively mineralizes by apatite. The first vertebrates had a cartilaginous skeleton. Some of the oldest fish grow very large because the skeleton can grow with the animal. Advantageous than exoskeletons

Jawless Fishes

Two key defining characters: the head and neural crest tissues

- The neural crest appears in the early embryo as a strip of cells where the backbone will develop
- The first vertebrates had no jaws
- Fossil sites at Chengjiang in China: Early Cambrian.
- Late Cambrian and Ordovician: commonest vertebrates were the conodont animals.
- **Ostracoderms:** Were jawless, generally armored, Had their heyday in the Devonian.
- **Hemicyclaspis:**Extinct genus of primitive jawless fish, closely related to Cephalaspis, that lived in the Devonian period
- Today, the 50 or so species of lampreys and hagfishes, eel-shaped animals.



The osteostracan Hemicyclaspis from the Devonian

Conodonts:

Animals of mystery

The commonest early vertebrates (Sweet & Donoghue 2001).

For over 150 years a mystery, known only from their jaw elements – no one knew which animal had produced them.

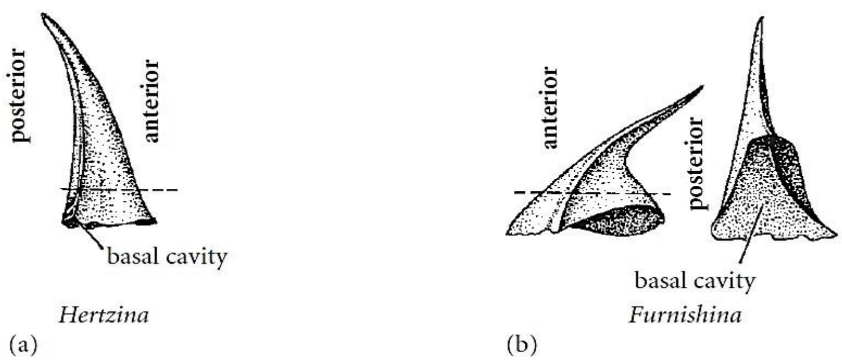
82 Conodonts

Animals of mystery. The commonest early vertebrates (Sweet & Donoghue 2001). For over 150 years a mystery, known only from their jaw elements – no one knew which animal had produced them.First identified by the Latvian embryologist and paleontologist Christian Pander in 1856.

They occur as phosphatic tooth-like microfossils, termed

elements. **Three main groups have been established**

- Protoconodonts such as Hertzina
- Paraconodonts like Furnishina
- Euconodonts more complex, with cones, bars and blades



Descriptive morphology of the main types of conodont elements:

(a) ***protoconodont Herzina* (×40);**

(b) ***paraconodont Furnishina* (×40)**

Conodonts

Conodonts are common in certain marine facies from the Cambrian to the Triassic& Paraconodonts in the Mid Cambrian

Conodont Element

The three main morphotypes. The basis of a crude single element or form taxonomy.

Coniformare simplest, with the base surmounted by a cone-like cusp

Bars or Ramiform

These elements consist of an elongate blade-like ridge with up to four processes developed posteriorly, anteriorly or laterally to the cusp

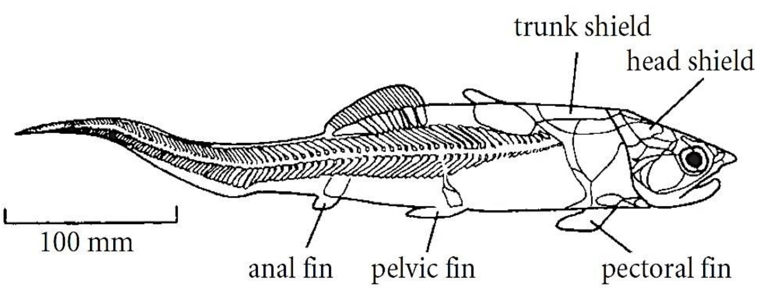
Pectiniform elements

Platforms have a wide range of shapes, with denticulate processes extending both anteriorly, posteriorly and/or laterally from the area of the basal cavity

83 Jaws and Fish Evolution

The First Jaws

The basal vertebrates, lacked jaws, jaws probably evolved during the Ordovician. Oldest jaw-bearing fishes were the placoderms, such as *Coccosteus* ***(Jawed Fish of the Devonian the placoderm Coccosteus)***



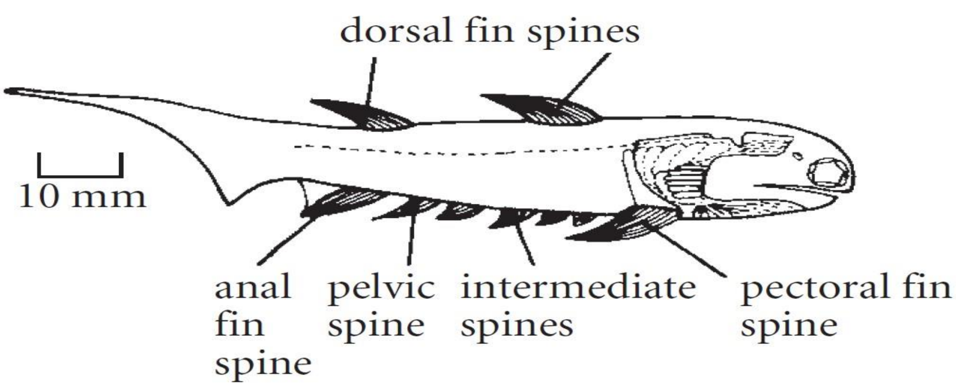
Jawed Fish of the Devonian the placoderm *Coccosteus*

Chondrichthyans

The first shark like chondrichthyans or cartilaginous fishes, came on the scene during the Early Devonian

Acanthodians

Small fishes, mostly in the range 50–200 mm in length, and they bore numerous spines at the front of each fin and spaced rows on their undersides.



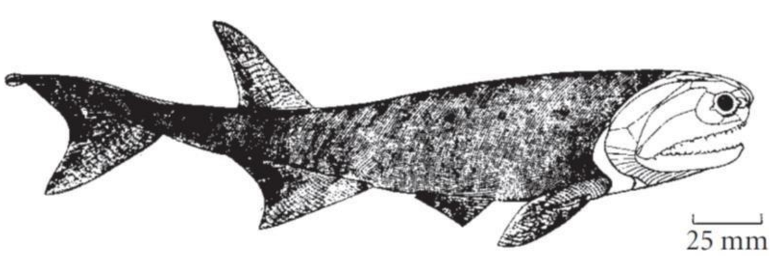
Jawed Fish of the Devonian the acanthodian *Climatius*

Bony fishes

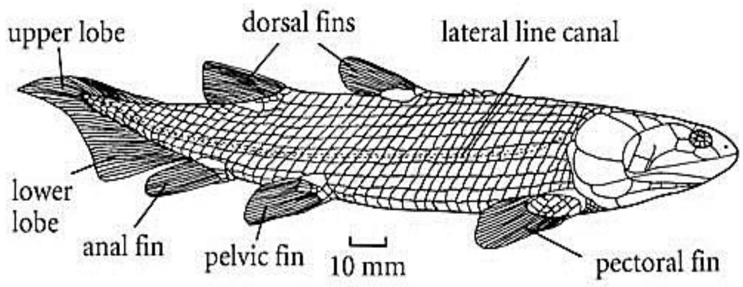
The osteichthyans, or bony fishes, also appeared in the Devonian.Two groups, Ray fins and lobefins. Jawed Fish of the Devonian the actinopterygian bony fish

, **Cheirolepis;** **Ray fins**

Those with ray-like fins, the actinopterygians. Ancestors of most fishes today, from carp to salmon, Seahorse to tuna.



Jawed Fish of the Devonian the actinopterygian bony fishCheirolepis;



 Jawed Fish of the Devonian The lobefin Osteolepis

84 Tetrapods

Fins to Limbs

- When a fish became a land animal, surely the key problem was breathing air?
- Not so, Early bony fishes almost certainly had both lungs and gills

Main problem

- **Support**

In water, an animal “weighs” virtually nothing. On land the body has to be held up from the ground. The internal organs have to be supported in some way

Other problems

Reproductive, osmotic (water balance) and sensory systems had to adapt. These changes did not happen all at once

Origins

Tetrapods arose from fishes during the Devonian. Closest fishy relatives? The lobefins. Complex bony and muscular pectoral (front) and pelvic (back) paired fins. The first good evidence of tetrapods comes from the Late Devonian. Bestknown forms are *Acanthostega* and *Ichthyostega*, which were 0.6 and 1 m long, respectively

Skull of the Late Devonian amphibian

Acanthostega, showing the streamlined shape, deeplysculpted bones and small teeth, all inherited from its fish ancestor

The Amphibians:

Half-way land animals. 4000 species of mainly small animals that live in or close to water. Still rely on the water for breeding and water balance. The oldest fossil form, with reduced limbs, is Jurassic in age. All living amphibians appear to be closely related. Forming a clade, the *Lissamphibia*

Subclass Lissamphibia

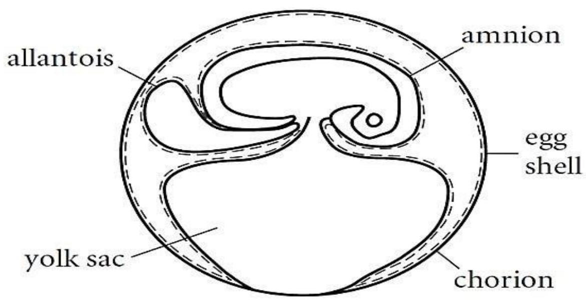
- Frogs, salamanders (newts) and caecilians (gymnophionans) **Subclass Reptiliomorpha**
- Narrow-skulled, fish-eating amphibians. Highskulled terrestrial amphibians
- Late Carboniferous to Late Permian, Early Triassic to Recent.

85 Reign of the Reptiles

Amphibians only made it halfway on to land. They still produce swimming tadpoles. Reptiles and their descendants: egg not
have to be laid in water. The cleidoic (“closed”) egg, Amniotic egg (Tough semipermeable shell), Clade Amniota (reptiles, birds, mammals**).**

Membranes

- Enclose the embryo (the amnion)
- Collect waste (the allantois)
- line the eggshell(the chorion)
- Yolk, a yellow material rich in protein**.**



Oldest Amniote

Oldest-known amniote, *Hylonomus* from the mid-Carboniferous of Canada. Only skeleton; no amniotic eggs are known from the Carboniferous. E.g The earliest reptile, The mid-Carboniferous Reptile *Hylonomus*

Radiation

Amniotes: Late Carboniferous Three main clades distinguished by the pattern of openings in the side of the skull. Temporal openings behind the eye socket.

The three major skull patterns seen in amniotes: anapsid, diapsid and synapsid. (Based on Carroll 1987.)

- **The anapsid** (“no arch”) skull pattern, no temporal openings.
- **The synapsid** (“same arch”), lower temporal opening,
- **The diapsid** (“two arch”) pattern, two temporal openings.
- **Early Reptile Evolution**
- **(c-e) The three major skull patterns seen in amniotes: anapsid, diapsid and synapsid. (Based on Carroll 1987.)**

86 Three Clades

- **The Anapsida**: early forms such as *Hylonomus*, as well as some Permian and Triassic reptiles, and the turtles.

- **The Synapsida**: “mammal-like reptiles” and the mammals
- **The Diapsida** : Early groups, as well as the lizards and snakes and the crocodiles, pterosaurs, dinosaurs and birds. All modern amniotes produce the cleidoic egg

The Anapsida

Turtles and relatives. The oldest were small insect eaters. During the Permian and Triassic. The turtles appeared first in the Late Triassic, *Proganochelys*.In fig.A Fossilized Snapping Turtle, with the head (bottom right) and skeleton at Steinheim, Germany.

The Synapsids

First synapsids, known from the Late Carboniferous and

Early Permian. Grouped loosely as “pelycosaurs”, insectivores and carnivores. With powerful skulls and sharp, flesh piercing teeth. e.g**Synapsids of the Permian: the carnivorous pelycosaur Dimetrodon; (Upper left) the carnivorous gorgonopsian Lycaenops**

Synapsids radiated dramatically in the Late Permian as a new clade, the Therapsida. The carnivores

were the *gorgonopsians*. The cynodonts, The Early Triassic form *Thrinaxodon*

Thrinaxodon

Looked dog-like. In the snout area the roots of sensory whiskers. Thrinaxodon had whiskers, hair on other parts of its body. Insulation and temperature control.

87 Dinosaurs and Mammals

The Transition

- The transition from basal synapsid to mammal is marked by an extraordinary shift of the jaw joint into the middle ear.
- Reptiles typically have six bones in the lower jaw and the articular bone articulates with the quadrate in the skull
- In mammals, on the other hand, there is a single bone in the lower jaw, the dentary, which articulates with the squamosa
- The reptilian articular–quadrate jaw joint became reduced in Triassic cynodonts, and moved into the middle ear passage. That is why we have three tiny ear bones, the hammer, anvil and stirrup, which transmit sound from the ear drum to the brain
- Reptiles have only one, the stirrup or stapes.

Transition to the mammals: skulls of an early synapsid (c) and a mammal (d) to show the reduction in elements in the lower jaw and switch of the jaw joint

A Misconception

People think of the dinosaurs as precursors of the mammals. Dinosaurs famously ruled the Earth for 160 Myr of the Mesozoic. Replaced by the mammals 65 Ma.

Evolution of Mammals

However, the mammals arose in the Late Triassic, about the same time as the first dinosaurs. Both groups of mammals and Dinosaurs evolved side by side through the Late Triassic, Jurassic and Cretaceous

88 Dinosaurs

- After the end-Permian mass extinction event **251 Ma**, **diapsid reptiles diversified in the Triassic**.
- Dinosaurs were a hugely successful group for **160 myr of the Mesozoic.**
- Pterosaurs: key Mesozoic flyers
- Most important marine reptiles: plesiosaurs and ichthyosaurs
- Birds evolved from dinosaurs, and radiated during Tertiary

The First Mammals

Small insect eaters of the latest Triassic. The mammals achieved great diversity and abundance only after the extinction of the dinosaurs.

Radiation of the Mammals

Molecular and paleontological evidence show that modern mammals radiated in the Late Jurassic and Early Cretaceous. Basic splits were geographic – with major clades separated in South America, Africa, Australasia and the northern hemisphere.

Emergence of Humans

Humans arose 6–8 Ma, and fossil evidence points to repeated human migrations out of Africa. Evolution of vertebrates forward into the Mesozoic and Cenozoic. The rise of the diapsids, and especially the dinosaurs and their descendants, the birds. Modest evolution of mammals through the Mesozoic set the scene for their explosive radiation at the beginning of the Cenozoic, after the dinosaurs had gone

Lecture No. 89 Dinosaurs and Their Kin

The Diapsids Take Over

Abundance of the synapsids in the Carboniferous or Permian.Change during the Triassic, (end-Permian extinction event). Devastating effect on therapsid communities. Small and large meat eaters such as *Erythrosuchus*. One of the first of the archosaurs. A group include the dinosaurs, pterosaurs, crocodilians and birds.

e.g: Archosaurs: Skull of the Early Triassic archosaurs

Erythrosuchus

- Triassic: diapsids diversified
- Archosaurs: large carnivores
- Proficient flyers: (pterosaurs)
- Another extinction Late Triassic (about 220 Ma)
- Another Diapsid radiation

The Diapsids

- New kinds of land tetrapods radiate
- The dinosaurs, pterosaurs, crocodilians and lizard ancestors, as well as the turtles
- Modern amphibians and true mammals

- **The Pterosaurs**

Proficient flapping flyers with a lightweight body. Narrow hatchet-shaped skull. A long narrow wing. Almost certainly endothermic. Fed on fishes and insectivorous. E.g

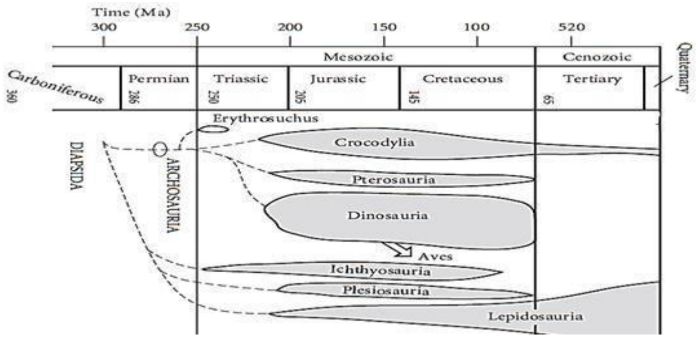
Archosaurs (The Late Jurassic pterosaur *Rhamphorhynchus*, showing the elongated wing finger on each side, and the long tail with its terminal "sail" made from skin (×0.3)).

Early crocodilian

Largely terrestrial in habits, walked on all fours and had an extensive armor of bony plates. More diverse and abundant during the Jurassic and Cretaceous than now. E.g,

Archosaurs: The Late Jurassic crocodilian Crocodilemus,showing the skeleton and armor covering (×0.2).

Lecture No. 90 Diapsid Diversification



Lepidosaurs

- The second major diapsid clade Lizards and snakes.
- Diversified in the Late Triassic.
- Key forms: sphenodontids – snubnosed, lizard-sized animals
- The group dwindled after the Jurassic, except for a single living representative.
- Sphenodon, the tuatara of New Zealand. A famous

  "living fossil.

- **First true lizards:** Mid and Late Jurassic, characteristic mobility of the skull. The quadrate is mobile, and the snout portion of the skull can tilt up and down

e.g:

Lepidosaurs: (a) the LateJurassic lizard Ardeosaurus; (b)The Late Triassic sphenodontid Planocephalosaurus

Loosening Skull

Taken further in the snakes. Known first in the Early Cretaceous. Snakes have mobile skulls, swallow prey animals several times the diameter of the head

Lecture No. 91 The Age of Dinosaurs

Dinosaurs

Most important of the new diapsid groups of the Triassic. In terms of their abundance and diversity. In terms of the vast size reached by some of them.

First Dinosaurs

Modest-sized bipedal carnivore. After the Late Triassic extinction a new group of herbivorous dinosaurs, the sauropodomorphs, radiated dramatically, some like *Plateosaurus.*

e.g: Sauropodomorph Dinosaurs: (a) theLate Triassic prosauropod Plateosaurus; and(b) the Late Jurassic sauropod Brachiosaurus.

The Theropods

Include all the carnivorous dinosaurs. In the Jurassic and Cretaceous, the group diversified to include many specialized small and large forms. *Deinonychus*

Shared Ancestors

The theropods and sauropodomorphs share the primitive reptilian hip pattern. The two lower elements point in opposite directions, the pubis forwards and the ischium backwards. The *Saurischia,* Cretaceous Theropod Dinosaurs:*Tyrannosaurus*

Herbivores

All other dinosaurs share a unique hip pattern in which the pubis has swung back and runs parallel to the ischium. These are termed the Ornithischia, all of which were herbivores. E.g **(a)** Armored Ornithischian Dinosaurs from the (Jurassic Stegosaurus) **(b)** Armored Ornithischian Dinosaurs from the Cretaceous (Euoplocephalus) (c) Armored Ornithischian Dinosaurs from the Cretaceous (Centrosaurus)

Dinosaurs

Dinosaur reproductive habits

- Eggs and nests in North America and Mongolia: Parental care.

e.g :*Massospondylus* eggs with a complete embryo skeletonInside, measuring some 15 cm in total length. It died just before
hatching. As an adult, it wouldhave grown to a length of 5 m.

Lecture No. 92 Dragons of the Deeps

Marine Predators

Mesozoic: several reptile groups became key marine predators.The *ichthyosaurs:* fish-shaped animals, adapted to life in the sea,evolved from land-living diaps. E.g: The ichthyosaur Stenopterygius

Ichthyosaurs

Long, thin, snouts lined with sharp teeth. Fed on ammonites, belemnites and fishes. Exquisite preservation: tail fin, dorsal fin and the paddle outlines. **Swam** by beating the body and tail from side to side. Front paddles for steering. **Specimens:** mothers with developing embryos inside their bellies: like whales and dolphins

Plesiosaurs

Second major marine reptile group. Long necks and small heads. The *pliosaurs* were larger: short necks and large heads.Fed mainly on fishes. Using long neck like a snake.

Swam by beating their paddles in a kind of "flying" motion.The extraordinary diversity of tetrapod predators in the sea came to an end 65 Ma. E.g: The plesiosaur, Cryptoclidus

Mass Extinction

During the great Cretaceous-Tertiary mass extinction. The end of the dinosaurs and pterosaurs.Followed by the rise of mammals

Lecture No. 93 Bird Evolution

Archaeopteryx

The most famous fossils. Oldest known bird found in Upper Jurassic sediments in southern Germany in 1861. Hailed as the ideal "missing link". E.g, The Oldest Bird, *Archaeopteryx,*from the Late Jurassic

Proof of evolution

A beak, wings and feathers, so it was clearly a bird. A reptilian bony tail, claws on the hand, and teeth. Since 1861, nine more skeletons have come to light. The skeleton of
Archaeopteryx is very like that of *Deinonychus*. Especially in the details of the arm and hindlimb, showing that birds are small flying theropod dinosaurs.

Modern Birds

Appeared in the latest Cretaceous and Early Tertiary. Flightless ratites and ancestors of water birds, penguins and birds of prey. The perching birds radiated in the Miocene. **Two examples of the Early Cretaceous bird**

Confuciusornis from Liaoning, China, showing a male (below, with long tail streamers) and a female.

Lecture No. 94 Rise of the Mammals

Primitive forms

- Small insect eaters in the Late Triassic and Early Jurassic
- Nocturnal
- Remained small through most of the Mesozoic

- Did not achieve high diversity, due to the dinosaurs
- most basal mammal groups did not outlive the Cretaceous-Tertiary mass extinction
- Three Surviving clades: Monotremes, marsupials and placentals

Monotremes

Restricted to Australasia, Platypus echidnas.Still laying eggs, as the cynodont ancestors. The young hatch out and feed on mother's milk until large enough to live independently.

Marsupials & Placentals

Marsupials, and Placentals, radiated dramatically in the Tertiary. A classic example of an adaptive radiation due to development of teeth

Diversification

Diversified within 10 myr to forms as disparate as bats and rats, monkeys and whales. Mammals uniquely have differentiated teeth, with incisors, canines and cheek teeth. Differentiated teeth: huge array of diets: Biting, and especially chewing. High metabolic rates need lots of nutritious food. Differentiated teeth allows mammals to improve the efficiency of their digestive systems

Classification

- **Subclass MONOTREMATA**

Females lay eggs, and newborn young grow in pouch. Early
Cretaceous to Recent

- **Subclass METATHERIA (marsupials and extinct relatives)**

Young are born live, but continue development in pouch.
Late Cretaceous to Recent

- **Subclass EUTHERIA (placentals and extinct relatives)**

Young are born live at an advanced stage, nourished by a placenta. Mid-Cretaceous to Recent

Lecture No. 95 The Line to Humans

Early Primates

- One of the oldest of the modern placental mammal groups. • The name "primate" (from primus,
  "first"). Humans are primates, and so "first" among animals.
- Homo sapiens ("wise person"), has the privilege of choosing the name!
- For most of their history, the primates were a rare and rather obscure group.
- All primates share a number of features
- Agility in the trees (mobile shoulder joint, grasping hands and feet, sensitive finger pads),
- A larger than average brain, Good binocular vision
- Enhanced parental care (one baby at a time, long time in the womb, long period of parental care, delayed sexual maturity, long lifespan).
- Early primates *(Plesiadapis)* were squirrel-like animals that may have climbed trees and fed on fruit, seeds and leaves. E.g The Paleoceneprimate Plesiadapis
- Basal primates radiated in the Paleocene, Eocene and Oligocene.

True monkeys

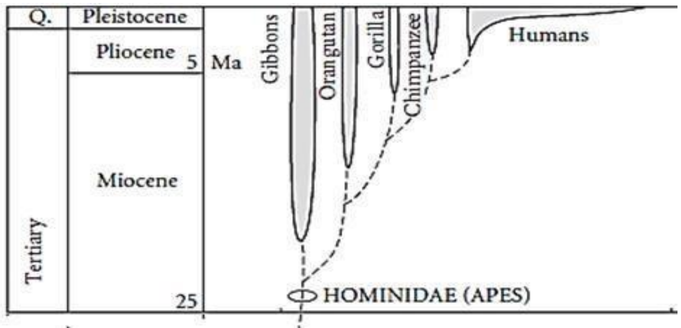
True monkeys arose in the Eocene and they diverged into two groups, The New World monkeys of South America, The Old World monkeys of Africa, Asia and Europe.

New World Monkeys

Marmosets and spider monkeys, have flat noses and prehensile tails used as extra limbs in swinging through the trees.

Old World Monkeys

Macaques and baboons: narrower projecting noses and nonprehensile tails, or no tails at all.Apes arose from the Old World monkeys before the end of the Oligocene



Lecture No. 96 The Apes and Humans

The Apes

- Radiated in Africa in the Miocene.*Proconsul*. Have no tail, large braincase, high intelligence. Ran about on the ground and along low branches on all fours, and fed on fruit. e.g The Paleocene primate Plesiadapis.
- The apes spread out from Africa into the Middle East, Asia and southern Europe by the mid-Miocene. Gave rise to some of the modern ape groups at that time.

- **Phylogeny of the Apes**

Early Apes

The gibbons of Southeast Asia are the most primitive living apes, having branched off 25– 20 Ma, followed by the orangutan 20–15 Ma.The focus of ape (and human) evolution remained in Africa.

Relatives of Humans

Gorillas, chimpanzees and humans appear to be very closely related. Share many anatomic characters and >94% of their DNA is identical.Gorillas seem to have diverged first, about 10 Ma, and the ancestors of humans and chimps separated about 8–6 Ma.

Human evolution

Humans are set apart from other primates by their large brain and their bipedalism, walking upright. Bipedalism came first than intelligence

Climatic Accident in Africa

In the **late Miocene**, Climates became arid and the East African rift valley began to open upseparating the forests in the west from the arid grasslands in the east. Tree-living apes (chimps and gorillas) retreated west. The remaining apes (our ancestors) remained in the eastern grasslands

Lecture No. 97 Oldest Human

- 4 Ma
- Molecular estimate of 5 Ma for the split between humans and chimps.
- In 2001 and 2002, two French teams announced human fossils that were 6 Ma.
- A number of incomplete human fossils reported during the 1990s from Africa, dated between 6 and 4 Ma.
- It may be that *Sahelanthropus* and *Orrorin* were already bipedal by 6 Ma
- The oldest clear evidence for bipedalism: human tracks in volcanic ash from Tanzania, 3.75 Ma.
- The oldest substantial skeletons, of *Praeanthropus afarensis*, 3.2 Ma

- **Our oldest ancestor?**

The spectacular skull of *Sahelanthropus* from the upper Miocene of Chad, over 6 Ma.

Lucy

The famous skeleton of a female *P. afarensis* from Ethiopia, called Lucy by its discoverer Don Johanson in the 1970s has a rather modern humanoid pelvis and hindlimb.

(**The pelvis is short and horizontal, rather than long and vertical as in apes, the thighbone slopes in towards the knee, and the toes can no longer be used for grasping. Lucy's brain, however, is small, only 415 cm3 for a height of 1–1.2 m – not much different from a chimpanzee).**

Australopithecus

Continued to evolve in Africa from about 3 to 1.4 Ma, giving rise to small & large robust speciesreached heights of 1.75 m, brain capacities did not exceed 550 cm3, a rather ape-like measure.

e.g Skulls of fossil humans in front and side views**: (a)** Australopithecus africanus**(b)*A. boisei***

Homo habilis

Lived in Africa from 2.4 to 1.5 Ma. Brain capacity of 630– 700 cm3 in a body only 1.3 m tall. Used tools. For over 1 myr, three or four different human species lived side by side in Africa

Lecture No. 98 Modern Peoples

Homo erectus

The focus of human evolution: Africa, a new species, *H. erectus*, which arose 1.9 Ma in Africa, spread to China, Java and central Europe. Brain size of 830–1100 cm3 in a body up to 1.6 m tall. Clear evidence that this early human species had semipermanent settlements, a basic tribal structure. Knew about use of fire for cooking, made tools weapons from stone and bone.

Homo sapiens

Truly modern humans, *H. sapiens*, may have arisen as much as 400,000 years ago, and certainly by 150,000 years ago, in Africa, evolved from *H. erectus*.All modern humans arose from a single African ancestor. Spread to the Middle East and Europe by 90,000 years ago.H. erectus stocks in Asia and Europe died out.

The European story

Includes a phase, from 90,000 to 30,000 years ago, when Neandertal man occupied much of Europe from Russia to Spain and from Turkey to southern England. Neandertals had large brains (on average, 1400 cm3), heavy brow ridges and stocky powerful bodies. Adapted to living in the continuous icy cold of the last ice ages, and had an advanced culture

Modern humans

Advanced across Europe from the Middle East. Spread over the rest of the world. Asia to Australasia before 40,000 years ago. A unique small-sized human species, *H. fl oresiensis*: 18,000 years ago

Lecture No. 99 Fossil Plants

Fungi & Algae

Fungi have a long fossil record, perhaps dating back to the end of the Precambrian, but they are not true plants. Green algae, and their relatives, are close to the origin of green

Plants on Land

Plants moved onto land in the Ordovician and Silurian, a move enabled by the evolution of vascular tissues, waterproof cuticles and stomata, and durable spores.

Non-seed-bearing plants

Arose during the Devonian, but tree-like lycopsids, equisetopsids. Groups such as ferns became established by the Carboniferous. These formed the great "coal forests".

Plant Fossils

Paleobotany, which concentrates on macroscopic (visible with the naked eye) plant remains. Palynology, the study of fossil pollen and spores, gives remarkable insights into paleoenvironments and biostratigraphy.

The Gymnosperms

Seed-bearing plants radiated in several phases. During the Carboniferous-Permian (medullosans, cordaites, cycads) and Mesozoic (conifers, ginkgos, bennettitaleans, gnetales).

The Angiosperms

Flowering plants radiated dramatically during the Cretaceous, fully enclosed and protected seeds, flowers and double fertilization.

Lecture No. 100 Trace Fossils

Represent the activities of organisms. Trace fossils may be treated as fossilized behavior, or as biogenic sedimentary structures.

Types

Trace fossils include

- Tracks and trails,
- Burrows and borings,
- Fecal pellets and coprolites,
- Root penetration structures
- Other kinds of pellets.

Naming

Trace fossils are named on the basis of shape and ornamentation, not on the basis of the supposed maker, environment or stratigraphy.

Origins

One animal may produce many different kinds of trace fossils, and one trace fossil type can be produced by many different kinds of animals.

Shapes

Trace fossils may be produced within a sedimentary layer, or on the surface. Trace fossils may be preserved in the round, and may be seen as molds and casts on the bottoms and tops of beds.

Lecture No. 101 Classification

Trace fossils may be classified according to the mode of behavior represented: Movement, Feeding, Farming, Dwelling, Escape, Resting.

Ichnofacies

Certain trace fossil assemblages (ichnofacies) appear to repeat through time, and may give clues about the environment of deposition.

Tiers

Trace fossils often occupy particular levels (tiers) in the sediment column, the depth of tiering has apparently increased through time. Limited use in stratigraphy, except in some special cases

Ichnology

The study of trace fossils, often called ichnology (from the Greek ichnos, a trace).German paleontologist Adolf Seilacher established a classification of trace fossils based on behavior

A. Traces on Bedding Planes

- **Tracks**: sets of discrete footprints, usually formed by arthropods or vertebrates
- **Trails:** continuous traces, usually formed by the whole body, either traveling or resting

B. Structures within the sediment

- **Burrows:** structures formed within soft sediment, either for locomotion, dwelling, protection or feeding, by moving grains out of the way
- **Borings**: structures formed in hard substrates, such as limestone, shells or wood, for the purpose of protection, Includes bioerosion feeding traces, such as drill holes in shells produced by gastropods

C. Excrement

- **Fecal pellets and fecal strings**: small pellets, usually <10 mm in length, or strings of excrement
- **Coprolites**: discrete fecal masses, usually >10 mm in length, and usually the product of vertebrates

D. Others

- **Root penetration structures:** impressions of the activity of growing roots
- **Non-fecal pellets:** regurgitation pellets of birds and reptiles, excavation pellets of crustaceans and the like

Naming

- Given formal names, often based on Latin and Greek, just like living and fossil plants and animals
- Trace fossil genera: ichnogenera
- Trace fossil species: ichnospecies

Lecture No. 102 Diversity of life

Diversity of life

- Onward and upward
- An accepted principle of evolution
- All modern and ancient life on Earth is part of a single great phylogenetic tree
- A Precambrian common ancestor
- A plot of species numbers through time must show a pattern of phenomenal increase over the past 3500 myr
- It is impossible many species were never fossilized
- Yet to be found and identified
- 5–50 million species
- **Logistic model**: Diversity reached a global equilibrium level,
- **Exponential model**: diversity continues to expand without reaching a global carrying capacity

Evolution

Many examples of evolutionary trends, one-way changes in a feature or features, are in reality more complex. The idea of progress in evolution, change with improvement in competitive ability, is hard to demonstrate

Patterns

It is important not to confuse pattern with process; too often scientists and the public assume such processes as competition, adaptation and progress without testing for alternatives

Major steps in Evolution

Major steps in evolution (e.g. evolution of wings and feathers in birds, evolution of limb loss in snakes) are well documented by fossils and evolutionary trees. An alternative, biological, view of the major steps focuses on fundamental subcellular systems, replicators and genetic systems.

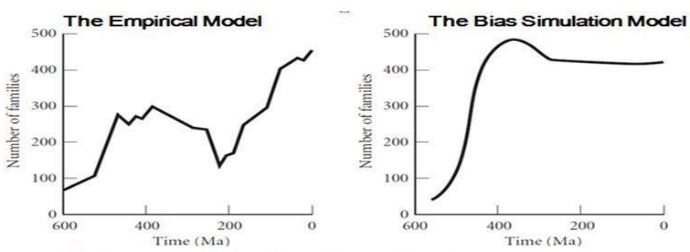
Lecture No. 103 Models:

Valentine (1969)

First serious effort. He plotted the numbers of families of skeletonized shallow marine invertebrates through the Phanerozoic. The pattern showed a jerky Increase, with several declines. Representative of all the diversification

Raup (1972)

Argued that the graph showed more about the sources of error in the fossil record than it did about the true pattern of the diversification of life. The low diversity values in the Early Paleozoic: such rocks were rare. The true pattern of diversification of marine invertebrates had been a rapid rise to modern diversity levels during the Cambrian and Ordovician, and a steady equilibrium level since then.Many diversification plots: similar patterns



Two models for the diversification of marine invertebrate life over the past 600 myr of good-quality fossil records.
(Based on information in Valentine 1969; Raup 1972)

Global

DiversificationPatterns

Three mathematical models

- The linear model : A straight line
- The exponential model: An exponential curve
- The logistic model: Logistic curve

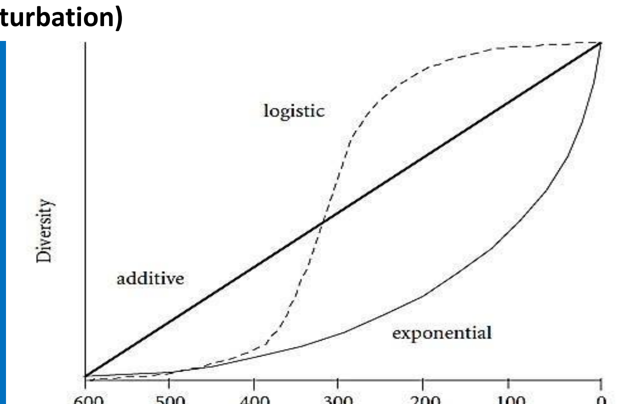
1. The linear model

The linear model represents additive increase, the addition of a fixed number of new species in each unit of time. Such a model has generally been rejected as improbable

2. Exponential model

More consistent with a branching mode of evolution. If speciation and extinction rates remain roughly constant, then there will be regular doubling of diversity within fixed units of time

(**Theoretical models for the diversification of life plotted as if for the last 600 myr in the absence of major perturbation)**



Lecture No. 104 Equilibrium or Expansion

Equilibrium or Expansion?

- If the logistic model is correct, life has diversified in a controlled manner, reaching one or more equilibria, each of which is probably density limited.
- Carrying capacity
- If the exponential model is correct, life has diversified in a less controlled manner • Rising continually and never reaching an equilibrium
- Food and space limitations slow the rate of increase.
- Eight observations
- For distinguishing equilibrium and expansion models of diversification of life.

The first four: in favor of equilibrium

- The last four: in favor of expansion

Observation 1

An evolutionary explosion of marine animals during the Early Cambrian, and diversification rates slowed after this initial exponential rise. This strongly suggests a logistic/equilibrium explanation

Observation 2

There were rapid rebounds after mass extinctions, in which local and global diversity recovered to pre-extinction levels during relatively short spans of time. Suggesting the refilling of vacated ecospaces

Observation 3

Late phases of diversification cycles are associated with declining rates of origination and increasing rates of extinction, as the logistic curve approaches the equilibrium level. Marine record affirms

Observation 4

The Paleozoic plateau in marine animal diversity is strong evidence for equilibrium.But note that the plateau appears clearly only in the family-level data compilation.

Observation 5

A single equilibrium level is easier to understand in terms of a global equilibrium model; otherwise each equilibrium level has to be justified as representing a complete overhaul of the evolutionary and ecological world.

Observation 6

There is no evidence for a global carrying capacity for species, and so a fundamental assumption behind the equilibrium model has yet to be demonstrated independently

Observation 7

The radiation of life on land, and of certain major marine clades, appears to have followed an exponential pattern. There is no sign of slowing down in the rate of increase, nor of the occurrence of any equilibrium levels.

Observation 8

The Modern "fauna" radiated dramatically over the last 100 myr and shows no sign of reaching an equilibrium level.

Conclusion: no point in seeking an overarching mathematical model to explain the diversification of life.

Lecture No. 105 Trends and Radiations

Progress & Trend

Progess means change with improvement. The later forms have to be demonstrably better than their predecessors. An evolutionary trend is a one-way change in some feature or features

Trend in Humans

A trend in human evolution has been for increasing brain size. Classed as progress if it is assumed that a larger brain means higher intelligence and so greater evolutionary adaptability.

Progress?

- Does horse evolution show progress?
- Harder to argue:
- Small camouflaged, forest-dwelling *Hyracotherium* of the Eocene was "better" than the plains-dwelling, larger, modern *Equus*

Idea of Progress

A long and checkered history.Evolution is progressive only in that advantageous adaptations may be inherited by the offspring of successful parents.

Adaptive Radiations

One of the classic observations of large-scale evolution. A radiation is when a clade expands relatively rapidly. The adjective "adaptive": happening because of some particular adaptation in the clade.

Patterns and Processes

- **Patterns** are observations of the appearance and disappearance of species.

  Processes are hypotheses that seek to explain the patterns.

Biotic Replacements

- An obvious feature of the history of life.
- These are times when one group of plants or animals replaces another.
- The replacement of brachiopods by bivalves is a famous example

Lecture No. 106 Ten Major steps

Major Steps

- The study of paleontology reveals a great deal about how life has achieved its present astonishing diversity.
- Some major events in the history of life may be identified, although these may be debated.

Adaptation 1

- The origin of life
- The biochemical model
- Complex organic molecules were synthesized naturally in the Precambrian oceans.
- First living organisms bacteria (3500 Ma).
- Prokaryotic cells, small and lacking nuclei.
- Operated in the absence of oxygen, and they caused one of the most significant changes in the history of the planet – the raising of oxygen levels in the atmosphere.

Adaptation 2

- Eukaryotes and the origin of sex.
- In marked contrast to the prokaryotes, eukaryote cells are usually large, with organelles and membrane-bounded nuclei containing the chromosomes
- The development of variation.

Adapatation 3

- Multicellularity.
- Clusters of eukaryote cells organized into different tissue types and organs, where different parts of the organism are responsible for particular functions and tasks
- Oldest multicellular eukaryotes: reported from rocks 1200 Ma in Canada
- These red algae were one of nearly 20 multicellular eukaryote lineages
- Some 400 myr later true metazoans

Adapatation 4

- Skeletons
- During an interval of a few million years in the earliest Cambrian, a variety of mineralized skeletons appeared
- These are seen spectacularly in the Mid Cambrian Burgess Shale fauna
- Advantage: by providing protection, support and areas for the attachment of muscles.
- Predator pressure may have been the main driving force behind the acquisition of hard parts.

Adaptation 5

- Predation
- The Late Precambrian Ediacara fauna was softbodied, and it appears likely that predators and scavengers were absent.

- This changed during the Early Cambrian.
- During the Early Cambrian Predation was an important part of the ecosystem.
- The rapid diversification of armored and protective strategies was a feature of the Cambrian radiation

Lecture No. 107 Adaptation 6

- Biological Reefs
- Marine equivalents of tropical rain forests.
- Modern reefs are highly diverse, colorful frameworks of brain, horn and staghorn corals, together with organ pipes, sea fans and sea whips.
- Throughout the Phanerozoic, the main reef builders have changed, with major changes punctuated by mass extinctions.

  The first reefal frameworks appeared during the Early Cambrian.

Adaptation 7

- Terrestrialization
- The colonization of the land added major new environments to those previously occupied by life.
- It is hard to date the first move of life on to land.
- Soils reported from Mid Precambrian sequences .
- Microbial life extended a greenish scum around the water's edge.
- Ordovician soils suggest that larger plants and animals had moved onto land.

Adaptation 8

- Trees and forests
- Next major expansion of living space on land took place during the Carboniferous, with the development of forests.
- The first tree sized plants: Late Devonian
- **Significance:** It created a vertically tiered range of new habitats.
- Trees, with their long roots, gained access to nutrients that were not available to smaller plants
- The addition of new stories of vegetation.

Adaptation 9

- Flight
- Expansion of land life was into the air.
- Evolution of trees led to this
- Having insect groups to move off the ground in search of edible leaves and fruits, gliding and true flight became inevitable.
- Insects arose in the Early Devonian, but the first true fliers are Carboniferous in age
- • Flight has doubtless been the clue to the vast success of insects
- Flight has arisen more than 30 times among vertebrates.

Adapatation 10

- Consciousness

- Human beings probably have to feature somewhere in a list of major biotic advances,
- How to view the role of humans in evolution has been a question that has dogged philosophers for centuries.

Lecture No. 108 An Alternative Top Eight Steps

An Alternative Top Eight Steps

In a biologically-oriented presentation, John Maynard Smith and Eörs Szathmáry (1997) identified eight major steps from the origin of life to human societies with language**.**

Step1

Replicating molecules.

The first objects with the properties of multiplication, variation and heredity were probably replicating molecules, similar to RNA but perhaps simpler, capable of replication.

Step 2

Independent replicators.

In existing organisms, replicating molecules, or genes, are linked together end to end to form chromosomes .

Step 3

RNA as gene and enzyme.

In modern organisms there is a division of labor between two classes of molecule: nucleic acids (DNA and RNA) that store and transmit information, and proteins.

Step 4

Eukaryotes and organelles

Prokaryotes lack a nucleus and have (usually) a single circular chromosome.Eukaryotes have a nucleus containing rodshaped chromosomes and organelles.

Step 5

Sexual reproduction.

A process of sexual reproduction in which a new individual arises by the fusion of two sex cells, or gametes, produced by different individuals**. Step 6**

Differentiated cells

Composed of many different kinds of cells – muscle cells, nerve cells, epithelial cells and so on. Each individual, therefore, carries not one copy of the genetic information (two in a diploid).

Step 7

Colonial living.

Most organisms are solitary, interacting with others of their species, but not dependent on them. Other animals, notably ants, bees, wasps and termites, live in colonies in which only a few individuals reproduce.

Step 8

Primate societies – human societies, and the origin of language and consciousness.

The decisive step in the transition from ape to human society was probably the origin of language, which led in turn to consciousness in human beings.

Lecture No. 109 The History of Biogeography

Biogeography

Biogeography is the study of the distribution of species and ecosystems in geographic space and through geological time.

The patterns of species distribution across geographical areas can usually be explained through a combination of historical factors such as: speciation, extinction, continental drift, and glaciation.

Organisms and Biological communities often vary in a regular fashion along

1. Geographic gradients of latitude
2. Elevation
3. Isolation
4. Habitat area

Biogeography is an integrative field of inquiry that unites concepts and information from

1. Ecology,
2. Evolutionary biology
3. Geology
4. Physical geography

Modern Biogeography

Combines info & ideas from many fields. The physiological & ecological constraints on organismal dispersal. Geological & climatological phenomena operating at global spatial scales & evolutionary time frames.

Geographic Information Systems

To predict future trends and understand the factors affecting organism distribution. Often mathematical models and GIS are employed to solve ecological problems that have a spatial aspect to them.

Schematic Distribution of Fossils on Pangea According To Wegener

Island Biogeography

Islands are also ideal locations because they allow scientists to look at habitats that new invasive species have only recently colonized and can observe how they disperse throughout the island and change it

Darwin

Recognized the importance of geographic locations

"The Zoology of Archipelagoes will be well worth examination".

Two chapters in On the Origin of Species were devoted to geographical distribution.

Lecture No. 110 Ecological vs. Historical Biogeography

The most fundamental split in biogeography is that between the ecological and historical aspects of the subject

Ecological Biogeography

Concerned with species confinement to its present range in space.

- What enables it to live where it does, and what prevents it from expanding into other areas?
- Roles of soil, climate, latitude, topography

Concerned with short term periods of time, at a smaller scale; with local, within habitat or intracontinental questions; and primarily with species or subspecies of living animals or plants

Historical Biogeography

Concerned with: How did the taxon come to be confined to its present range in space? , When did distribution come to have its present boundaries? , How have geological events shaped that distribution?

Concerned with long term, evolutionary periods of time; with larger, often sometimes global areas; and often with taxa above the level of the species and with taxa that may now be extinct

Plant Biogeography

Plants are static. Their form and growth much more closely conditioned by their environmental, ecological conditions. It is also far easier to collect and preserve plants.

Conclusion:

The biogeography of the more distant past was, until recently, largely the preserve of zoologists, whereas plant scientists were far more concerned with ecological biogeography.

Lecture No. 111 Biogeography and Creation

Began in the mid 18th century.At that time, most people accepted the statements in the Bible as the literal truth, that the Earth and all living things that we see today had been created in a single series of events.

The Realization

Both the living world and the planet that it inhabits are continually changing. Driven by two great processes – the biological process of evolution and the geological process of plate tectonics.

Linnaeus in 1735

Swedish naturalist. Started to name and describe the animals and plants. Assumed organisms as unchanging species, created by God. But he soon found that opposite was true

Noah's Ark

The different environments to be found at different altitudes had been colonized in turn by different animals and plants from the Ark as the floodwaters receded, progressively

Georges Buffon

French naturalist: The first person to realize that "similar environments, found in different regions of the world, contained different groupings of organisms". He Proposed

Buffon's Law.He noted many of the mammals of North America, such as bears, deer, squirrels, hedgehogs and moles, were found also in Eurasia. Travelled via Alaska, when climates were warmer. Most of the mammals of South America are quite different from those of Africa, even though they live in similar tropical environments.Accepting that all were originally created in the Old World. Buffon strongly felt that one had to be guided by study of the facts, and this conviction drove him to accept that geography, climate and even the nature of the species were not fixed, but changeable. His observations on the differences between the mammals of the two regions were soon extended to land birds, reptiles, insects and plants.

Lecture No. 112 The Distribution of Life Today

18th century Concept:

- The concepts of ecological biogeography, botanical regions and island biogeography had, then, all been recognized by the end of the 18th century.
- Explorers and naturalists revealed more and more of the world, they also extended the horizons of biogeography itself, discovering a greater diversity of organisms.

Discoveries

British botanist *Joseph Banks* and the German *Johann Reinhold Forster*, together with his son *Georg Forster* who collected thousands of species of plants, many of them new to science.

***Forster's* Findings**

Forster found that *Buffon's* Law applied to plants as well as to animals, and also applied to any region of the world that was separated from others by barriers of geography or climate. There are gradients of diversity. There being more plant species closer to the equator and progressively fewer as one move towards the poles.First observations of island biogeography.

Question of Naturalists

- How all these different floras had come into existence, widely scattered over the Earth's surface?
- German botanist *Karl Willdenow* (1792)
- **Karl Willdenow**

German botanistsuggested that, although there had been only one act of creation, it had taken place simultaneously in many places. In each area, the local flora had been able to survive the Flood

Other Scientists

- ***German Alexander*** *von Humboldt*: the founder of plant geography
- ***Humboldt***believed that the world was divided into a number of natural regions, each with its own distinctive assemblage of animals and plants
- ***Augustin*** *de Candolle* of Geneva who, in 1805 together with *Lamarck*, published a map showing France divided into five floristic regions with different ecological conditions.
- coined the word endemic

Vegetation Maps

Danish botanist *Joakim Schouw* was the first to classify the world's flora and show the results on maps.

The distribution maps of particular groups of plants, rather than maps of regional floras. *Grisebach's* more detailed mapThe History of Biogeography. Grisebach's more detailed, Coloured map of 1866was similarly a vegetation map.

Lecture No. 113 Evolution – A Dangerous Idea

18th century Europe

Leading work on biological and geological subjects had been carried out in Prussia. French Revolution of 1789 led to a flowering of French science. Power of the Church was broken. New National Museum of Natural History became a powerhouse of ideas and debate in Europe.One of those employed in this new museum was *Jean Baptiste Lamarck.*

Jean-Baptiste Lamarck

He believed that there was some underlying pattern and structure to every aspect of the physical and biological world. A mind set common in18th century inquirers of nature. No extinction. In 1802, Lamarck suggested that 'Lower' organisms might also be found earlier in time and that they might gradually change into the 'higher' forms. Due to an 'inherent tendency of life to improve itself.

Georges Cuvier

The science of comparative anatomy. Used this new branch of science to prove that such great fossil mammals belonged to quite different species from those of today and were extinct. So, to *Cuvier, Lamarck's* theory of continual transformation was deeply unacceptable. Rejected Evolution. So throwing out the baby of evolution with the bathwater of extinction.

Geoffroy St Hilaire

1818–1828. Geoffroy suggested evolutionary homologies and links between such widely different animals as fish and cephalopods. Evolutionary record vindicated *Cuvier*. Vicious attacking on *Lamarck* Continues

Case for Evolution

Further damaged in 1844. Scottish journalist *Robert Chambers* published a book, *Vestiges of the Natural History of Creation*. Contained astonishingly ignorant ideas.

Robert Jameson

Translated *Cuvier's* ideas into English in 1813. Suggesting that *Cuvier's* continent wide catastrophes as the biblical Flood. *Cuvier* accepted that science and religion should not interfere in each other's affair.

Lecture No. 114 Enter Darwin – and Wallace

Early 19th century

Evolution: a slightly disreputable, anarchic and Nihilistic idea for the structure of society .

Young *Charles Darwin* was cautious, secretive and reluctant to publish his ideas by invoking evolution

Darwin's Voyage

Interested in geology & natural history. In 1831 joined the crew of a *HMS Beagle*, to act as a companion to the captain and also as a naturalist for6 year voyage to survey the coasts of *South America*. Mocking Bird, Finches and fossils mammals. Idea that the living species were descended from the fossil species that had existed in the same part of the world was a straightforward explanation

Alfred R. Wallace

Organisms were related to one another by evolution. Thinking along exactly the same lines as Darwin. First to publish that closely related species were often also found close to one another geographically.

- **A letter from Wallace**

To *Darwin* then working in the East Indies, stimulated *Darwin* to publish his ideas after many years of agonizing over its possible hostile reception by the vociferously antievolutionary sections of *British* society.

Natural Selection

- In the case of both workers, it was observation of the patterns of distribution of individual species of animals, i.e.
  their biogeography, that led them to consider the possibility of evolution.
- Their great discovery: natural selection
- The idea of natural selection was announced by short papers from both Darwin and Wallace, read at a meeting of the *Linnean Society of London* on 30 June 1858
- Darwin quickly went on to publish his great book the next year
- On the Origin of Species."
- Darwin had spent the 40 years after his voyage in detailed research on many other areas of biology that provided evidence for evolution
- Extremely logical and persuasive

Charles Lyell

British geologist argued that many lines of evidence suggested that the Earth must be many millions of years old. Discovered in the 20th century, leading to the eventual realization that the Earth is several billion years old.

Two Paradigms

Plate tectonics is the central paradigm of the earth sciences and Theory of evolution is of the biological sciences. Biogeography provides a striking example of the concordance of the implications of these two paradigms.

Lecture No. 115 World Maps: Biogeographical Regions of Plants and Animals

Darwin and Wallace

Evolution: the living world's reactions to changes in the physical world. Genetics was yet to be identified. Mechanisms of the geological process responsible for those changes

Adolf Engler (1879)

Differences between the floras and faunas of the separate continents resulted from their having had separate evolutionary histories.Engler *was* first to make a world mapfour major floral regions, or 'realms'

- **Floras of Engler**

The system of plant regions accepted today is very similar to that of Engler. No systematic comparison and contrast of the composition of the floras of these different realms.

Floral kingdoms, according to Good and Takhtajan

- Holarctic
- Neotropical
- Antarctic

- Paleotropical
- Australian

Old Ocean Realm

- **Joseph Hooker**

Floras of the continents and islands of the Southern Hemisphere, and had suggested that these might be explained partly by the dispersal of floating seeds.

Zoogeography

Developing from early 19th century onward with a different emphasis Birds and Mammals. Do not show a close correlation to local ecology. Early Zoogeographer: Prichard in 1826 and Swainson in 1835. Six regions. This was first formalized in 1858 by the British ornithologist *Philip Sclater*. He believed that all species had been created within the area in which they are found today.

Alfred Wallace

Made his living by collecting bird skins, butterflies and beetles in the East Indies, and selling them to naturalists. His travels and collections led him to be interested in their patterns of distribution just like *Darwin*. He immediately accepted *Sclater's* scheme, including his names for the regions, and expanded it to include the distribution of mammals and other vertebrates. Identified/commented on many aspects of biogeography

Zoogeographical Regions, According to Sclater and Wallace

- Nearctic
- Neotropical
- African
- Palearctic
- Oriental
- Australian

Lecture No. 116 Getting Around the World

Acceptance of evolution gave a new importance to biogeography, posed new problems. Until mechanics of continental drift or plate tectonics, were revealed.

Dispersalism

- Where a taxon or two related taxa are found on either side of a barrier to their spread, this is because they had been able to cross that barrier after it formed. Inadequate to explain the patterns of distribution of past.
- **Joseph Hooker**, found these explanations quite unconvincing. Instead, Narrow land bridges, or by wider tracts of dry land across the present South Atlantic and Indian Oceans
- Distribution of the Glossopteris Flora (shaded area). 300 million years ago, existed in Africa, Australia, Antarctica, southern South America and, most surprisingly of all, India

Alfred Wegener

German meteorologist (1912). Presented his theory of continental drift in. Wegener suggested that all of today's continents had originally been part of a single supercontinent, Pangaea . Today's landmasses were originally linked together to form a single supercontinent, Pangaea, according to Wegener.

- Walter Matthew in his 1924 paper 'Climate and Evolution'
- George Simpson
- Karl Schmidt,
- George Myers (who worked on freshwater fishes)
- The zoogeographer Philip Darlington

Lecture No. 117 Leon Croizat

He amassed a vast array of distributional data, representing each biogeographical pattern as a line, or track, connecting its known areas of distribution. Croizat studied the distribution patterns of many unrelated taxa, and for each he drew lines or
'tracks' on the map linking the areas in which they are found. In many cases, these lines were similar enough in position to be combined as 'generalized tracks', shown here. He found that the tracks of many taxa, belonging to a wide variety of organisms, could be combined to form a generalized track that connected different regions of the world

- **Panbiogeography**

Argued that all of the areas connected by one of these tracks had originally formed a single, continuous area that was inhabited by the groups concerned.

- **Vicariance**

Croizat believed that any barriers that exist today within the pattern of distribution of the taxa had appeared after that pattern had come into existence, so that these taxa had never needed to cross them.

- **Coizat**

Croizat published his ideas in the 1950s and 1960s, his major presentation being his 1958 book Panbiogeography.
Croizat was correct, and ahead of time 'Dispersal explains everything', vs 'Vicariance explains everything

- **Croizat's Supporters**

Biogeographers, most of whom worked in New Zealand. These panbiogeographers accepted his generalized tracks running across the ocean basins, referring to them as Ocean Baselines.

Lecture No. 118 The Origins of Modern Historical Biogeography

Dispersal of Life?

Could organisms have dispersed across oceans to reach these scattered locations? Wegener's theory of continental drift had provided an explanation to this conundrum early in the 20th century.

Plate Tectonics

The 1960s,Strong new evidence of the mechanism for Wegener's theory, now

renamed plate tectonics, led to the acceptance of the reality of this phenomenon. It was only now that geologists were able
to provide a series of palaeogeographic maps that showed, from the Silurian Period onward, the changing patterns of association of the various tectonic plates

Paleobiogeography

Biogeographers had tried to analyze the biogeography of the past according to the different geological periods. The new maps identify stretches of time within which the geographical patterns had remained constant.
Palaeobiogeographer had to summate the faunas and floras from every locality within each of the resulting Palaeocontinents.Elements of these faunas and floras showing clear evidence of endemicity. At long last, biogeographers could build up a coherent, increasingly detailed set of pictures of the geography of the world over many millions of years.

Palaeogeographical map of the Carboniferous–Lower Permian period of time, as reconstructed in 1973. The seas and oceans are tinted blue.

Cladistics

Provides a rigorous methodology for analyzing the patterns of evolutionary relationship between the different members of a group. Characters used in this evaluation were morphological ones

Molecular Systematics DNA and Proteins Provides confidence in accuracy of reconstructions of the patterns of evolutionary divergence of group under study. Indicates the times at which the different branching events took place.

Lecture No. 119 The Development of Ecological Biogeography

Ecological biogeography

- **Linnaeus**: simple observations, Recorded, what type of environment each plant was found
- **Forster**: recognized latitudinal gradients of diversity,
- Humboldt: altitudinal gradients,
- **Candolle**: importance of competition

Developed In the 20th century: It depended on the rise of modern science with its techniques of experimental, physiological studies. Its history was not complicated. The development was strongly dependent on the increasing application of chemical and physical concepts and techniques to the understanding of plant and animal function, and hence distribution.

Early Botanists

Distribution of plants was closely linked to climate. To structure the results of this relationship. They focused either on the demands of environment on physiology of plants, or on type of vegetation that resulted.

Candolle(1855)

Three physiologically different types of plant that resulted from their adaptations to different levels of heat and moisture. Botanists soon also started to analyze the effects of the geology of the area in which the plants lived i.e. Soil.

- **Megatherms:** High
- **Mesotherms:** Moderate
- **Microtherms:** Low levels of heat and moisture.
- **Hekistotherms:** live in the polar regions.
- **Xerophytes:** tolerate low levels of moisture

E.W. Hilgard (1860)

How climate and plant life combined to gradually break down the native rock into smaller fragments and provide an increasing component of soil as a product of the biological activity.

V.V. Dokuchaev

Analysed the mineralogical and physical attributes of the soils that resulted from the breakdown of different types of rocks.
The alternative focus: Engler's map

Categorizing Vegetation

The first clear and simple system of categorizing the different types of vegetation was produced by the German botanists **Hermann Wagner and Emil von Sydow** in 1888.**Clements and Shelford** in 1916, were plant formation or, with the addition of its animals, a biome. **Tansley** in 1935 added the climatic and soil aspects of the complex, calling it an ecosystem, which became the basic unit of ecology.

Lecture No. 120 Living Together

Julius von Sachs

- German botanist and plant physiologist
- Physiological approach
- **Environmental stresses**: limiting factors in plant distribution patterns,
- Morphology, anatomy & physiology: capacity to cope with these stresses

Plant Form

These features were recognized as a more effective way of defining the formations and biomes than any taxonomic or evolutionary system of classification. **Christen Raunkiaer:** Proposal of life forms of plants

Community

Plant ecologist Frederic Clements: Communities resemble individual organisms in their degree of internal organization, and may similarly behave as units in their patterns of distribution

Succession & Climax

The linked concepts of succession and climax, first developed by Henry Cowles. Alternative approach: chaos theory. A concept: the outcome of a process is highly dependent on the initial conditions

The Ecosystem Concept

One of the most influential ideas of ecological studies. Useful in biogeographical studies. Work of Raymond Lindemann, who in 1942 put forward a formal account of energy flow in nature. Expanded by the work of American ecologists Howard and Eugene Odum, and named by the British botanist Arthur Tansley. Any selected portion of nature is an entity, within which energy flows and elements cycle.In the early 1960s, the first landscape scale ecosystem was subjected to monitoring and manipulative management at Hubbard Brook, a forested mountainside in New Hampshire

Ecophysiology

Examines how plants and animals vary in their physiological processes in response to the environment. Subtle differences in organism's systems provide some species with capacity to survive in stressful environments.

Neutral Theory of Biodiversity

The assemblage of species in a site is entirely a matter of chance. The arrival of a species is a stochastic process. The best predictive models are based on this concept of chance dispersal.

Lecture No. 121 Marine Biogeography

Marine biogeography

Biogeography of the oceans is similar to that of the continents. Concerned with the biota of vast areas of the surface of the globe. Different: because of the nature of the environment and of the organisms that it contains.

- **James Dana:** (1853), divided the surface waters into several different zones based on mean minimum temperature.
- **Edward Forbes:** (1856) published Five depth zones and 25 faunal provinces along the coasts of the continents
- In 1880, **Albert Günther** published a book on fishes in which he recognized 10 different regions in the distribution of shore fishes,
- **Arnold Ortmann** published work based on the distribution of crustaceans such as crabs and lobsters

Atlas of Zoogeography

1911: Assembled by three British zoologists (John Bartholomew, William Clark and Pery Grimshaw). 30 maps of the distributions of fishes based on the patterns of distribution of 27 families.

An Influential Review

Carried out by the Swedish worker Sven Ekman; German in 1935, English translation in 1953. This divided the faunas of the shallow seafloors into seven (mainly climatic) areas

Sven Ekman

Panama barrier must have been absent. Island free East Pacific acted as a barrier to dispersal of organisms.

Phenomenon of 'bipolarity', where a species is found on either side of the equatorial regions, but not within them.

Jack Briggs (1974)

Marine Zoogeography: Briggs used the patterns of endemicity of coastal faunas to identify locations where there appears to be a zone of unusually rapid faunal change, and then used this to distinguish 23 zoogeographical regions.

Recent Advances

Ability to explore the Depths of the sea. Sensing & recording satellites in space. Deepest part of the oceans– the strange hydrothermal vent faunas. **Nimbus:** Monitor and record the changing patterns of planktonic life.

Lecture No. 122 Island Biogeography

Island Biogeography

The ecology of island faunas and floras is far more fragile than that of the continents. Natural laboratories for evolutionary change. Contain a high proportion of the biotic diversity that we need to conserve. New Guinea contributes only 3% of the world's land area, it contains some 10% of its species of terrestrial organism.

Georg Forster

First biologist to identify particular features of island biogeography. Fewer species than the mainland, but that the number of species varies according to the size and ecological diversity of the island

Candolle

Pointed out that the age, climate and degree of isolation of an island, and whether or not it was volcanic, would also affect the diversity of its flora. Sheer variety and volume of the works published by Alfred Wallace

Philip Darlington (1943)

Larger islands contain a greater number of individuals, and a greater diversity of species, than smaller islands. The species diversity increasing by a factor of 10 for every doubling of island area.

MacArthur and Wilson

Nevertheless revolutionized the study of island biogeography, for they led the way in introducing mathematical techniques, and in providing a standard format for analysis and comparison.

Mathematical Analyses

The Theory of Island Biogeography. Published 1967 written by two American biologists. The mathematical ecologist Robert MacArthur. The taxonomist–biogeographer Edward Wilson **Area and the Number**

- Swedish worker Olof Arrhenius in 1921, and the Americans Eugene Munroe in 1948 and Frank Preston in 1962, had noted the relationship between the area of an island and the number of species that it contains.
- **The Song of the Dodo** – Island Biogeography in an Age of Extinction, by the American science writer **David Quammen**. Story of the rise of the theory and of the later mounting wave of criticism has been told in the book.

Lecture No. 123 Finding a Home

Aim of Biogeography

To understand underlying patterns of distribution of organisms on our planet, Such studies must be based on an appreciation of the nature of the species with which one is dealing.

Subspecies

Some species, for example, exist in a number of different forms that are sufficiently stable to be termed subspecies, and these often have different distribution patterns.

Polytypic and Monotypic

A species that exists as a series of subspecific forms is termed A Polytypic Species. As opposed to a less variable species that exists in just one form – called a Monotypic Species.

Genetic Analyses

Biologists apply these more widely. The complex relationships within species are becoming increasingly evident. Such complexity is reflected in distribution patterns.

Larus argentatus

An example of a polytypic species. The Herring Gull was regarded as polytypic with about a dozen subspecies spread around the entire Northern Hemisphere. Aa distribution termed circumboreal.

Gradual Change

Where there is gradual change in genetics and form along a gradient, taxonomists refer to a cline, and the variation is said to be clinal.

Evolution of Bonobo

A consequence of separate genetic development resulting from the presence of a major barrier to interbreeding (River Congo). All chimpanzee subspecies lie to the north or east of this river

Microhabitats

Such as forest canopies or forest floors. New Zealand forest Brown Kiwi Apteryx australis forest floor. The Fantail Rhipidura fuliginosa nests in canopy. Occupy different microhabitats.

Approximate Breeding Distributions of Various Taxa Within the Herring Gull Complex

(1) European herring gull (Larus argentatus)
(2) American herring gull (L. smithsonianus);
(3) yellow-legged gull (L.michahellis);
(4)Caspian gull (L. cachinnans);
(5) Heuglin's gull (L. heuglini);
(6) Taymyr gull (L.taimyrensis);
(7) Vega gull (L. vegae);
(8) steppe gull (L. barabensis);
(9) Mongoliangull (L. mongolicus);
(10) Armenian gull (L. armenicus)

Distribution Patterns of chimpanzee subspecies and bonobo in Central and West Africa

(1–4) the subspecies of chimpanzee, Pan troglodytes;
(5) the bonobo or pygmy chimpanzee, Pan paniscus.
More specifically:
(1) the nominate Pan troglodytes troglodytes; (2) Pan troglodytes vellerosus;
(3) Pan troglodytes verus; (4) Pan troglodytes schweinfurthii.
The bonobo is found south of the River Congo and is hence separated from other chimpanzees by a formidable barrier to movement.

Lecture No. 124 Limits of Distribution

There are limits within which distribution of an organism is spatially confined. Beyond these limits, it is unable to sustain its population. Determined by barriers, but the barriers may be of various kinds.

Physical Barriers

There are physical barriers that may prevent the spread of an organism. High mountain chains, expanses of water or areas of arid desert may confine a species to one particular region. The Himalayan mountain chain.

Climatic barriers

Frost can prove fatal to many tropical plants because the formation of ice within the cells of the plant, followed by melting, disrupts the cell membranes and results in death.Drought can cause problems of desiccation

Geological Barriers

Geology, and its effect on soil chemistry and structure, is often limiting for plants and for soil inhabiting invertebrate animals and microbes.Overcoming demands effective
dispersal strategies

Nature of the Habitat

At a lower level: can impose limits to a species. A forest species may be deterred from crossing an area of grassland; or a marsh organism may fail to travel across dry habitats to reach the next area of wetland

Biological Barriers

Increased predation, parasitism, disease or competition from more robust species if it were to move beyond specific area limits. Insect that leaves its forest floor log, is exposed beetles, shrews and insectivorous birds.

Historical Factors

Create barriers that confine species to a limited area. Changes in the pattern of land masses over the surface of the Earth have resulted in the creation of physical barriers, sometimes between closely related taxa.

Chance

Sheer chance in the distribution of organisms. The arrival of a wind-borne insect or a seed at a particular point in space cannot be predicted with certainty, and the first arrival may well be at an advantage over those arriving later

Endemic

Some plants and animals are confined in their distribution, within the areas in which they evolved; these are said to be endemic to that region. Palaeoendemics recently evolved (neoendemics).

Lecture No. 125 The Niche

The demands that an organism places on its environment in terms of physical and chemical conditions, space and food supply help to define what ecologists call its niche.Covers all aspects of the basic physics and chemistry of habitat and how the organism makes a living. Includes the food an animal requires, but also encompasses the way in which it acquires that food

Niche Partitioning

The subdivision of resources

Plants: similar requirements for water and chemical elements from soil. Roots at different depths, or flower at different times, tap slightly different resources. Differ in their niche.

Kleptoparasitism

A very widespread duck in the gadwall (Anas strepera). Coots (both Eurasian coot, Fulica atra, and the American coot, Fulica americana). Dive for their food and bring vegetable matter to the surface from greater depths.The coots are messy eaters, and it is not difficult for gadwall to move in and collect some of the loot. This behavior is called kleptoparasitism, and it is an effective way of widening the niche of the gadwall.

Fundamental Niche

There is the theoretical or ideal type of niche, usually called the fundamental niche, which is the sum of all the niche requirements under ideal conditions when the species is given unimpeded access to resources.

The Realized Niche

Species compete for resources (i.e. have overlapping niches). Perform better in their efficiency of acquisition.

The result is that the observed distribution of the organism is confined by species interactions

Importance

These concepts are important in biogeography, especially when attempts are made to model potential niches as an aid to predicting distribution patterns

Lecture No. 126 Topographical limits & Endemism

MUHAMMAD IMRAN

Distribution n Pattern

Confined to specific range by the topographical factors such as expanses of ocean or areas of lowland forest between mountain habitats. Such isolation may lead to the evolution of new forms or even new species.

Endemism:

Species may evolve in one region, spread to other locations and then become extinct in all but a restricted area where it survives. Species restricted in this way are said to be endemic to that area. In general there are two major factors influencing the degree of endemic in an area:

1. Isolation
2. Stability

Isolated islands and mountains are often rich in endemics.

Australia

The islands of Australia for example has long been isolated from outside influences, until the arrival of European people with their associated invasive organisms. Although not particularly stable in its climate, Australia covers a very considerable area, so on simple area basis it should be expected to have an extensive range of endemics. Australia also contains few physical barriers to movement during times change, so extension by local isolation has not been an important factor. Australia is indeed rich in endemics, many of which have a long geological history. This kind of fossil endemism is called **palaeorndemism,** in contrast to neoendemis.

Lecture No. 127 Physical Limits

Physical Limits

Often, a species' distribution is limited by a particular factor in the environment that influences its ability to survive or reproduce adequately. Physical factors such as temperature, light, wetness and dryness

Biotic factors

Biotic factors such as competition, predation, parasitism or the presence or absence of suitable food. All of these factors contribute to the niche of the organism.

Environmental Variable

Taking a single environmental variable. Any species will have certain limits along a gradient of that factor. Optimum for that factor, at which it populations will grow most effectively

Limiting Factor

Of these factors, there is often one that is particularly important and that may be over-riding in determining survival and hence distribution. This is called the **limiting factor.**Anything that tends to make it more difficult for a species to live, grow or reproduce in its environment may prove to be a limiting factor for the species in that environment.

Zonation

Any regular change in physical or chemical conditions through space thus creates a sequence of replacement of one species by another, among both animals and plants. This is known as zonation

Distribution along a river of three closely related species of amphipod (Crustacea), relative to the concentration of salt in the water are;

1. Gammarus pulex
2. Gammarus Zaddachi
3. Gammarus locusta

Studying Distribution

Potential distributions of species cannot be fully understood without reference to the influence of other organisms and their respective distribution and ecological requirements

Lecture No. 128 Competition

When two species are attempting to tap a resource in the same way, and when that resource is in short supply, the two are said to be in competition. Weaker species may be excluded from access to the resource entirely.

Competitive Exclusion

When a species is prevented from occupying an area by the presence of another species in this way, it is termed competitive exclusion. Not easy to observe this ousting of one species by another in nature

Example: The barnacle species that occupy the rocky seashores of western Europe and northeastern North America.

Reducing Competition:

An organism may find considerable advantage in avoiding competition with other species or other members of its own species. Many different ways of reducing competition between organisms have evolved.

Sometimes, species with similar food or space requirements exploit the same resources at different seasons of the year, or even at different times of day.Owl hunt at night, Hawks and falcons are daytime hunters

Temporal Separation

Many bats are night active insectivores, avoiding competition for prey with insectivorous birds during the day, and also avoiding the predatory attention of day active hawks and falcons. Described as temporal separation

Spatial Separation

Each species must be adapted to live within the fixed set of physical conditions of its particular microhabitat. Bird species have different preferences for the available feeding areas. E.g; Three species of tanager that coexist in the same forest on the island of Trinidad in the West Indies.

Lecture No. 129 Predators and Prey, Parasites and Hosts

Predators

Predators may be another biological factor influencing the distribution of species, as may the presence and abundance of parasites in a habitat, but their effects have been much less studied than those of competition. The simplest influences that predators might have is to eliminate species by eating them or, alternatively, to prevent the entry of new ones into a habitat

Prey Switching

Species is preyed upon too heavily, and the predators can always turn to alternative food species if the numbers of their usual prey should be reduced by climatic or other influences. This is termed prey switching.

Parasites

Parasites reduce the rate of growth of populations because of their negative influence on general fitness, survival and fecundity. Rarely cause the complete extinction of the host species; this would hardly be in their interests

Species Diversity

A parasite may increase diversity, but it may also reduce it.The presence of predators is likely to increase rather than reduce the numbers of species present. Predators broaden the distribution of species.In a grassland, the complicated sets of interactions between predator, grazer and plant can lead to the development of a finely balanced and diverse community. E,g; Coral reefs in oceans

Keystone Species

The removal of certain species could create effects far in excess of what may originally have been expected. Influential species of this kind are known as keystone species.Identifying the keystone species in an ecosystem is clearly a very important task, especially if biodiversity is to be maintained. The loss of a keystone species can cause an avalanche of local extinctions.

Lecture No. 130 Migration

Environmental conditions alter with seasons, especially in the higher latitudes, and some animals alter their distribution patterns in concert with the seasons. This is called **migration.**

- Not to be confused with range expansion, or spread, of a species, Consists of the temporary occupation (usually seasonal) of a region and then mass movement to an alternative region.
- **Motile organisms:** Microscopic plankton are capable of changing the depth at which they live, depending on conditions, and this can be regarded as a form of vertical migration. Diurnal rather than seasonal.
- Migration often takes the form of latitudinal movements of animals in order to take advantage of long summer days and high productivity in the high latitudes, and then to retreat to lower latitudes to avoid the stresses of the winter season.
- Energetically expensive and also exposes animals to the risks of predation, In the case of caribou by wolves that follow the herds. But the benefits of migration in terms of food availability and quality must outweigh these costs.
- Birds are among the most mobile of animals, and many species resort to migration in order to maximize food supply, especially during the breeding season.
- Most extraordinary of all migrant birds, is the Arctic tern (Sterna paradisaea) which, nests in the Arctic and travels to the Antarctic during the northern hemisphere winter. This bird must enjoy more daylight in the course of its life than any other organism

Breeding grounds, migration routes and wintering area of the Arctic tern (Sterna paradisaea).

Lecture No. 131 Invasion

The capacity to spread is important to all organisms. Success of a species can be measured by its geographical distribution, and the ability to move into new areas is one of the attributes required in order to achieve thisHabitats may alter or be lost, so a species needs to be capable of moving to more appropriate sites. Climate may change, and species will then need to alter their ranges to cope with the new conditions. Often this involves overcoming physical barriers.All organisms need to disperse to ensure survival. Many of the animals that have failed to survive and have become extinct have failed in this respect.The flightless birds, such as the great auk and the dodo, are examples. Species need to be able to move to new areas if local conditions deteriorate for them.

But range expansion for organisms with little or no mobility of their own presents problems, and these have been overcome in a variety of ways.

Ecological Imperialism

Greatly assisted by humans. Ecological imperialism is a term sometimes used to describe the wave of biological invasions that has occurred in the wake of human invasions, by either accidental transport or deliberate introduction

Lecture No. 132 Living Together

No organism lives in total isolation from all others. Different organisms interact with one another in both the long and the short term, competing for resources and sometimes excluding one another from certain areas. Over evolutionary time, this can lead to populations specializing in certain ways, perhaps in the way they obtain food, or the type of food they eat or the type of microclimate in which they perform best.

The Community

Species rarely occur as single populations; usually they occur in a mixture of different species, and such an assemblage is termed a community.

The Guild

The term guild is used for animals that play a particular role in the community, such as plant sucking insects or insectivorous birds. Some plants and animals occur together and are associated with specific habitats.

Co evolution

Co evolution: species tolerating one another, or becoming dependent on one another. Species adapt to cope with the physical demands of their environment, to cope with the presence of other species.

Phytosociology

Discipline of vegetation science summarized by the views of the two American ecologists, Frederic Clements and Henry Gleason who began the discussion in the 1910s and 1920s.

Clements

Clements regarded the plant community as an organic entity in which the positive interactions and interdependencies between plant species led to their being found in distinct associations that were frequently repeated in nature.

Gleason: Individualistic concept. Pointing out that no two species have quite the same needs. Very rarely do the distributional or ecological ranges of any two species coincide precisely.

Two models of vegetation

1. The model of Clements in which species' requirements coincide, leading to the separation of distinct 'communities'.
2. The 'individualistic' model of Gleason in which each species is distributed independently and no clear 'communities' are apparent.

Lecture No. 133 The Ecosystem

If we include environmental features, including the underlying soil, the water, and the atmosphere and surrounding vegetation. More complex, interactive system that is called the ecosystem. The concept of the ecosystem can be applied at various levels. The entire Earth can be viewed as an enclosed ecosystem, but so can a lake, a forest, a stream or even a clump of grass.

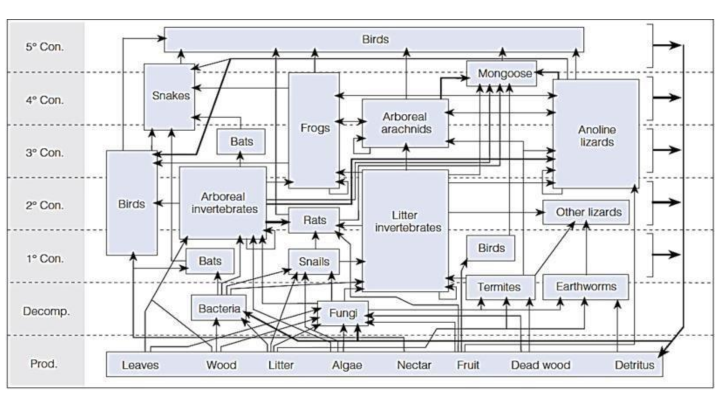
Two fundamentals underlying the ecosystem concept.

- Energy flow
- and nutrient cycling.

Energy is fixed from solar radiation into a chemical form by green plants & moves through ecosystem.

Feeding Relationships

We can classify all the organisms in any community in terms of their feeding relationships. In practice, a series of complex feeding webs are usually formed, relating each species to many others, whether as feeder or food.



Food web of a tropical rainforest derived from the observations of Reagan and Waide at El Verde, PuertoRico

Movements of Elements

Occurs between ecosystems. Hydrological cycle plays a major role in both delivering and removing elements to and from ecosystems. Gradual degradation of rocks, weathering, replenishes elements removed by plants

The Ecosystem Concept

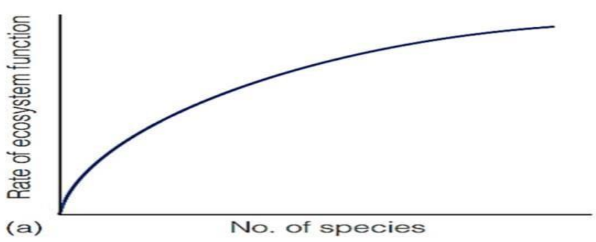
Involves all the complexity of species interactions within the system, but views these in relation to the processes, in which the ecosystem is engaged, including productivity, energy flow, nutrient cycling and so on.Very useful in the assistance it provides in understanding the relationships between organisms and the interactions with the environment. Gives us a basis for the rational use of natural resources for the support of human populations

Lecture No. 134 Ecosystems and Species Diversity

Redundant Species Hypothesis

Removal of certain species from an ecosystem would have little or no effect on the functioning of that ecosystem.

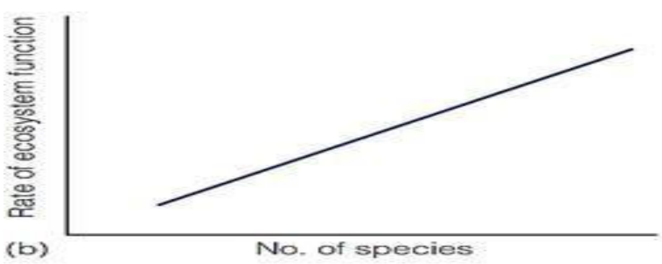
The possible relationships between the number of species in an ecosystem and its rate of function



(a) Redundant species hypothesis, where at high species density some species can be lost without affecting ecosystem function

Linear Relationship Model

A possible alternative model is based on the supposition that all species are equally important to ecosystem function, In which case the loss of each species renders it a little less efficient, This is a linear relationship model.The possible relationships between the number of species in an ecosystem and its rate of function



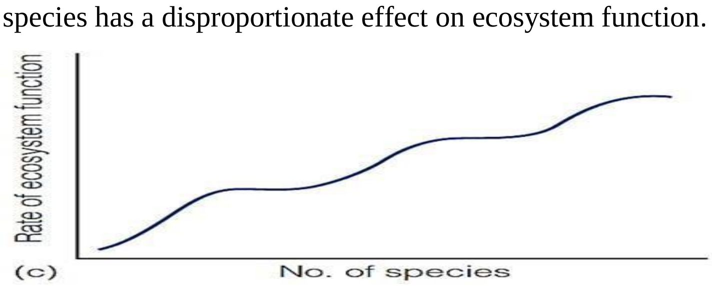
(b) Linear model, in which every species is equal in functional importance and the loss of any species reduces the efficiency ofecosystem function accordingly.

The Rivet Hypothesis

A third option, is that certain species play key roles in the ecosystem, and when they are lost there is a sudden drop in the capacity of the ecosystem to function. This is sometimes referred to as the rivet hypothesis

The possible relationships between the number of species in an ecosystem and its rate of function

Rivet hypothesis, in which certain species are critical in supporting ecosystem function ('rivets'). Loss of these species has a disproportionate effect on ecosystem function.



Functional Types

The roles that species play within an ecosystem can vary in importance to general ecosystem function, and it is possible to divide species into functional types according to their physiological and ecological capacities.

Stability

British ecologist Charles Elton first proposed (in the 1950s) that a more complex and rich ecosystem should also be more stable, Less prone to violent fluctuations such as those caused by epidemic disease or pest outbreaks. Defined in terms of inertia, or resistance to change. A stable ecosystem could be defined as one which rapidly returns to its original state following disturbance. The concept of resilience as a basis for defining stability.

Lecture No. 135 Biotic Assemblages on a Global Scale

Biotic Assemblages

A general classification of terrestrial, large-scale ecosystems. First based simply on vegetation, called formations, **Animal life:** included in descriptions and definitions and they are called biomes.

Raunkiaer

The concept of a life form among plants, He analyzed the flora of different parts of the world into component functional types and found that each region had its own distinctive biological spectrum.

An idealized Northern Hemisphere continent showing the pattern of climate and biome types over its surface.IV, Mediterranean forest/scrub (maritime and continental forms). Vm, (West coast) temperate rainforest. Ve, (East coast) warm temperate forest. VI, Temperate forest.

Climatic Envelope

Each biome is said to fit within a certain climatic envelope,
i.e. the sum of all the climatic variables that limit that biome. A refinement of conventional biome definitions, particularly
in the case of forests and grassland.

Ian Woodward

Proposed the classification of these vegetation types.

1. Evergreen needleleaf forests – tall (over 2 m high), dense (over 60% cover) forests of evergreen trees with narrow leaves (e.g. boreal coniferous forests).
2. Evergreen broadleaf forests – tall, dense forests of evergreen trees with broad leaves (e.g. tropical rainforests).
3. Deciduous needleleaf forests – tall, dense forests of narrow leaved trees that seasonally lose their leaves (e.g. larch).
4. Deciduous broadleaf forests – tall, dense forests of broad leaved trees that seasonally lose their leaves (e.g. beech, maple, some oaks).
5. Mixed forests – tall, dense forests with an intermixture or a mosaic of deciduous and evergreen trees.
6. Woody savannas – trees > 2 m high, cover only 30– 60% of the land surface; with herbaceous vegetation.
7. Savanna – trees >high, widely scattered, covering only 10%-30% of the surface, rest is herbaceous vegetation.
8. Grasslands – land with herbaceous cover and with less than 10% tree or shrub cover.
9. Closed shrublands – lands with woody vegetation less than 2 m tall and with a shrub cover (evergreen or deciduous) of more than 60%.
10. Open shrublands – lands with woody vegetation (evergreen or deciduous) less than 2 m tall and with a shrub cover of between 10% and 60%.
11. Objective advantage: Recognized from satellite imagery.

Lecture No. 136 Global Patterns of Climate

Climate

The climate of an area consists of the whole range of weather conditions experienced within that area, including temperature, rainfall, evaporation, sunlight and wind through all the seasons of the year.

Factors Determining Climate

Particularly latitude, altitude and location in relation to oceans and land masses. The climate is a very important factor in determining the species of plants and animals, and even the life forms or functional types, that can live in an area.

Lecture No. 137

Latitude

Climate varies with latitude. The spherical form of the Earth results in an uneven distribution of solar energy with respect to latitude. In the high latitudes, energy is spread over a wide area; thus, polar climates are generally cold. As the angle of incidence of the sun's rays approaches 90°, the area over which the energy is spread becomes smaller, so that there is an increased heating effect.The precise latitude that receives sunlight at 90° at noon varies during the year; it is at the equator during March and September, at the Tropic of Cancer (23°28′N) during June and at the Tropic of Capricorn (23°28′S) during December.The effect of this seasonal fluctuation is more profound in some regions than in others, with the greatest contrasts experienced at high latitudes.

Movement of Air Masses

- Variations in climate also result from the pattern of movement of air masses. Air heated most strongly over the equator and therefore rises (causing a low pressure area) and moves towards the pole. Air moves towards the pole & gradually cools & increases in density until it descends, where it forms a subtropical region of high pressure, known as the **Horse Latitudes.**
- Air then either moves toward the equator or else moves poleward. This simplified and idealized picture is complicated by the **Coriolis effect** (named in honour of the French mathematician Gaspard Coriolis, who analyzed it), which is a consequence of the west– east rotation of the Earth. This spinning force tends to deflect any freely moving object to the right of its course in the Northern Hemisphere and to the left in the Southern Hemisphere.
- As a result, the winds moving toward the equator in both hemispheres are deflected and consequently blow from east to west. The 'trade winds', found in both the Northern and Southern Hemispheres, meet in the region of the equator, and this is known as the **intertropical convergence zone (ITCZ).**
- In the Northern Hemisphere summer, strong southerly winds are generated in the Indian Ocean, carrying warm, moist air into India and East Africa. These winds bring the monsoon rains to these regions.
- The oceanic conveyor belt carrying warm, low salinity surface waters northwards into the North Atlantic and deep, higher salinity cold waters from west to east into the Indian Ocean and the Pacific. From here, water receives a renewal of its heat content, rises to the surface and returns westward into the Atlantic.

Causes of global patterns of climate

(a) Due to the spherical shape of the Earth, polar regions receive less solar energy per unit area than the equatorial regions.

(b) The major patterns of circulating air masses (cells) in the Northern Hemisphere: H, high pressure; L, low pressure. **Global Pattern of Oceans And Land Masses**

Modifies the climatic patterns yet further. The global circulation patterns of water within the oceans are also of great importance in determining world climate patterns.

Lecture No. 138 Biodiversity

Biodiversity is an expression of the great variety of living things on our planet, but it is far more than a simple count of species. We take a species and analyze its composition, we find that it consists of a series of populations

Metapopulation

A fragmented population. Isolated populations are genetically distinct and can be classified as subspecies, but even within single populations there is often great variation between individual organisms.

How many Species?

Many species are difficult to identify. The numbers of expert scientists in the field of taxonomy are relatively few. The task of counting species is much more difficult to accomplish than might at first appear.The convenient idea that two species cannot interbreed is not actually workable because it is often found that interbreeding is possible between several animal and plant species that are morphologically distinct.Undoubtedly many species yet to be discovered, Approximately 1.8 million species of organism that have been described. Many may have been described and named twice, or even more times ‘Alias problem. The diversity of microbes (bacteria, fungi, viruses etc.) is difficult to estimate, not as well-known as the mammals or the flowering plants. Of the bacteria, only about 4000 species have so far been described.

Group	Number of described species	Likely total	%
Insects	950 000	8 000 000	12
Fungi	70 000	1 000 000	7
Arachnids	75 000	750 000	10
Viruses	5000	500 000	5
Nematodes	15 000	500 000	3
Bacteria	4000	400 000	1
Vascular plants	250 000	300 000	83
Protozoans	40 000	200 000	20
Algae	40 000	200 000	20
Molluscs	70 000	200 000	35
Crustaceans	40 000	150 000	27
Vertebrates	45 000	50 000	90

The numbers of described species in selected groups of organisms, together with the likely total numbers on Earth, and the percentage of the group that is currently known. Data from Groombridge.

Extinction is occurring all around us. The biologist Edward O. Wilson has calculated that the loss of species from the tropical forest area alone could currently be as high as 6000 species per year.

Lecture No. 139 Latitudinal Gradients of Diversity

Latitudinal Gradients

The distribution of biodiversity over the land surface of the planet is far from even. The tropics contain many more species, of both plants and animals, than an equivalent area of the higher latitudes.Regions with the highest evapotranspiration are able to support the highest diversity of tree species. Evapotranspiration itself also correlates closely with the potential productivity of a region. In general, the equatorial regions are the areas in which highest productivity is possible because of the prevailing climate, which is hot, wet and relatively free from seasonal variation.

Energy Hypothesis

Latitudinal gradient of species diversity suggests that the critical factor is how much energy is captured by the vegetation. Supported by plant based data

Metabolic Theory:

Higher biomass and more complex vegetation architecture to host more animals. Warm moist climates in which high productivity occurs can also lead to greater metabolic rates in organisms.

Lecture No. 140 Is Evolution Faster in the Tropics?

Evolution:

Evolution, the process by which new species are generated. It essentially involves genetic variation and subsequent selection of the most suitable genetic combinations within a particular environment. Whether evolution proceeds more rapidly under tropical conditions. If it does, then the richness of the tropics could simply be due to the continual evolution of new forms there.

Whether the tropics have acted as a centre of evolution for groups of organisms in the past?

Plants and their fossils provide a useful group in which to investigate this possibility.

Estimated percentage representation of flowering plants (angiosperms) at different times in geological history and at different latitudes. Angiosperms have always been most abundant in the low-latitude (tropical) regions. From Crane and Lidgard.

(Biogeography: An Ecological and Evolutionary Approach, Ninth Edition. Edited by C. Barry Cox, Peter D. Moore, Richard J. Ladle. © 2016 John Wiley & Sons, Ltd. Published 2016 by John Wiley & Sons, Ltd.)

Metabolic Theory

In an environment where energy is abundant and temperature is consistently high, such as the tropics, metabolic rates in organisms tend to be faster. Fecundity is greater, and generation times may be shorter.

Ultraviolet Radiation

Generally greater in the tropics, and this can increase mutation rates. There is a positive feedback in that the new varieties are in competition with one another, leading to an intense degree of selection for the most fit.

High Diversity

Regions with high diversity exhibit a faster rate of diversification. Argument is circular. External factors likely to create the required environment for enhanced diversification like metabolism

High Biomass

Jonathan Davies & his colleagues from I.College London and from Kew Gardens. Accumulation of species was indeed faster in regions of high biomass. Either of speciation being rapid, or of extinction rates being lower

Energy–biomass Model

Energy–biomass model remains the most robust explanation currently available for latitudinal gradients in diversity.

There remain, however, additional factors that need to be considered.

Lecture No. 141 The Legacy of Glaciation

Extinctions Rates

Fast rate of speciation in the tropics: increased biodiversity, less extinction rates. Greater extinction rates in the higher latitudes is the instability of climatic conditions over the past 2 million years

Earth's Climate

Constantly changing. Considerably colder over the past 2 million years than was the case for the previous 300 million years. A high amplitude of variation between warm and cold conditions during that time.During cold episodes, the high latitudes have been disrupted by the development of glaciers over the land surface. Biogeographical patterns of plants and animals were most severely disrupted.

Stable Tropics

This idea of a climatically stable tropical belt, if it is indeed true, could account for some of the diversity still found in the tropics as the plants and animals could be a relic accumulation of species from a former age.

Equatorial Forests

Had to endure less disturbance than their temperate counterparts, maintained themselves in a forested form during the period of stress. Their species composition and architectural structure changed.

Uninterrupted forest hypothesis of Colinvaux. It is reasonable to conclude, therefore, that many factors contribute to the species richness of the tropical regions and the lower richness of higher latitudes

Lecture No. 142 Latitude and Species Ranges

Ranges & Latitudes

High ‐ latitude organisms have broader geographical ranges than those from the low latitudes. General feature of biogeography first pointed out by E.H. Rapoport in the 1970s, Rapoport's rule. There remains doubt as to whether this is a local effect that only makes itself felt in more northerly latitudes (above about 40–50°N), or whether it continues to be operative in the equatorial regions.Klaus Rohde of Armidale, Australia, considers that Rapoport's rule is of local application only and cannot be applied in the tropical regions. Broad range species in the high latitudes: successive glaciations. Greater seasonal fluctuations of the high latitudes will select for wide tolerance organisms. Detailed testing has failed to support a global relationship between latitude or elevation and range among species. Katherine Smith and James Brown examined the diversity of fish as one proceeds deeper Species of greater depth have wider tolerance species tolerating more extreme conditions tend to occupy wider ranges.Although the Rapoport effect has proved more restricted in its application than was originally anticipated, it provides an excellent example of the kind of question that biogeographers are now asking.Ecological questions within a much larger scale framework of space and time. James Brown of the U. of New Mexico has coined the term macroecology to cover this approach to biogeographical and ecological research.

Lecture No. 143 Diversity and Altitude

Altitude

Patterns of vegetation and hence of biomes are generally related to latitude, and these are broadly repeated with respect to altitude, with higher altitudes often bearing biome types more typical of higher latitudes.Many studies investigated the changes in species richness with altitude. Concentrated on tropical mountains, where the full range of climatic variation is found. Not generally conformed with expectation.Many studies have demonstrated that the richness of species, particularly plants, increases with altitude, reaches a peak and then declines again at very high altitudes.The overall conclusion regarding patterns of diversity with altitude, is that the energy model used in latitudinal studies probably holds good for many types of organism in relation to altitude.The complications found in altitude patterns of diversity probably largely relate to the peculiarities of local climates in mountain regions

Lecture No. 144 Biodiversity Hotspots

Species Richness

The Amazon basin contains approximately 90 000 flowering plant species, whereas equivalent areas in Africa and in South East Asia contain only about 40,000 each.

Biodiversity Hotspots

Norman Myers: There appear to be certain areas of the world that are exceptionally rich in species, termed biodiversity hotspots by the conservationist Norman Myers. Originally proposed 10 hotspots.Largely identified on the basis of plant diversity, based on the idea that if vegetation is diverse all else will follow. Not always true. The areas of high plant diversity in Africa compared with areas of high bird diversity. The original work of Myers has been developed and expanded. The location of 25 of the hottest spots for biodiversity on Earth based on a consideration of many of the better known groups of organisms. All the land surface area of the hotspots together comprise only about
1.4% of the Earth's terrestrial total. Contain about 44% of the world's vascular plants and 35% of the vertebrates from the four main groups

Stuart Pimm & Peter Raven: research conservationists calculated that even if the 25 hotspots were given protection the likely extinction rate of species would be about 18%.If protection is delayed: as high as 40%

Global richness pattern of bird species showed no significant correlation between overall richness and the richness of endemic species. Biological diversity & human population density are positively related

Lecture No. 145 Plate Tectonics

Plate Tectonics

- The idea that continents could fragment and move across the face of the planet was first suggested by the German meteorologist Alfred Wegener in 1912.
- The ocean floors move as well as the continents, the study of their movements is known as plate tectonics rather than continental drift. The different plates may also move past one another at regions known as transform faults.
- In the 1960s, new discoveries revealed the motive force. All this evidence for the theory of plate tectonics was so overwhelmingly convincing that it quickly gained general acceptance by biogeographers during the 1960s.

The major tectonic plates.

Lines within the oceans show the positions of spreading ridges: dotted lines indicate the positions of trenches. Lines within the continents show the divisions between the different plates. Arrows indicate the directions and proportionate speeds of movement of the plates. The Antarctic plate is rotating clockwise.

First Breakthrough

The invention of techniques that used the phenomenon of Palaeomagnetism. Used the presence of magnetized particles in many rocks to trace the movements of the rocks, and therefore also of the landmasses in which they lie

Harry Hess (1962)

American geophysicist. Suggested that the Volcanic chains were spreading ridges, where new seafloor is being formed. The trenches are where old ocean floor is consumed, downward into the Earth.

How and why South America and Africa drifted apart

(a) The two continents were originally part of a single continent, Gondwana (the rest of which is not shown). An upward convection current from the deeper layers of the Earth appeared under them, with the corresponding downward current further to the west, in the Pacific Ocean.

b) The two continents moved apart, separated by the new South Atlantic Ocean. Down the centre of this runs the mid Atlantic spreading ridge, on either side of which new ocean crust is continually created. This extension movement is balanced by the appearance, in the Pacific, of an ocean trench where old ocean crust disappears into the Earth.

(c) South America has moved westwards until it is adjacent to the ocean trench. To continue to balance the still widening South Atlantic Ocean, the ocean crust that disappears into the trench is now derived from the west. This old crust now disappears below western South America, causing earthquakes and the rise of the volcanic Andes Mountains.

Lithosphere

The surface of the Earth, known as the lithosphere, is occupied by a number of areas known as tectonic plates, which may contain continents and parts of oceans, or may consist only of ocean floor

Lecture No. 146 Changing Patterns of Continents

Gondwana

1. In the middle of the Palaeozoic, 400 mya, a large landmass that we call Euramerica, lay across the equator. To its south lay a great continent known as Gondwana, a huge area of land. **World geography at Early Devonian Tripel– Winkel projection.**

Dark tint indicates ocean; epicontinental seas (light shading) after Smith et al. Dotted lines indicate modern coastlines. Continental positions after Metcalfe (1)Siberia; (2) Euramerica; (3) Gondwana; (4) southern China; (5) northern China; (6) Kazakhstan.

2. Antarctica ,South America, Africa, Australia and India. Gondwana and Euramerica, joined together (340 mya). About 295 mya, the resulting supercontinent was joined by two other Northern Hemisphere continents, Ural Mountains.

- **World geography at Late Carboniferous Tripel– Winkel projection**.

Dark tint indicates ocean; epicontinental seas (light shading) after Smith et al. Dotted lines indicate modern coastlines. Continental positions after Metcalfe (1)Siberia; (2) Euramerica; (3) Gondwana; (4) southern China; (5) northern China; (6) Kazakhstan.

Pangea(260 mya)

Joined by a number of smaller fragments (including north China, south China, Tibet, Indochina and South East Asia) that had split off from the northern edge of Gondwana and moved northward.Single world continent: **Pangaea.**

- **World geography at Middle Permian: Tripel– Winkel projection.**

Dark tint indicates ocean; epicontinental seas (light shading) after Smith et al. Dotted lines indicate modern coastlines. Continental positions after Metcalfe (1)Siberia; (2) Euramerica; (3) Gondwana; (4) southern China; (5) northern China; (6) Kazakhstan.

Pangea(160 mya)

Pangaea started to become divided. Gondwana separated from the northern landmass, now made up of North America and Eurasia, that we call Laurasia. The new ocean between the two landmasses is known as the Tethys Ocean

- **World geography at Early Cretaceous: Tripel Winkel projection;**

Outlines of epicontinental seas (light shading) after Smith et al. Dotted lines indicate modern coastlines. Continental positions after Cambridge Palaeomap Services

- **World geography at Middle Cretaceous: Tripel Winkel projection;**

Outlines of epicontinental seas (light shading) after Smith et al. Dotted lines indicate modern coastlines. Continental positions after Cambridge Palaeomap Services

- **World geography at Late Cretaceous: Tripel Winkel projection;**

Outlines of epicontinental seas (light shading) after Smith et al. Dotted lines indicate modern coastlines. Continental positions after Cambridge Palaeomap Services

- **World geography at Eocene: Tripel Winkel projection;**

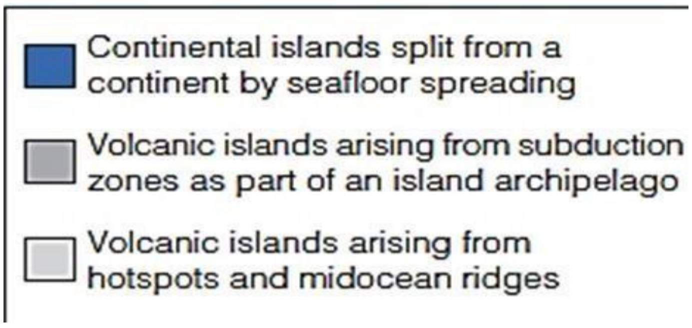
Outlines of epicontinental seas (light shading) after Smith et al. Dotted lines indicate modern coastlines. Continental positions after Cambridge Palaeomap Services

Changing Earth

Continental movements, the expansion or contraction of shallow seas and the rise or erosion of mountain chains. The resulting changes in the relationships between their floras and faunas.

Lecture No. 147 Islands

The nature of islands and the biotas that they contain are also affected by the way in which the direct or indirect effects of plate tectonics created them.



These islands may be of three different types

1. **Continental Islands**

The first type of island was originally a part of a nearby continent, but it became separated from it by rising sea levels or by tectonic processes that split them away from an adjacent continent.

2. **Volcanic Island Arc**

The most obvious of these are the Kurile and Aleutian island arcs that lie along the edge of the Pacific. Here, old ocean crust is being forced into the depths of the crust, and the resulting stresses cause the appearance of volcanic islands.

3. **Volcanic Island Hotspots**

Other islands form as a result of the activity of what geologists call **hotspots**. These are scattered, but fixed, locations over 700 km deep within the Earth, from which plumes of hot material rise to form volcanoes at the Earth's surface.

- **Plateau**

A hotspot may also cause the appearance of a larger area or plateau that, if exposed and colonized by animals and plants, could play a role in their dispersal between continents.

- **Terranes**

Volcanic islands remains reach the edge of a trench. They collide with the adjacent continent. Individual patches known as terranes – regions within which the rocks are quite different from those of the surrounding area.

Lecture No. 148 Evolution, the Source of Novelty

Sympatry versus Allopatry

Sympatry

An initially interbreeding population that splits into two or more distinct species sharing a common range exemplifies sympatric speciation. Darwin's finches and their beak sizes

Allopatric speciation

Also referred to as geographic speciation, is a mode of speciation that occurs when biological populations of the same species become isolated from each other.

Defining the Species

There is a great variety of definitions of the species which focus on a variety of different aspects of the organisms, so let's first of all consider what type of data are normally the concern of the biogeographer

Biological Species Concept

Focuses on its reproductive isolation: 'The species is a group of natural populations whose members can all breed together to produce fertile offspring'

Ecological Species Concept

Arises from the organism's need to find its own place in the natural world. In the face of competition from other organisms, it must develop a set of characteristics that give it an advantage over those competitors.

Scientific Definition

Reflects the nature and detail of the information available at the time. Definitions of the species have changed over time. More knowledge about the genetic, ecological nature, & population structure, of the species we observe.

Lecture No. 149 Patterns in the Past

Early Land Life on the Moving Continents

Patterns

- How the very different geographies, climates, faunas and floras of our planet gradually changed, over the last 400 million years, into those that we see today?

The movements of the continents and of the timing of the different events of continental fragmentation/union is fairly understood. The distribution of fossil organisms correlates very well with the varying patterns of land.

Early Devonian (380mya)

Separate floras and/or fish faunas can be distinguished in the northerly placed Siberian continent, the equatorially placed Euramerican continent, Kazakhstan, northern Africa and Australia. The fossil record suggests that all the early amphibian and reptile groups evolved in the continent called Euramerica

One World – for a While

The coalescence of the different continental fragments to form Pangaea led to climatic changes. In general, the world became steadily warmer and drier during the Triassic.

Jurassic & Early Cretaceous

Floras become more similar, approaching the modern pattern in which there are gradual latitudinal changes governed by climate, the patterns of dominance of different groups changing from lower latitudes to higher latitudes.

Early & Middle Triassic

The bulk of the Permian faunas had been made up of synapsid or 'mammal_like' reptiles and other older types of reptile, but these disappeared during the Early and Middle Triassic.

Subdivision of Pangaea

Some fundamental biogeographical consequences, for evolution could now take place independently in each new continent to produce new, unique groups, thus leading to greater global diversity.

Lecture No. 150 Biogeographical Regions Today

Geographical Region

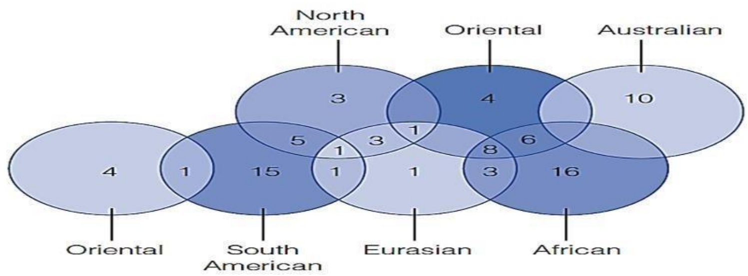
- Candolle (1820) & Engler (1879) used the patterns of distribution of flowering plants
- Sclater (1858) working on birds, & Wallace in 1860–1876, working on mammals, defined the system of zoogeographical regions.
- **Zoogeographical regions, according to Sclater & Wallace:** Neartic, Neotropical, African, Australian, Oriental, Palearctic.

Mammal Biogeography

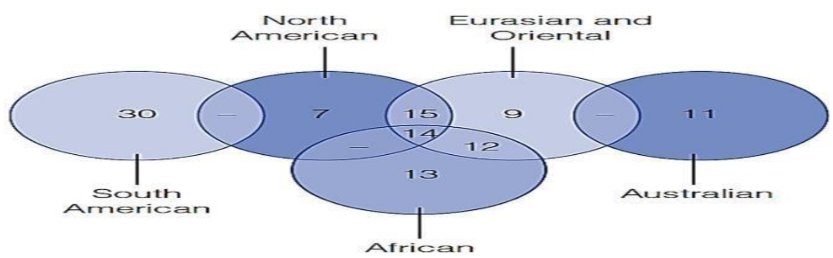
We can trace the histories of continent based mammal faunas through time, Relate their histories to movements of the continents, How the dispersal of a fauna or group from one continent to another permitted. Possibilities for mammals to disperse between the different continents varied in the past due to changes in the positions of the continents, in the climate or owing to the rise or withdrawal of shallow seas that from time to time subdivided the continents. Eisenberg has made an interesting analysis of the extent to which the different ecological niches have been filled in the different mammalian biogeographical region.

- **Venn diagram showing the interrelationships of the families of terrestrial mammals of their =six zoogeographical regions today, excluding the 11**

  'wandering' families



- **Candolle (1820) & Engler (1879) used the patterns of distribution of flowering plants. Sclater (1858) working on birds, & Wallace in 1860–1876, working on mammals, defined the system of zoogeographical regions**



Lecture No. 151 History of Today's Biogeographical Regions

Continents

Southern continents: complex, as these are all the result of the break-up and dispersal of Gondwana, Northern continents: mainly the result of the appearance and disappearance of land or sea barriers within North America and Eurasia.

- **Southern continents:** complex, as these are all the result of the break up and dispersal of Gondwana,
- **Northern continents:** mainly the result of the appearance and disappearance of land or sea barriers within North America and Eurasia.
- Further west, the comparatively small northern movement of South America led to its connection with Northern America about 3 mya, which led to a complex interchange between their faunas and floras.
- India moved rapidly northward; its northeastern corner collided with an island arc about 57 mya, before finally colliding with Tibet in southern Asia about 35 mya, near the Eocene/Oligocene boundary. Australia itself gradually separated from Antarctica 52–35 mya and moved far northward to its present position near South East Asia, allowing a complex interchange between the biotas of those two areas.
- Further east, New Zealand separated from Australia 84 mya, followed by the small continental fragment we call New Caledonia 80–65 mya.
- India–Madagascar parted from Antarctica about 132 mya, while the split between India and Madagascar took place 90–85 mya
- This seaway gradually extended clockwise around Africa, to form in turn the southern South Atlantic about 135 mya, and the northern South Atlantic about 105 mya.

Lecture No. 152 The Old World Tropic: Africa

Continents

Two continents, India and Africa originally part of Gondwana. Africa became united with the northern continents during the Mid Miocene, 16–10 mya it was probably from Africa that tropical flowering plants dispersed to the tropics of southern Asia.

Old World tropical biota

It is not yet possible to trace in full the separate contributions of Africa, India and South East Asia to the final Old World tropical biota. The fossil record of mammals is easier to interpret

Africa

- Contains the best known & most distinctive of Old World tropical mammal fauna. Molecular studies of the interrelationships of the different orders of placentals suggest that the common ancestor of a group of African placentals entered the continent in the Late Cretaceous.
- This group is made up of the elephants, hyracoids (conies), aquatic sirenians (sea cows), elephant shrews, aardvarks, Cape golden moles, insectivorous tenrecs and extinct embrithopods; they have been placed together in a superorder, Afrotheria that is endemic to Africa.
- Much of the continent was covered by rainforests of the tropical ever wet and subtropical summer wet biomes for much of the early Cenozoic, until the Late Miocene. About 19 mya in the Miocene, a firm land connection with Eurasia took place in what is now the Middle East
- The seaway was finally broken near the beginning of the Late Miocene, 12 mya, by rising mountains in Arabia, Turkey and the Middle East. It was at this time that the early horse Hipparion, which had evolved in North America, appeared in both Eurasia and Africa
- The elephant originated in Africa in the Eocene, migrated into Eurasia in the Early Miocene and migrated back later in the Miocene The ancestors of the mammoths and modern Asian elephant probably evolved in Africa 4 to 5 mya and migrated back into Eurasia 2 million years later.

Madagascar

Area of 587 000 km2, Madagascar is second only to New Guinea in size. Madagascar reached its present position relative to Africa by 121 mya; it separated from India about 88 mya. Became an island, while India continued its journey toward Asia.

Lecture No. 153 The Old World Tropic: India

India:

- After its separation from Madagascar, India was isolated from direct contact with other land masses during its long journey northward to collide with southern Asia that probably took place less than 35 mya.
- **Ali and Aitchison** believe that oceanic islands and now-submerged oceanic plateau could have provided stepping stones for organisms to disperse between it and other parts of East Gondwana in the Late Cretaceous and early Paleocene.
- There were once islands on the 5000 km long Ninety east Ridge, so named because it approximately parallels that longitude today. Now eroded away, in the Paleocene to Late Oligocene
- The mammal fauna of India in the Cretaceous and Paleocene is unknown, but it must have been quickly colonized by the placental mammals of
- Asia after its collision with that continent.
- About 3 mya, an increase in aridity, related to the uplift of the Himalayan Mountains to new heights, led to the northern parts of the Indian subcontinent becoming much drier and also

Led to an increase in the numbers of grazing mammals such as horses, antelope and camels, and of elephants.

East Indies

A complex pattern of islands lies on the continental shelves of South East Asia (the Sunda shelf) and that of New Guinea– Australia (the Sahul shelf), and these have been colonized from both these areas.

Lecture No. 154 Australia

- The history, characteristics and biogeographical affinities of the biota of Australia are the most unusual and interesting. Their explanation requires a rewarding understanding of the interplay between continental movement, climatic change and biotic dispersal. By the Middle and Late Cretaceous, Gondwana had lost both India and Africa and retained only a narrow connection with South America, so that Antarctica–Australia was the most substantial remnant of the old supercontinent. Its fauna included marsupial mammals. In the early Cenozoic, when its marsupials were undergoing their great radiation, whose diversity paralleled that of the absent placentals. It was also the time and environment in which the songbirds (oscines) started their diversification

- The Oscines then dispersed to Asia in the Eocene, where their descendants started the worldwide radiation that today comprises nearly half of all living species of bird. Australia only started to move rapidly northward 46 mya, in the Eocene. By the Early Oligocene, around 35 mya, it had separated sufficiently far from Antarctica for the deep water Antarctic Circumpolar Current of cooler water and associated westerly winds to become established. Cooling

  of Antarctica. Increase in its arid, desert areas. Australia's northward movement brought it into the 30°S high pressure zone of low rainfall. Australia became increasingly arid from the Late Oligocene and into the Miocene.

Australia's annual rainfall is also extremely variable due the El Niño events.

- The mammals of Australia had to adapt to these climatic changes. This fauna is made up of marsupials alone (plus the few egg laying monotremes), and they have radiated into a great variety of forms, occupying the niches that placentals have filled everywhere else in the world. The marsupial equivalents of rats, mice, squirrels, jerboas, moles, badgers, anteaters, rabbits, cats, wolves and bears all look very like their placental counterparts – only the kangaroo looks quite unlike its placental equivalent, the horse.
- Molecular results; Arboreal possum families radiated in the Eocene in Nothofagus forests. The early marsupial herbivores: kangaroos and wallabies appeared after the Eremean grassland ecosystem appeared in the Pliocene.

  Apart from humans and the aerial bats, only the rats spread naturally as far as Australia, 50 species now form 50% of the diversity of the Australian land mammal fauna. Human beings probably arrived 60 000 to 40 000 years ago and brought the domestic dog (the ancestor of the dingo) about 3500 years ago.

Lecture No. 155 New Caledonia

Geological studies show that New Caledonia is the smallest (about 1600 km2) surviving fragment of Gondwana. Rifted away from Australia in the Late Cretaceous 80–65 mya and reaching its present position 1500 km east of it 50 mya. It is a hotspot for diversity.

In view of the large amount of research that shows the frequency of long distance dispersal in such scenarios, most biogeographers today believe that this was the mechanism of arrival of the ancestors of the New Caledonian taxa. Geological studies show that the island was submerged for long periods in the Paleocene–Eocene, so that the island was not available for colonization until about 37 mya. The New Caledonian species must therefore have diverged from their ancestors after this date

- Panbiogeographers reject long distance dispersal.They theorize that the Cretaceous ancestors of the present biota were widespread across the Pacific islands, including on supposedly formerly exposed large plateaux such as the Ontong Java plateau
- Biogeographers have investigated the history of the angiosperm family Sapotaceae. Resulted from nine colonizations of the island between 33 and 4.2 mya, dates that are about 40 million years after the rifting of New Caledonia from Australia.

New Guinea and Australia were the most important sources of the arrivals, those from Pacific islands arriving only more recently, 27–24 mya. These results are clearly totally incompatible with the panbiogeographers' theories.

Lecture No. 156 New Zealand

- New Zealand is unique. Its total area, 270 000 km2, makes it far larger than any other Pacific oceanic island. It is therefore not so vulnerable to the fluctuations of population and diversity that characterize them. When it first separated from Gondwana in the Late Cretaceous, about 82 mya, it was part of a minicontinent known as Zealandia almost half the size of Australia.

- Stretching as far as New Caledonia to the northwest and Chatham Island to the southeast. This small landmass drifted northeastward to its present position, separated from Australia by the Tasman Sea, 1400 km wide. Most of it sank below sea level 30–25 mya, during the Oligocene, and it is possible that all of it was submerged at this time. Molecular studies that provide the dates of divergence of the New Zealand lineages from their closest external relatives have shown that many of New Zealand's organisms (especially the plants) reached there in comparatively recent times, and therefore by dispersal.

- A group of mainly New Zealand scientists has recently reported the results of an analysis of the mitochondrial genome of the endemic New Zealand frog Leiopelma. The divergence times between the two species are well over 65 mya, far earlier than the suggested total drowning of the islands.

- The ancient and diverse fauna, unlikely to have been able to arrive by overseas dispersal. This includes earthworms, the velvet worm Peripatus, arachnids, the unusual endemic lizard Sphenodon (from Miocene) and the flightless birds the moa and the tinamou. The New Zealand flora is highly endemic at the species level (86% of its less than 2500 species are endemic), but with no endemic families, perhaps because as yet there has not been sufficient time for their evolution to have taken place.

157 Biogeographical Regions Today: The West Indies

The West Indies

- Though superficially similar in their geographical position, poised between two continents the islands of the Caribbean do not present the same fascinating problems as the islands of Wallacea because they do not lie between continents with totally different faunas and floras.

- **Instead, they have posed a different, interesting problem:** Are their faunas and floras primarily the result of vicariance, due to evolution on islands that arose by the break-up of a larger 'proto Antillean' landmass, or are they the result of dispersal from the neighbouring continents?What is now the Caribbean region began as merely a gap between North America and South America and therefore also between the Atlantic plate to the east and the Pacific plate to the west.

- **The formation of the West Indies:** Dark grey tint indicates dry land; light blue tint indicates shallow water; dark blue tint indicates deep water. Filled arrows indicate plate motion: AP, Atlantic Plate; CP, Caribbean Plate; PP, Pacific Plate. Smaller arrows indicate where ocean crust is being consumed, leading to the appearance of volcanic islands;

a) Late Cretaceous 150Ma b) Eocene 50 mya

- In the Early Cenozoic, a northward component of movement as South America approached North America, resulting in the appearance of the Greater Antilles (the larger islands of Cuba, Jamaica, Hispaniola and Puerto Rico) along the northern margin of the Caribbean plate.

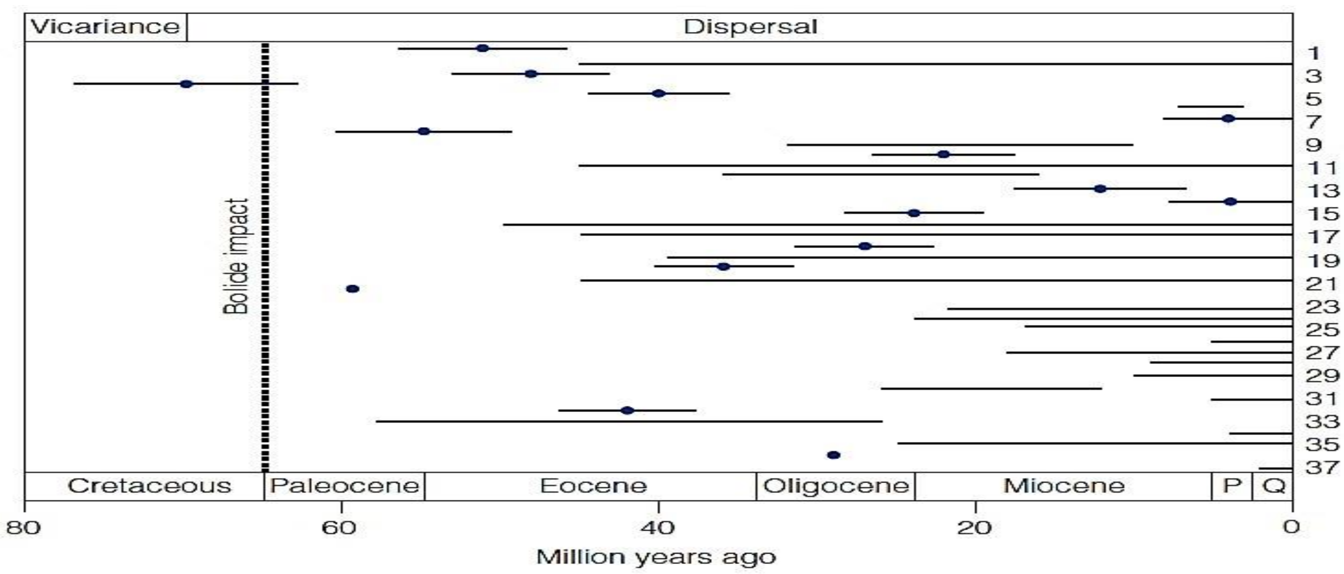
- The ecological diversity of the islands is largely based on the radiation of a comparatively small number of higher taxa, some of which contain a very large number of species. This suggests that a small number of immigrants, finding themselves in environments lacking their normal competitors, were able to diversify opportunistically into the vacant ecological niches.
- 1300 native species of freshwater or terrestrial vertebrate in the islands, of which 75% are endemic contain 672 species of amphibian and reptile, which belong to about 75 different evolutionary lineages. Of these 75 different evolutionary lineages, 49 are related to South American taxa, and only four to

North American taxa (the origins of the remaining 22 lineages are Africa, Central America or uncertain).

- The West Indies islands thus provide a fascinating picture in which geological, faunal and molecular studies seem to be converging on a convincing story of dispersal into and through a region of complex history. It is also an interesting contrast to the East Indies or Wallacea, where the history of the neighbouring continents has been quite different

Lecture No. 158 South America

- The history of the biota of South America has been dominated by the effects of the great earth engine of plate tectonics. Westward drift of the continent, mountain building and consequent climatic changes changes in its relationship with North America.
- There had been islands in that region ever since the Americas started to move westward in the Early Cretaceous. This may have been the route by which some North American dinosaurs dispersed southward in the Mid Cretaceous, with some early types of marsupial and placental mammal.
- But this connection has always been tenuous, sometimes permitting passage and sometimes becoming broken. This led to cycles of immigration, isolation and evolution, and final new immigration and extinction.



Times of origin of 37 independent lineages of endemic West Indian amphibians and reptiles From *Hedges*

- The mammal fauna of South America today is characterized by a few marsupials (opossums) and a diversity of edentate placental mammals known as the Xenarthra (sloths, armadillos and South American anteaters) that are hardly known elsewhere.

- In the Late Cretaceous, South America had a mammal fauna of strange marsupials and of ungulate placentals quite unlike anything known elsewhere in the world. Alfred Wallace, noted that the range boundaries of Amazonian birds seemed to coincide with the pattern of the rivers. It is fascinating that recent research shows that closely related taxa of some birds are to be found on either side of rivers throughout Amazonia.

159 Biogeographical Regions Today : The northern Hemisphere Holarctic mammals

Northern Hemisphere

- In contrast to the Southern Hemisphere, that of the Northern Hemisphere has been comparatively uniform. Although shallow epicontinental seas and the developing North Atlantic have from time to time subdivided the land areas of North America and Eurasia into different patterns.

The biogeographical results of plate tectonic movements in the Northern Hemisphere were far less complex and dramatic than those in the Southern Hemisphere.

- In addition, their faunas and floras have in the recent past all suffered from the severe climatic effects of the Ice Ages. There are the two great regions of temperate and cold adapted biota. Although the two continents are usually distinguished as being separate 'North American' and 'Eurasian' zoogeographical regions, they are sometimes considered as a single 'Holarctic' or 'Boreal' region.
- The controls on the dispersal of animals and plants in these northern continents have therefore been changes in sea level or climate, and the effects of these in four different crucial areas have recently been described by the Greek biogeographer **Leonidas Brikiatis**
- **Simplified palaeogeographical reconstruction of the high northern latitudes during the Paleocene, to show the key dispersal locations in the Paleocene and earliest Eocene.**

(1) de Geer route (1) connected northeastern Greenland to Scandinavia in the Latest Cretaceous–Early Paleocene (71–63 mya)
(2) Thulean route: connected northern North America to Europe via a ridge of land that is now submerged.
(3) Beringia: the route of land across the Bering Sea between Siberia and Alaska was dry during parts of the Paleocene.
(4) Turgai Sea way: From Brikiatis ran from north to south near the Ural Mountains.

1. Much of Europe was, until about 30 mya, covered by a shallow epicontinental sea, so that the area was an archipelago of islands of varying size, rather like the East Indies today. Because of their position in fairly high northern latitudes, some of these routes acted as a filter whose intensity varied according to the climate.
2. The biogeographical importance of the climate of the Bering region can be seen in its influence on faunal exchange between North America and Eurasia. In the Early Oligocene, few mammals crossed. In the Oligocene, a number of Asian mammals dispersed to North America.

160 Ice and Change: The Ice ages

- Ice Ages are relatively rare events in the Earth's 4.6 billion years of history.
- Although the polar regions receive less energy from the sun than the equatorial regions, they have been supplied with warmth by a free circulation of ocean currents through most of the world's history
- Only occasionally do land masses pass over the poles, or form obstructions to the movement of waters into the high latitudes, which can result in the formation of polar ice caps.
- The approximate timing of glacial episodes during Earth's history.

Table 12.1 The occurrence of Ice Ages in the history of the Earth.

Name	When?	Putative cause
Huronian Glaciation	2.4 to 2.1 billion years ago	Volcanic activity
Cryogenian Ice Ages	850 to 630 million years ago	Loss of CO_2 from the atmosphere due to recently evolved multicellular organisms sinking to the sea bed
Andeab-Saharan Ice Age	460 to 430 million years ago	Triggered by volcanic activity that deposited new silicate rocks, which draw CO_2 out of the air as they erode
Karoo Ice Age	360 to 260 million years ago	Falling CO_2 as a result of the expansion of land plants. As plants spread over the planet, they absorbed CO_2 from the atmosphere and released oxygen
Antarctica freezes	14 million years ago	Falling CO_2 caused by the rise and subsequent erosion of the Himalayas. The weathering sucked CO_2 out of the atmosphere and reduced the greenhouse effect
Quaternary glaciations Older Dryas Younger Dryas	2.58 million to 12 000 years ago 14 700 to 13 400 years ago 12 800 to 11 500 years ago	Triggered by a fall in atmospheric CO_2 due to continued weathering of the Himalayas. Timing of the glacials and interglacials driven by periodic changes in Earth's orbit and amplified by changes in greenhouse gas levels (see the main text)

161.Causes of Glaciation

Antarctica

During the most recent Ice Age, the movement of Antarctica into its position over the South Pole led to the development of a Southern Polar Ice Cap 42 mya. Falling global temperature then led to then development of the Greenland Ice Cap around 34 mya.

Rearrangements

Rearrangements of the Northern Hemisphere land masses have subsequently resulted in the isolation of the Arctic Ocean so that it received relatively little influence from warm-water currents, leading to its becoming frozen some 3 to 5 million years ago.

Albedo

The presence of two massive polar ice caps increased the albedo, or reflectivity, of the Earth, for whereas the Earth as a whole reflects about 40% of the energy that falls on it, the ice caps reflect about 80%. .Significantly reduced the amount of energy retained by the Earth.

Milankovich

- Why the recent Ice Age has not been a period of uniform cold, but has consisted of a sequence of alternating warm and cold episodes.
- A proposal to explain this pattern was put forward in the 1930s by the Yugoslav physicist Milutin Milankovich.
- Milankovich constructed a model based on the fact that the Earth's orbit around the sun is elliptical and that the shape of the ellipse changes in space in a regular fashion, from more circular to strongly elliptical.It takes about 96 000 years to complete a cycle of this change in orbital shape.When the orbit is fairly circular there will be a more regular input of energy to the Earth through the year, whereas when it is strongly elliptical the contrast between winter and summer energy supply will be much more pronounced.
- **Tilt of the Earth's Axis**
- A second source of variation is produced by the tilt of the Earth's axis relative to the sun, which again affects the impact of seasonal changes, with a cycle duration of about 42000 years
- Wobble of the Earth's axis
- The third consideration is a wobble of the Earth's axis around its basic tilt angle, which shows a cycle of about 21 000 years.

Milankovich Cycles

- All of these cycles affect the strength of solar intensity that is received by the Earth, and the pattern of climatic change should, according to Milankovich, be a predictable consequence of summing the effects of these three Milankovich cycles.

Volcanic Eruptions

- Produce large quantities of dust, which are thrown high into the atmosphere.
- Reducing the amount of solar energy arriving at the Earth's surface, and dust particles also serve as nuclei on which condensation of water droplets occurs, thus increasing precipitation.
- Both of these consequences would favour glacial development.
- Attempts to correlate volcanic ash content with evidence of climatic changes in ocean sediments, however, have not met with much success.

162 The Human Intrusion: Animal Domestication

The Pleistocene

- The Pleistocene was a time of climatic instability, which had considerable impact on the distribution patterns of organisms over the face of the Earth.
- It was a time of extinctions, but also one of diversification for some types of organisms.

Rate of Evolution

- There has been much debate concerning whether speciation became faster or slower during the Quaternary Ice Age, and the general conclusion is that extinction rates within the Pleistocene exceeded speciation rates

Mammals

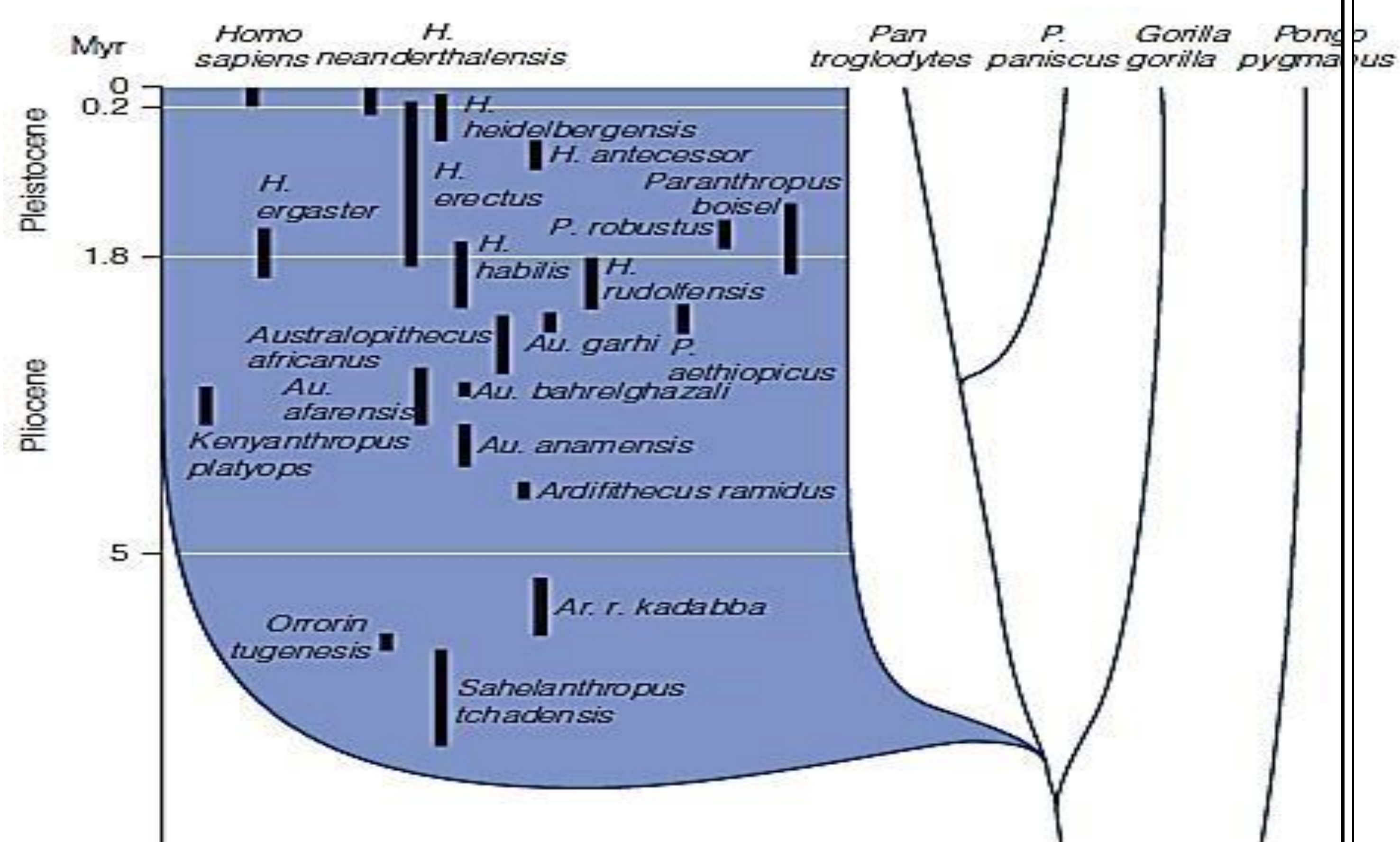
- For mammals, it was a time of extensive evolution, and most living species of mammal evolved during Quaternary times, driven by climatically unstable Quaternary environments
- One of the species that evolved at this time was, Homo sapiens

Effect of Humans

- Human has had an even greater impact on the biogeography of the Earth than even the Ice Ages.
- It has therefore been suggested that this period of time should be known as the 'Anthropocene'

The Emergence of Humans

- The fossil history of humans is still very incomplete, but each year brings new material to light, helping to fill in the gaps and providing a more detailed picture of how anatomically modern humans emerged.
- The primates of the New World and the Old World became separated from each other some 40 (mya), and it is the Old World branch that is ancestral to humans.
- Closely related to the great apes, which include the orangutan *Pongo*, and especially to the gorilla *Gorilla* and the chimpanzees *Pan*
- The separation of the human ancestral branch (the hominins) from the great apes (the two groups are known jointly as hominids) taken place about 7 mya.
- Almost 99% of human genetic makeup is shared with the chimpanzee



The relationships between the hominins and the great apes. From Carroll. From McDowell

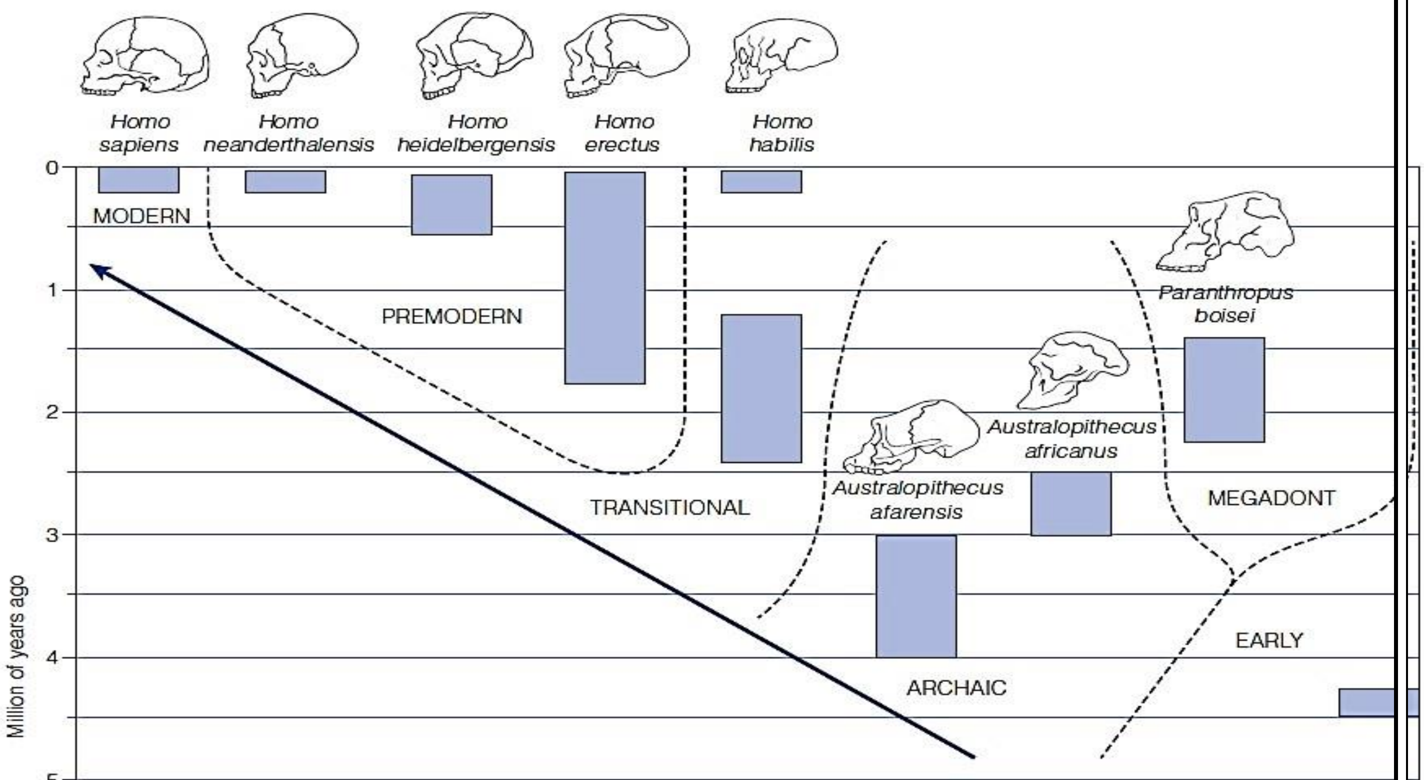
- The hominin line became more bipedal and developed a larger brain and greater manual dexterity.
- While chimpanzees remained in the lower canopy of the forest, the ancestors of humans took to the savanna woodlands and grasslands.

163 The Human Intrusion: Diversification of Homo sapiens

Miocene (5 mya)

- Biogeography of the early hominids, which lived during the Miocene (5 mya)
- We can study the fossil record of other, larger and more common mammal groups, such as the *hyaenids* and the proboscideans associated with *hominids*

- These share a common set of patterns involving speciation in Africa in the Early Miocene and expansion into Europe, Asia and North America during the Middle Miocene, followed by a movement back into Africa.
- It is very likely that hominids (which include the ancestors of apes and humans) followed similar changing patterns of distribution in the Miocene.



Early Hominins

- In 2002, Michel Brunet and his fellow researchers discovered six fossil bones (a cranium and some lower jaws) that had hominin similarities
- They were assigned to a new genus on the human line of evolution and called *Sahelanthropus tchadensis.*

Archaic Hominins

- The earliest finds were in Tanzania and Ethiopia and dated from around 4 mya.
- Among the fossils of this age is the partial skeleton known as *'Lucy,'* which has supplied a great deal of anatomical information about early hominins

Megadont Hominins

- A short-lived side-line of hominin evolution lived in East Africa 2.3–1.4 mya.
- Characterized by heavy, strong jaws and large molar teeth with a thick coating of enamel, this hominin was originally named *Zinjanthropus* but is now known as *Paranthropus.*

Transitional Hominins

- *Homo habilis*, a species that lived nearly 2 mya.
- It is different from the australopithecines in having an upright posture and larger brain.
- Structure of its arms and hands suggests it was still quite adept at climbing, and its ankle has australopithecine characteristics.

Pre-modern Homo

- A new hominin, *Homo ergaster,* appeared around 1.9 mya, closely followed *Homo erectus* • *Homo erectus* left Africa about 1.7 mya, and had spread into eastern Asia by 100,000 years later
- *Homo heidelbergensis,* which lived between 600,000 and 100,000 years ago.
- Appearance of *Homo neanderthalensis* about 200,000 years ago with evidence of *Homo sapiens* appearing later, in 160,000-year-old deposits from Ethiopia
- *H. neanderthalensis* and *H. sapiens* co-existed in Europe and Asia Minor 40,000 to 35,000 years ago

164 The Human Intrusion: Modern Homo

The Spread

- Even before the last glaciation had begun, H. sapiens was spreading into the Middle East and also further south into the African continent.
- By the middle of the glaciation, our ancestors had reached the Asian interior and north of the Caspian sea
- By the middle of glaciation they spread across the Tibetan Plateau into South-East Asia.
- Australia became populated by about 50,000 ya, and humans had reached northern Europe and eastern Asia by the time the glaciation was at its peak, 20,000ya
- Only the Americas remained empty of our species
- The sea levels were lower, perhaps by around 100 m.
- A land bridge formed across the Bering Straits, linking Siberia to Alaska.
- This is the most likely route by which North America was colonized.

Map showing the probable routes taken during the spread of *Homo sapiens* out of Africa over the past 100,000 years.

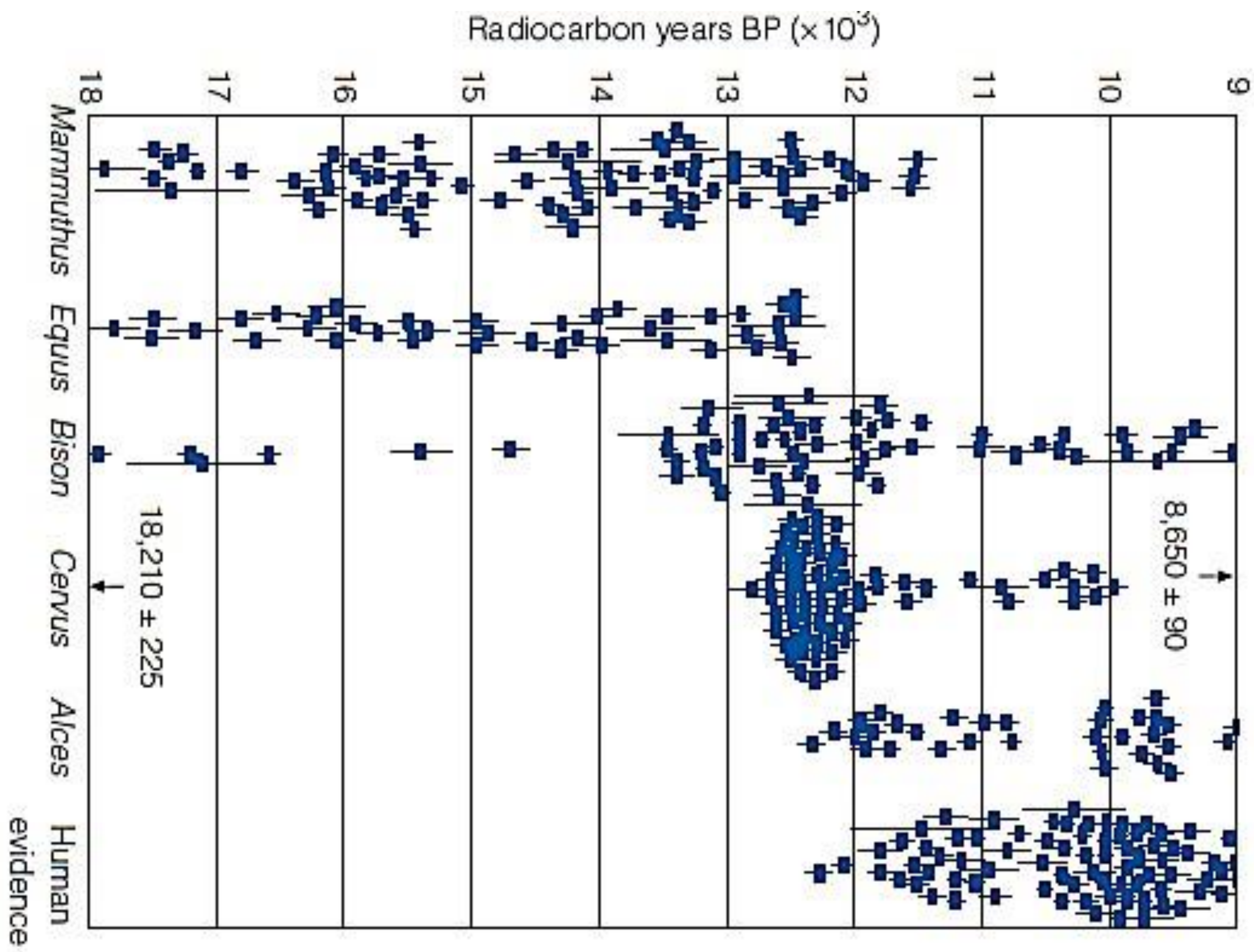
- A human skeleton dated to 13,000–12,000 ya, found in Mexico, that shows a mixture of Asian and Native American features
- Traces of human occupation about 15,500 ya north of Austin in Texas, at Monte Verde in southern Chile about 14 000ya
- Human bones dated to about 13000 ya found in the Channel Islands off California also suggest that some, at least, of the early Americans may have arrived by boat
- Evidence of a maritime culture, similar to that on the Asian Pacific coast, on those same islands
- A completely different line of enquiry on this problem comes from the study of the geography of human languages, which suggests that the colonization of the New World must have taken place before the major advance of the last glaciation about 22,000 years ago.
- R.A. Rogers revealed three distinct groups of Native American languages centred on the three ice-free refugial areas of North America during the height of the last glaciation
- The current view of most researchers is that there was a single origin for the all the native peoples of America

165 The Human Intrusion: Modern Homo & Megafaunal Extinctions

Extinctions

- The spread of the human species during the last glaciation was accompanied by the extinction of many species of large mammals, known as the megafauna – first in Australia, then in Eurasia and finally in North America

- Who did that?
- It was long assumed that these extinctions were the result of the climatic changes, but the American anthropologist *Paul Martin* suggested that humans may have been the culprits
- He pointed out that most of the animals that became extinct were large herbivorous mammals or flightless birds, weighing over 50 kg body weight
- In other words, precisely the fauna humans might have been expected to hunt • The record of extinctions has been studied in the greatest detail in North America.
- *Martin* suggests that 35 genera of large mammal (55 species) became extinct in North America at the end of the last (Wisconsin) glaciation
- The debate continues, and the extinction of so many different species of mammals may not have been caused by one single factor.
- Studies show that the time of extinction can be correlated with the arrival, or intensification, of settlement by human populations.
- Dale Guthrie of the University of Alaska has obtained radiocarbon dates for the Late Pleistocene and Early
  Holocene remains of many large mammal fossils from Alaska and the Yukon Territory



Radiocarbon dates of fossil mammal bones from North America showing the loss of mammoth and horse around the time of the Pleistocene–Holocene transition.

- The case for human involvement in the megafaunal extinction process is complicated by the fact that it took place at a time of rapid climatic and environmental change.